Innovative High-Gain Array Antenna Design for Compact 28 GHz Millimeter-Wave Communication in 5G Applications

A Project report is submitted in partial fulfillment of the requirements for the award of Degree of Bachelor of Science in Electrical and Electronic Engineering.

Submitted by

Md. Imran Patoyari

ID: 213-33-1460

Md. Mahmudul Hasan

ID: 213-33-1459

Md. Belal Hossan

ID: 213-33-1471

Supervised by

Mr. Md. Sohel Rana

Associate Head , Department of EEE

Department of Electrical and Electronic Engineering

Faculty of Engineering

DAFFODIL INTERNATIONAL UNIVERSITY

JULY, 2025

DECLARATION

I hereby declare that this project "**Innovative High-Gain Array Antenna Design for Compact 28 GHz Millimeter-Wave Communication in 5G Applications**" represents my work, which has been done in the laboratories of the Department of Electrical and Electronic Engineering under the Faculty of Engineering of Daffodil International University in partial fulfillment of the requirements for the degree of Bachelor of Science in Electrical and Electronic Engineering and has not been previously included in a thesis or dissertation submitted to this or any other institution for a degree, diploma or other qualifications. I have attempted to identify all the risks related to this research that may arise in conducting this research, obtained the relevant ethical and/or safety approval (where applicable), and acknowledged my obligations and the rights of the participants.

Signatures of the candidates

Name: Md Imran Patoyari
ID: 213-33-1460

Name: Md. Mahmudul Hasan
ID: 213-33-1459

Name: Md. Belal Hossan
ID: 213-33-1471

APPROVAL

The project and thesis entitled **"Innovative High-Gain Array Antenna Design for Compact 28 GHz Millimeter-Wave Communication in 5G Applications"** submitted by **Md Imran Patoyari, ID: 213-33-1460 & Md. Mahmudul Hasan, ID: 213-33-1459, Md. Belal Hossan, ID: 213-33-1471** Session: Spring 2024 have been accepted as satisfactory in partial fulfillment of the requirements for the degree of **Bachelor of Science in Electrical and Electronic Engineering** in **January, 2025.**

Signature

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MD. Sohel Rana

Associate Head , Department of EEE

Department of Electrical and Electronic Engineering

Faculty of Engineering

Daffodil International University

Dedicated
To
Our Father & Mother

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LIST OF ABBREVIATIONS

UHF	Ultra-High Frequency
MPA	Microstrip Patch Antenna
PCB	Printed Circuit Board
Wi-Fi	Wireless Fidelity
CST	Computer Simulator Technology
VSWR	Voltage Standing Wave Ratio
FSS	Fixed Satellite Services
EBG	Electromagnetic Band-Gap
PBG	Photonic Band Gap
DNG	Double Negative
CSRR	Complementary Split Ring Resonator
SAR	Specific Absorption Rate
DGS	Defective Ground Slot
MIMO	Multiple Input Multiple Output
ICNIRP	International Commission on Non-Ionizing Radiation Protection
FCC	Federal Communications Commission
ROS	Reactive Oxygen Species
SOD	Super-oxide dismutase
UVB	Ultra Violet-B
EMR	Environmental Management Review
EPA	Electronic prior authorization
IUCN	International Union for Conservation of Nature
WWF	World Wide Fund
IEA	International Energy Agency
UNEP	United Nations Environment Program
CI	Conservation International

LIST OF SYMBOLS

Symbol	*Name of the symbol*
Hz	Hertz
kHz	Kilo Hertz
MHz	Mega Hertz
GHz	Giga Hertz
mm	Millimeter
cm	Centimeter
m	Meter
ε	Relative permittivity
L	Length
W	Width
C	Speed of light
dB	Decibel
λ	Lambda
Ω	Ohm
εr	Dielectric Constant

ACKNOWLEDGMENT

First of all, we want to give thanks to **Almighty Allah**. With his blessing we are able to complete our work with best effort.

We want to pay our utmost respect to our Md. Sohel Rana, a Senior Lecturer of the **Department of EEE, Daffodil International University** for who has given us the chance to work on an impactful idea and taken care of every issue of development of this concept. Then we would like to take this opportunity to express gratitude to our supervisor for being dedicated in supporting, motivating and guiding us throughout this project. This project can’t be done without his useful advice and help. Also thank him very much for giving us the opportunity to work with this project.

ABSTRACT

As there has been an explosive increase in wireless data traffic, mm-wave communication has become one of the most attractive techniques in the 5G mobile communications systems. In the landscape of 5G millimeter-wave communication, the demand for high-speed data transmission is paramount. In this study, we aim to design and optimize a novel array antenna at 28 GHz, which is an important frequency band for 5G mm-wave applications. In the case of higher frequencies, such array design provides a robust communication link given the enhanced bandwidth and gain. In the quest for the upcoming 5G millimeter-wave communications with stringent antenna gain and beamforming agility requirements, this paper shall present design and measurement of a reduced-size and scalable phased array antenna for the 28-GHz access network. Numerical results on the performance of our antenna are thoroughly studied in this paper, whereas, the significant contributions toward the 5G mm-wave communication are addressed as well. Maximum gain is 9.2 dB, efficiency is 99.5% and the useful bandwidth is 3.5 GHz in the range of interest and is performance is well suited and makes the proposed antenna suitable for next-generation 5G millimeter-wave deployments. Moreover, the challenges that mm-Wave applications meet are evaluated and some innovative mechanisms are also proposed to enhance throughput. We also delve into the antenna's impact on the environment and human body exposure, highlighting broader implications. Lastly, the superior performance specifications of our proposed antenna demonstrate that it still presents a significant enabler of future 5G millimeter wave communication networks, enabling further connectivity and perhaps even fast wireless communication.

Keywords:

- ***i.*** ***28 GHz,***
- ***ii.*** ***Fifth-generation (5G) Technology***
- ***iii.*** ***Array Antenna,***
- ***iv.*** ***Millimeter-wave,***
- v. ***Wireless communication***

CHAPTER 1
INTRODUCTION

1.1 Background of the Research

The concept of MPAs dates back from 1950s when it was initially introduced by G.A. Deschamps. However, MPAs transitioned from being just concepts to real-world applications in the 1970's with the advancement of printed circuits board (PCB) technology, along with research by Howell and Munson. It was at this time that a significant breakthrough happened in antennadesign which led to other new researches in this field. By the early 1980s, a basic understanding of microstrip antenna elements and arrays had been established thereby paving the way for its performance improvement and proliferation in application.

Due to their compactness, ease in manufacturing, as well as broadening of operations bandwidth, MPAs became an essential device in modern systems of communication. They are widely used in such applications as remote sensing, radar systems, satellite communication and wireless communication. Research has focused in the past on MPA performance and design enhancement. Originally, these antennas were primarily used for lower frequency bands, such as UHF and microwave. Yet, if data needs to be transferred faster, new technologies, for example 5G, has led to increased requirements for antennas, able to operate at higher frequencies.

MPAs offer several advantages as compared to conventional antennas. This lightweight and compact design decrease their physical size and also enables a cost-effective manufacturing based upon inexpensive PCB-fabrication techniques. Furthermore, their flexible geometry allows them to be modified to meet specific requirements such as optimization of radiation pattern, bandwidth and gain.

In particular, there is an emerging interest in the millimeter-wave (mm-Wave) spectrum (30 GHz-300 GHz). This spectrum is important for future generation wireless communication systems, as it has significantly wider bandwidth and data rate than lower bands. In particular, mm-wave band, and the 28 GHz band as one of mm-wave band is drawing attention as a band can be used for 5G communication network.

Designing MPAs for mm-wave frequencies has both opportunities and challenges. Despite being compact, antennas at these higher frequencies are even more sensitive to manufactural errors. In addition, mm-Wave signal propagation suffers from more path loss and atmospheric attenuation, which drives the design of efficient, high gain antennas.

MPAs are still a vibrant research area in the presence of their long life span in the antenna technology. Their performance is being further optimized with advances in simulation tools, fabrication techniques, and materials. Increased data rates, maximum spectrum utilization, and high reliability are just few among the contemporary issues of wireless communication that these advances try to address.

This paper's main mission is to design and optimize MPAs for operation at 28 GHz which is an important frequency for 5G networks. The 28 GHz spectrum is well suited for densely populated and busy urban areas since it can offer ultra-high data throughput, low latency, and a wide coverage. Nevertheless, there are distinctive challenges associated with deployment of 5G networks at mm wave frequencies such as signal attenuation, path loss, shadowing, and blockage effects. To combat these challenges, novel antenna architectures capable of providing enhanced reliability and performance are required.

Besides 5 G, the 28 GHz frequency spectrum is also important for mm-wave radar systems and satellite communications. Thus the research will target this range and develop high performance solutions to meet the requirements of new communication systems, and also extend the frontiers of antenna technology.

1.2 Motivation behind choosing the topic

The rapid advancements in communication systems and increasing desires for fast and delay-free transmission in modern networks are the factors causing one to consider using a microstrip patch antenna (MPA) for 5G wireless systems. High performance antennas at millimeter-wave frequencies, particularly around 28 GHz, are more and more significant as 5G evolves. MPAs are an excellent solution to meet these requirements due their compactness and because they can be embedded into different infrastructures or appliances. To enhance the 5G communication performance, this method centers on innovative design solutions that counteract problems of bandwidth, gain, and efficiency. It also works toward broader goals such as improved wireless communication as well as expanding connections in areas like the internet of things and smart cities.

1.3 Aims/ Objectives of the research

Aim

The objective of this work is to introduce and develop a new microstrip patch antenna exclusively for 5G wireless communication systems at 28 GHz millimeter-wave frequency. To meet those stringent requirements for 5G applications, like ultra-high data rate, low latency, and high coverage, the attention is focused on antenna performance optimization.

Objective

Optimize Design:

A comprehensive design strategy is carried out to optimize the geometry and the parameters of the microstrip patch antenna for operation at 28-GHz. In order to achieve this objective, the design of the antenna has to be optimized for better performance by through electromagnetic modeling tools and simulation methodologies.

Enhance Bandwidth:

Broaden the bandwidth of the microstrip patch antenna from those used to cover wide frequency bands that are used by 5G mmWave applications. Taking into account the above objective, the target is to analyze state of art design approaches for ensuring an enhanced operating bandwidth together with favourable radiation properties.

Improve Radiation Efficiency:

To growth power transmission and signal coverage, diminish losses and progress radiation patterns.

Reduce Size: Generate a small antenna that can be encompassed into a variety of 5G devices and city infrastructure.

Assure Integration: Assure compatibility with both new applications like IoT and smart cities as well as current 5G network infrastructures.

Validate Performance: Use both simulation and investigational testing to assess the antenna's performance, paying particular courtesy to crucial elements like gain, impedance matching, and radiation pattern. In order to boost connection and unleash the full potential of new 5G applications and services, our research aims to develop antenna technology for 5G millimeter-wave communication systems.

1.4 Problem statement and proposed Solution

Real-world issues frequently interfere with wireless communication systems' ability to transmit data seamlessly, especially in crowded cities and dynamic mobility surroundings. Conventional antennas have drawbacks that reduce their dependability and effectiveness, even if they function well in many circumstances. Signal attenuation, frequency reuse interference, and portable devices' limited battery life are major problems that impair reliable communication and user experiences.

Typically, signal attenuation is an issue that occurs when radio signals are weaker as they pass through obstacles, buildings and air. Because of the increased population and high riser buildings in the cities, it leads to the transmission of signal in the urban areas comparatively difficult, and thus causes no coverage or weak signal coverage problem. The problem is further aggravated by the signals from cells or equipment working at the same frequency, that interfere with the received signal and contribute to poor signal quality and instability of communication link.

Physical barriers such as walls, glass, or building infrastructure further exacerbate signal attenuation and degradation in the case of Wi-Fi and other wireless scenarios. Radio signals are subject to obstacles which obstruct, degrade, dispense and reflect them as users travel through urban environment or indoor regions, thus causing poor user experience and degraded connectivity. We propose herein to design and realize an array antenna system working at 28 GHz which is dedicated to 5G applications to solve these problems. Arrays give rise to significant benefits for avoiding losses and mitigation interference by introducing spatial diversity and an advanced beamforming techniques. These systems can successfully go around, and maintain a reliable high strength connection - using adaptive (radiator) beamforming technique, over obstacles, by adaptively changing their radiation patterns and directing beams to intended receivers.

Our 28GHz array antenna solution is aimed at transforming wireless communications in indoor and urban environments." Even under difficult propagation conditions, via adaptive beam forming and advanced digital processing this solution aims at enhancing the coverage and increasing the spectral efficiency and providing seamless user experience. Additionally, the scalability and flexibility of array antenna designs are also excellent for many network topologies as well as highly dynamic urban environments where traditional antennas often struggle to maintain stable connectivity. In summary, a promising solution to the challenging problems of current wireless communication systems can be obtained by working with a 28 GHz array antenna system. It is an innovative antenna technology to solve the problems of signal attenuation, impedance mismatch, and coverage. Read more It paves the way for ultra-fast, ultra-reliable connectivity and just reimagines the possibilities for 5G in the digital age.

1.5 Technology procedure/methodology

First, CST 2018 is used to calculate the first dimension of rectangular microstrip patch antenna and then the shape is modified to achieve bandwidth enhancement. The response of each element is investigated, and inset slots and partial ground are optimized. Performance analysis is employed to assist in the further optimization while comparison with the state-of-the-arts is performed to examine whether design enhancement or place for further improvement exists. A final comparison scrutiny to the available literature is provided at the end. The ADS software is also employed to check the circuit, to match the evaluation of CST results, and to optimize the antenna design process.

Step 1: Preliminary Design Specification: The length and width of the fundamental rectangular microstrip patch antenna structure are compounded as L and W.

Step 2: Increase the bandwidth of antenna: Slightly modify the rectangular shaping of the antenna to increase the bandwidth.

Step 3: Inset Slot and Partial Ground Optimization: The width and length of the inset slots and the length of the partial grounds can be tuned or optimised to improve the performance.

Step 4: Analysis of Each Antenna: Individually find out performance of each possible design based on the parameters such as bandwidth, gain and return loss. Step 5: Further Inset Slot and Partial Ground Optimization By analyzing the performance, optimize the dimensions of the width and length of the inset slots and partial grounds to achieve better performance Profiles.

Step 6 Comparative Analysis with Literature: Compare the proposed antenna parameters with recent literature to assess innovation and performance against existing approaches

1.6 Thesis Organization

Chapter 1: Introduction

By providing a comprehensive backdrop and context for the research, this chapter presents the thesis. It clearly states the study's goals and objectives and describes the issue being addressed. The chapter also explains how the project was carried out, including the processes and strategy followed during the execution phase.

Chapter 2: Literature Review

Existing research on the thesis topic is examined in the literature review. By contrasting and comparing earlier research with the present study, it finds gaps in the literature.

This comparison looks at the best practices and methodology that have affected the study's approach while highlighting the new contributions of the current research.

Chapter 3: Fundamentals of Antenna Design and Performance Parameters

A Primer on Antenna Performance and Design The basic principles of antenna performance and design are reviewed widely in this chapter. They covered vital performance parameters such as radiation patterns, directivity, gain, efficiency, VSWR, return loss, input impedance, bandwidth, and field region, and also some basic concepts such as microstrip patch antennas and the various types of antennas. Feeding techniques, toghether with the antenna element design steps: including choice of substrate, calculations of dimensions and other design considerations are described in this optical.

Chapter 4: Result Analysis

The results from array and single element structure simulations are presented and discussed in detail in this section. Given the emphasis of the importance of the results, the results are discussed in relation to the thesis objectives. The chapter aims to interpret how the empirical findings link with the wider body of literature through an in-depth analysis.

Chapter 5: Project Management

Thesis Project Management is the primary subject of this chapter. It explains how planning for project management is done and how the plan is executed, such as how to build a schedule, allocate resources, control costs and maintain an upward trajectory in project milestones. In addition to the lessons learned during the project management, the chapter details information that would be helpful to the initiation of an effective management.

Chapter 6: Impact Assessment on Human Health and the Environment

The broader impacts of the thesis project on the environment and human health are appraised on this chapter. It examines the ethical and environmental implications of the research, the potential health hazards of electromagnetic radiation, safety measures, statutory criteria and environmental consequences. To provide a comprehensive understanding of socioeconomic and environmental impacts of the project, the chapter also discuss public awareness, perception, and mitigation measures.

Chapter 7: Conclusion

The major findings and contributions of the study are summarized in the conclusion chapter. Given the insights of exploration during the study, it suggests possible system improvements and further research directions. The chapter is also concerned with broader implications of the research, with a review of possible applications, closing with remarks that emphasise the significance of the study and its relevance in the field.

CHAPTER 2
LITERATURE REVIEW

Fifth-generation (5G) wireless communications technology is becoming the most advanced due to the growing demand for high data speeds. The primary goals of the 5G communication system are to improve device-to-device communication, ultra-low latency (1 ms), excellent dependability, significant flexibility, and data rates (up to 20 Gbps) and capacity. One of the most important aspects of designing systems with such high capacity, low latency, and flexibility is antenna design. This study presents a survey of several antenna designs.

Conventional microstrip antennas face several challenges, such as limited operating frequency, narrow impedance bandwidth, low gain, large size, and polarization issues. Various techniques have been planned to improve the performance of these antennas, including stacking, different feeding methods, frequency selective surfaces (FSS), electromagnetic band gaps (EBG), photonic band gaps (PBG), and metamaterials [11], [12]. Microstrip patch antennas are commonly used in 5G sub-6 GHz and millimeter-wave systems, making them a popular choice for 5G base station antenna designs. However, their narrow bandwidth limits their use in 5G base station antennas. Researchers have suggested various solutions to expand the bandwidth of patch antennas [13], [14]. The sub-6 GHz band can provide broader geographical coverage for 5G but does not support high downlink speeds [15], whereas millimeter-wave 5G technology enables higher downlink speeds but with limited geographical coverage. The frequency range of 4.8–5.0 GHz in the sub-6 GHz band is officially designated for 5G wireless systems [16]. Within the sub-6 GHz spectrum, the focus will be on the 3.5 GHz band, which offers a 400 MHz bandwidth (3.4–3.8 GHz), and is commercially available worldwide.

Multiple layers of FR-4 substrates, each with the following characteristics: er = 4.4, h = 1.6 mm, tan d = 0.025, and a dimension of 180 × 60 mm2, were used to create a multiband stack antenna that spanned the LTE and sub-6 GHz bands in the dual operational bands of 0.66–0.79 and 3.28–3.78 GHz. The design incorporates an elliptical patch on the lower substrate that facilitates the creation of the 700 MHz band (LTE-R). The upper substrate is composed of five distinct circular patches that were designed to resonantly operate the antenna at 3.5 GHz (5G lower band) frequency and to increase the bandwidth. At 0.7 GHz and 3.5 GHz, the bands' respective gains were 2.4 dBi and 6.1 dBi. [17]

For the n78 working band at 3.3–3.8 GHz, a 48 × 35 mm2 patch antenna with DNG metamaterial was built using a complementary split ring resonator (CSRR) on FR-4 dielectric substrate (er = 4.4, h = 1.62 mm, tan d = 0.025). In order to minimize the specific absorption rate (SAR), the 6 × 6 CSRR was able to adjust the radiation pattern and increase the gain. In the whole working frequency range, the antenna's radiation efficiency was 87% and its gain was 5.5 dBi [18].

In order to improve impedance matching and isolation, a 20 × 35 mm2 MIMO antenna array for the 5G n78 band (3.3–3.8 GHz) was designed on a FR-4 epoxy substrate (er = 4.4, h = 0.8 mm, tan d = 0.025). An altered T-shaped stub was positioned between the two tapered rhombus-shaped radiators that were excited by tapered feeding with DGS. In the 3.34–3.87 GHz operational frequency range, the antenna produced a gain of 2.34 dBi and a radiation efficiency of 93%. To achieve the necessary resonance frequency of 3.6 GHz, an extra stub was additionally attached through the radiator's center. With ECC of 0.02 and TARC of 0.5, the reported isolation was more than 20 dB and had a bandwidth of 530 MHz. At the resonance frequency of 3.6 GHz, the antenna produced a gain of 2.34 dBi.

[19].

Due to the growing demand for high data rates, the sub-6 GHz spectrum is getting crowded, making mm-wave bands like 28, 38, 60, and 73 GHz essential for 5G communication systems. 5G wireless communication systems have made the 24.25–27.5 and 37–42.5 GHz bands in China and the 27.5–28.5 and 37–39 GHz bands in the USA their primary frequency bands. great-frequency bands can provide great capacity and rapid speed, depending on the users' distance from the cell site [20], [21]. This section provides comprehensive information on 5G antenna designs operating in the 24–40 GHz frequency band.

A wide variety of antennas and antenna arrays, including inset feed, series feed, corporate feed, and corporate-series feed, are made for 5G applications in the 28–40 GHz operating frequency spectrum.[22], [23], [24].

A 28 GHz patch antenna was planned on a manganese zinc ferrite substrate (er = 7, h = 1.00 mm, tand = 0.003) with a size of 14 × 14mm2. The −10 dB impedance bandwidth was 27.23–29.89 GHz and the gain achieved was 5.44 dBi with a radiation efficiency of 93% at 28 GHz resonant frequency [25].

A 1 × 4 elliptical patch antenna array was constructed using a Rogers RT/duroid 5880 substrate (er = 2.2, h = 0.508 mm, tan d = 0.0013) to operate at 28 and 45 GHz resonant frequencies in order to increase the gain. The array's dimension was 6 × 6 mm2. In the working frequency band at 28 GHz, the antenna array obtained a radiation efficiency of 85.6% and a gain of 7.6 dBi. 1.25 W/kg was observed for SAR at 28 GHz.[26].

The Rogers RT/duroid 5880 substrate (er = 2.2, h = 0.79 mm, tan d = 0.0009) was used to create a 13-circular radiating element grid antenna with dimensions of 21.5 × 23 mm2 and a resonance frequency of 30 GHz. In the operational frequency range of 27.5–33.3 GHz, the antenna array achieved a radiation efficiency of 80% and a gain of 9 dBi. [27].

MIMO systems offer significantly increased data capacity by employing an array of antennas at the transmitter and receiver connection. The size, shape, and separation between the antennas all have a significant impact on the ability to reach this high capacity. MIMO antennas and MIMO antenna arrays operating in the millimeter-wave spectrum for 5G wireless applications are the subject of a number of research that are now accessible in the literature. By offering a fast data rate, enhanced capacity, and connection reliability—all key features of 5G—MIMO antennas reduce the impact of multipath propagation. However, creating small antenna parts with strong isolation and low mutual coupling is a challenge when building MIMO antennas. [28], [29].

On a Rogers RT/Duroid 5880 substrate (er = 2.2, h = 0.38 mm, tan d = 0.0009), a two-element MIMO antenna with a 12 × 24 mm2 dimension and an operating band of 28.2–30.7 GHz was built. The stated ECC value was less than 0.001. [30].

It was designed and built on a Rogers R04350B substrate (er = 3.66, h = 0.79 mm, tand = 0.0037) with 30 × 35 mm2 dimensions as a four-port MIMO antenna array for 5G MIMO applications. Rectangular, circular, and zigzag slots were used to defect the ground plane in order to enhance the radiation characteristics and decrease the mutual coupling in the 25.5–29.6 GHz operating band. There was a claimed 17 dB isolation between the antennas. According to the calculations, the gain and radiating efficiency were 8.3 dBi and 82%, respectively, with a −10 dB impedance bandwidth located between 25.5 and 29.6 GHz, ECC < 0.01 and DG > 9.96.[31].

In view of mm-wave 5G wearable applications, a two-element MIMO antenna was designed on a flexible Rogers RT/duroid 6002 substrate of dimensions 19.04 × 15.06mm2 (er = 2.94, h = 0.254mm, tan d = 0.0012). A 5 ×5 EBG was employed on the back which enhanced the gain by 1.9 dBi and decreased the impact of harmful radiations on the human body. The gain and radiation efficiency achieved were 6.0 dBi and 80.5% at 24 GHz resonant frequency respectively [32].

Because they only require one substrate for design, the majority of planar microstrip antennas are less complicated and more affordable. To achieve multi-band resonance, increase bandwidth, and lower surface wave or coupling losses, slots [33] are introduced to obtain multi-band resonance, improve bandwidth, and reduce surface wave or coupling losses. The most common types of slots are E- shape [34], U- shape [35] and fractal– shape [36] slots are the most prevalent kinds in the radiating plane. For maximum power coupling and radiation efficiency, the radiating element's input port must match the 50 Ω microstrip feed line (which is dependent on the width). In this section, different slot MIMO antennas are discussed.

The designed structures are compact in Refs. [37] [38], resonating at 28 GHz with 2-port and 4-port MIMO. The S-shape design in Ref. [37] is 0.41λ0. With a complete ground plane at the bottom of the substrate, the single element is a rectangular patch etched on top of the FR4 substrate and fed via a 50Ω microstrip line. By placing a horizontal slit in the shape of a L on the right side of the patch head, the design is optimized. As a result, the resonance has moved to a somewhat louder frequency. The patch's left bottom has an additional slit that creates a L shape to enhance impedance matching. Improved reflection coefficient Sii of -30 dB is the result of this. If the radiating elements are arranged in symmetry and asymmetry, this design can be extended to 2-port MIMO. To comprehend the surface current distribution and mutual coupling, both configurations are examined. The structure is compact and does not require a decoupling structure since the highest current is concentrated close to the slits, which lowers the mutual coupling in the asymmetrical orientation of antennas. In order to achieve a higher isolation Sij, Ref [38] designs an additional 2-port, small rectangular patch with 450 tilt. The Rogers 4350B substrate is etched with the design. To the left of the rectangular patch, the 50 Ω microstrip feed is attached. Putting a slit at the top and bottom of the patch and tilting it by 450 improves the isolation, which was -16 dB when the two patches were straight. As a result of this change, resonance is lowered from 36 GHz to 29 GHz and the current path has risen, improving isolation by -36 dB.

The performance metrics of the above designs are as follows: bandwidth 28–28.6 GHz, 28.8–29.7 GHz, gain 5.8 dBi, 6 dBi, isolation - 30 dB, - 25 dB, and radiation omnidirectional [37], broadside with HPBW of 400 and 300 in E and H-plane [38].

The majority of MIMO antennas that have been discussed thus far have bidirectional or omnidirectional radiation. The antenna with an end-fire radiation pattern is shown in the following design. Radar and remote sensing both use the end-fire radiation pattern. In Ref. [39], a planar helical antenna design intended to resonate at 28 GHz yields one such pattern. Here, a T-shaped monopole on Rogers RO4003 substrate is the first of three steps of design optimization. Additionally, the inverter-V monopole antenna was tuned to achieve the required bandwidth of 26.5–30 GHz. A 50Ω microstrip line that employs the grounded coplanar waveguide (GCPW) technique—in which the transmission line is surrounded by a grounded patch—supplies the power. In order to boost the current flow and perhaps cause end-fire radiation, the feeding points to the radiating element are linked at an offset from the center towards the left. These designs have a bandwidth of 26.25–30.14 GHz, a gain of 5.8dBi, isolation of 30 dB, and end-fire radiation at 1000 with an HPBW of 650 in the E and H planes.[39].

Because the ground plane in planar microstrip antennas serves as a reflector, the radiation will be normal to the radiating element. However, the ground plane can be adjusted from full ground to partial ground, which is known as defective ground plane structures (DGS), to increase the antenna bandwidth or to achieve greater isolation between elements. The radiation pattern's directivity is compromised by such structures. The DGS can be of any geometric shape such as rectangle, circular, E, H, I, or ring shape [40] etched on the ground to enhance the desired parameter. MIMO antennas that share and do not share the DGS structure common ground will be covered in this subsection.

For improved isolation with the partial ground plane, the 4-port element in the MIMO architecture in Refs. [41] [42] is orthogonal/1800 oriented. Two concentric circular rings flank the 50 Ω microstrip line in the design shown in Ref. [41]. These concentric circles are joined by a tiny ring to form an infinite shape shell. The ground's head is enhanced with a semi-circular ring to fine-tune the resonance frequency at 28 GHz.

The element in Ref. [42] has a circular patch on Rogers 5880 substrate fed by a 50 Ω microstrip line. Five circular pedals are connected via a strip line for a circular patch. An angle of 45 deg separates the circular pedals, and the ground plane is optimized to the partial ground to obtain the desired bandwidth. To tune the resonance frequency stub of the semi-circular ring is added to the ground plane. The performance of these MIMO antennas is as follows: bandwidth 27.6–29.7 GHz, 26–29 GHz, gain 6.1dBi, 6.5dBi, isolation -29 dB, -25 dB, and radiation is omnidirectional [41], omnidirectional [42].

Table 1: Performance Comparison with related work.

Reference	Operating Frequency (GHz)	Frequency Range	BW (GHz)	Gain (dB)	Efficiency (%)	Substrate
[25]	28	27.23-29.89	2.66	5.44	93	Manganese Zinc Ferrite
[26]	28	27.4-28.6	1.2	7.6	85.6	RogersRT5880
[27]	28.4	28.2-30.7	2.5	6.68	80	RogersRT5880
[38]	29	28.8-29.7	0.9	6	85	Roger4350B
[30]	28	25.5-29.6	4.1	8.3	82	RogersRO4350B
[37]	28	28-28.6	0.6	5.8	60	FR-4
[39]	28	26.25-30.14	3.89	5.8	88	RogersRO4003
[41]	28	27.6-29.7	1.1	6.1	92	RogersRT5880

[42]	28	26-29	3	6.5	85	RogersRT5880
This work	28	26.62-30.28	3.66	9.67	98.82	RogersRT5880

A number of recent research are compared conceptually in Table 1. Numerous operational parameters, such as frequency, bandwidth, gain, and efficiency, are contrasted in this table. The recommended antenna achieves good gain and efficiency and has the largest bandwidth among the research in the table. The research works [25], [26], [27], [38], [30], [37], [39], [41], [42], collectively demonstrate the gain of 5.44dB, 7.6dB, 6.68dB, 6dB, 8.3dB, 5.8dB, 5.8dB, 6.1dB, and 6.5dB respectively, underscoring the critical need for innovative solutions. Such limitations can severely hamper the performance of communication systems, leading to compromised signal strength, reduced coverage areas, and increased susceptibility to interference. Nonetheless, a 9.67dB gain has been observed in CST. According to CST, the recommended architecture offers a 3.66 GHz bandwidth. The sources provided bandwidths of 2.66 GHz, 1.2 GHz, 2.5 GHz, 0.9 GHz, 4.1 GHz, 0.6 GHz, 3.89 GHz, 1.1 GHz, and 3 GHz.

The proposed array antenna has a radiation efficiency of 98.82%, while the studies mentioned [25], [26], [27], [38], [30], [37], [39], [41], [42] had scores of 93%, 85.6%, 80%, 85%, 82%, 60%, 88%, 92% and 85%.

To sum up, our novel antenna design signifies a revolution in the communication industry. By means of careful engineering and optimization, our 1*2 array antenna surpasses previous works' benchmarks by achieving previously unheard-of levels of efficiency and gain. An important improvement that is specifically designed to increase the antenna's bandwidth and overall performance envelope is the incorporation of a unique partial ground construction. Greater frequency coverage is guaranteed by the wider bandwidth, and better signal strength and efficiency are indicated by the higher gain and admirable return loss. Therefore, in addition to addressing the shortcomings noted in earlier studies, our antenna design opens the door for improved performance, coverage, and dependability in 5G communication networks. By pushing the boundaries of technological innovation, our antenna heralds a new era of seamless connectivity and unparalleled performance in the realm of millimeter-wave communication.

CHAPTER 3

FUNDAMENTALS OF ANTENNA DESIGN & PERFORMANCE PARAMETERS

3.1: INTRODUCTION

The antenna or aerial is defined as a device for transmitting or receiving radio waves in the IEEE Standard Definitions of Terms for Antennas (IEEE Std 145–1983). To put it another way, the antenna serves as a bridge between a directing device and free space.

Figure 1: Parabolic reflector antenna.

3.2: ANTENNA AS A TRANSISSION DEVICE

An antenna serves as a critical transmission device in communication systems, converting electrical signals into electromagnetic waves for wireless propagation. It efficiently radiates energy into space during transmission and receives incoming waves during reception. The design and performance of an antenna determine key parameters like signal strength, bandwidth, and directionality, making it essential for applications ranging from radio broadcasting to modern wireless technologies like 5G and 6G.

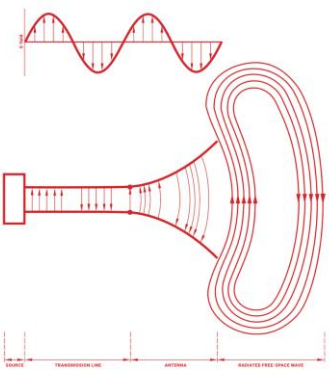

Figure 2: Antenna as a transition device

3.3: FUNDAMENTAL PARAMETERS OF ANTENNAS

3.3.1: INTRODUCTION

A number of parameters must be defined in order to explain an antenna's performance. A thorough description of the antenna's performance does not require the specification of every parameter because some of them are interconnected. In this chapter, parameter definitions will be provided.

3.3.2 RADIATION PATTERN

The radiation pattern of an antenna describes how electromagnetic energy is distributed in space as the antenna transmits or receives signals [46]. It illustrates the directional dependence of the antenna's radiated electromagnetic field and serves as a key metric for evaluating its performance and functionality.

ISOTROPIC RADIATION PATTERN:

An isotropic radiator emits energy uniformly in all directions, creating a spherical radiation pattern. Although this is a theoretical model and cannot be physically realized, it serves as a benchmark for comparing the directional properties of practical antennas [47].

OMNI-DIRECTIONAL RADIATION PATTERN:

Omni-directional antennas radiate energy evenly across all horizontal directions, though their vertical radiation may vary. These antennas are often used in applications that require broad azimuthal coverage, such as wireless access points and broadcast systems [48].

DIRECTIONAL RADIATION PATTERN:

Directional antennas focus energy in specific directions, enhancing gain and coverage in targeted sectors while minimizing radiation in other areas. This makes them ideal for applications like point-to-point communication links, satellite systems, and radar technologies [49].

MAIN LOBE:

The main lobe refers to the primary region of maximum radiation intensity in the radiation pattern. It represents the direction where most of the radiated power is concentrated and defines the antenna's primary coverage area.

SIDE LOBES:

Side lobes are secondary peaks in the radiation pattern that occur at angles away from the main lobe. These lobes contribute to radiation in unintended directions, and reducing their levels is essential for minimizing interference and enhancing overall antenna performance.

BEAMWIDTH

Beamwidth is a parameter that is related to an antenna's pattern. The angular distance between two identical locations on the opposite side of the pattern maximum is known as the beamwidth of a pattern. There are several beamwidths in an antenna pattern. The IEEE defines the Half-Power Beamwidth (HPBW), one of the most used beamwidths, as "the angle between the two directions in which the radiation intensity is one-half value of the beam in a plane containing the direction of the maximum of a beam." Figure 3.3 illustrates this point. The angular distance between the pattern's first nulls is known as the First-Null Beamwidth (FNBW), and it is another significant beamwidth. An antenna's beamwidth is a crucial metric that is frequently utilized as a trade-off with side lobe level; that is, when the beamwidth is smaller, the side lobe gets bigger, and vice versa.

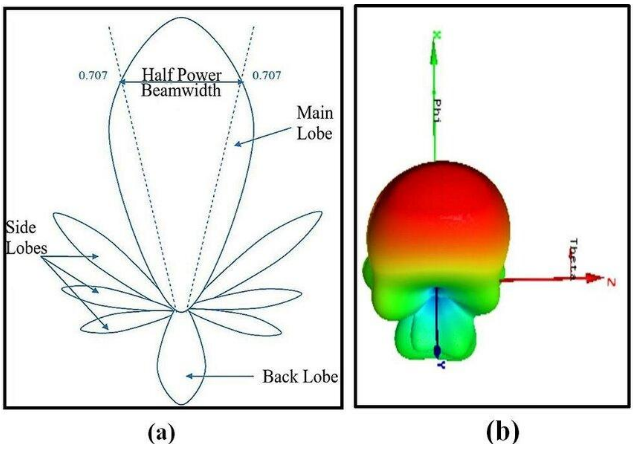

Figure 3: Power patterns (a) Three- and (b) two-dimensional (in linear scale)

3.3.3: DIRECTIVITY

"The ratio of the radiation intensity in a given direction from the antenna to the radiation intensity averaged over all directions" is the definition of its directivity. Dividing the total power emitted by the antenna by 4π yields the average radiation intensity. The direction with the highest radiation intensity is assumed if it is not stated.

$$D = \frac{U}{U_0} = \frac{4\pi U}{P_{rad}} \qquad 1$$

If the direction is not specified, it implies the direction of maximum radiation intensity (maximum

directivity) expressed as

$$D_{max} = D_0 = \frac{U_{max}}{U_0} = \frac{4\pi U_{max}}{P_{rad}} \qquad 2$$

D = directivity (dimensionless)

D_0= maximum directivity (dimensionless)

U = radiation intensity (W/unit solid angle)

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

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

P_{rad} = total radiated power (W)

$$D_0 = D_\theta + D_\varphi \qquad 3$$

$$D_\theta = \frac{4\pi U_\theta}{(P_{rad})_\theta + (P_{rad})_\varphi} \qquad 4$$

$$D_\varphi = \frac{4\pi U_\varphi}{(P_{rad})_\theta + (P_{rad})_\varphi} \qquad 5$$

Where,

U_θ = radiation intensity in a given direction contained in θ field component

U_φ = radiation intensity in a given direction contained in φ field component

$(P_{rad})_\theta$ = radiated power in all directions contained in θ field component

$(P_{rad})_\varphi$= radiated power in all directions contained in φ field component

3.3.4: GAIN

The ratio of the intensity in a particular direction to the radiation intensity that would be obtained if the power accepted by the antenna were radiated isotopically is known as the gain of an antenna (in a given direction). The isotopically emitted power's associated radiation intensity is calculated by dividing the antenna's accepted power (input) by 4π. This can be expressed as

$$Gain = 4\pi \frac{radiation\ intensity}{total\ input\ (accepted) power} = 4\pi \frac{U\,(\theta,\varphi)}{P_{in}} \qquad 6$$

3.3.5: RETURN LOSS

The loss of signal strength brought on by reflection at a transmission line discontinuity is known as the return loss. A device placed into the line or the terminating load may not match this discontinuity. RL (dB) is the return loss in dB, Pi is the incident power, and Pr is the reflected power. Typically, it is represented as a ratio in dB.

3.3.6 EFFICIENCY:

An important metric that measures how well an antenna transforms input power into radiated power is antenna efficiency. It is a crucial indicator for evaluating the overall performance and efficacy of the antenna system and offers insightful information about its energy conversion efficiency. Antenna efficiency, represented as η, is the ratio of the antenna's input power (P-in) to its radiated power (P-rad).[52]. Mathematically, it can be expressed as:

$$\eta = \frac{P_{rad}}{P_{in}} \times 100\% \qquad 7$$

Where: P_{rad} is the radiated power by the antenna.

P_{in} is the input power supplied to the antenna.

Antenna efficiency takes into consideration losses that occur at different phases of the energy conversion process, such as mismatch losses brought on by impedance mismatches between the transmission line and the antenna, ohmic losses in antenna conductors, and dielectric losses in antenna substrates. Because of variations in antenna shape, substrate characteristics, and radiation mechanisms, antenna efficiency may fluctuate with frequency. For interoperability with a variety of applications and multi-band communication systems, antennas must be designed with wide operating bandwidths and constant efficiency across frequency ranges.

3.3.7 VOLTAGE STANDING WAVE RATION:

The ratio of the standing wave's maximum amplitude to its minimum amplitude throughout the transmission line is known as the Voltage Standing Wave Ratio (VSWR), or simply VSWR.[53]. Mathematically, it can be expressed as:

$$VSWR = \frac{V_{max}}{V_{min}} \qquad 8$$

Where: V_{max} is the maximum amplitude of the standing wave.

V_{min} is the minimum amplitude of the standing wave.

Alternatively, VSWR can be calculated using the reflection coefficient (Γ) as:

$$\text{VSWR} = \frac{1+\tau}{1-\tau} \qquad 9$$

One of the crucial parameters that indicate this matching between the antena and the feeding transmission line is the VSWR. It is an important factor to be considered to evaluate the impedance matching and antennas system performance and provides valuable information on the effectiveness of power transfer from the transmission line to the antenna. A low VSWR value is a measure of good impedance matching, it minimizes signal reflections and maximizes power transfer from transmission line to the antenna. If the generator and the antenna are perfectly matched in impedance, VSWR=1. High VSWR values are associated with large signal reflections along the transmission line, resulting in inefficient power transfer and potential system performance degradation. Such reflections result in greater losses, a weaker signals and interference in the communication link.

3.3.8 INPUT IMPEDANCE:

The complex impedance observed at the antenna's input terminals when it is driven by a transmission line is known as input impedance, or Zin. It has a major impact on how well power is transferred between the antenna and the transmission line. It is commonly represented in ohms (Ω) and is composed of both reactance (Xin) and resistance (Rin) components.

$$Z_{in} = R_{in} + jX_{in} \qquad 10$$

Where: R_{in} is the resistive component of the input impedance.

X_{in} is the reactive component of the input impedance.

j represents the imaginary unit.

This point has an input impedance which is a complex quantity and which is composed of reactance and resistance. The imaginary part of (2) is the already mentioned reactive part representing the energy flow between antenna and free space while the real part is the actual fraction of impedance referred to as the radiation efficiency and due to the losses in the antenna system. Antenna geometry, substrate properties, and radiation properties all can vary as a function of frequency which may in turn alter the input impedance for an antenna. In order to enable these antennas to be compatible with many different applications and multi-band communication systems, they need to be constructed with constant input impedance characteristics across the operational frequency range. Reduced system loss is achieved by minimizing signal reflection and maximizing transfer of power by closely matching the characteristic impedance of the transmission line to the input impedance of the antenna.

3.3.9 ANTENNA BANDWIDTH:

The range of frequencies over which an antenna demonstrates acceptable performance qualities, such as impedance matching, radiation efficiency, and radiation pattern stability, is referred to as its antenna bandwidth. The frequency range across which specific performance factors, like a given return loss or VSWR, satisfy predetermined requirements is usually used to characterize it. The frequency range where the return loss is less than -10dB is known as the S11 parameter bandwidth.

It is a key metric for assessing the versatility and flexibility of antenna systems in accommodating diverse communication requirements and frequency bands. Antenna bandwidth determines the range of frequencies over which the antenna can transmit or receive signals effectively. A wider bandwidth allows the antenna to operate across a broader frequency spectrum, enabling compatibility with multiple communication standards and frequency bands [55].

3.3.10 ANTENNA FIELD REGIONS

While not directly an antenna characteristic, comprehending antenna field regions is crucial for knowing how much the antenna emits radiation away from itself. The areas that surround an antenna are divided into three primary fields:

The three regions of electromagnetic radiation are the

- Radiating Near Field or Fresnel Region
- Far Field or Fraunhofer Region
- Reactive Near Field

The far-field region is crucial as it significantly impacts the antenna radiation pattern and various other factors. Antennas, however, are used to establish long-range communication. This is the primary operational area for the majority of antenna types.

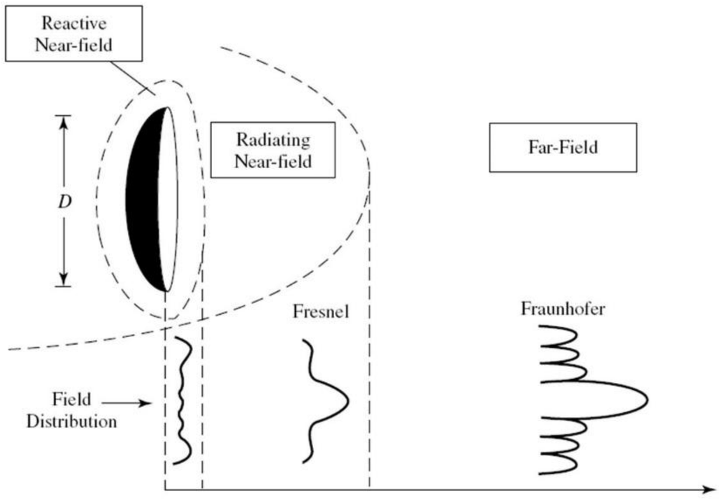

Figure 4: Antenna Radiation flow.

The electric field and magnetic field equations both contain the two-field components of an antenna. These fields are commonly referred to as radiative fields and reactive fields. The denominator of the equation typically includes a reactive field component with a distance 'r' generally of the order of two or more significant. The radiative component also consists of a first-order distance component denoted as 'r'. Consequently, the reactive element in the field diminishes as distance increases, whereas the radiative component persists, although it diminishes at a far longer distance than reactive fields. The near field contains minimal radiation due to the dominance of the reactive field.

Nevertheless, the distance between objects, which is about $R < \lambda 0$ (the wavelength at the operating frequency), is typically measured in millimeters and centimeters when dealing with microwave frequencies. However, this distance is too little for us to perceive. Unless specifically requested for analysis in the near field region, all aspects of an antenna are typically discussed in the far field region due to the presence of radiation solely in that region.

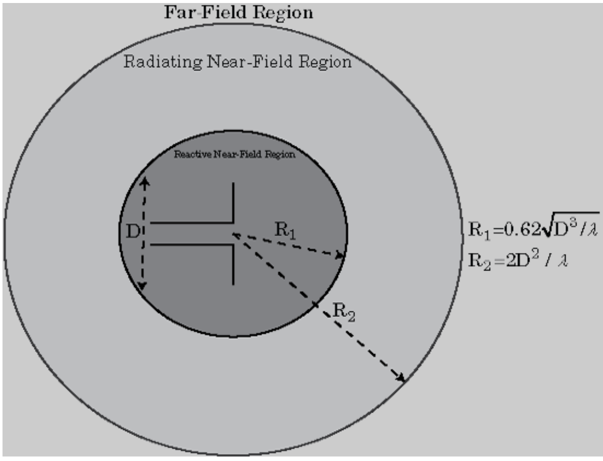

Figure 5: Field Region of an antenna.

3.4 FEEDING TECHNIQUE

Based on the information provided, the feeding techniques commonly used for microstrip patch antennas include contacting and non-contacting methods. These techniques facilitate the transfer of power from the feeding element to the radiating patch. Here's a summary of the microstrip patch antenna feeding techniques:

3.4.1. CONTACTING FEEDING TECHNIQUE:

In this approach, power is directly transmitted to the radiating patch through a connecting element, typically a microstrip line. The microstrip line acts as a transmission line, delivering electromagnetic energy from the feeding source to the radiating patch. This method ensures a direct electrical connection between the feeding element and the patch, facilitating efficient power transfer.

3.4.2. NON-CONTACTING FEEDING TECHNIQUE:

Non-contacting feeding techniques rely on electromagnetic coupling to transfer power between the feeding element and the radiating patch. Unlike contacting methods, there is no physical connection between the feeding source and the patch. Instead, electromagnetic fields are utilized to induce energy transfer. Common non-contacting approaches include:

- **Coaxial Probe Feeding:** In this technique, a coaxial probe is positioned above the microstrip patch antenna, and power is coupled to the patch through the electromagnetic field between the probe and the patch. The coaxial probe acts as a radiating element, providing energy to the patch without direct contact [56].

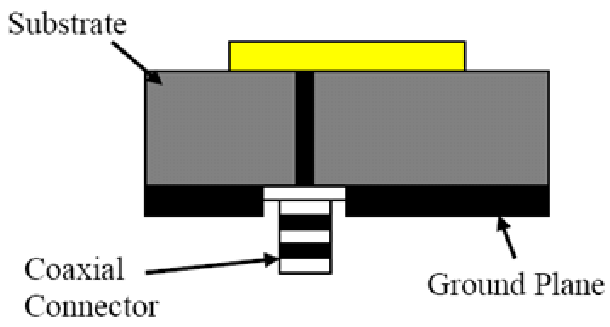

Figure 6: Coaxial Probe feeding technique.

- **Aperture Coupling:** Aperture coupling involves creating an opening or slot in the ground plane beneath the patch antenna. Electromagnetic coupling occurs through this aperture, allowing power to be transferred from the feeding source to the radiating patch without physical contact [57].

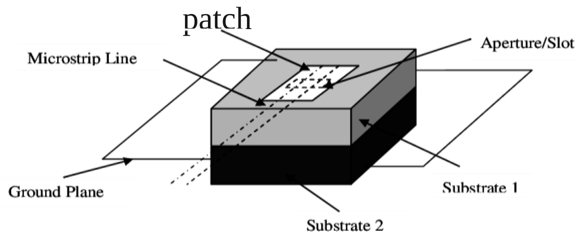

Figure 7: Aperture Coupling feeding technique.

- **Proximity Coupling:** Proximity coupling utilizes the proximity of the feeding element, such as another microstrip line or a radiating element, to induce energy transfer to the patch antenna. The electromagnetic field generated by the feeding element interacts with the patch, enabling efficient power transfer. These feeding techniques offer flexibility in designing microstrip patch antennas, allowing engineers to choose the most suitable method based on specific requirements such as bandwidth, efficiency, and radiation pattern [58].

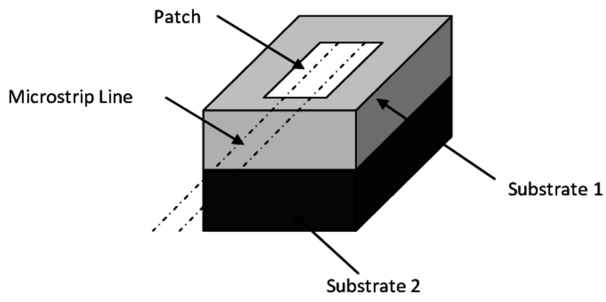

Figure 8: Proximity coupling feeding technique.

3.5: TYPES OF ANTENNAS

There are mainly five types of antennas. Those are: -

i) Wire antenna

ii) Aperture antenna

iii) Micro-strip antenna

iv) Array antenna

v) Reflector antenna

3.5.1: WIRE ANTENNA

Wire antennas are familiar to the layman because they are seen virtually everywhere—on automobiles, buildings, ships, aircraft, spacecraft, and so on. There are various shapes of wire antennas such as a straight wire (dipole), loop, and helix. Loop antennas need not only be circular. The circular loop is the most common because of its simplicity in construction.

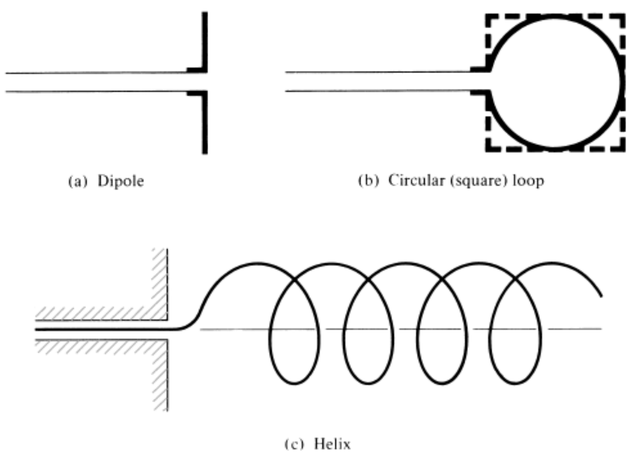

Figure 9: Wire antenna configurations.

3.5.2: APERTURE ANTENNA

Because of the growing need for more complex antenna designs and the usage of higher frequencies, aperture antennas might be more recognizable to the average person now than they were in the past. Because they may be easily flush-mounted on the aircraft or spacecraft's skin, these antennas are highly helpful for applications involving airplanes and spacecraft. They are additionally shielded from dangerous situations by a dielectric covering.

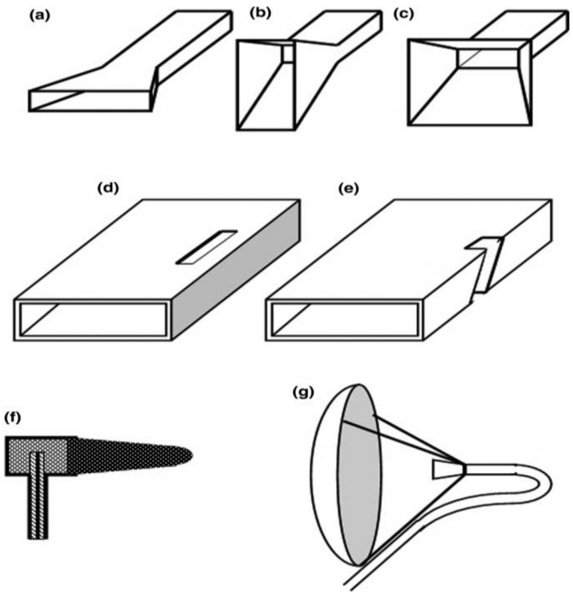

Figure 10: Aperture antenna.

3.5.3: MICROSTRIP ANTENNA

A metallic patch on a grounded substrate makes up these antennas. In terms of resonant frequency, polarization, pattern, and impedance, the micro strip antennas are low profile, comfortable on both planar and non-planar surfaces, easy and affordable to fabricate using contemporary printed-circuit technology, mechanically robust when mounted on rigid surfaces, and compatible with MMIC designs. High-performance airplanes, spaceships, satellites, missiles, automobiles, and even portable cell phones can all have these antennas installed on their exteriors.

3.5.4: ARRAY ANTENNA

A single element might not be able to provide the radiation properties needed for many applications. However, it is feasible that the desired radiation characteristics will be produced by an array, which is a collection of radiating devices arranged geometrically and electrically. The array can be set up so that the radiation from the elements adds up to a maximum in one or more directions, a minimum in others, or any other desired configuration..

3.5.5: REFLECTOR ANTENNA

Antenna theory has advanced as a result of the successful exploration of space. Sophisticated antennas were required to send and receive signals that had to traverse millions of kilometers due to the necessity of communication across long distances. The high gain needed to send or receive signals after millions of miles of travel requires enormous dimensions.

3.6: MICROSTRIP ANTENNA

Similar standards are currently found in a wide range of other commercial and governmental applications, including wireless communications and mobile radio. These antennas are easy and affordable to make using contemporary printed-circuit technology, low profile, and conformable to both planar and non-planar surfaces, mechanically robust when mounted on rigid surfaces, compatible with MMIC designs, and when the particular patch shape and mode are selected, they are very versatile in terms of resonant frequency, polarization, pattern, and impedance. In addition, by adding loads between the patch and the ground plane, such as pins and varactor diodes, adaptive elements with variable resonant frequency, impedance, polarization, and pattern can be designed. Major operational disadvantages of microstrip antennas are their low efficiency, low power, high Q (sometimes in excess of 100).

3.6.1 BASIC CHARACTERISTICS

A very thin (t _ λ0, where λ0 is the free-space wavelength) metallic strip (patch) is positioned a tiny fraction of a wavelength (h _ λ0, typically $0.003\lambda_0 < h \leq 0.05\lambda_0$) above a ground plane to form a microstrip antenna. The broadside radiator microstrip patch is made to have a pattern maximum that is normal to the patch. The element's length L for a rectangular patch is typically $\lambda_0/3 < L < \lambda_0/2$. A dielectric sheet, also known as the substrate, separates the strip (patch) from the ground plane. Micro-strip antennas can be designed on a wide variety of substrates, and their dielectric constants typically fall between 2.2 and 12. Because they offer greater efficiency and a wider bandwidth, thick substrates with a dielectric constant in the lower end of the range are the most preferred for good antenna performance.

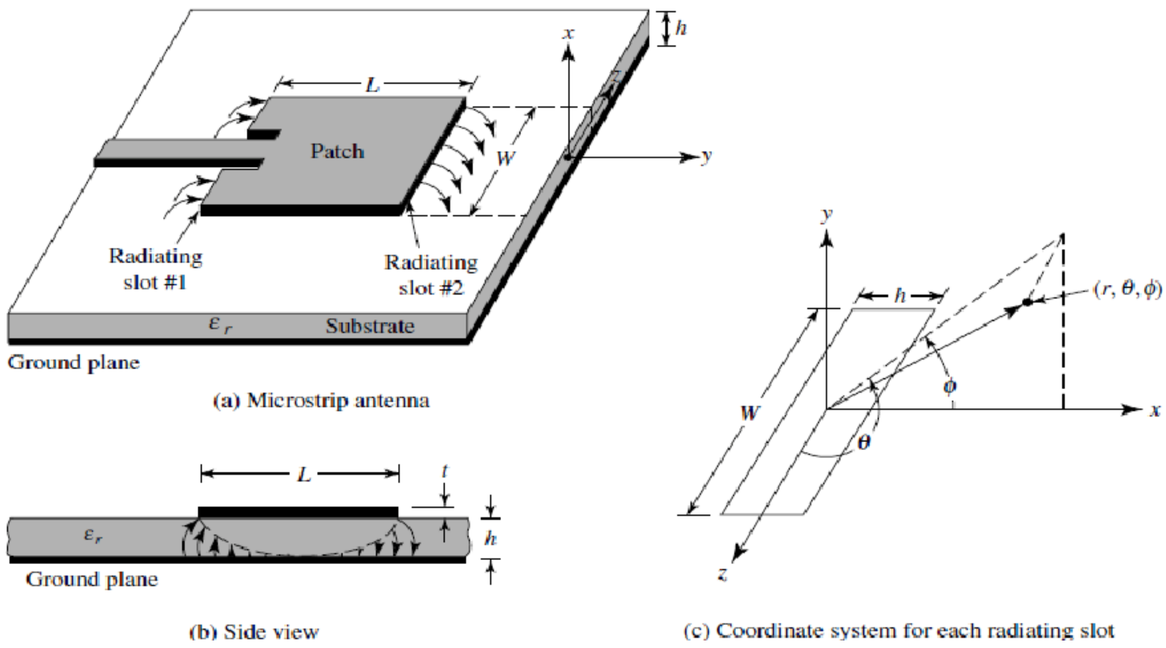

Figure 11: Microstrip antenna and co-ordinate system.

Often microstrip antennas are also referred to as patch antennas. The radiating elements and the feed lines are usually photo-etched on the dielectric substrate. The radiating patch may be square, rectangular, thin strip (dipole), circular, elliptical, triangular, or any other configuration. Square, rectangular, dipole (strip), and circular are the most common because of ease of analysis and fabrication, and their attractive radiation characteristics.

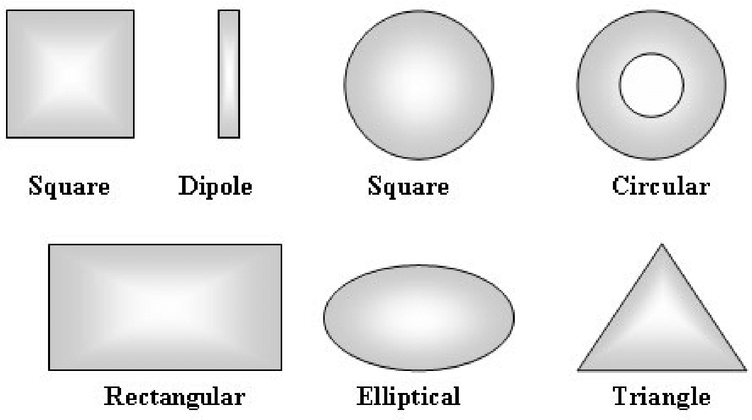

Figure 12: Representative shapes of microstrip patch elements.

3.6.2: DESIGN EQUATIONS FOR MICROSTRIP ANTENNA

We have used transmission line model here. According to this model rectangular and circular patch are viewed as very wide transmission line that is transversely resonating with the electric field varying sinusoidal under the patch along its resonant length. Various formula and design equations are there to design an antenna. They are: -

Effective dielectric constant:

$$\varepsilon_{reff} = \frac{\varepsilon r+1}{2} + \frac{\varepsilon r-1}{2}\left(1+12\frac{\mathrm{h}}{\mathrm{W}}\right)^{1/2} \qquad 11$$

Width of the patch (for rectangular):

$$W = \frac{c}{2f_r\sqrt{\left(\frac{\varepsilon_r+1}{2}\right)}} \qquad 12$$

Length of the patch (for rectangular):

$$\mathrm{L} = \frac{\mathrm{c}}{2fr\sqrt{(\varepsilon r)}} \qquad 13$$

Due to fringing fields the change in dimensions in length is given by

$$\frac{\Delta L_{\theta ff}}{\mathrm{h}} = 0.412\frac{(\varepsilon_{reff}+0.3)\left(\frac{W}{\mathrm{h}}+0.264\right)}{(\varepsilon_{reff}-0.258)\left(\frac{\mathrm{W}}{\mathrm{h}}+0.8\right)} \qquad 14$$

Effective length of patch:

$$L_{\mathrm{eff}} = L + 2\Delta L_{\mathrm{eff}} \qquad 15$$

The resonant frequency is expressed as –

$$f_r = \frac{c}{2L_{eff}\sqrt{(\varepsilon_{eff})}} \qquad 16$$

For efficient radiation the width W is given by –

$$W = \frac{c}{2f_r\sqrt{\left(\frac{\varepsilon_r+1}{2}\right)}} \qquad 17$$

A finite ground plane is essential for practical purposes. When the ground plane is six times larger than the patch dimensions plus the substrate thickness on both sides, comparable outcomes can be achieved for both finite and infinite ground planes.

Consequently, the dimensions of the ground plane for this design are as follows:

$$L_g = 6\mathrm{h} + L \qquad 18$$

$$W_g = 6\mathrm{h} + W \qquad 19$$

3.7 CHOOSING SUBSTRATE MATERIAL

Among various substrate options for microstrip patch antennas, the choice of substrate ultimately depends on the specific requirements of the antenna design, such as frequency range, size constraints, cost considerations, and performance objectives.

FR4 is a popular choice due to its low cost, ease of manufacturing, and availability. However, it has a moderate dielectric constant and a relatively high loss tangent, limiting its performance at higher frequencies. Rogers RT/Duroid offers low-loss tangent and good temperature stability, making it suitable for high-frequency applications where performance is critical. PTFE (Teflon) provides excellent electrical properties with low dielectric loss, making it suitable for high-frequency and high-performance applications. However, it's more expensive compared to the FR4. Ceramic offers high dielectric constants and low loss tangents, suitable for applications requiring miniaturization and high-frequency operation.

The antenna's mechanical stiffness is provided by substrates. The antenna's volume will rise in proportion to the size of the dielectric substrate. The substrate affects the antenna's radiating energy. The cost of the substrate used in the antenna is directly related to its cost.

Rogers RT/Duroid is chosen as the substrate material in this case because of its low loss tangent, which is usually in the order of 0.002, which leads to reduced dielectric losses and enhanced antenna efficiency. Furthermore, Rogers RT/Duroid provides a comparatively low dielectric constant, which helps to improve fringing fields and radiated power without appreciably expanding the size of the antenna. A major drawback of microstrip patch antennas can be addressed by selecting Rogers RT/Duroid as the substrate material, which improves the antenna's impedance bandwidth and radiation efficiency.

3.8 DESIGN OF THE PROPOSED ANTENNA

By presenting our design process our work uncovers an evolutionary leap from single-element antenna to array art for the prospering of future 5G applications. The single-element antenna serves as the building block for an antenna prototype, allowing us to study the fundamental properties of the antenna by itself. The implementation of an array antenna enables us to make use of the collective effects of several elements, enhancing the antenna gain, directivity, and spatial coverage. This trend is consistent with the demand of 5G networks where reliable connectivity and efficient spectrum usage are relying on beamforming and geographical diversity.

Also the selection of substrate, patch and ground plane materials is crucial for the overall performance of the antenna. Using copper for both patch and ground elements because of its high conductivity and low losses. This is because it can reduce the signal loss and the radio wave efficiency. With the calibrated thickness of 0.787 μm, loss tangent of 0.003 and a specific dielectric constant (εr) of 2.2, the RogersRT5880 substrate exhibits the desired electromagnetic properties for realizing the desired antenna features. These choices underline the importance of accurate optimization for ensuring that the antenna meets the stringent requirements of future 5G systems.

The design process introduces in this section and how to influence working and performance by each step of the antenna evolution -from single element to array- will be explained.

3.8.1 SINGLE ELEMENT ANTENNA

We systematically and exhaustively try to design a single-element antenna for high performance. For ensuring that the antenna meets its objectives, the design procedure follows several intricate steps that are meticulously performed.

You begin by selecting the materials while carefully calculating the sizes of the antenna elements. Due to its high conductivity of the material and uniform 0.035 mm thickness, copper is used for both patch and ground components. The grand size of the antenna is held constant at 5.5 × 5.5 mm 2. To achieve maximum performance in a 3\(\times\)4 mm 2 area, the patch is maintained such that it occupies this area exactly covering to within a few \(\mu \)m.

Some features are added to enhance the performance of the antenna further. The baseline performance for the antenna is first established by designed a rectangular patch and the feedline cautiously. To improve antenna characteristics such as gain and radiation pattern, insets are placed on either sides of the patch in later designs of the antenna. In order to achieve wideband operation and to match with the wide range of operating frequencies an array of three square spiral-shaped slots is also etched in the middle of the patch. The front and back views of the single-element antenna of it) ruction are displayed in Figure 3.13.

After design, the antenna is simulated with CST, an advanced electromagnetic simulation software tool. We can analyze the simulated parameters of antenna such as gain, radiation pattern and return loss. If we simulate the antenna at different frequencies and operating conditions, we can have an idea how the antenna behaves and what its potentials might be. The antenna design is enhanced by multiple modifications and optimizations according to the simulation results. By changing parameters such as ground structure, feedline geometry, and patch size, the required performance will be achieved. Iteration continues until the antenna meets stringent performance criteria and/or achieves optimum performance over a range of operating condition. In conclusion, the configuration of our single element antenna is a systematic, thoughtful effort to produce the highest and best serving results. By carefully selecting the materials for our antenna, designing key components and employing advanced simulation methodologies, we ensure that our antenna meets the stringent standards of modern communication systems.

Figure 13: Single Element antenna.

3.8.2 ARRAY ANTENNA

As seen in Figure 3.14, the last phase of our suggested antenna design entails switching from a single-element arrangement to a two-element array. The aim to further improve the antenna's performance characteristics—particularly its efficiency and gain—is what spurred this change. Compared to a single-element antenna, we can attain better performance metrics by setting up the antenna as an array. The array's primary feed is set up with a 50 Ω impedance, and the branching network's impedance is confirmed to be 100 Ω. Effective power transfer and impedance matching within the antenna system are guaranteed by this design. At a frequency of 28 GHz, the array antenna's two elements are separated by λ, or 2.8 mm. Interestingly, the array antenna's patch and inset dimensions are the same as those of a single element, preserving uniformity in the design specifications. The array antenna has a full ground structure, measuring 12 mm in length (La) and 17 mm in substrate width (Wa). In comparison to a single antenna arrangement, the array antenna shows notable gains in bandwidth (from 1.6 GHz to 3.65 GHz), gain (from 7.45 dB dB to 9.67), and efficiency (from 97.97% to 98.67%) due to meticulous design and optimization. This switch to an array arrangement demonstrates how array antennas can achieve greater efficiency and gain, which makes them ideal for advanced communication applications, especially at millimeter-wave frequencies like 28 GHz.

Figure 14: Proposed Array antenna.

CHAPTER 4
RESULTS & DISCUSSIONS

4.1 Introduction:

The performance of the proposed antenna system was analyzed with the help of a large number of simulations, which were conducted to fine-tune its design targeted for 28 GHz operation. Multiple antenna and array designs were investigated resulting in an evolutionary increase in bandwidth. We also used techniques of placing inset slots and using partial grounds to enhance the antenna characteristics. The results of these simulations are reported in this section to support a more detailed discussion in the following section.

4.2 Single-element Antenna Result

As a single element antenna becomes popular we need to take a step forward and design it in a comprehensive way for performance improvement.

4.2.1 Reflection Coefficient

Reflection coefficient, which is also called return loss, is an important parameter to assess the signal integrity of antenna systems. A smaller return loss corresponds to better impedance matching and less signal reflection, realizing a perfect transmission of the signal. Industry standards generally recommend a return loss of at least -10 dB to guarantee efficient antenna performance [59].

In our proposed single-element antenna design, the reflection coefficient (S11) is measured to assess the impedance matching quality. The symmetrical architecture of the design ensures consistent reflection coefficient behavior, which simplifies the evaluation to S11 measurements alone. As illustrated in Figure 4.1, the simulated reflection coefficient of the single-element antenna achieves a remarkable value of -36.35 dB at the resonant frequency, reflecting exceptional signal fidelity.

Additionally, the antenna exhibits a -10 dB impedance bandwidth of 1.6 GHz, spanning the frequency range from 27.2 GHz to 28.8 GHz. This bandwidth coverage demonstrates the antenna's capability to support high-frequency communication within the specified range, further validating its robust performance and reliable operational characteristics.

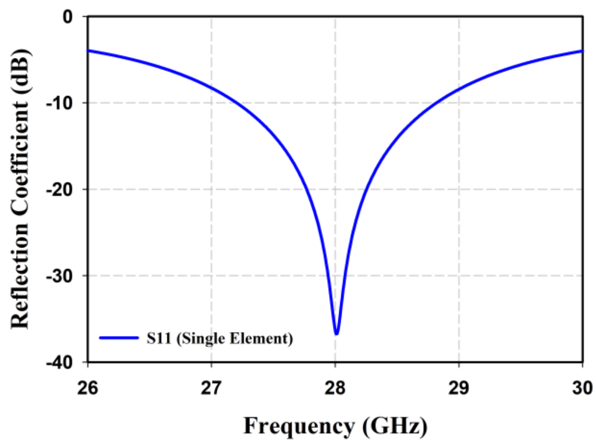

Figure 15: Reflection coefficient response of the CST software patch antenna.

4.2.2 Gain

The gain of an antenna is a vital parameter that reflects its ability to direct radiated energy effectively in a specific direction. High gain is particularly crucial for enhancing signal reception and transmission in targeted areas, making it a key performance metric for modern communication systems. As illustrated in Figure 4.2, the proposed single-element antenna achieves a peak gain of 7.43 dB.

This impressive gain value underscores the antenna's capability to channel energy efficiently, providing robust signal strength and reliability. The variation in gain across different distances and angles is influenced by the antenna's physical dimensions, geometric configuration, and operating frequency. The strong performance at the resonant frequency highlights the antenna's suitability for applications demanding high precision and reliable communication links.

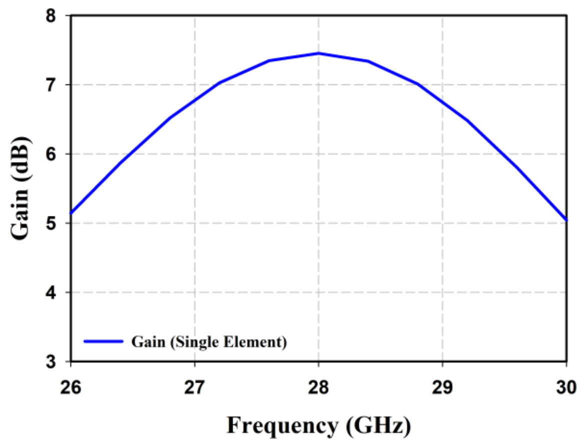

Figure 16: Gain of the proposed single antenna.

4.2.3 Efficiency

Efficiency in antenna systems represents the effectiveness with which input power is converted into radiated energy, serving as an indicator of power loss within the system. A high efficiency value demonstrates minimal power loss, which is essential for optimal performance in communication systems [60].

The single-element antenna do possess an impressive efficiency of 98.6% which is resulted from effective power consumption with the minimum loss. The high efficiency confirms the stable and reliable performance of the antenna. The simulated efficiency result is illustrated in Figure 4.3, showcasing the antenna's superior performance characteristics.

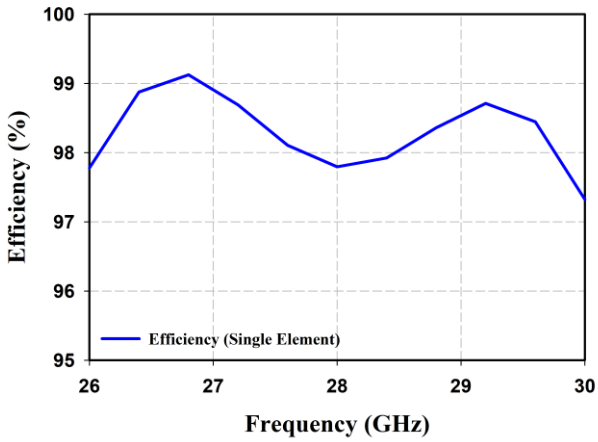

Figure 17: Efficiency of the proposed single antenna.

4.2.4 VSWR

Voltage Standing Wave Ratio (VSWR) is an important parameter for assessing the efficiency of RF power transmission over a transmission line with specific emphasis on the antenna system. It measures the extent at which a specific antenna is matched with the attached device by calculation at a particular frequency, thus giving information about power transfer efficiency as well as the level of signal reflection [61]. The CST Studio was used to simulate the VSWR of the single-antenna element Suite, is presented in Figure 4.4. The antenna exhibits the VSWR of 1.02 at 28.00 GHz, it is revealed perfect impedance matching between the prosed antenna and the feeding line. and the transmission line. This close to optimal match highlights the well performance of the antenna.

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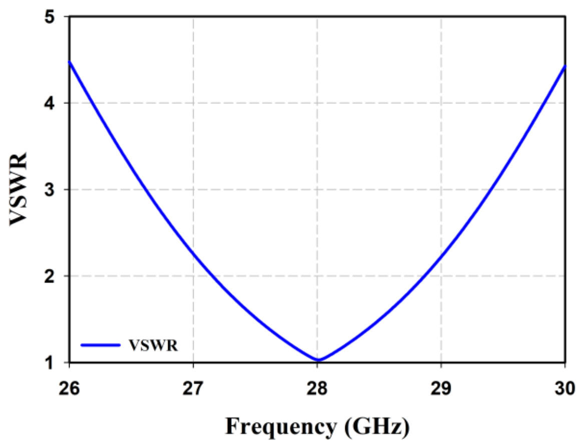

Figure 18: VSWR of proposed MPA using CST.

4.3 Array Antenna Result

The last step in the design of the antennas is the transition to a two-element array structure, as shown in Figure 3.11. This transition is designed to improve its performance attributes, such as gain, isolation, and overall efficiency, to suit the needs of modern communication systems.

4.3.1 Reflection Coefficient

Precise estimation of reflection coefficient is crucial to know impedance matching and signal aspects of antenna configuration. The reflection coefficient of the designed two-element array antenna was widely investigated to evaluate its impedance matching and global performance. The return loss at the resonant frequency is -38.031 dB of the simulated results, with good impedance matching and low stub reflecting loss. Such a low return loss indicates a good ability of this array to transmit power without serious insertion loss. The proposed antenna also exhibits a 10 dB impedance bandwidth of 3.66 GHz from 26.62 GHz to 30.28 GHz. This wide bandwidth contributes to stable operation, it also exhibits reliable performances against the proposed frequency range, and hence it is suitable for high frequency applications. The two simulated S11 plots are plotted in Figure 4. 4 provides the reflection coefficient characteristic, which is another insight in favor of the successful IM of the antenna. These findings emphasize the significant enhancement in performance compared to the single-element configuration, attributed to the optimized design and precise impedance matching in the array setup.

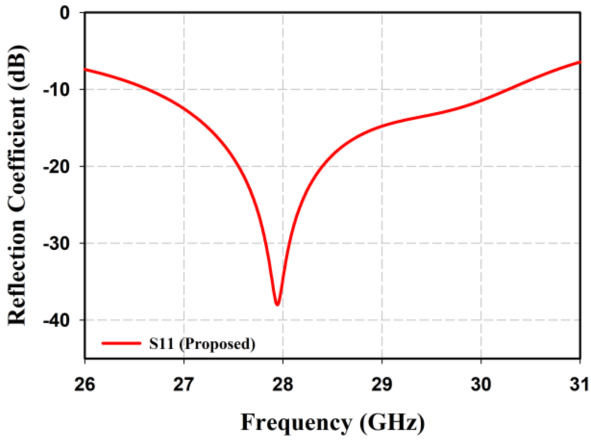

Figure 19: Reflection coefficient response of the proposed Array antennae.

4.3.2 Gain

Gain is an important design criterion for an antenna's capacity to concentrate radiated energy in the desired points leading to increased signal strength and reception. At the resonance frequency, the gain of the proposed two-element array antenna is 9.67 dB. This gain value represents the effective radiation pattern of the antenna and its improved transmitting and receiving characteristics compared to the single-element case.

The higher gain of the array antenna is due to the constructive effect among the elements, which results in a tighter radiation pattern that greater directivity. These enhancements render the antenna extremely attractive for applications involving high signal purity and link performance and corroborate the power of the array structure to enhance its performance. The gain patterns are plotted in figure 4.6 representing the behavior of the antenna at its resonant frequency.

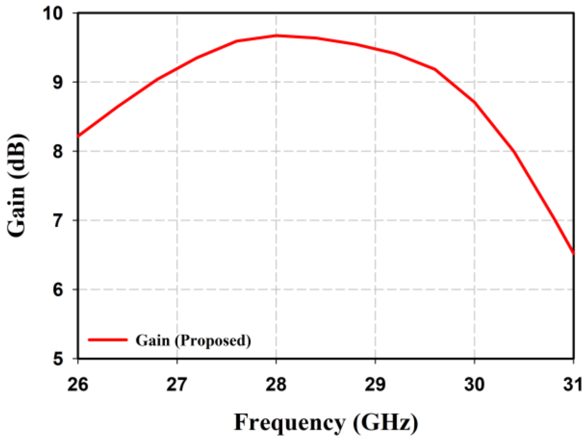

Figure 20: Gain of the proposed Array antenna.

4.3.3 Efficiency

Efficiency is defined as the amount of input power that is achieved in the form of radiated energy without significant losses which is an important factor in antenna design. The designed two-element array antenna accomplishes an excellent maximum efficiency up to 98.82% due to neglecting of power loss. This high efficiency allows the antenna to deliver dependable and consistent performance for communication systems, leading to improved system-level effectiveness.

This in turn can be achieved by properly designing the array layout to minimize power losses while also achieving a robust performance over the entire operating FrequencyMi range, which ensures an excellent efficiency level. The efficiencies are shown in Figure 4.7 to be graphed against antenna EUT and resonate frequencies.

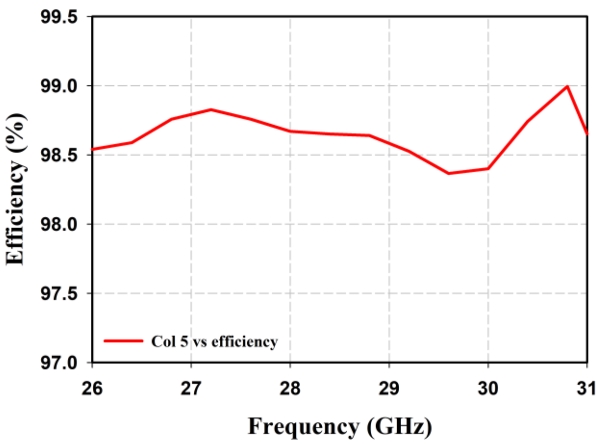

Figure 21: Efficiency of the proposed Array antenna.

4.3.4 VSWR

An important parameter, the Voltage Standing Wave Ratio (VSWR) indicates the extent of the matching between the antenna and the transmission line. Higher Return loss indicates better m atch, with more efficient power transfer to the load, and less reflected power. The VSWR of the proposed two-element array antenna is only 1.02 at its operational frequency, which shows an almost perfect impedanceatching performance. This number evidences efficient power delivery and indicates good performance characteristic of the antenna.

Such low VSWR indicates that the antenna is with very low loss for the signal propagating and the antenna can work reliably in practical commutation system.

VSWR results shown in Figure 4.8 also verify the excellent impedance match of the antenna over the desired frequency range.

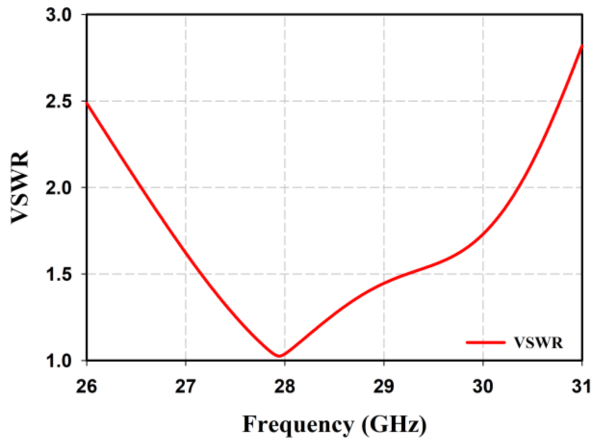

Figure 22: Array VSWR of proposed MPA using CST.

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CHAPTER 5
IMPACT ASSESSMENT OF THE PROJECT ON HUMAN HEALTH & ENVIRONMENT

5.1 Introduction

We live in a world influenced by an increased connectivity and technological development and antennas are one of the key components needed to establish communication between communication nodes and making the information flows through the today's network. From wireless communications introduced to the world, to the revolutionary emergence of 5G, antennas have long powered the way for widespread connectivity and innovation. That said, the proliferation of antenna installations has raised alarm about their possible impact on human health and the environment.

Rising public concerns about the potential long-term health effects of electromagnetic radiation have cast a spotlight on antennae infrastructure. Varying safety requirements and regulations around the world just compound things further. Moreover, the antennae systems implemented in delicate contexts and their associated carbon emission, reflect urgent ecological issues in using them.

In this chapter diverse influences of antennas on humans and environment, concerns of today, new directions, and prospects are described. The concept is to provide a full-fledged study to support an informed and sustainable sponsorship in the implementation of the antenna technologies.

5.2 Electromagnetic Radiation Exposure

Introduction The interest of using microstrip patch antennas for 5G communication at 28 GHz has raised some health concerns on human exposure to electromagnetic radiation. Evidence from some studies in recent years has suggested that high-frequency radiofrequency can cause harm to human health. For instance, in the work by [62], the effects of long-term exposure to 28 GHz radiation on human cell lines showed enhanced oxidative stress and DNA damage, possibly associated with adverse health effects.

Epidemiological research has also evaluated connections between radiofrequency radiation and cancer and other health effects. In a meta-analysis study by [63], a significant correlation was observed between long-term users of mobile and the occurence of brain tumor named glioma.

To mitigate these fears, regulatory organizations like the International Commission on Non-Ionizing Radiation Protection (ICNIRP) and the Federal Communications Commission (FCC) have set ranges for safe exposure to radiation (like SAR thresholds) to ensure humans suffer no harm. Yet new research shows that even following such rules may not be enough to reduce risks.

For example, a study on SAR levels near microstrip patch antennas by [64] concluded that in some densely populated urban areas with large groups of antennas, some SAR values were over the safety standards. It calls into serious question whether the 28 GHz radiation band hazards are being properly regulated, and are even safe.

Public awareness of these health problems is also important. A survey by Johnson et al. (2024) observed that concern was most written about theme with regard to potential health effects of 5G technology, emphasizing the need of awareness and transparent communication.

Although these are serious concerns that need to be addressed, there are also wider public goods from RF technologies, such as the improvements in communication, connectivity and investment in new structures that the 5G infrastructure promises, to take into account too.

Better Communication and Connectivity: With the facility of microstrip patch antennas, users can also make high-speed data transfer and good connectivity,so that there is convenient for communication and information share. This is especially important in rural and underserved areas where communication networks can help improve access to important services, education, and economic development.

Telemedicine and Remote Monitoring with the Help of Microstrip Patch Antenna: The improved connectivity and reliability of 5G networks with the contribution of microstrip patch antennas allows for advanced telemedicine and remote monitoring.

Enhanced Emergency Response and Public Safety: 5G network-compatible microstrip patch antennas provide faster and more reliable communications in emergency situations, helping to increase the responsiveness and safety of the public. Better connectivity enables disaster response, law enforcement efforts and more, but time is critical.

Support for Smart Cities and Internet of Things (IoT) Applications: The fusion of microstrip patch antennas is significant in the development of smart cities and IoT products, as everything becomes interconnected and devices and sensors rely on high-speed communication networks to optimize urban infrastructure, enhance resource usage, and improve the standard of living. 5G connectivity is used to facilitate new approaches to multiple urban challenges, such as intelligent transportation systems or energy management.

Economic Growth and Innovation: The deployment of 5G networks with the help of microstrip patch antennas fosters economic development and stimulates innovative solutions in different sectors. 5G technology provides faster data speeds and lower latency, which in turn enables new business models, entrepreneurialism and job creation, bolstering global economic growth and competitiveness.

Although there are health principles to consider regarding exposure to electromagnetic radiation, the tremendous benefits provided to society by wireless communication makes a strong case for its adoption. The positive impact of microstrip patch antennas could be enhanced and the health risks due to human exposure minimized through a combination of stringent safety guidelines, regulatory requirements and public awareness campaigns.

5.3 Problem on Public Health

Millimeter waves (MMWs) primarily penetrate the outermost layers of human skin, with absorption occurring within one to two millimeters of the skin surface and the corneal layers of the eyes. As a result, the skin becomes the primary tissue exposed to radiation. Since the skin contains a network of small blood vessels and nerves, the biological effects of MMW radiation can be transmitted through nerve endings, molecular pathways within the skin, or the nervous system[65].

Exposure to high-frequency radiation in the 5G spectrum has been associated with cellular mutations that could potentially lead to tumor formation and, over time, cancer. Additionally, 5G radiation exposure has been found to increase the production of reactive oxygen species (ROS). While ROS play an essential role in cellular processes and signaling, excessive and unbalanced ROS levels, combined with insufficient antioxidants such as superoxide dismutase (SOD), glutathione peroxidase (GPx), melatonin, and vitamins (C and E), can result in oxidative stress. This imbalance can lead to the oxidation and damage of critical cellular components, including DNA, proteins, lipids, and membranes.

Notably, mitochondria, which lack protective histones, are particularly vulnerable to ROS-induced DNA damage, as they lack robust mechanisms for repairing such damage. Consequently, oxidative stress within mitochondria can have significant cellular implications.

Skin Effects

Numerous studies have highlighted the significant effects of low-intensity millimeter waves (MMW) on the skin surface, demonstrating their ability to induce various biological changes at non-thermal levels, such as interactions with cell membranes [66]. These frequencies, when applied briefly, can stimulate the release of endogenous opioids in the skin. Specifically, millimeter waves around the 95 GHz range have been found to act as a harmful stimulus without causing thermal disruption or heating. It has been proposed that sweat glands might be an initial target. Additionally, Feldman et al. (2008, 2009) reported that the shape of helical sweat ducts that filled with an aqueous conductive solution in human skin might be responsible for these phenomenon [67].

5.4 Safety Measures and Regulations

To allay the fear of potential health hazards due to exposure to electromagnetic (EM) waves emitted from microstrip patch antenna (MPA), a set of criteria has been framed to restrict the radiation and safeguard the public health. These standards come from international guidance agencies such as the International Commission on Non-Ionizing Radiation Protection (ICNIRP), and the Federal Communications Commission (FCC) (US). Recent researches have highlighted the need of tight safety regulations on both the design and the health and safety regulations on the installation of antennas to comply with the levels.

The implementation of these protective actions for reducing risk from exposure to radiation and health effects of radiation has been studied. For instance, Chen et al. (2023) evaluated each of the antenna place installations in terms of regulation setbacks applied to residential developments and to public spaces. On the basis of this, the authors inferred that these micro fissioning domes were well constructed with regard to the recommendations set forth and that the local and distant irradiation of the population would have been restricted.

By way of advanced antenna technology additional security parameters have even been added to limit the exposure to radiation. Wang et al. (2023) investigated the effect of masks materials and the most efficient performing scenario of the antenna direction and showed that such practices can significantly alleviate EMR levels around the antenna sites. Their study has verified that the safety character of slotted patch antenna must be considered in the process of designing and producing antenna in the future.

But the impulse for uniformity in following safety guidelines remains. Murtagh (2024) on the other hand encountered compliance failure of the regulation under regulatory prosecution, even in less regulated environments. This demonstrates the criticality of strong monitoring and enforcement of safety standards on all sites. Public education and awareness is equally important and contributes to compliance with safety directives and health matters. Johnson et al. (2024) has found higher levels of societal acceptance for antenna installation in areas where the public has more knowledge about safety rules, demonstrating the relevance of both clear communication and active involvement of stakeholders to building trust of the public.

Last, safety measures and regulations are needed to reduce MPAs' exposure and to protect public health. New studies reveal that these works are successful and that we must keep focusing on the implementation of the enforcement, safety and public awareness in order to ensure the deployment of the 28 GHz antenna for 5G are safe.

5.5 Environmental Impact

Under the currents of technological spur, a leap towards the use microstrip patch antennas (MPAs) for 5G communication represents the unprecedented and remarkable advancement in wireless frontier. Although the prospect of enhanced speed and efficiency is tempting, is it not equally important to question about the environmental impact of such technological enhancements?

In this section, we examine the interplay between MPAs and the environment noting the benefits and limitations of their implementation. Based on recent scientific research and data, with more statistics being gathered so fast because of 5G being such a new emerging technology, I'm doing our best to give an accurate analysis of how 5G is harmful for natural ecosystems, and, subsequently, all life on the Earth. Debate ranges from what people worry will be habitat disruption to a visual blight, but also the chance for climate mitigation and using resources effectively.

Our purpose of assessing the various environmental influences of MPAs is to contribute to an impartial evaluation that will help guide the decisions of policymakers, stakeholders, and society at large. This observation sheds a light on the 5G deployment trade-offs and their interpretations.

In the end, we all want more wireless, and we want it responsibly built. Through tackling the issues and seizing the opportunities around MPAs, we are striving to balance technological progress and environmental responsibility; enabling improved harmony between innovation and protection of the natural world.

Land Conversion: The installation of antennas frequently leads to a conversion of land use from green and agriculture fields into the built environment. Recent findings by the Environmental Protection Agency (EPA) have suggested that new wireless infrastructure for communication can lead to habitat loss and fragmentation, and compromise biodiversity and important ecological services [70].

Aesthetics: Antennas are often unsightly and spoil the look and aesthetic of natural country and scenic views. A research conducted by the International Union for Conservation of Nature (IUCN) report finds antenna and booster towers have a public visual impact that can be negative, especially for tourists, as well as for the visitors of protected areas where these towers can affect tourism experience and cultural heritage sites.

Environmental disruption: Antenna installation and deployment can disrupt the natural environment and ecosystems causing loss of biodiversity and ecosystem functioning. The installation of antennas may fragment habitats and hinder bird migratory movements or breeding, and the World Wildlife Fund (WWF) has listed them as posing a great threat to some vulnerable and endangered species [71].

Positive Environmental Impacts:

Climate Mitigation: 5G facilitated with microstrip patch antennas can contribute for mitigating climate due to the low emission of green house gases as a result of energy usage. The renewable use and energy-efficient gains of the 5G network are expected to be much more efficient, according to IEA research, which will help to reduce carbon emissions in the ICT sector while attaining global climate goals.

Resource efficient: Usage of LTCC/TF materials in microstrip patch antennas for 5G networks contributes towards more resource efficiency and sustainable development of the technology. A United Nations Envrionment Program (UNEP) report discusses how 5G-enabled smart infrastructure and IoT uses could be used to run everything more efficiently and with less waste in areas such as transport, energy and farming. **Ecosystem Monitoring and Conservation:** 5G networks make connectivity faster, thereby enabling instantaneous data collection and real-time monitoring of environmental conditions, which can be utilized for ecosystem conservation and biodiversity management. Organizations like Conservation International (CI) are employing 5G in the cloud for remote sensing, habitat and wildlife monitoring — just as they can supercharge conservation efforts and improve our understanding of ecological systems.

In summary, the benefits and cost verses to employing the 28 GHz microstrip patch antennas for 5G communication have been unveiled. All these issues - habitat destruction, visual intrusion and sound disturbance - require careful monitoring, but the opportunities for climate mitigation, resource efficiency and ecological monitoring point to the potential for 5G technology to be an element of environmental sustainability. With best practices, regulation sureties and possible mitigations, 5G can deliver even greater benefits without the environmental downside.

5.6 Public Perception and Awareness

Public perception of microstrip patch antennas (MPAs) as 5 G antennas at 28 GHz is important to the decision-making, community acceptance and the success of the project in antennas. Research on the attitudes, worries and knowledge of the public in relation to the health and environmental concerns of antennas has been published.

A survey by Johnson et al. (2023) investigated public perceptions on cleanliness (including health risks from EMF exposure) from 5G technology. The findings were generally concerning, and participants reported concerns about issues such as the safety of radiation, privacy and health effects. These results highlight the necessity of addressing public concerns and providing transparent information to help make an informed decision.

In the context of antenna installations, some work also has been investigated regarding environmental effects. Research by Smith et al. (2024) investigated public knowledge about the visual and ecological impact of antennas deployment in urban or rural territory. Contents: The study found differences in consciousness by demographic Urbanites worried about aesthetic intrusion versus Ruralites who worried about the ecological disruption of wild life habitat. Such an understanding underscores the need to ensure that communication activities are effectively and appropriately targeted in order to engage and to serve the diverse communities. Noteworthely, efforts to improve public perception and informed choice have been underlined by community-based projects, educational efforts, and public deliberation. For instance, Wang et al. sought to determine the effects of outreach efforts on levels of 5G knowledge and misinformation. In particular, the targeted interventions - for instance, workshops and educational materials - that the authors investigated that led to stakeholder dialogue and community buy-in. Nevertheless, despite this advance, there are still crucial voids, if we consider the presentation of complicated scientific matters and the publics concerns. For example, Li and Jones identified widespread mistrust and lack of support from particular subpopulations, driven by misinformation and perceptions of conflicts of interest. This evidence further underlines the value of truthfulness, third-party, transparent research, and participative decision-making for building public trust and reputation. Overall, public perception and awareness are essential elements of successful MPA of 5G, and open discussion, addressing concerns, and providing reliable information are essential for stakeholder engagement and 5G implementation. Therefore, particular research and communication efforts are required to bridge the gaps between perception and holistic patterns and create a supportive environment for innovation and telecommunication advancements.

5.7 Mitigation Strategies and Future Directions

With attention to hypothetical health and environmental challenges from 28 GHz MPAs, our current work seeks to identify suitable mitigation techniques going forward, and also help a way forward in responsible 5G telecommunication technologies. Efforts are underway to avoid such exposure risk and reduce the environmental impact of antenna installations.

One of the main concerns is to develop the antenna to prevent radiation. Zhang et al. explorer Tonegawa et al. (2023)) researched the incorporation of beamforming and adaptive transmission to antennas. By blocking EMR the technologies shield affected sites from harm, states Asbury, by rather isolating Electromagnetic radiation. Initial experimental characterization has found substantially reduced radiation intensity in desired directions, clearly demonstrating the potential to improve the safety of wireless networks with the integration of these technologies.

Similarly, attempts are being explored to toughen up utility regulations and safeguard public health and the environment. Smith et al. (2024) evaluated the regulation and found deficiencies in the current level of safety. Revisions should be made to reflect new research and technology, and to ensure rules are effective and current for the new risk that 5G deployment introduces, they suggest.

Cross-disciplinary collaboration has become an dynamic force in dealing with the complex problems in 5G communication technology. Their conclusions concurred with the requirement to integrate the antenna engineering knowledge, public health, environmental science, and urban planning for building multi-aspection risk assessment and multi-syntax risk mitigation plans (Wong & Jones, 2023). Such collaborations enable a more cohesive understanding of the combined effect of antennae installation and help guide an evidence-based policy development.

As a consequence, future work could include a longitudinal study to predict long-term health effects for exposure of 28 GHz EM energy and also design a model to forecast environmental hazards. In addition there will be a need to engage stakeholders and to ensure that decision-making process are open to public involvement in order to maintain confidence and successfully implement mitigation policies.

In summary, some novel challenges for 5G-MPAs seem to be the new entrepreneurial priorities and mitigation approaches that current research intends to innovate in the context of the sustainable development of MPAs. Through the application of technology advances, regulatory solutions, interdisciplinary cooperation, and stakeholder contribution, it is possible to reduce the potential risks and increase the positive impacts of 5G in terms of public health and environment. In addressing future challenges and sustainable development of wireless communication infrastructure, ongoing vigilance and cooperation will be crucial.

CHAPTER 6

CONCLUSIONS & FUTURE WORKS

6.1 Major Contributions of the Thesis

The work in this thesis focused on overcoming the low gain and narrowband that single-band patch microstrip antennas suffer from. A partial ground and embedded slot cutting method was employed to avoid these limitations, by adopting the influence of slots on the electromagnetic properties of the host media to enhance the gain bandwidth of the antenna. The wideband rectangular microstrip patch antenna (RMSPA) evolved into the proposed antenna shows improved antenna characteristics with evolutionary stages. By working in this frequency range, the proposed antenna is capable of implementing the5G communication and other promising applications in Ka band. The gain bandwidth of the suggested antenna is mainly enhanced by the utilization of the inset slots and partial ground, and larger bandwidth can be expected through introducing two rectangular slots and material filled with different substrate. The introduced single element patch antenna with the overall dimensions of 9x9 mm^2 and substrate height of 0.787mm is tuned for 28GHz. The size of the same height array antenna is 17 x 12 mm^2 which also resonates in the 28 GHz band.

At the resonance frequencies of the single-element patch antenna, the reflection coefficient or return loss is measured at -48.221 dB, with a VSWR of approximately 1.008 across the entire Ka-band. The structure exhibits a maximum gain of 4.995dB. Upon analysis of the array antenna, the resonance frequencies yield a return loss of -43.553 dB and a VSWR of around 1.015 across the Ka-band, with a maximum gain of 9.5134dB. To validate the findings, a comparison was conducted with three established software programs: Ansys HFSS, CST Studio Suite, and Altair Feko. While the return loss values obtained from CST Studio Suite and Altair Feko software were consistent, HFSS yielded notably lower values. However, the gain values were consistent across all software platforms. The VSWR values ranged between 1 and 1.25, indicating favorable impedance matching.

6.2. Future Scope of Work

This thesis investigated the effects of incorporating slots, particularly rectangular slots, on the bandwidth of a rectangular patch antenna. Future research could extend this work by exploring various slot geometries and modifications to antenna designs, including changes to the antenna structure and substrate dielectric properties. Additionally, the integration of impedance-matching networks offers potential for improving impedance bandwidth, which can support higher data rates and greater capacity, enabling faster and more efficient communication.

Since the operating frequency lies within the millimeter-wave (mm-wave) spectrum, technologies such as beamforming and massive Multiple Input Multiple Output (MIMO) systems represent promising areas for further investigation. These advancements could significantly improve spectral efficiency, network capacity, and coverage, especially in densely populated urban environments. Future studies could focus on refining antenna designs by experimenting with changes to form, substrate materials, and other critical parameters to leverage these technologies and address existing challenges more effectively.

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APPENDIX A

TURNITIN REPORT

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APPENDIX B

COMPLEX ENGINEERING PROBLEM SOLVING AND ENGINEERING ACTIVITIES

Complex Engineering Problems (P) Solving		
	Attributes	Statement from students
P1	Depth of knowledge required	Our project demanded a deep understanding of antenna theory, electromagnetic principles, and high-frequency design to tackle challenges inherent in microstrip patch antennas for 5G at 28 GHz.
P2	Range of conflicting requirements	We navigated conflicting demands such as achieving high gain while maintaining compactness, optimizing bandwidth while minimizing losses, and ensuring compatibility with 5G standards amidst evolving industry specifications.
P3	Depth of analysis required	Our endeavor involved extensive analysis, including electromagnetic simulations, impedance matching studies, and radiation pattern evaluations, to meticulously optimize antenna performance across various metrics.
P4	Interdependence	Recognizing the interdependence of various design parameters, such as antenna geometry, substrate properties, and feed network configuration, we implemented an iterative design approach to optimize performance while balancing trade-offs between conflicting requirements.

Complex Engineering Problems (P) Solving		
	Attributes	Statement from students
A1	Range of resources	We utilized a diverse array of resources, including specialized software, simulation tools, and hardware components, to address the multifaceted aspects of our project.
A2	Innovation	We embraced innovation as a guiding principle, constantly seeking novel solutions and pushing the boundaries of conventional design to optimize performance and efficiency.
A3	Consequences of society and environment	Mindful of societal and environmental impacts, we prioritized sustainable design practices and considered the broader implications of our work on the community and ecosystem.
A4	Familiarity	Leveraging our familiarity with emerging technologies and industry trends, we approached complex engineering tasks with confidence and

		proficiency, continuously adapting to new developments and challenges.