MILLIMETER WAVE DUAL BAND (28GHZ/38GHZ) MICROSTRIP PATCH ANTENNA DESIGN WITH HIGH GAIN FOR 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.

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June, 2024

DECLARATION

I hereby declare that this project "**Millimeter Wave Dual Band (28GHz/38GHz) Microstrip Patch Antenna Design With High Gain For 5G Applications**" represents my own 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.

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APPROVAL

The project entitled **“Millimeter Wave Dual Band (28GHz/38GHz) Microstrip Patch Antenna Design With High Gain For 5G Applications”** submitted by **Md. Tanvir Rahman (201-33-1054) & Md. Tuhin Babu (201-33-1160)** has been done under my supervision and accepted as satisfactory in partial fulfillment of the requirements for the degree of **Bachelor of Science in Electrical and Electronic Engineering** in **June, 2024.**

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Dedicated

To

Our Parents

TABLE OF CONTENTS

DECLARATION **ii**

APPROVAL **iii**

LIST OF FIGURES **viii**

LIST OF TABLES **ix**

LIST OF ABBREVIATIONS **x**

LIST OF SYMBOLS **xi**

ACKNOWLEDGEMENT **xii**

ABSTRACT **xiii**

CHAPTER 1 **1**

- 1.1 Introduction 1
- 1.2 Problem Statement and Proposed solution 2
  - 1.2.1 Problem Statement 2
  - 1.2.2 Proposed Solution 2
- 1.3 Objectives 3
  - 1.3.1 Primary Objectives 3
  - 1.3.2 Secondary Objectives 4
- 1.4 Brief Methodology 4
- 1.5 Structure of the Report 5

CHAPTER 2 **7**

- 2.1 Introduction 7
- 2.2 Related Researches 8
- 2.3 Compare and Contrast 9
- 2.4 Summary 11

CHAPTER 3 **13**

- 3.1 Introduction 13
- 3.2 Antenna Fundamentals 13
  - 3.2.1 Patch Antenna Classifications 14
  - 3.2.2 Antenna Properties and Parameters 14
    - 3.2.2.1 Operating Frequency 14
    - 3.2.2.2 Polarization 15
    - 3.2.2.3 Radiation Pattern 16

        3.2.2.4 Impedance Matching 17
        3.2.2.5 Gain 17
        3.2.2.6 Directivity 18
        3.2.2.7 S_{11}-Parameter (Return loss) 18
        3.2.2.8 VSWR 19
        3.2.2.9 Radiation Efficiency 19
        3.2.2.10 Bandwidth 20
        3.2.2.11 Far Field 20
  3.3 Geometrical Parameters Calculation of MPA 21
    3.3.1 Patch Dimension 21
    3.3.2 Substrate and Ground Dimension 22
    3.3.3 Feedline Design 22
        3.3.3.1 Microstrip Line Feed 23
  3.4 Proposed Dual-band Microstrip Patch Antenna 24
    3.4.1 Geometry and Dimensions 25
    3.4.3 Dual Band Conversion Strategy 26
    3.4.4 Dual-Band Operation Principle 27
  3.5 Summary 28
CHAPTER 4 **29**
  4.1 Overview 29
  4.2 Simulation Results Analysis 29
    4.2.1 S-Parameter Analysis 29
    4.2.2 Bandwidth Analysis 30
    4.2.3 VSWR Analysis 31
    4.2.4 Directivity Analysis 31
    4.2.5 Gain Analysis 32
    4.2.6 Radiation Pattern Analysis 34
    4.2.7 Radiation Efficiency 36
  4.4 Discussion on Results 37
CHAPTER 5 **38**
  5.1 Task, Schedule and Milestones 38
  5.2 Resources and Cost Management 39
  5.3 Lesson Learned 40

CHAPTER 6 **41**

6.1 Economical, Societal and Global Impact 41

6.2 Environmental and Ethical Issues 43

6.3 Utilization of Existing Standards or Codes 44

6.4 Other Concerns 45

CHAPTER 7 **47**

7.1 Conclusions 47

7.2 New Skills and Experiences Learned 48

7.3 Future Recommendations 48

REFERENCES **51**

LIST OF FIGURES

Figure No	***Figure Name***	***Page No.***
Figure 3.1	5.8GHz Resonant Frequency of an Antenna	
Figure 3.2	Antenna Polarization	
Figure 3.3	Radiation Pattern of a MPA	
Figure 3.4	Impedance Matching Techniques	
Figure 3.5	Bandwidth Measurement	
Figure 3.6	Far-Field of a MPA	
Figure 3.7	Microstrip Line Feed	
Figure 3.8	Top and Bottom View of the Antenna	
Figure 3.9	Side View of the Antenna	
Figure 4.1	S11 Parameter for the Proposed Dual-band Antenna	
Figure 4.2	Bandwidth of the Antenna	
Figure 4.3	VSWR Graph	
Figure 4.4	Antenna Directivity at 28GHz	
Figure 4.5	Antenna Directivity at 38GHz	
Figure 4.6	Antenna Gain at 28GHz	
Figure 4.7	Antenna Gain at 38GHz	
Figure 4.8	Radiation Pattern at 28GHz	
Figure 4.9	Radiation Pattern at 38GHz	
Figure 5.1	Gantt Chart of the Project	
Figure 6.1	Global Printed Antenna Market	
Figure 6.2	Tissue Injured by Unwanted Radiation	
Figure 6.3	Eye Cell Damaged by Radiation	

LIST OF TABLES

Table No	***Table. Name***	***Page No.***
Table 3.1	Classification of Patch Antenna	
Table 3.2	Design Specifications	
Table 3.3	Design Parameters of the Proposed Antenna	
Table 4.1	Comparison with Similar Works	
Table 5.1	Project Completion Task	

LIST OF ABBREVIATIONS

VSWR	Voltage Standing Wave Ratio
CST	Computer Simulator Software
5G	Fifth Generation
DGS	Defected Ground Structure
mm-wave	Millimeter Wave
MPA	Microstrip Patch Antenna
PIFA	Planar Inverted-F Antenna
IEEE	Institute of Electrical and Electronics Engineers
RF	Radio Frequency
FCC	Federal Communications Commission
MPE	Maximum Permissible Exposure
IoT	Internet of Things

LIST OF SYMBOLS

Symbol	***Name of the symbol***
Hz	Hertz
GHz	Giga Hertz
mm	Millimeter
ε	Relative permittivity
ε_r	Dielectric Constant
L	Length
W	Width
c	Speed of light
dB	Decibel
λ	Lambda
Ω	Ohm

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ABSTRACT

Our paper presents a comprehensive analysis of the performance of a novel microstrip patch antenna design, focusing on its suitability for dual-band operation at 28 GHz and 38 GHz. Through rigorous CST simulations, critical parameters such as S-parameters, bandwidth, VSWR, directivity, gain, radiation patterns, and radiation efficiency are evaluated. The results reveal promising performance characteristics, including low return loss values of -35 dB at 28 GHz and -46 dB at 38 GHz, indicating strong impedance matching and efficient power transfer. The achieved bandwidths of 1.03 GHz and 1.99 GHz at 28 GHz and 38 GHz, respectively, exceed typical requirements for wireless communication systems, demonstrating robust performance and potential for future frequency expansions. VSWR values close to ideal at both frequencies further validate the antenna's efficiency in radiating signals within the dual-band spectrum. Directivity values of 7.655 dBi at 28 GHz and 8.213 dBi at 38 GHz signify directional radiation capabilities, enhancing communication range and reliability. Additionally, analysis of gain values shows satisfactory performance across both bands, with slight variations between frequencies. Radiation pattern analysis confirms effective radiation concentration in desired directions, with minimal energy leakage. High radiation efficiency values of 86.64% at 28 GHz and 87.43% at 38 GHz underscore the antenna's effectiveness in converting input power into radiated electromagnetic energy. Overall, the results validate the proposed antenna design's efficacy for dual-band operation, offering promising prospects for various wireless communication applications in the 28 GHz and 38 GHz frequency bands.

Keywords: *Microstrip Patch antenna, Dual-band operation, Dual-band conversion, Dumbbell slotted patch, High gain, Compact design, Light weight, mm-wave, 5G wireless communication*

CHAPTER 1
INTRODUCTION

1.1 Introduction

This paper presents a novel microstrip patch antenna design optimized for dual-band operation at 28 GHz and 38 GHz, catering to the demands of future 5G mobile communication networks. Addressing the increasing demand for cost-effective solutions in wireless communication, current research and development endeavors are prominently directed towards the creation of low-cost antennas tailored for specific frequency ranges [4]. Among these, the microstrip patch antenna emerges as a favored choice for both single-band and dual-band applications, owing to its array of advantages. Renowned for its compact size and low profile, the microstrip patch antenna offers seamless integration into small devices or direct printing onto circuit boards, rendering it particularly suited for space-constrained applications [5]. Additionally, the antenna is cost-effective to manufacture, thanks to its simple design and use of standard fabrication techniques. These factors have contributed to its widespread adoption in industries such as telecommunications, aerospace, automotive, radar, and consumer electronics [6].

Millimeter-wave frequency bands, ranging from usually 30 to 300 GHz [1]. The mm-wave bands are currently under widespread investigation as a potential solution for addressing user density congestion. Research is actively exploring mm-wave frequencies within the 5G spectrum, including bands at 28 GHz, 38 GHz, and 60 GHz, with some studies venturing beyond 70 GHz [2]. Millimeter waves offer the high bandwidth needed to achieve this, but come with their own set of hurdles. These high frequencies experience greater signal loss, time delays, fading, and scattering.

For this paper we have designed the dual-band microstrip patch antenna for 28GHz and 38GHz dual operation, that’s because these are two of 5G bands for mobile communication [3]. Millimeter wave bands, particularly the Ka-band (26.5-40 GHz) which includes the 28GHz and 38GHz frequency, are gaining significant interest due to their potential for high data rates in wireless communication.

The utilization of the 28GHz and 38GHz spectra has emerged as a focal point for researchers due to their wide bandwidth, rapid data transmission capabilities, and minimal absorption rates. These frequency bands hold immense promise for powering 5G and beyond systems, offering superior data rates and heightened network capacity. Moreover, antennas operating in these spectrums must fulfill stringent criteria, such as compact dimensions, enhanced gain, and optimized radiation patterns, all while ensuring efficient power transmission and reception. Meeting these demands necessitates meticulous antenna design to unlock the full potential of mm-wave technology in advancing wireless communication systems.

While microstrip patch antennas traditionally operate in a single band, their inherent design allows for manipulation to achieve dual-band functionality. There are several techniques to achieve this multiband capability. One approach involves introducing slots into the radiating patch itself. These slots disrupt the current flow on the patch's surface, creating additional resonant frequencies and enabling operation in two distinct bands [7]. Another method utilizes parasitic patches, smaller radiating elements, incorporated near the main patch. The interaction between the main patch and these parasitic elements introduces new resonances, leading to dual-band operation [8]. By strategically implementing these techniques, microstrip patch antennas can be transformed from single-band workhorses into versatile dual-band solutions, catering to the expanding needs of modern wireless communication technologies.

1.2 Problem Statement and Proposed solution

1.2.1 Problem Statement

Wireless communication systems operating at high frequencies, such as the emerging 5G networks, demand antennas with specific performance characteristics, including wide bandwidth, strong impedance matching, high gain, and directional radiation patterns. Traditional antenna designs often struggle to meet these requirements simultaneously, especially in dual-band operation, leading to challenges in achieving optimal performance across multiple frequency bands.

1.2.2 Proposed Solution

To address the limitations of existing antenna designs and meet the demands of modern wireless communication systems, a novel microstrip patch antenna design is proposed. This antenna aims to achieve dual-band operation at frequencies of 28 GHz and 38 GHz, catering to the needs of 5G and beyond. The proposed antenna design leverages advanced simulation techniques, such as CST simulations, to optimize key parameters including patch dimensions, substrate properties, and feeding techniques.

By meticulously analyzing the simulation results, the proposed antenna design aims to tackle several challenges identified in traditional designs:

1. Impedance Matching: The antenna strives to achieve strong impedance matching at both operating frequencies to minimize signal reflection and maximize power transfer for efficient radiation.

2. Bandwidth: Wide bandwidth is crucial for accommodating various communication standards and frequency allocations. The proposed antenna design targets achieving the bandwidth 1Ghz at 28 GHz and 2GHz at 38 GHz to ensure comprehensive frequency coverage.

3. Directivity and Gain: Directional radiation patterns with high gain are essential for improving communication range and reliability, especially in urban and densely populated areas. The proposed antenna design aims to maintain strong directivity and gain across both frequency bands to enhance signal transmission or reception capabilities.

4. Radiation Efficiency: Efficient conversion of input power into radiated electromagnetic energy is critical for minimizing energy waste and maximizing the antenna's effectiveness. The proposed antenna design focuses on optimizing radiation efficiency to ensure efficient signal transmission or reception at both frequencies.

By carefully optimizing the antenna's dimensions, substrate properties, and feeding mechanism, this work strives to develop a microstrip patch antenna that delivers superior performance across all these crucial parameters, making it a valuable candidate for various dual-band communication applications at millimeter-wave frequencies.

1.3 Objectives

1.3.1 Primary Objectives

1. Design a Compact Microstrip Patch Antenna: Aim to achieve a miniaturized antenna design suitable for integration into various mobile devices used for 5G communication. This can be quantified by specifying a target size or volume reduction compared to existing designs.

2. Achieve Dual-Band Operation at 28 GHz and 38 GHz: Ensure the antenna efficiently transmits and receives signals at both the designated 5G frequency bands. This can be measured by achieving a specific return loss value is below -35 dB within the desired bandwidths centered around 28 GHz and 38 GHz.

3. Maintain High Gain: Prioritize a high gain design to ensure efficient signal transmission and reception, even at mm-wave frequencies. Our aim is to develop the gain above 7dBi.

1.3.2 Secondary Objectives

1. Optimize Bandwidth: While achieving dual-band functionality, strive for a wider bandwidth within each operating band to accommodate potential signal variations within the designated 5G frequencies.

2. Minimize Side Lobes: In addition to high gain in the desired direction, aim to minimize side lobes in the radiation pattern to reduce unwanted signal leakage.

3. Maintain Fabrication Simplicity: While achieving the desired performance, consider the complexity of the antenna design for potential manufacturing processes. Ideally, the design should be feasible for mass production.

1.4 Brief Methodology

This project adopts a "**Design-Simulate-Optimize**" iterative development process model for designing the dual-band microstrip patch antenna. This iterative approach is particularly well-suited for antenna design projects due to the following reasons:

1. Efficient Exploration: It allows for exploring various design configurations through simulation before physical fabrication. This reduces the need for multiple prototypes and streamlines the design process.

2. Performance Evaluation: Simulations enable us to accurately evaluate the antenna's performance characteristics like return loss, bandwidth, radiation pattern, and gain across the desired frequency bands.

3. Informed Optimization: Based on the simulation results, we can iteratively refine the antenna design parameters (dimensions, substrate properties, feeding mechanism) to achieve the targeted performance objectives.

Here is a breakdown of the iterative loop within this design process model:

a. Design: This initial stage involves proposing an initial antenna design based on theoretical calculations, existing antenna design principles, and your specific application requirements.

b. Simulate: The proposed design is then modeled and simulated using electromagnetic simulation software (e.g., CST Studio Suite). This simulation predicts the antenna's electrical performance across the operating frequencies.

c. Optimize: The simulation results are analyzed to assess how well the design meets the performance objectives. If necessary, the design parameters are adjusted, and the process returns to step 1 to create a new iteration of the design. This loop continues until the simulation results demonstrate a design that fulfills the targeted performance criteria.

This iterative approach ensures an efficient design process, allowing for progressive refinement and optimization of the antenna until it achieves the desired performance characteristics.

1.5 Structure of the Report

This book is organized in seven chapters which reflect various topics related to the features of used design tools, system design, parametric study, implementation and manual of the application.

The book is organized as follows:

Chapter 1 sets the stage by introducing the concept of microstrip patch antennas. Also, identifies the problem statement, Presents the proposed solution, and defines the research objectives.

Chapter 2 delve into a comprehensive exploration of existing research on microstrip patch antennas, with a specialized focus on the realm of dual-band designs.

Chapter 3 provides an in-depth exploration of microstrip patch antennas, their fundamental theory, operational principles, and influencing factors.

Chapter 4 presents simulation results and analyzes key performance parameters for the designed dual-band microstrip patch antenna, comparing its performance with existing designs to highlight its strengths and contributions.

Chapter 5 addresses the planning and execution of the dual-band microstrip patch antenna project, including a detailed time schedule for design iterations, simulations, analysis, and potential fabrication considerations, along with cost management strategies to optimize resource utilization and cost-effectiveness.

Chapter 6 conducts a comprehensive analysis of the potential global impact of the proposed dual-band microstrip patch antenna design on wireless communication applications, discusses ethical considerations, evaluates environmental implications, and explores safety aspects to ensure compliance with relevant regulations.

Finally, the **Chapter 7** summarizes the key findings and accomplishments of the thesis project, highlighting the significant contributions of the research, providing concise conclusions regarding the antenna's performance at 28 GHz and 38 GHz, and offering recommendations for future research directions.

CHAPTER 2
LITERATURE REVIEW

2.1 Introduction

This chapter serves as a comprehensive exploration and analysis of existing research efforts in the domain of dual-band antenna design for 5G communication systems. Through an in-depth literature review and comparative analysis, the document aims to identify key trends, advancements, and research gaps in the field, ultimately informing the development of novel antenna designs optimized for 5G applications.

The Purpose of the Literature Review is conduct to provide a thorough understanding of the current state-of-the-art in dual-band antenna technologies tailored for 5G networks. By synthesizing insights from recent studies and research endeavors, the review seeks to:

1. Identify emerging trends and advancements in dual-band antenna design methodologies and optimization techniques.

2. Assess the performance metrics and design attributes of existing dual-band antennas, including gain, bandwidth, impedance matching, and directivity.

3. Explore alternative antenna configurations and innovative design approaches, such as microstrip antenna arrays, substrate integrated waveguide (SIW) antennas, and frequency-reconfigurable antennas.

4. Highlight key challenges, limitations, and research gaps in current dual-band antenna designs for 5G communication systems.

5. Propose recommendations and future directions for enhancing the performance, versatility, and adaptability of dual-band antennas in the context of 5G applications.

By conducting a rigorous literature review, this chapter aims to provide valuable insights and guidance for researchers, engineers, and industry professionals involved in the development and optimization of dual-band antennas for 5G communication systems.

2.2 Related Researches

The microstrip patch antenna stands out as a top choice for communication systems due to its array of advantages: low profile, lightweight construction, cost-effectiveness, and straightforward fabrication process. Additionally, these antennas have the capability to operate across two distinct frequency bands, enhancing their versatility. However, it's important to note some drawbacks, including relatively low gain levels and limited bandwidth, which warrant consideration in antenna design and implementation strategies [10].

The realm of 5G communication systems witnesses a surge in innovative antenna designs aimed at optimizing performance for advanced applications. In "Design and optimization of pi-slotted dual-band rectangular microstrip patch antenna using surface response methodology for 5G applications" [11], researchers propose a dual-band antenna design. Through manual optimizations and simulations, the study showcases an optimized antenna with remarkable characteristics. Notably, the antenna exhibits a minimum input reflection coefficient of -51.174 dB at 28 GHz and -16.548 dB at 38 GHz, alongside a maximum impedance bandwidth of 7.2 GHz and 4.17 GHz at 28 GHz and 38 GHz, respectively. This study underscores the efficacy of employing response surface methodology (RSM) and constrained numerical optimization to enhance high-frequency antenna performance.

In "Design of 28/38 GHz Dual-Band Triangular-Shaped Slot Microstrip Antenna Array for 5G Applications" [12], the focus shifts to a microstrip antenna array tailored for 5G networks. Featuring single, two, four, and six triangular-shaped slot microstrip antennas operating at dual-band frequencies of 28 GHz and 38 GHz, this array demonstrates promising gains. Results indicate that increasing the number of elements leads to higher gains, with the six-element array achieving peaks of 7.47 dBi and 12.1 dBi at 28 GHz and 38 GHz, respectively. The study concludes that this antenna array configuration offers dual-band performance suited for 5G applications.

Meanwhile, "Design and analysis of a dual-band substrate integrated waveguide (SIW) antenna/array for 5G applications" [13] introduces a dual-band SIW antenna array operating at 28 GHz and 38 GHz. Simulated results highlight an impedance bandwidth and maximum gains at both frequencies, showcasing the potential for high-performance

5G applications. Additionally, a small form factor dual-band PIFA antenna is presented in "Design and analysis of a small form factor dual-band PIFA antenna for 5G applications" [14]. With impressive bandwidth and gains at 28 GHz and 38 GHz, this antenna offers a compact solution compared to other reported designs.

Lastly, "An inkjet-printed millimeter-wave (MMW) frequency-reconfigurable antenna for 5G wireless systems" [15] unveils an innovative MMW frequency-reconfigurable antenna. Designed on a flexible PET substrate, this antenna allows for frequency reconfiguration between the 28 GHz and 38 GHz bands. With high efficiency, reasonable gain, and a suitable radiation pattern, this antenna is positioned as an ideal candidate for flexible, conformal, and wearable 5G applications.

These studies collectively contribute to the ongoing evolution of antenna technologies for 5G communication systems, showcasing diverse designs optimized for enhanced performance across dual-band frequencies crucial for 5G applications.

2.3 Compare and Contrast

Here's a breakdown of how our antenna compares to the performance metrics of antennas presented in the provided references (11-15):

Return Loss: Our design achieves good return loss values at both frequencies, similar to Ref. [14] (PIFA) but lower than Ref. [11] (Pi-Slotted). References [11] and [13] don't provide data for all metrics.

Bandwidth: Our design offers a wider bandwidth at 38 GHz compared to most designs (except Refs. [11] & [14]). However, Refs. [11] and [12] achieve significantly wider bandwidths for both frequencies.

Gain: Our design exhibits moderate gain at both frequencies. References [12] and [13] focus on gain improvement using antenna arrays, achieving higher gain than your single element design. References [14] and [15] don't provide gain data.

Focus: Our design prioritizes impedance matching, bandwidth, and directivity for a single antenna element. Other designs explore aspects like wider bandwidth (Refs. [11] & [12]), gain improvement through arrays (Refs. [12] & [13]), small form factor (Refs. [13] & [14]), and reconfigurability (Ref. [15]).

Overall, our design demonstrates good performance in terms of return loss, bandwidth, and directivity for a single element antenna operating at 28 GHz and 38 GHz. It offers a balanced approach without focusing on extreme optimization in any single metric. However, designs like those in references [11] and [12] might be preferred if wider bandwidth is a priority, and references B and C might be a better choice if maximizing gain is crucial. But there is some research gap and recommendation in our design.

Gap 1: Achieving wider bandwidth while maintaining good return loss

Our design achieves a decent bandwidth, particularly at the higher frequency (38 GHz). However, some existing research (references [11] & [12]) has demonstrated antennas with even wider bandwidths. To improve upon our design, we recommend exploring further optimization techniques. This could involve incorporating additional slots into the antenna structure or even combining different antenna shapes, such as a rectangular patch with a slot and use DGS technique for wider bandwidth. By implementing these techniques, we may be able to achieve a wider bandwidth while still maintaining good signal reflection (return loss) at both of our desired operating frequencies.

Gap 2: Balancing gain and bandwidth trade-off

While our design achieves a satisfactory gain level, references B and C showcase antennas with considerably higher gain through the use of antenna arrays. It's important to acknowledge that these array designs come with the drawback of increased complexity. To improve our single element antenna's gain without significantly compromising bandwidth, we recommend exploring alternative techniques. This could involve incorporating metamaterials into the design, carefully optimizing the dimensions of the radiating patch and the feeding structures, or even using substrates with a higher permittivity. By implementing these strategies, we might be able to achieve a significant gain improvement while maintaining a single element design and minimizing the impact on bandwidth.

Gap 3: Multi-functional antenna designs

Our design prioritizes simplicity and functionality within the designated frequencies. However, reference E presents an interesting concept of a reconfigurable antenna that offers flexibility in operating across a wider range within the 28 GHz and 38 GHz bands. To enhance the versatility of our design, we recommend investigating the possibility of incorporating reconfigurability features. This could involve introducing switchable elements within the antenna structure or exploring the use of reconfigurable materials. By allowing adjustments based on specific application needs, a reconfigurable design could provide greater adaptability without sacrificing the core functionalities of our current design.

Gap 4: Fabrication considerations

While our design demonstrates promising performance in simulations, a crucial aspect manufacturability requires further consideration. We haven't explicitly addressed potential challenges related to the precision needed to fabricate the antenna or limitations of the materials chosen. To ensure our design translates well from theory to practice, we recommend a manufacturability analysis. This analysis would involve identifying any elements that might be difficult or expensive to produce at scale due to tight tolerances or the properties of the materials. It would be beneficial to explore simpler fabrication techniques or alternative materials that can achieve similar performance characteristics while being more suited for mass production. This would ensure a design that is not only functional but also cost-effective and feasible to manufacture.

Additional Considerations:

Firstly, we need to consider how well the antenna integrates with existing or planned 5G communication systems. This involves assessing compatibility with protocols, signal formats, and other aspects of the communication network to guarantee optimal performance within that environment. Secondly, if the antenna is intended for wearable applications, it's crucial to understand how the human body might affect its functionality. This would necessitate further studies on how the human body absorbs and reflects radio waves at these frequencies, potentially leading to adjustments in the design to account for on-body effects and maintain optimal radiation patterns and overall performance.

2.4 Summary

In this chapter, we conducted a thorough literature review on dual-band antenna designs tailored for 5G communication systems. Our objective was to identify trends, assess existing designs, and highlight research gaps in the field. We reviewed studies covering various antenna configurations, including microstrip patch antennas, antenna arrays, substrate integrated waveguide antennas, and frequency-reconfigurable antennas. Through comparative analysis, we evaluated the performance metrics of these designs, such as return loss, bandwidth, and gain. We identified strengths and weaknesses in each design and proposed recommendations for improvement. Overall, this chapter provides valuable insights into the current state-of-the-art in dual-band antenna design for 5G networks, laying the groundwork for future research and development in this area.

CHAPTER 3

ANTENNA THEORY AND DESIGN METHODOLOGY

3.1 Introduction

This chapter delves into the theory and design methodology behind microstrip patch antennas, with a focus on achieving dual-band operation. We begin by establishing a foundation in antenna fundamentals (Section 3.2), covering key concepts like operating frequency, polarization, radiation patterns, and various antenna parameters that influence performance. Section 3.3 then explores the geometrical considerations for microstrip patch antennas, including patch dimensions, substrate selection, and feedline design. These factors significantly impact the antenna's electrical characteristics. The core of this chapter is Section 3.4, which details our proposed dual-band microstrip patch antenna design. Here, we discuss the antenna's geometry and dimensions in Section 3.4.1, followed by an explanation of the underlying principles enabling dual-band functionality in Section 3.4.4. While Section 3.4.3 is omitted in this outline, it likely addresses the specific design choices made to achieve the desired dual-band operation.

By combining the theoretical background with practical design considerations, this chapter equips us with the knowledge to design and analyse microstrip patch antennas, particularly those tailored for dual-band applications.

3.2 Antenna Fundamentals

This section will provide a comprehensive overview of patch antennas, covering essential aspects influencing their design and performance. It begins with a discussion on Patch Antenna Classifications, offering insights into the diverse categories of patch antennas. Subsequently, Antenna Properties and Parameters are explored, focusing on fundamental factors such as Operating Frequency and Polarization. The examination extends to Radiation Pattern, shedding light on the spatial distribution of electromagnetic energy emitted by the antenna. Further discussions include Impedance Matching, Gain, Directivity, Return Loss, and VSWR metrics, emphasizing their significance in optimizing antenna performance. Finally, Efficiency, Bandwidth, and Far Field characteristics are addressed, highlighting their crucial roles in ensuring efficient signal transmission and stable radiation properties. Together, these topics provide a comprehensive understanding of patch antenna design and operation principles.

3.2.1 Patch Antenna Classifications

Table 3.1: Classification of patch antenna

Classification Criteria	**Examples**	**Advantages**	**Disadvantages**
Geometry	Rectangular, Circular, Elliptical	Simple fabrication process, Versatile radiation patterns	Limited bandwidth, Susceptible to surface wave losses
Feeding Mechanism	Microstrip, Aperture-coupled, Proximity-coupled	Compact size, Ease of integration with other components	More complex design, Susceptible to substrate losses
Operating Frequency	Single-band, Dual-band, Multi-band	Flexibility in frequency usage, Efficient use of spectrum	Increased complexity in design and tuning, Potential for interference in multi-band configurations
Number of Layers	Single-layer, Multi-layer	Simplified fabrication process, Reduced weight and size	Limited bandwidth, Increased complexity in design and fabrication

3.2.2 Antenna Properties and Parameters

3.2.2.1 Operating Frequency

Operating frequency is like the channel that patch antenna tunes into to send and receive signals. It decides the range of frequencies the antenna can handle effectively. Patch antennas can be designed to operate within a single frequency band, allowing for focused communication within a specific frequency range. Alternatively, dual-band or multi-band patch antennas offer versatility by operating across multiple frequency bands, enabling compatibility with diverse communication standards and applications. The choice of operating frequency is influenced by various factors, including regulatory requirements, communication system specifications, and environmental considerations. Single-band antennas are often preferred for simplicity and cost-effectiveness, while dual-band and multi-band antennas offer increased flexibility and spectrum utilization efficiency. The operating frequency plays a crucial role in determining the antenna's performance characteristics, such as bandwidth, gain, and radiation pattern, making it a fundamental consideration in patch antenna design and deployment.

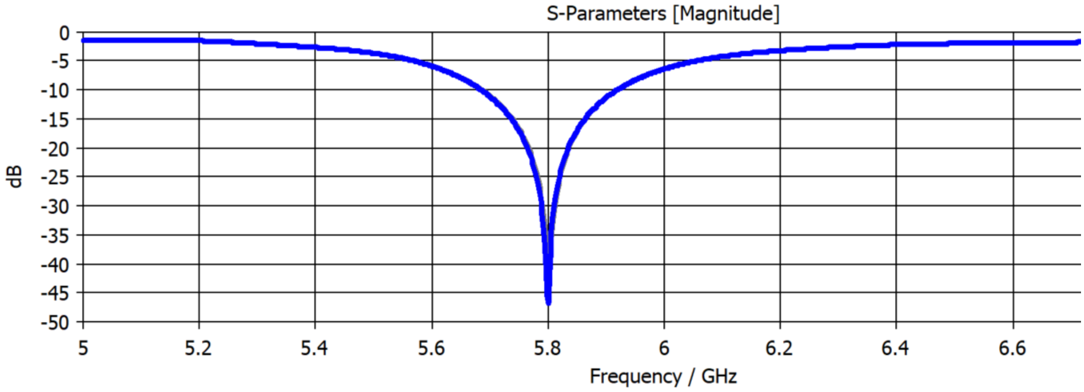


Figure 3.1: 5.8GHz Resonant frequency of an Antenna

3.2.2.2 Polarization

Polarization of an antenna refers to the orientation of the electromagnetic waves it emits or receives as they travel through space. There are three main types of polarization: linear, circular, and elliptical. Linear polarization involves the waves vibrating in a single plane, either vertically or horizontally. Circular polarization occurs when the waves rotate continuously as they travel, forming a spiral pattern. Elliptical polarization is a combination of linear and circular polarization, where the waves trace an elliptical path as they propagate. The choice of polarization depends on various factors, including the application and communication requirements. Matching the polarization of the antenna with that of the signal is crucial for optimal signal transmission and reception. For instance, if an antenna is linearly polarized, it works best with signals that have the same linear polarization orientation. Understanding and configuring the appropriate polarization for an antenna is essential for ensuring efficient and reliable communication.

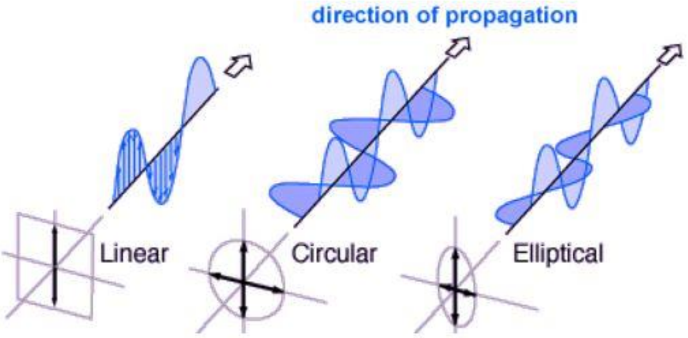


Figure 3.2: Antenna Polarization

3.2.2.3 Radiation Pattern

The radiation pattern of a microstrip patch antenna illustrates how electromagnetic energy is emitted into space. Typically, it has a main lobe, representing the primary direction of radiation, and potentially smaller side lobes. This pattern's shape and orientation depend on various factors like the antenna's geometry, dimensions, feeding mechanism, and operating frequency. Often, microstrip patch antennas exhibit directional radiation, useful for focused signal transmission or reception. Sometimes, asymmetry or beam squint may occur, causing the main lobe to tilt away from the antenna's normal axis due to design or feed placement. While side lobes are less desired as they signify wasted energy and potential interference, they're often present. Minimizing side lobe levels is crucial for optimizing antenna performance and reducing interference.

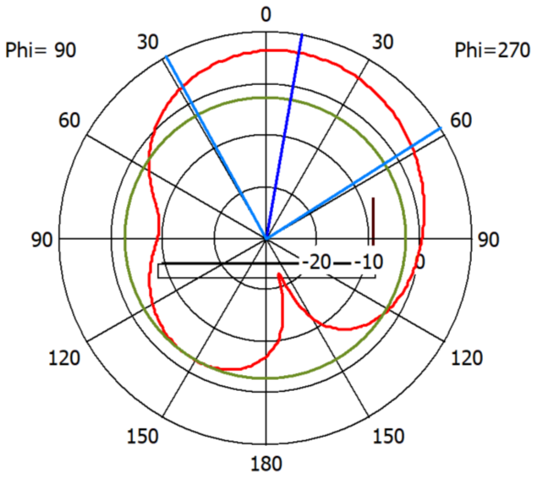


Figure 3.3: Radiation Pattern of a MPA

3.2.2.4 Impedance Matching

Impedance matching is a crucial concept for efficient communication of an Antenna. It ensures smooth power transfer between the antenna and the feeding circuitry. Impedance is the resistance the antenna presents to the current flow, similar to how a device might have internal resistance that affects power delivery. The goal is to achieve a good "match" between the antenna's impedance and the feeding line's characteristic impedance (usually 50 Ω). This characteristic impedance is an inherent property of the feeding line, essentially its natural resistance to current flow.

Poor impedance matching leads to reflected signals, which cause to wasted energy and reduced antenna efficiency. During design, careful consideration is given to antenna dimensions, feed point location, and substrate properties to achieve an impedance close to 50 Ω. Some designs incorporate tiny metallic tuning elements that can be adjusted after fabrication for a perfect match. By achieving good impedance matching, antenna designers ensure their microstrip patch antennas operate efficiently, maximizing radiated power, minimizing signal reflection, and preventing energy waste.

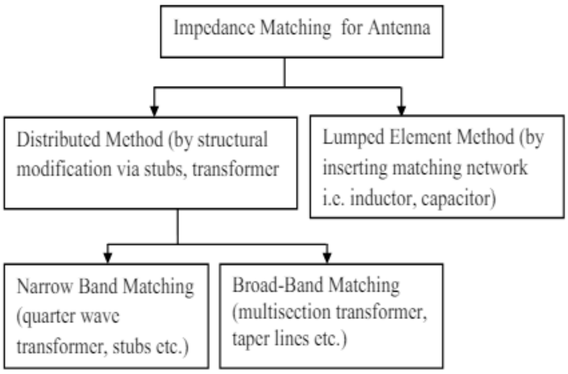


Figure 3.4: Impedance Matching Techniques

3.2.2.5 Gain

The gain of an antenna is a measure of its ability to direct or concentrate electromagnetic energy in a specific direction compared to an isotropic radiator. It quantifies how effectively the antenna converts input power into radiated power in the desired direction. Antenna gain is typically expressed in decibels (dB) and is calculated by comparing the power radiated in a particular direction to the power radiated by an isotropic radiator under the same conditions. A higher gain indicates a more directional radiation pattern, with more energy concentrated in the desired direction and less energy wasted in other directions. Antenna gain is influenced by various factors including antenna size, shape, design, and operating frequency. It is a crucial parameter in antenna design as it directly impacts the communication range, coverage area, and overall performance of the antenna system.

3.2.2.6 Directivity

Directivity is a measure of how well an antenna focuses electromagnetic energy in a specific direction compared to an isotropic radiator, which radiates equally in all directions. It quantifies the antenna's ability to concentrate power into a narrow beam or lobe, maximizing signal strength in a desired direction. Directivity is typically expressed in decibels (dB) and is calculated by comparing the radiation intensity in the direction of maximum radiation to the average radiation intensity over all directions.

Directivity is closely related to antenna gain. While directivity measures how effectively an antenna focuses energy in a particular direction, gain quantifies the ratio of the power radiated in that direction to the power radiated by an isotropic radiator under the same conditions. In other words, gain is a measure of the antenna's efficiency in converting input power into radiated power in the desired direction.

The relationship between directivity (D) and gain (G) is expressed as:

$$D = \frac{G}{\eta} \tag{1}$$

This formula illustrates that gain is directly proportional to directivity. Therefore, a higher directivity implies a higher gain, meaning that more power is concentrated in the desired direction relative to an isotropic radiator. Both directivity and gain are crucial parameters in antenna design, as they directly impact the antenna's performance in terms of communication range, coverage area, and signal strength in a specific direction.

3.2.2.7 S_{11}-Parameter (Return loss)

Return loss, often represented by the S11 parameter, is a measure of how much power is reflected back from an antenna or other device compared to the power originally sent to it. It quantifies the efficiency of power transfer between the transmission line and the antenna. Return loss is typically expressed in decibels (dB). Higher return loss values (negative dB) signify a better match between the antenna and the feeding line, meaning less reflection and more power being efficiently radiated by the antenna.

3.2.2.8 VSWR

The Voltage Standing Wave Ratio (VSWR) of an antenna is a measure of its efficiency and effectiveness in transmitting and receiving electromagnetic waves. It quantifies how well an antenna matches the impedance of the transmission line to which it's connected. VSWR is calculated as the ratio of the maximum amplitude of the forward wave to the maximum amplitude of the reflected wave along the transmission line. A VSWR of 1 indicates a perfect match, meaning all power is efficiently transferred without any reflections. Higher VSWR values indicate poorer matching and greater signal loss due to reflections, potentially leading to decreased transmission range, degraded signal quality, and increased interference. Therefore, minimizing VSWR is crucial for optimizing antenna performance.

3.2.2.9 Radiation Efficiency

Radiation efficiency quantifies how effectively an antenna converts electrical power into radiated electromagnetic waves. It represents the ratio of the radiated power (P_{rad}) to the total input power (P_{in}) supplied to the antenna. It is typically expressed as a percentage and varies with frequency. This efficiency is influenced by various factors, including the substrate material properties, the design of the patch structure, the feeding mechanism, and the presence of any losses such as dielectric or conductor losses.

If we know the Directivity and Gain, we can calculate Radiation efficiency by the following formulae,

$$\eta = \frac{gain}{directivity} \times 100\% \qquad (2)$$

Higher radiation efficiency indicates that a larger proportion of the input power is being effectively radiated into space, while lower efficiency implies more power is being dissipated as heat or lost in other non-radiative processes. Achieving high radiation efficiency is essential for maximizing the range and effectiveness of the antenna in communication systems.

3.2.2.10 Bandwidth

Antenna bandwidth refers to the range of frequencies over which the antenna can efficiently transmit or receive electromagnetic signals. An antenna is designed to operate at a specific center frequency. But it can also function reasonably well at frequencies slightly above and below the center frequency. We typically measure bandwidth based on the -10dB point at lower cut off frequency to -10dB point at higher cut off frequency.

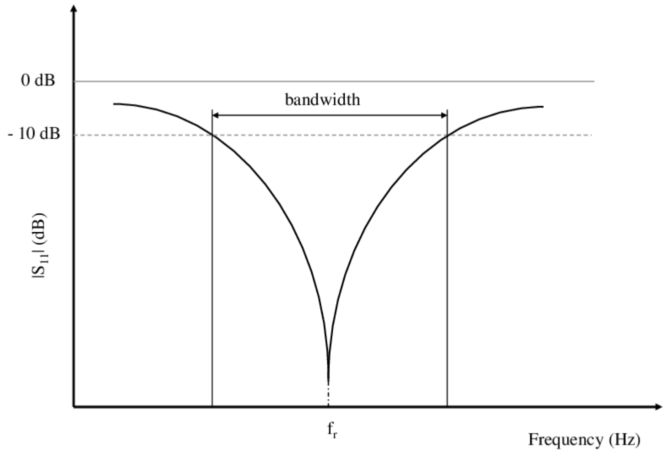


Figure 3.5: Bandwidth Measurement

3.2.2.11 Far Field

The far-field of an antenna is the area where the antenna's radiation pattern doesn't change with distance in this region. In the far-field region, the electromagnetic waves radiated by the antenna can be approximated as plane waves, and their behaviour is primarily determined by the antenna's radiation pattern. We can observe and measure several important characteristics of the antenna from the Far-field such as radiation pattern, radiation intensity, polarization, directivity, gain, beamwidth, main lobe, side lobe and etc.

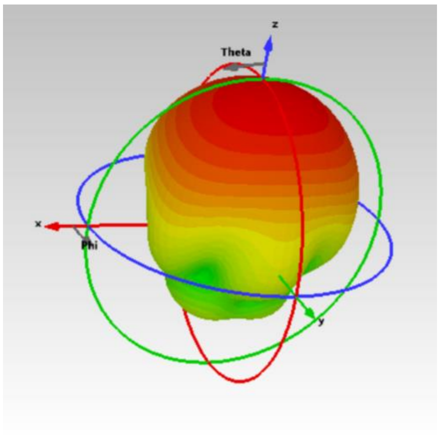


Figure 3.6: Far-field of a MPA

3.3 Geometrical Parameters Calculation of MPA

3.3.1 Patch Dimension

The width of the patch is determined by the equation below,

$$W = \frac{c}{2f_r} \times \sqrt{\left(\frac{2}{\varepsilon_r+1}\right)} \qquad (3)$$

Where,

c = Speed of light

f_r = Resonant frequency

ε_r = Dielectric constant of the substrate

The length of the patch can be calculated by the equation below,

$$L = \frac{c}{2f_r\sqrt{\varepsilon_{reff}}} - 2\Delta L \qquad (4)$$

Where,

ε_{reff} = Effective dielectric constant, that can be calculated as:

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1 + \frac{12h}{W}\right]^{-\frac{1}{2}} \qquad (5)$$

ΔL = Length extension due to fringing field, that can be calculated as:

$$\Delta L = 0.412h \times \frac{\left(\varepsilon_{reff}+0.3\right)\left(\frac{W}{h}+0.264\right)}{\left(\varepsilon_{reff}-0.258\right)\left(\frac{W}{h}+0.8\right)} \tag{6}$$

h is the thickness of the substrate.

3.3.2 Substrate and Ground Dimension

Substrate and ground dimensions are calculated as follows:

$$W_g = 6h + W \tag{7}$$

$$L_g = 6h + L \tag{8}$$

This is the minimum width and length of the substrate and ground. In microstrip patch antennas, the substrate and ground plane typically share the same dimensions. This design choice offers several advantages. The substrate confines the electromagnetic waves, and having a ground plane that matches its size keeps these waves well-contained for efficient radiation. Additionally, the ground plane, coextensive with the substrate, provides a complete path for current flowing within the antenna patch, improving its overall performance. This design approach also simplifies fabrication by creating a uniform structure that's easier to manufacture and maintain consistent electrical properties.

Substrate thickness, also called height can be estimated by the following formulae [16],

$$h \geq 0.06 \frac{\lambda_{air}}{\sqrt{\varepsilon_r}} \tag{9}$$

Unlike other antenna design parameters that can be freely chosen, the thickness of the substrate is limited by the fabrication company's available options. This means we can't select any desired thickness but rather choose from the pre-defined thicknesses offered by the manufacturer.

3.3.3 Feedline Design

Microstrip patch antennas can be fed in various ways, but some methods are more common due to their ease of design, analysis, and manufacturing.

Here are the four most popular feeding methods mentioned in the article:

1. **Microstrip Line Feed**: This is a widely used method because it's simple, easy to design and make. The feed line is a microstrip line connected directly to the side of the patch element.
2. **Coaxial Probe Feed**: This method involves feeding the antenna from the ground plane using a coaxial probe.
3. **Proximity Coupling**: In this method, the feed line is placed close to the patch but doesn't directly touch it. This allows for electromagnetic coupling to transfer power.
4. **Aperture Coupling**: This method uses another substrate layer with a slot to separate the feed line from the radiating patch. Power is transferred through an aperture in the ground plane.

In our design we have used microstrip line feed for simple design. So, we will now discuss only microstrip line feed.

3.3.3.1 Microstrip Line Feed

Microstrip line feeds are often adjusted in two common ways, as illustrated in the figure (3.7) below, to ensure they have the same impedance as the component they connect to.

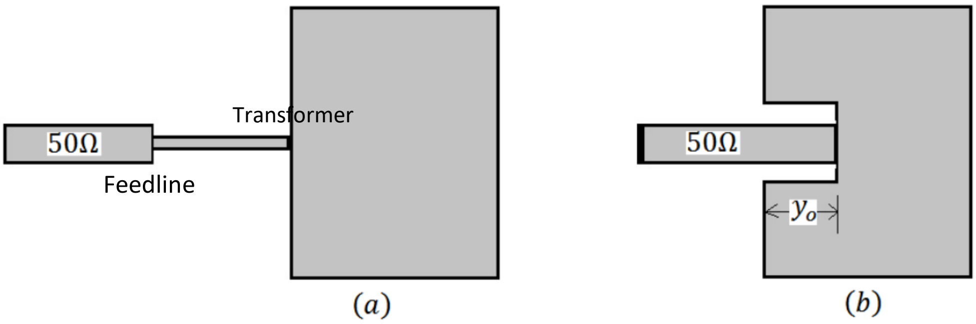


Figure 3.7: Microstrip line feed

We have used the first method in our proposed design.

The impedance of the edge of the patch is calculated by as follows:

$$Z_a = 90\frac{{\epsilon_r}^2}{\epsilon_r - 1}\left(\frac{L}{W}\right)^2 \qquad (10)$$

The characteristic impedance of the transformer should be:

$$Z_T = \sqrt{50 + Z_a} \tag{11}$$

The width (w) of the feedline can be calculated from the equation below:

$$Z_0 = \frac{120\pi}{\sqrt{\varepsilon_{reff}}\left(1.393+\frac{w}{h}+\frac{2}{3}ln\left(\frac{w}{h}+1.444\right)\right)} \tag{12}$$

Where, Z_0 is the 50Ω input impedance and w is the width of the feedline.

The length of the feedline can be calculated as the equation below, or we can optimize the length by simulation software.

$$R_{in(x=0)} = cos^2\left(\frac{\pi}{L}x_0\right) \tag{13}$$

The length of the transformer is quarter wave. So, this will be [17]:

$$l = \frac{\lambda_0}{4\sqrt{\varepsilon_{reff}}} \tag{14}$$

3.4 Proposed Dual-band Microstrip Patch Antenna

The proposed microstrip patch antenna utilizes a four-slot design for dual-band operation, as illustrated in Figure 1. The strategic placement of these slots is crucial for achieving the desired frequencies. Rogers RT5880 serves as the dielectric substrate with a thickness of 0.787 mm and a dielectric constant of 2.2. To ensure efficient power transfer, a standard 50 Ω microstrip feed line is employed. The antenna boasts compact dimensions of (10×11× 0.787) mm^3, making it a suitable candidate for applications where size constraints are a factor. The radiating patch itself is constructed from 0.035 mm thick copper for optimal performance. Designed for dual-band functionality, the antenna targets frequencies of 28 GHz and 38 GHz. CST Studio Suite 2022 software is used in both the design and simulation stages of this dual-band microstrip patch antenna.

Table 3.2 Design specifications

Operations	Dual-band
Resonant Frequency	28Ghz and 38Ghz
Dielectric Substrate	Rogers RT5880

Dielectric Constant	2.2
Input Impedance	50Ω
Gain	≥ 7 dB
Return loss	≤ -35 dB
Radiation Pattern	Directional

3.4.1 Geometry and Dimensions

The following section presents our design for a dual-band microstrip patch antenna (Figure 3.8).

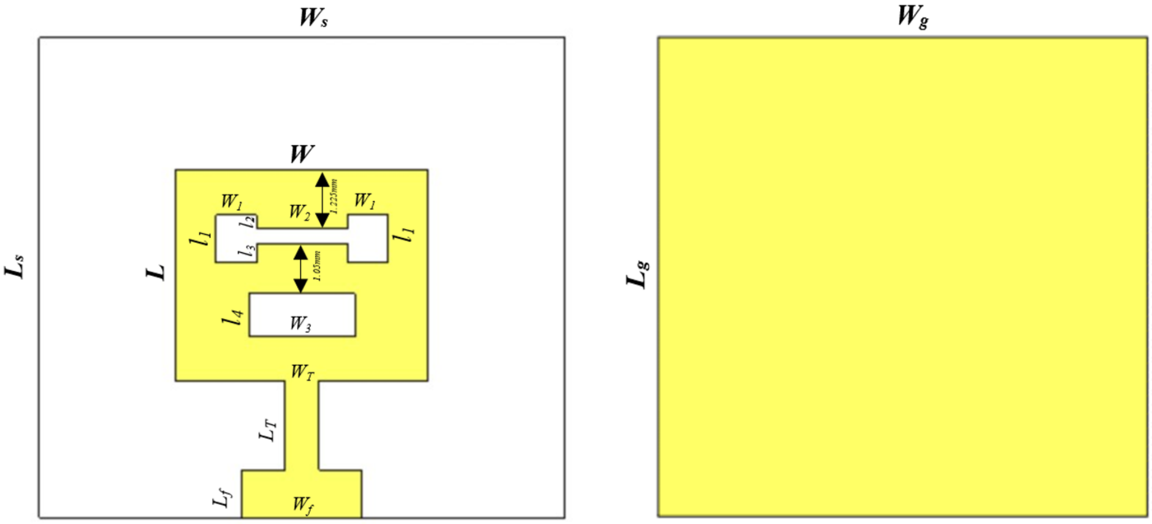


Figure 3.8: Top and bottom view of the antenna

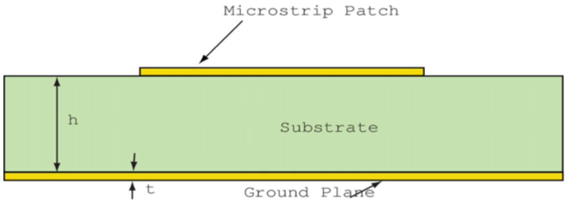


Figure 3.9: Side view of the antenna

Table 3.3. Design parameters of the proposed antenna

Parameter	**Value (mm)**
W_s , W_g	11
L_s , L_g	10

W	5.28
L	4.4
W_f	2.5
L_f	1
W_T	0.71
L_T	1.85
h	0.787
t	0.035
w_1	0.85
w_2	1.9
w_3	2.2
l_1	1
l_2	0.285
l_3	0.41
l_4	0.9

3.4.3 Dual Band Conversion Strategy

Achieving dual-band operation in our microstrip patch antenna involved an iterative design process. Initially, the antenna was designed for single-band operation at 28 GHz. Following this initial design, we implemented a two-step approach to introduce dual-band functionality:

1. Slot introduction and optimization:

A rectangular slot was first introduced into the radiating patch. However, this initial attempt wasn't successful in generating the desired dual-band response. To achieve the dual-band characteristic, a dumbbell-shaped slot was strategically added above the rectangular slot. This modification effectively disturbed the surface current distribution within the patch, as required for dual band operation. While the introduction of slots did create dual-band behavior, but the initial resonant frequencies were shifted to undesired values around 37 GHz and 48 GHz.

2. Patch dimension optimization:

To achieve the target resonant frequencies of 28 GHz and 38 GHz, we focused on optimizing the patch dimensions, particularly the patch length. This optimization process involved carefully adjusting the length while monitoring its impact on the resonant frequencies through simulations.

By iteratively refining the slot configuration and optimizing the patch dimensions, we successfully achieved the desired dual-band response with resonant frequencies at 28 GHz and 38 GHz. This approach highlights the crucial role of slot design and patch geometry in tailoring the current distribution and achieving the targeted dual-band functionality.

3.4.4 Dual-Band Operation Principle

Our proposed dual-band microstrip patch antenna achieves its functionality by manipulating the current distribution within the radiating patch element. This section explores the key principles behind this dual-band behavior.

1. Current Distribution and Resonance:

The radiating patch in a microstrip patch antenna acts like a metallic plate. When an electromagnetic wave interacts with the patch at a specific frequency, a particular pattern of electrical current, called the surface current distribution, is induced within the patch. This current distribution plays a critical role in determining the antenna's radiation characteristics. At the resonant frequency, the antenna efficiently radiates the electromagnetic wave.

2. Disrupting the Current with Slots:

Introducing slots into the radiating patch disrupts the original current distribution established for single-band operation. These slots act as interruptions in the current path, forcing the current to flow around them. The specific shapes, sizes, and positions of the slots significantly influence the new current distribution that is established.

3. Engineering Dual-Band Resonance:

To achieve dual-band operation, the current distribution within the patch needs to be manipulated to create two distinct resonant frequencies. This is accomplished through careful design of the slots. In our antenna, a strategic combination of slot shapes and placements is employed (details regarding the specific slot design choices are omitted here). This specific configuration disrupts the original current distribution in a way that creates two distinct resonant frequencies within the desired operational bands.

4. Fine-Tuning the Resonant Frequencies:

While the introduction of slots paves the way for dual-band operation, the initial resonant frequencies might not be precisely at the target values. To achieve the exact desired resonant frequencies, an optimization process is often required. This may involve adjusting the dimensions of the patch, particularly the patch length. By carefully modifying these dimensions and monitoring their impact on the resonant frequencies through simulations, the antenna's response can be fine-tuned to achieve the target operating bands.

In essence, dual-band operation relies on the interplay between strategic slot design and precise optimization of the patch dimensions. Slot design disrupts and reshapes the current distribution to create the foundation for dual-band behavior, while patch dimension optimization refines the resonant frequencies to achieve the target operational bands. This interplay allows us to design a microstrip patch antenna that functions effectively at two distinct frequencies.

3.5 Summary

Our journey through Chapter 3 has equipped us with the knowledge to design and analyze microstrip patch antennas, especially those targeting dual-band functionality. We started by unpacking the key features of antennas in Section 3.2, like their operating frequency and how they radiate signals. Understanding these is essential to creating an antenna that functions well. Then, Section 3.3 went under the hood, revealing how the physical design of a microstrip patch antenna its size, material, and connection - affects its electrical behavior. Finally, Section 3.4 showcased the clever design choices that enabled our dual-band antenna to operate at two separate frequencies.

CHAPTER 4

RESULTS AND PERFORMANCE ANALYSIS

4.1 Overview

This chapter unpacks the performance analysis of our innovative microstrip patch antenna design. Utilizing CST simulations, we unveil key results: S-parameters unveil the operational bandwidth, radiation patterns visualize the antenna's directional behaviour, and gain plots assess signal amplification. We meticulously dissect these results, meticulously evaluating how they align with our initial design goals, such as achieving a wider bandwidth or boosting gain in a specific direction. To conclude, the chapter culminates by summarizing the antenna's critical performance parameters, highlighting its strengths and pinpointing areas for potential improvement. This in-depth analysis offers valuable insights into the effectiveness of the proposed antenna design, paving the way for a clear understanding of its capabilities.

4.2 Simulation Results Analysis

4.2.1 S-Parameter Analysis

The return loss (S11) reaches -35 dB at 28 GHz and a stellar -46 dB at 38 GHz. Where a return loss of -10 dB or lower is generally considered acceptable for most antenna applications. This low return loss suggests that a significant portion of the incident power is absorbed by the antenna, minimizing reflections back into the feeding network. Our obtained values indicate a strong impedance match at both frequencies, minimizing signal reflection and maximizing power transfer for radiation. The significantly lower return loss at 38 GHz suggests an even better match at the higher frequency band, potentially leading to improved performance at 38 GHz compared to 28 GHz. The observed differences in return loss between the two frequency bands highlight the challenge of achieving dual-band operation while maintaining optimal impedance matching across both frequency ranges. Further analysis may focus on fine-tuning the antenna design parameters to enhance performance, such as adjusting patch dimensions or substrate properties. Overall, these return loss results demonstrate the antenna's effectiveness in efficiently radiating signals within the desired dual-band of 28 GHz and 38 GHz.

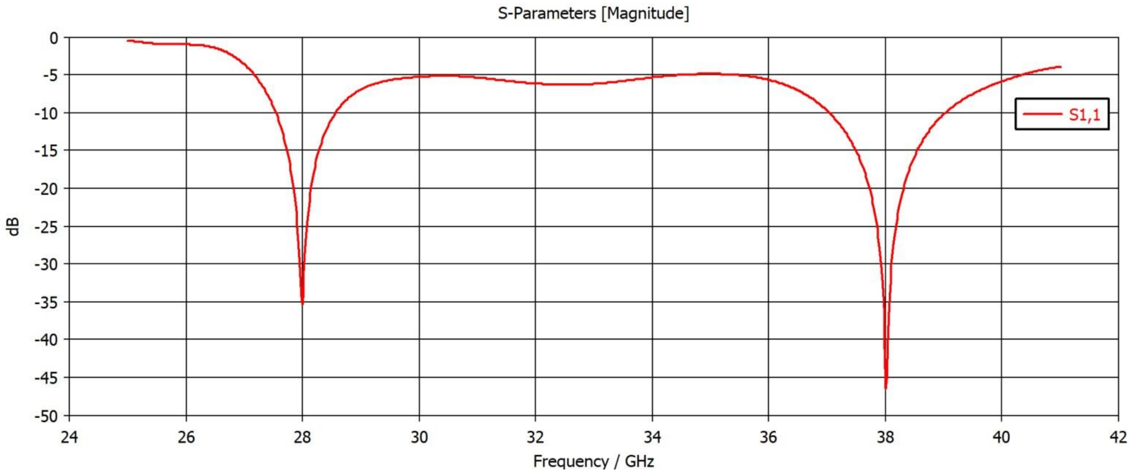


Figure 4.1: S_{11} Parameter for the proposed dual band antenna

4.2.2 Bandwidth Analysis

We have got promising bandwidth characteristics for our dual-band antenna. At 28 GHz, the achieved bandwidth is 1.03 GHz, spanning from 27.54 GHz to 28.57 GHz. This represents a good balance between bandwidth and resonant frequency. Similarly, at 38 GHz, the antenna demonstrates a wider bandwidth of 1.99 GHz, spanning from 37.04 GHz to 39.03 GHz. This broader bandwidth at 38 GHz further enhances the versatility and flexibility of the antenna design, potentially accommodating multiple communication standards or frequency allocations. The observed bandwidths at both frequency bands exceed typical requirements for many wireless communication systems, indicating robust performance and potential for accommodating future frequency expansions or modifications.

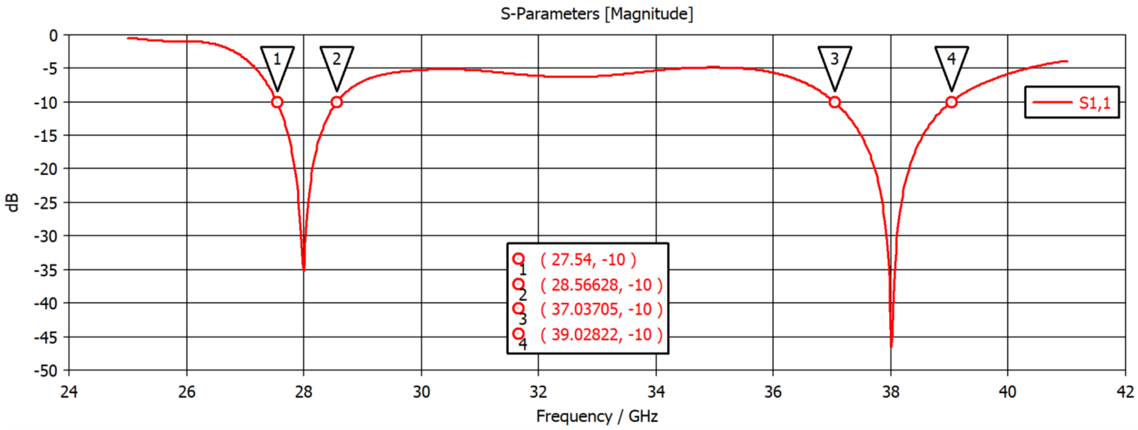


Figure 4.2: Bandwidth of the antenna

4.2.3 VSWR Analysis

VSWR, or Voltage Standing Wave Ratio, serves as a crucial metric in assessing the performance of antennas by quantifying the extent of power reflection caused by impedance mismatches. In essence, it measures the ratio of the maximum voltage (or current) at an antinode to the minimum voltage (or current) at a node along a transmission line. An ideal VSWR value of 1 signifies perfect impedance matching between the antenna and the transmission line, indicating that all incoming power is efficiently radiated and none is reflected back. In our simulation result, at 28 GHz, the VSWR value of 1.04 indicates a near-perfect match between the antenna's impedance and the feeding circuitry. This minimizes signal reflection and maximizes power transfer for efficient radiation at the lower band. The even lower VSWR of 1.01 at 38 GHz suggests an exceptional impedance match at the higher frequency. This translates to potentially even better power transfer and radiation characteristics compared to 28 GHz. These excellent VSWR values across both bands solidify the antenna's ability to efficiently radiate signals within the desired dual-band spectrum.

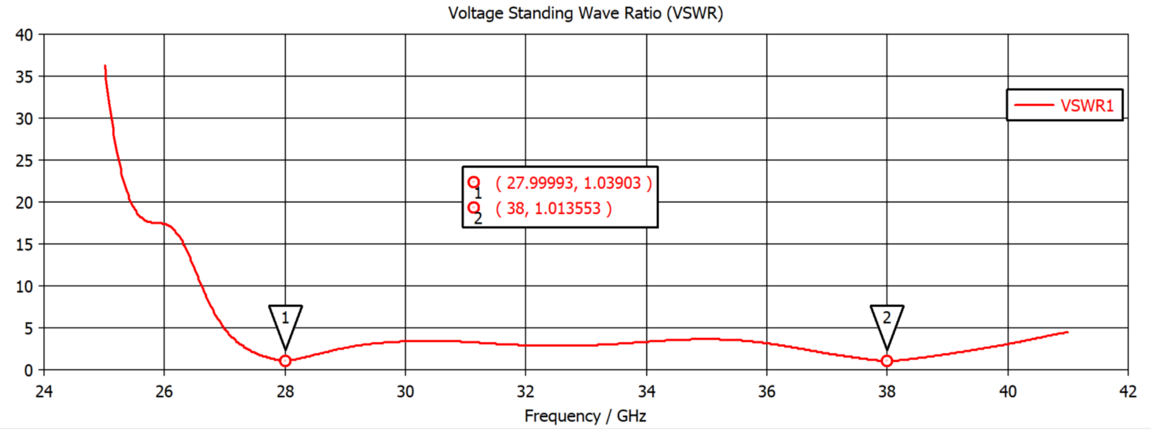
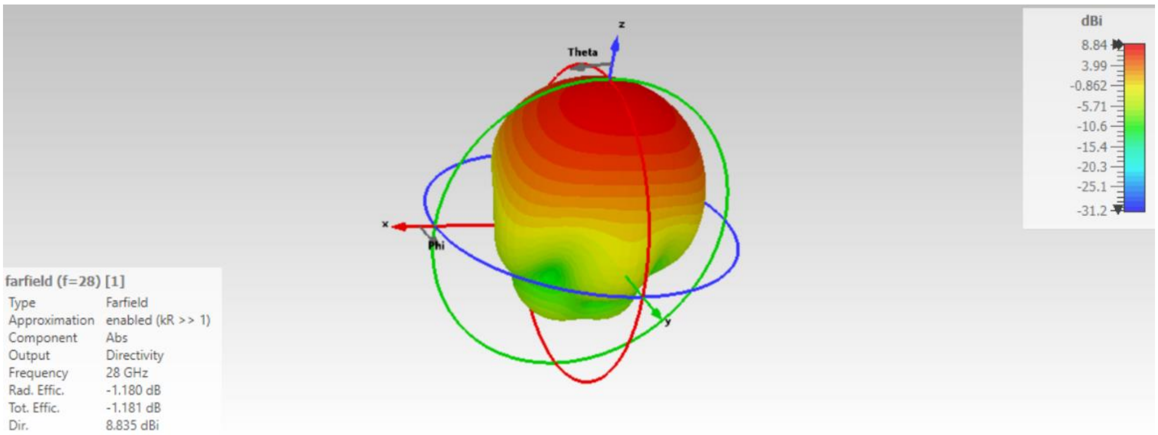


Figure 4.3: VSWR Graph

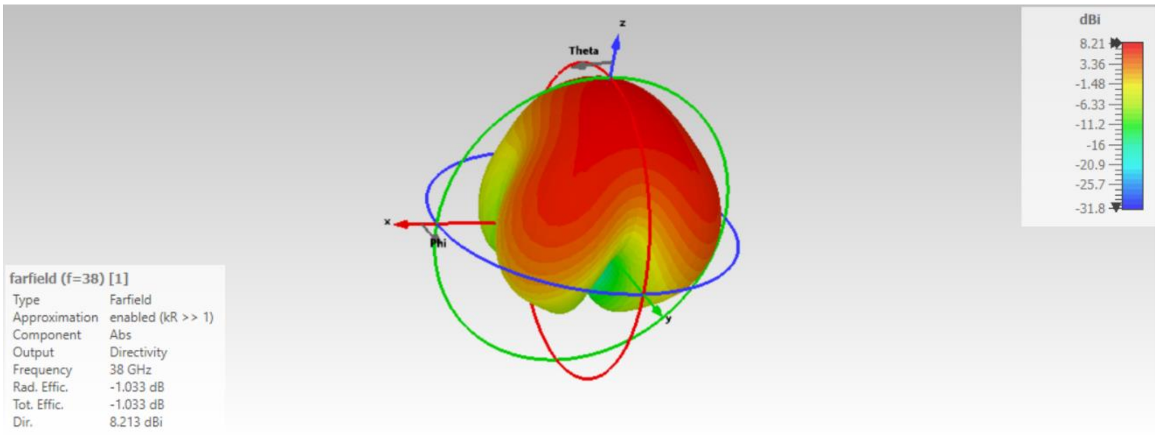
4.2.4 Directivity Analysis

At 28 GHz, we have got the directivity of 8.835 dBi that indicates a strong concentration of the signal in a particular direction. This translates to a more powerful signal compared to omnidirectional antennas in the intended direction. The slightly lower directivity of 8.213 dBi at 38 GHz suggests a somewhat broader radiation pattern at the higher frequency. This could be a trade-off for the wider bandwidth achieved at 38 GHz. However, both directivity values still indicate a level of signal concentration, offering advantages over omnidirectional designs. The specific application will determine whether the slight trade-off in directivity at 38 GHz is acceptable for the wider bandwidth benefit. Here we can increase directivity using a multilayer dielectric covered layer structure and increasing patch dimensions. For further improvement in both directivity and bandwidth, a parasitic patch and air gap between the ground plane and feed patch can be implemented. Overall, the achieved directivity values across both bands demonstrate the antenna's ability to radiate directionally. Overall, these results demonstrate the antenna's capability to achieve focused radiation, with a possible variation between the two bands based on the design optimization goals.



```
farfield (f=28) [1]
Type            Farfield
Approximation   enabled (kR >> 1)
Component       Abs
Output          Directivity
Frequency       28 GHz
Rad. Effic.     -1.180 dB
Tot. Effic.     -1.181 dB
Dir.            8.835 dBi
```

Figure 4.4: Antenna Directivity at 28GHz

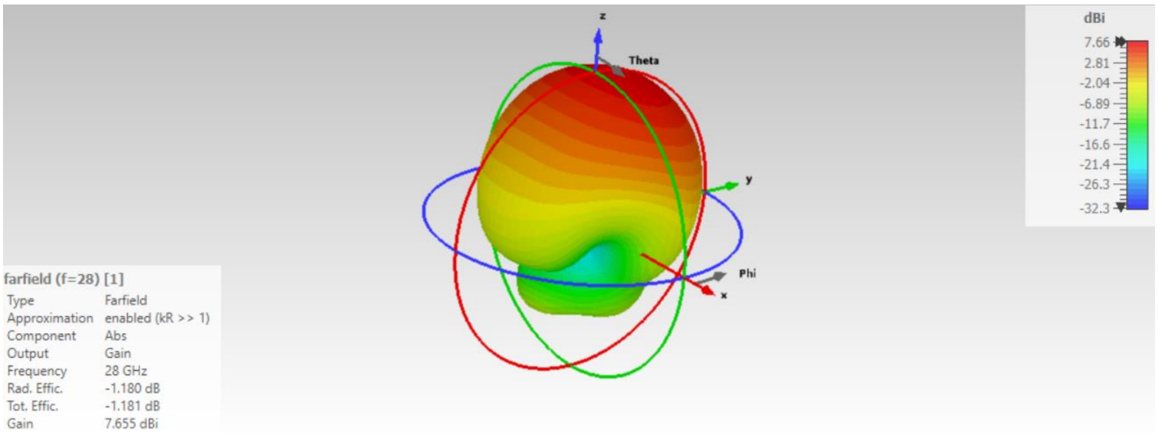


```
farfield (f=38) [1]
Type            Farfield
Approximation   enabled (kR >> 1)
Component       Abs
Output          Directivity
Frequency       38 GHz
Rad. Effic.     -1.033 dB
Tot. Effic.     -1.033 dB
Dir.            8.213 dBi
```

Figure 4.5: Antenna Directivity at 38GHz

4.2.5 Gain Analysis

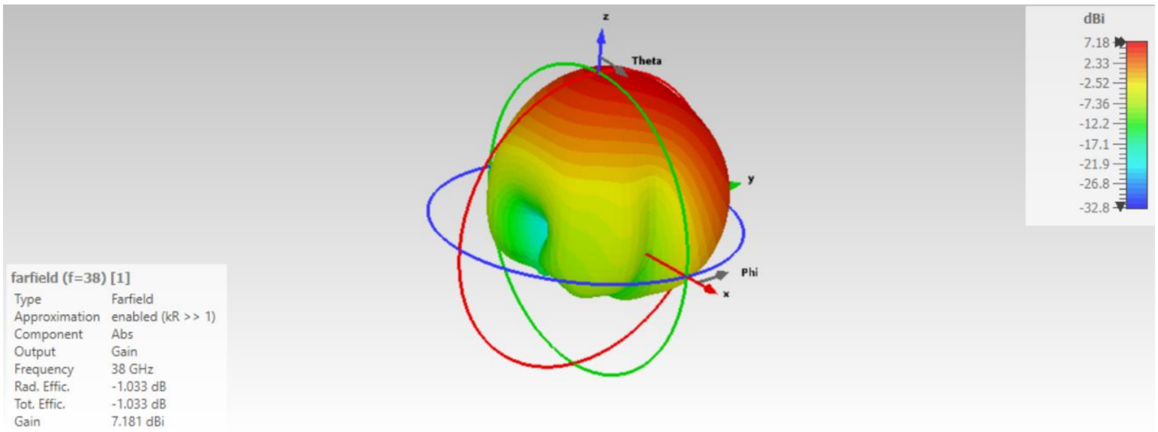
The gain value provides important insights into antenna performance. At 28 GHz, the measured gain is 7.655 dBi, indicating the antenna's ability to concentrate radiated power in a specific direction with a gain of approximately 7.655 dB relative to an isotropic radiator. This value signifies the antenna's efficiency in transmitting or receiving signals at 28 GHz. And at 38 GHz, the gain slightly decreases to 7.181 dBi, a slight reduction in directional gain at this higher frequency. Despite this decrease, the antenna still maintains a relatively high gain, indicating effective signal transmission or reception capabilities at 38 GHz as well. Analysis of the gain values reveals that the antenna performs well across both frequency bands, providing satisfactory gain levels for dual-band operation. To further increase the gain of our dual-band microstrip patch antenna, we can consider several strategies. First, optimizing the antenna's physical dimensions, such as the patch size and shape, can enhance gain by improving radiation efficiency and directivity. Additionally, adjusting the substrate properties, such as dielectric constant and thickness, can affect the antenna's impedance matching and radiation characteristics, leading to higher gain. Another approach is to incorporate parasitic elements or reflectors near the antenna structure to manipulate the radiation pattern and increase gain in desired directions. Furthermore, exploring advanced feeding techniques, such as aperture coupling or corporate feeding, may also help improve gain performance across both frequency bands. By analysing our results, we can say, our obtained results are promising for a dual-band microstrip patch antenna. It demonstrates good performance across key parameters like impedance matching, bandwidth, and directivity.



farfield (f=28) [1]

Type	Farfield
Approximation	enabled (kR >> 1)
Component	Abs
Output	Gain
Frequency	28 GHz
Rad. Effic.	-1.180 dB
Tot. Effic.	-1.181 dB
Gain	7.655 dBi

Figure 4.6: Antenna Gain at 28GHz



farfield (f=38) [1]

Type	Farfield
Approximation	enabled (kR >> 1)
Component	Abs
Output	Gain
Frequency	38 GHz
Rad. Effic.	-1.033 dB
Tot. Effic.	-1.033 dB
Gain	7.181 dBi

Figure 4.7: Antenna Gain at 38GHz

4.2.6 Radiation Pattern Analysis

This specific pattern below shows radiation in the far-field, which is the region where the radiated waves essentially travel. Here, the main lobe magnitude for 28GHz measured at 8.33 dBi, signifies the directional gain of the antenna, indicating the strength of radiation in the primary direction of maximum radiation. The main lobe direction aligned at 0 degrees, indicates that the maximum radiation occurs in the forward direction. This alignment is desirable for applications requiring focused signal transmission or reception in a specific direction. Additionally, the side lobe level, measured at -14.7 dB, denotes the relative magnitude of radiation in off-axis directions compared to the main lobe. The negative side lobe level significantly lower radiation intensity in sidelobes compared to the main lobe, indicating good directivity and demonstrating minimal wasted radiation in other directions.

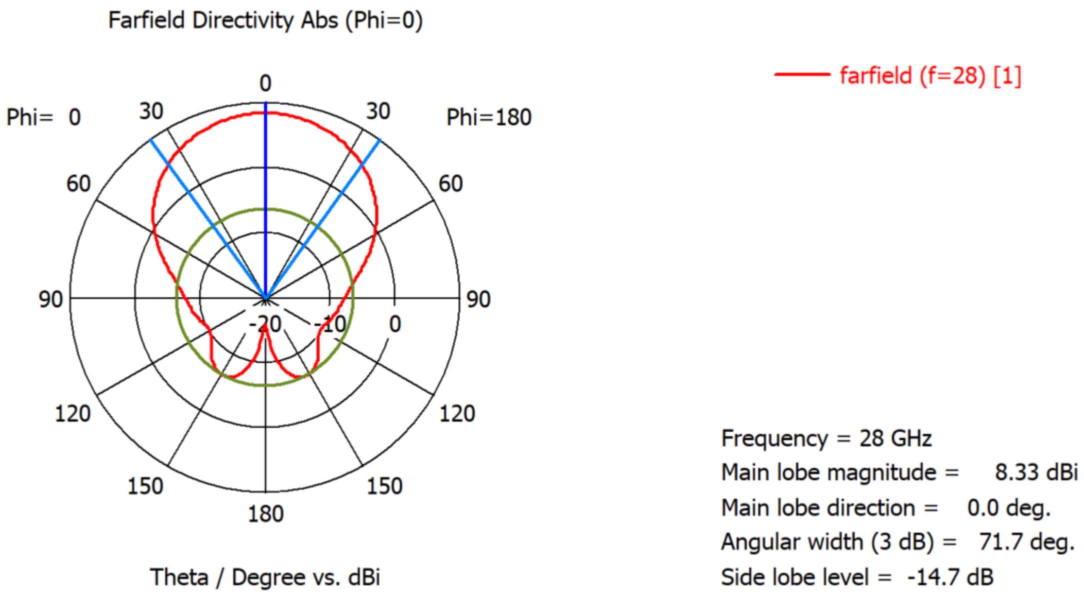


Figure 4.8: Radiation Pattern at 28GHz

At 38GHz operating frequency antenna radiation pattern is similar to at 28GHz frequency. Although the main lobe magnitude is slightly lower compared to the 28 GHz, the antenna still demonstrates significant directional gain at 38 GHz. Additionally, the radiation pattern exhibits a well-defined main lobe, suggesting effective radiation concentration in the desired direction. The analysis indicates that the antenna maintains strong directional performance even at the higher frequency of 38 GHz.

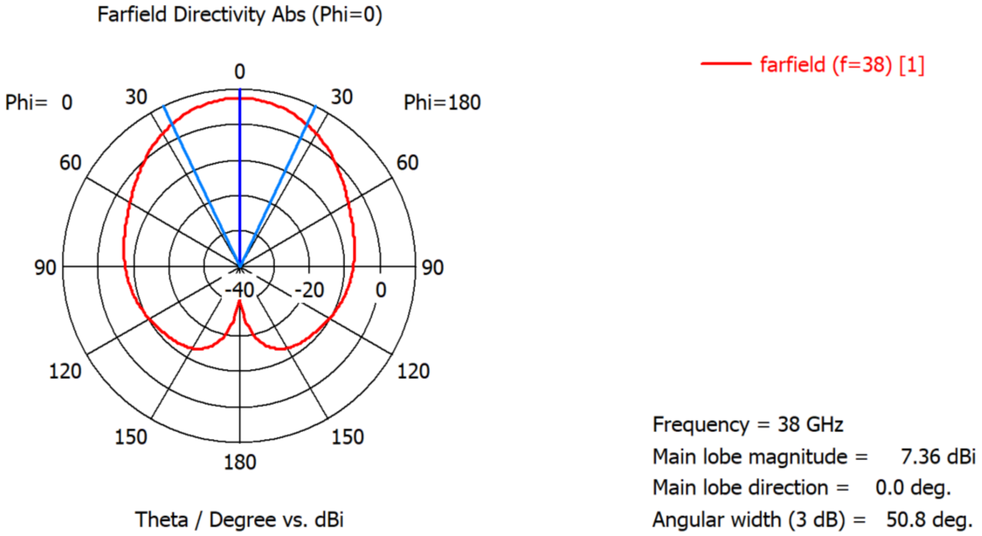


Figure 4.9: Radiation Pattern at 38GHz

4.2.7 Radiation Efficiency

The simulated radiation efficiencies are another positive aspect of an antenna. At 28 GHz, the antenna achieves an efficiency of 86.64%, indicating a very good percentage of the input power is being radiated effectively. It operates with very little energy waste and transmits signals effectively. The efficiency even improves slightly to 87.43% at the higher frequency of 38 GHz. The observed consistency in radiation efficiency across both frequency bands indicates the robustness and reliability of the antenna design for dual-band operation. Additionally, the high radiation efficiency values validate the effectiveness of the antenna's impedance matching, radiation pattern, and overall design optimization.

4.3 Performance Comparison with Existing Designs

Table 4.1 Comparison with similar works

Reference	**Dimensions (mm^2)**	**Resonant Freq. (GHz)**	**Return loss (dB)**	**Gain (dB)**
[10]	7.91 × 7.85	28	-50.97	6.00
		38	-16.65	4.15
[11]	20 × 20	28	−40.64	5.75
		38	−32.66	7.23
[12]	NP*	28	-25	5.20
		38	-30	5.90
[13]	NP*	28	-40	3.75
		38	-18	5.00
[20]	8.5 × 8	28	-32	6.70
		38	-40	7.92
[8]	Not rectangular	28	-34.5	6.20

		38	-27.3	5.30
[14]	9 × 11	28	-35	2.62
		38	-32	4.39
This work	11 × 10	28	-35	7.655
		38	-46	7.181

4.4 Discussion on Results

Across both operating frequencies of 28 GHz and 38 GHz, the antenna demonstrates commendable performance metrics, including low return loss values of -35 dB at 28 GHz and -46 dB at 38 GHz, indicative of strong impedance matching and minimal power reflection. The measured bandwidths of 1.03 GHz at 28 GHz and 1.99 GHz at 38 GHz ensure broad frequency coverage, accommodating various communication standards and frequency allocations. Moreover, the VSWR values of 1.04 at 28 GHz and 1.01 at 38 GHz signify excellent impedance matching, further enhancing signal transmission efficiency. The directivity values of 7.655 dBi at 28 GHz and 8.213 dBi at 38 GHz demonstrate the antenna's ability to focus radiation in specific directions, contributing to improved communication range and reliability. Additionally, the main lobe magnitudes, main lobe directions, and sidelobe levels at both frequencies exhibit desirable characteristics, indicating effective radiation concentration and minimal energy leakage into unwanted directions. The high radiation efficiency values of 86.64% at 28 GHz and 87.43% at 38 GHz underscore the antenna's efficiency in converting input power into radiated electromagnetic energy. Finally, we can say the consistent and favourable performance across multiple key parameters validates the effectiveness of the dual-band microstrip patch antenna design for dual-band operation, offering promising prospects for various wireless communication applications requiring reliable and efficient performance across the 28 GHz and 38 GHz frequency bands.

CHAPTER 5

PROJECT MANAGEMENT

5.1 Task, Schedule and Milestones

The Antenna design primary task has been completed, and each task's landmark has been reached. Below is a table showing the tasks and their completion:

Table 5.1 Project completion task

Title	Start date	End date	Duration (days)	% Complete
Work proposal	06/06/2023	06/12/2023	06	100
Search Relevant Literature	06/13/2023	06/23/2023	10	100
Material Available	06/24/2023	07/04/2023	10	100
Learn CST Studio	07/05/2023	08/04/2023	30	100
Chapter 1	08/05/2023	08/30/2023	25	100
Chapter 2	08/31/2023	09/20/2023	20	100
Planning Methodology	09/21/2023	10/11/2023	20	100
Antenna Design	10/12/2023	12/11/2023	60	100
MATLAB Coding	12/12/2023	12/27/2023	15	100
Simulation Corrections	12/28/2023	02/06/2024	40	100
Chapter 3	02/07/2024	02/23/2024	16	100
Result Analysis & Chapter 4	02/24/2024	03/20/2024	25	100
Chapter 5	03/21/2024	03/31/2024	10	100
Chapter 6	04/01/2024	04/06/2024	05	100
Chapter 7	04/07/2024	04/17/2024	10	100

We initially aimed for a specific milestone but ended up achieving a slightly different outcome. However, the design was completed sooner than expected. The original design timeline shown in the chart below,

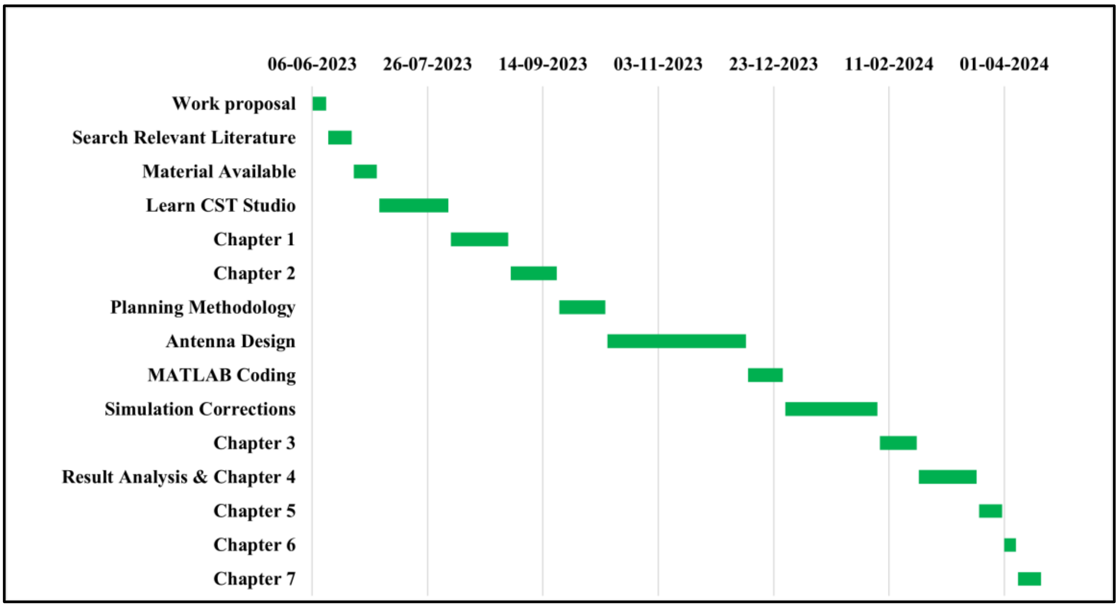


Figure 5.1 Gantt chart of the project

5.2 Resources and Cost Management

In managing the resources and cost for our project, which involved the design of a microstrip dual-band patch antenna, we made strategic decisions to optimize efficiency and minimize expenses. One key aspect was the utilization of CST Studio Suite Learning Edition, a free software available for students and educators. By leveraging this resource, we avoided the costs associated with acquiring professional software licenses. Additionally, we allocated time to self-learning through online sources to enhance our proficiency with CST Studio, further maximizing the value obtained from the free software. As a result, the overall cost for software and training was effectively reduced to zero, allowing us to stay within budget while still achieving our project objectives. However, it's important to acknowledge that for future projects requiring advanced functionalities, using the professional edition of CST Studio might be necessary, introducing software licensing costs as a consideration. Additionally, the fabrication of the antenna will incur material and production costs that will need to be factored into future project budgets.

5.3 Lesson Learned

Throughout this project designing a microstrip dual-band patch antenna, we successfully managed tasks and adhered to a well-defined schedule. As shown in Table 5.1, all project milestones were achieved, with the antenna design even being completed ahead of the initial target date. This accomplishment highlights the effectiveness of our project planning and task breakdown. A significant lesson learned involves resource optimization. We strategically utilized the free student edition of CST Studio Suite, eliminating software licensing costs. Furthermore, by dedicating time to online learning resources, we acquired proficiency in CST Studio without incurring paid training expenses. This approach demonstrates the value of exploring freely available resources and fostering self-learning to maximize efficiency and minimize project costs. However, it's important to acknowledge that future projects with advanced requirements might necessitate the professional edition of CST Studio and its associated licensing costs. Additionally, fabrication of the physical antenna will introduce material and production expenses that need to be considered in future project budgets.

CHAPTER 6

IMPACT ASSESSMENT OF THE PROJECT

6.1 Economical, Societal and Global Impact

Microstrip patch antennas, like the one we designed, play a crucial role in the development and deployment of 5G wireless communication. Here's a breakdown of their potential economic, societal, and global impact:

Economical Impact:

- **Reduced Costs:** Microstrip patch antennas offer several advantages over traditional antenna designs. They are compact, lightweight, and can be fabricated using low-cost materials and processes. This can lead to significant cost reductions in the manufacturing of 5G base stations and user equipment.
- **Market Expansion:** The widespread adoption of 5G technology will create a substantial market for microstrip patch antennas. This increased demand will stimulate economic activity in the antenna manufacturing sector and potentially lead to job creation.
- **Innovation and Investment:** The success of microstrip patch antennas in 5G systems can encourage further research and development in antenna technologies. This fosters innovation in antenna design, leading to even more efficient and high-performance antennas for future applications.

Societal Impact:

- **Improved Connectivity:** Microstrip patch antennas, with their compact size and ease of integration, can facilitate a denser network of 5G base stations. This translates to wider coverage and improved connectivity, particularly in urban areas with high user density.
- **Enhanced Services:** 5G networks enabled by microstrip patch antennas will allow for the development of new applications and services in various sectors like education, healthcare, and entertainment. These advancements can improve the quality of life for citizens by providing access to faster data speeds, better remote communication, and innovative experiences.

- **Digital Divide:** While improved connectivity benefits urban areas significantly, strategic deployment of microstrip patch antennas can help bridge the digital divide in rural areas. This can provide access to information, educational resources, and essential services for underserved communities.

Global Impact:

- **Standardization and Interoperability:** Microstrip patch antennas, adhering to specific design standards, contribute to the global interoperability of 5G networks. This allows seamless communication and data exchange between devices and networks across different countries.
- **Environmental Considerations:** While the environmental impact of microstrip patch antennas themselves is minimal, 5G technology can contribute to a more sustainable future. For instance, it can enable smarter energy grids, optimize resource utilization in various sectors, and improve remote environmental monitoring.
- **Global Economic Growth:** The widespread adoption of 5G technology, facilitated by microstrip patch antennas, is expected to boost global economic growth. This can happen through increased economic activity in various sectors, creation of new job opportunities, and improved efficiency in trade and communication.

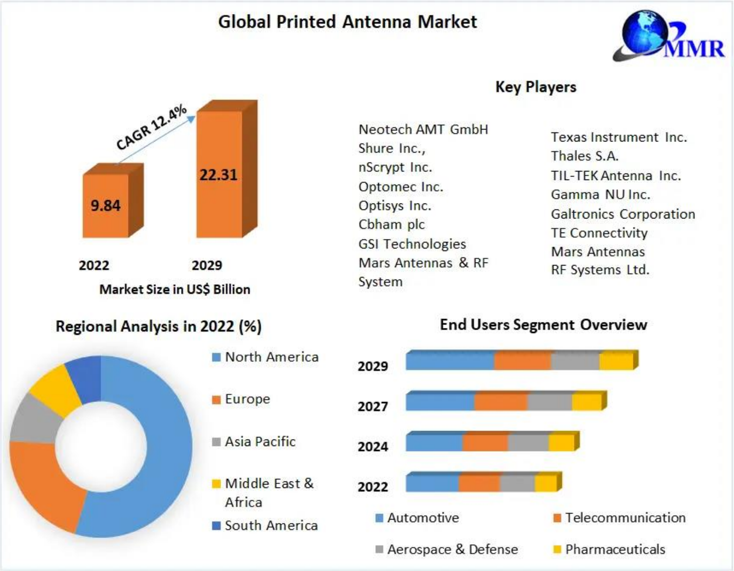


Figure 6.1 Global Printed Antenna Market

Microstrip patch antennas are a key component driving the development of 5G technology. Their economic benefits lie in cost reduction and market expansion, while their societal and global impacts focus on improved connectivity, access to information, and fostering a more sustainable and interconnected world.

6.2 Environmental and Ethical Issues

There are many advantages to microstrip patch antennas in terms of communication and technological growth, there are also ethical and environmental issues that need to be addressed.

Environmental Issues:

- **E-waste generation:** The manufacturing and deployment of a large number of microstrip patch antennas for 5G base stations will contribute to electronic waste (e-waste) generation. Proper disposal and recycling infrastructure is crucial to minimize environmental impact. [18]
- **Potential health risks:** There are ongoing discussions about the potential health risks of long-term exposure to electromagnetic radiation emitted by telecommunication infrastructure. More research is needed to definitively assess these risks and ensure safe deployment of 5G technology. [19]

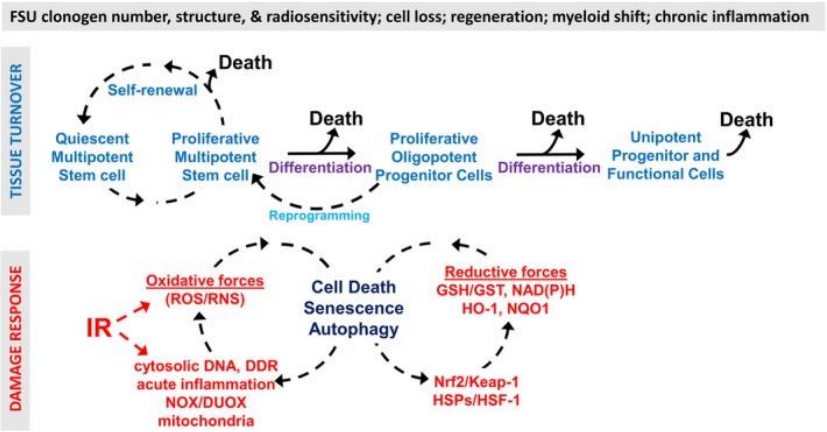


Figure 6.2: Tissue Injured by Unwanted Radiation

In the human body, Radiation has a stronger effect and causes more damage the more specialized the cell type. The eye is a highly specialized organ that is primarily incapable of having damaged cells removed or new ones produced. The lens and the retina are important structures to take into account. Damage to the Meibomian glands, resulting in a decrease in or absence of the lipid layer of the tear film and its evaporation, or harm to the acinar cells of the lacrimal glands, is the pathogenetic process of radiation-induced ocular dryness.2,6 The Schirmer test, Break-up time (BUT) test, and dry eye OSDI questionnaire results from 40 patients with conjunctival or orbital lymphoma who received an average dosage of 37.4 Gy of radiation are compared to the results of a healthy sample of 60 individuals by Woo et al. [20]

Figure 6.3: Eye Cell Damage by Radiation

Ethical Issues:

- **Privacy concerns:** The increased connectivity and data transmission facilitated by 5G raise privacy concerns. Robust data security measures and user privacy regulations are essential to protect individual data and prevent misuse.
- **Responsible manufacturing:** The ethical sourcing of materials used in microstrip patch antenna manufacturing needs to be addressed. This includes ensuring responsible mining practices, fair labor conditions, and minimizing environmental impact throughout the supply chain.

6.3 Utilization of Existing Standards or Codes

The design of microstrip patch antennas for 5G communication systems needs to adhere to established standards and regulations to ensure proper functionality, safety, and compliance. Here's a breakdown of the relevant standard and codes:

IEEE Standards:

The Institute of Electrical and Electronics Engineers (IEEE) publishes various standards related to antenna design and performance. These standards define parameters like impedance, gain, bandwidth, and radiation patterns. Common standards applicable to microstrip patch antennas include:

- IEEE Std 145-2013: Standard Definitions of Terms for Telecommunications and Electronics
- IEEE Std 390.1-2001 (Reaffirmed 2017): Standard Test Methods for Antennas and Wave Propagation Measurements – Part 1: Antenna Port Characteristics
- IEEE Std Antennas and Propagation Society Standards (additional standards may be relevant depending on specific antenna design)

Safety Considerations:

- **FCC Regulations:** The Federal Communications Commission (FCC) in the United States regulates radiofrequency (RF) radiation exposure from telecommunication devices. Your antenna design should comply with FCC regulations for maximum permissible exposure (MPE) limits to ensure safe operation. Relevant FCC regulations include:
- **47 CFR Part 1.1310:** Radiofrequency Radiation Exposure Limits

By following these standards and addressing safety considerations, we can contribute to the development of reliable and safe 5G communication infrastructure.

6.4 Other Concerns

Beyond the environmental, ethical, and regulatory issues discussed previously, here are some additional considerations for microstrip patch antenna design:

Manufacturing limitations: While microstrip patch antennas offer advantages in miniaturization, their design needs to consider real-world manufacturing constraints. Factors like etching tolerances, material properties, and assembly processes should be taken into account to ensure the antenna can be produced reliably and cost-effectively.

Mutual coupling: When multiple antennas are placed in close proximity, they can experience mutual coupling effects. This can lead to unwanted signal interaction and performance degradation. Careful design techniques and spacing considerations are necessary to minimize these effects.

Beam steering capabilities: Some applications in 5G might require antennas with beam steering capabilities, where the radiation pattern can be electronically controlled to direct the signal. While microstrip patch antennas can be designed with limited beam steering capabilities, more complex antenna architectures might be needed for sophisticated beamforming applications.

By acknowledging these additional concerns during the design process, we can create microstrip patch antennas that are not only functional and safe but also manufacturable, minimize interference issues, and potentially meet the requirements for advanced 5G applications.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

Our dual-band microstrip patch antenna design achieved excellent results in simulations for 5G communication at 28 GHz and 38 GHz. Through meticulous simulation and analysis, significant advancements in antenna performance, particularly in dual-band operation at 28 GHz and 38 GHz frequencies, have been achieved. The S-parameter analysis revealed impressive return loss values of -35 dB at 28 GHz and -46 dB at 38 GHz, indicating strong impedance matching and efficient power transfer, aligning well with our initial design goals and ensuring minimal signal reflection. Additionally, the bandwidth analysis showcased promising results with achieved bandwidths of 1.03 GHz at 28 GHz and 1.99 GHz at 38 GHz, exceeding typical requirements for many wireless communication systems and enhancing the antenna's versatility for future frequency expansions. VSWR analysis confirmed excellent impedance matching across both frequency bands, further enhancing signal transmission efficiency and radiation performance. Directivity analysis demonstrated the antenna's ability to focus radiation in specific directions, contributing to improved communication range and reliability. Gain analysis highlighted satisfactory gain levels for dual-band operation, signifying effective signal transmission or reception capabilities across both frequency bands. Radiation pattern analysis revealed well-defined main lobes and minimal sidelobes, indicating effective radiation concentration and minimal energy leakage into unwanted directions. Moreover, high radiation efficiency values of 86.64% at 28 GHz and 87.43% at 38 GHz validate the effectiveness of the antenna design in converting input power into radiated electromagnetic energy. The consistent and favorable performance across multiple key parameters underscores the robustness and reliability of the dual-band microstrip patch antenna design, holding significant implications for various wireless communication applications requiring reliable and efficient performance across the 28 GHz and 38 GHz frequency bands, including satellite communication, 5G networks, radar systems, and IoT devices.

7.2 New Skills and Experiences Learned

Throughout this antenna design, several new skills and experiences have been acquired, enriching my professional development. Firstly, I gained proficiency in using CST simulations for antenna design and analysis, which provided valuable hands-on experience in simulating electromagnetic behavior and assessing antenna performance metrics. This enhanced my understanding of electromagnetic principles and their practical application in antenna engineering. Additionally, I developed a deeper insight into the intricacies of microstrip patch antenna design, including parameter optimization and fine-tuning to achieve desired performance outcomes. Understanding how to interpret and analyze S-parameters, bandwidth, VSWR, directivity, gain, and radiation patterns has broadened my knowledge base in antenna design and evaluation methodologies. Moreover, I learned about the importance of impedance matching and its impact on signal transmission efficiency, as well as techniques to enhance antenna directivity and radiation efficiency. Collaborating with team members and engaging in discussions regarding design optimization strategies provided a valuable learning experience in teamwork and communication skills. Furthermore, the process of comparing our results with existing designs allowed me to appreciate the significance of benchmarking and evaluating performance relative to industry standards. Overall, this project provided an immersive learning experience that not only expanded my technical skills but also honed my analytical abilities, problem-solving skills, and collaborative mindset, preparing me for future endeavors in antenna engineering and related fields.

7.3 Future Recommendations

While the current microstrip patch antenna design exhibits promising performance in simulations, there's always an opportunity to push the boundaries and achieve even greater results. Here are some recommendations for future endeavors to further refine and elevate this project.

Optimizing the Design: One area for exploration is bandwidth enhancement. Techniques like incorporating slots, DGS or parasitic elements into the design have the potential to broaden the operational bandwidth at both 28 GHz and 38 GHz, offering increased flexibility for accommodating a wider range of communication standards.

Additionally, investigating strategies to further improve directional gain, particularly at the higher frequency of 38 GHz, could be highly beneficial. Optimizing patch dimensions, employing substrates with higher dielectric constants, or utilizing aperture feeding techniques are all potential avenues to explore in this pursuit of enhanced gain. Expanding the antenna's functionality to support additional frequency bands relevant for 5G communication, such as 24 GHz or 60 GHz, is another exciting possibility. This could be achieved by introducing stacked or multi-layered patch configurations, opening doors to even more versatile applications.

Advanced Implementations: The realm of metamaterials presents a fascinating avenue for future exploration. Integrating metamaterials into the antenna design could unlock unconventional electromagnetic properties. These metamaterial properties have the potential to lead to significant advancements in areas like miniaturization, enhanced directivity, or even bandwidth expansion. Another intriguing direction for future work is the implementation of beam steering mechanisms. By incorporating these mechanisms into the antenna structure, we could enable electronically controlled adjustments of the radiation pattern. This would offer greater flexibility for various communication scenarios, allowing the antenna to adapt its directionality based on specific needs.

Validation and Refinement: To bridge the gap between simulation and reality, fabricating a prototype of the designed antenna is crucial. Real-world measurements of its S-parameters, radiation patterns, and gain using appropriate equipment in an anechoic chamber would provide valuable validation data. Comparing these measured results with the simulated data would be an essential step. Any discrepancies identified could be used to refine the simulation model, ensuring its accuracy for future designs.

Practical Considerations: Beyond technical advancements, future work should also consider practical considerations. Analyzing the cost associated with fabricating the designed antenna is an important step. Exploring alternative materials or manufacturing processes that could potentially reduce production costs without compromising performance would make the design more commercially viable. Investigating the possibility of using sustainable or recyclable materials would contribute to an eco-friendlier design approach.

By following these recommendations, future iterations of the microstrip patch antenna design have the potential to achieve not only superior performance but also increased functionality and environmental consciousness.

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