Dual Band 28/38 GHz Microstrip Patch Antenna for 5G mmWave applications and the Improvement of antenna operating Bandwidth by applying Defected Ground Structure Technique

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

Submitted by

Name: Md Arman Ali Mredha

ID: 203-33-1308

Name: Md. Rabiul Islam

ID: 203-33-1319

Name: Md Forkan Hossen

ID: 203-33-1346

Name: Nyma Sarker

ID: 203-33-1351

Supervised by

Md. Sohel Rana

Senior Lecturer

Department of Electrical and Electronic Engineering

Faculty of Engineering

DAFFODIL INTERNATIONAL UNIVERSITY

January 2025

DECLARATION

We declare that the project entitled "Dual Band 28/38 GHz Microstrip Patch Antenna for 5G mmWave Applications and the Improvement of Antenna Operating Bandwidth by Applying Defected Ground Structure Technique" is our own original work, carried out under the guidance of the Department of Electrical and Electronic Engineering, Faculty of Engineering, at Daffodil International University.

This work has been prepared to fulfill the requirements for the Bachelor of Science degree in Electrical and Electronic Engineering. We confirm that it has not been submitted to any institution for a degree or other academic qualifications.

We confirm that appropriate safety and ethical guidelines were followed throughout the research process. All sources and references used have been properly acknowledged, and We take full responsibility for the content and findings presented in this work.

Signature of the candidates

Arman.

Name: *Md Arman Ali Mredha*

ID: 203-33-1308

Rabiul

Name: *Md. Rabiul Islam*

ID: 203-33-1319

Forkan Hossen

Name: *Md Forkan Hossen*

ID: 203-33-1346

Nyma

Name: *Nyma Sarker*

ID: 203-33-1351

APPROVAL

The project entitled “**Dual Band 28/38 GHz Microstrip Patch Antenna for 5G mmWave Applications and the Improvement of Antenna Operating Bandwidth by Applying Defected Ground Structure Technique**”, submitted by **Md Arman Ali Mredha (203-33-1308), Md. Rabiul Islam (203-33-1319), Md Forkan Hossen (203-33-1346) & Nyma Sarker (203-33-1351)** has been completed under my supervision and is hereby approved as satisfactory in partial fulfillment of the requirements for the degree of Bachelor of Science in Electrical and Electronic Engineering, in December 2024.

Md Sohel Rana
06.01.2025

Md. Sohel Rana

Senior Lecturer

Department of Electrical and Electronic Engineering

Faculty of Engineering

Daffodil International University

Dedicated

To

Our Parents

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LIST OF ABBREVIATIONS

DGS	Defected Ground Structure
CST	Computer Simulation Technology
5G	Fifth Generation
GHz	Gigahertz
dB	Decibel

IoT	Internet of Things
mmWave	Millimeter Wave
MIMO	Multiple-Input Multiple-Output
SIW	Substrate Integrated Waveguide
RF	Radio Frequency
IEEE	Institute of Electrical and Electronics Engineers
PCB	Printed Circuit Board
EMI	Electromagnetic Interference
PIFA	Planar Inverted-F Antenna
AFSL	Air-Filled Substrate Integrated Waveguide
VSWR	Voltage Standing Wave Ratio

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ABSTRACT

This study presents the enhancement of a microstrip patch antenna's performance through the Defected Ground Structure (DGS) technique, a method that introduces deliberate modifications to the ground plane geometry. The primary objective is to optimize key performance metrics—such as reflection coefficient, impedance matching, and gain—at two critical millimeter-wave frequencies, 28 GHz and 38 GHz, which are vital for emerging 5G and satellite communication applications. The proposed antenna design was developed using CST Microwave Studio, with the ground plane dimensions meticulously defined as 6 mm × 7 mm × 0.035 mm.

Key performance results demonstrate the effectiveness of the DGS approach in achieving superior performance. The reflection coefficient (S11S_ {11}) values at the two operational frequencies were significantly improved, achieving -32.356 dB at 28 GHz and -51.504 dB at 38 GHz. These values indicate excellent impedance matching and minimal power reflection, highlighting the antenna's efficiency in energy transmission. The achieved bandwidth is 2.444 GHz at 28 GHz and 3.397 GHz at 38 GHz, supporting broader operational capabilities. Furthermore, the voltage standing wave ratio (VSWR) values were observed to be 1.05 at 28 GHz and 1.06 at 38 GHz, signifying nearly perfect impedance matching across the intended frequency spectrum. In terms of gain, the antenna exhibited a peak gain of 5.875 dB at 28 GHz and 3.74 dB at 38 GHz. These gains are substantial for compact microstrip patch antennas and emphasize the role of the DGS technique in enhancing radiation performance. Additionally, surface current distribution analysis revealed concentrated currents along the patch's edges at both frequencies, providing insights into the antenna's radiation mechanism and the impact of ground plane modifications.

The findings validate the DGS technique as a robust method for improving microstrip antenna performance at high frequencies. The optimized design is well-suited for applications in 5G communications, where bandwidth, efficiency, and compactness are critical. By leveraging the DGS approach, this work contributes to the development of advanced antenna designs with enhanced operational characteristics, offering a reliable solution for modern wireless communication systems.

Keyword: DGS (Defected Ground Structure), Microstrip Patch Antenna, mmWave, Dual Band, Reflected Co-efficient, Gain, VSWR, Frequency spectrum, Bandwidth.

Chapter-1
Introduction

1.1 Introduction

The rapid evolution of wireless communication systems has driven an unprecedented demand for high-performance, compact, and efficient antenna designs. With the advent of 5G technology, achieving reliable communication at higher frequencies has become a cornerstone of modern telecommunication networks. As global efforts to deploy 5G networks continue to gain momentum, the development of antennas that operate efficiently at millimeter-wave (mmWave) frequencies, specifically at 28 GHz and 38 GHz, becomes crucial. These frequencies offer significant advantages in terms of data transmission speed and low latency, making them ideal for applications such as IoT, satellite communication, and high-speed wireless systems. [1]

The objective of this project is to design and develop a dual-band microstrip patch antenna tailored for 5G communication systems. This antenna is expected to meet the critical requirements of high efficiency, compact design, and superior performance in the targeted mmWave bands. Leveraging advanced materials such as Rogers RT5880, known for its low dielectric constant and loss tangent, the design focuses on optimizing parameters like bandwidth, gain, and impedance matching. Furthermore, innovative techniques such as the use of parasitic patches and defected ground structures (DGS) are employed to enhance the antenna's performance and adaptability to real-world applications. [2]

The choice of operating at 28 GHz and 38 GHz is motivated by their designation as critical frequency bands for 5G mmWave networks. In Bangladesh, the existing 5G trials and rollouts predominantly utilize mid-band spectrums, such as 2.3 GHz and 3.5 GHz, which are suitable for urban and industrial applications. However, the absence of high-band mmWave deployments presents a significant opportunity to harness the potential of these frequencies. The proposed dual-band antenna design bridges this gap, offering an effective solution to support the future expansion of 5G networks in the country.

Microstrip patch antennas have emerged as a preferred choice for modern communication systems due to their lightweight, compact form, and ease of integration with other electronic components. This project justifies the adoption of microstrip technology by highlighting its ability to achieve multiband or wideband operation, cost-effective fabrication, and robust performance at mmWave frequencies. Additionally, these antennas demonstrate versatility in design, allowing customization for specific applications such as satellite systems, wearable devices, and drone communication.

The iterative "Design-Simulate-Optimize" methodology employed in this project ensures that the final antenna design meets stringent performance standards. This approach involves theoretical calculations, computer-aided simulations using tools like CST Studio Suite, and iterative refinements to optimize key performance metrics such as return loss, bandwidth, and radiation patterns. The culmination of this process is a dual-band antenna that not only satisfies technical specifications but also aligns with sustainable and practical implementation goals.

In conclusion, this project represents a significant step toward advancing antenna technology to meet the demands of 5G communication systems. By addressing the challenges of operating at 28 GHz and 38 GHz, this design contributes to the ongoing evolution of wireless networks, fostering innovation and enabling new applications in high-speed data transmission, IoT, and beyond. The results of this project have the potential to influence future research and deployment strategies, laying the groundwork for more efficient and reliable wireless communication infrastructure.

1.2 Problem Statement and Proposed solution

Problem Statement

Modern wireless communication systems, particularly 5G networks, require antennas that operate efficiently at high-frequency bands such as 28 GHz and 38 GHz. Meeting these requirements demands antennas with specific characteristics, including wide bandwidth, strong impedance matching, high gain, and efficient radiation patterns. Traditional microstrip patch antennas often face challenges in achieving these parameters simultaneously due to limited bandwidth, poor impedance matching, and reduced gain at millimeter-wave frequencies. Additionally, ensuring dual-band operation with optimal performance at both frequencies is a complex task, requiring advanced design techniques to overcome these limitations.

Proposed Solution

To address these challenges, this project proposes a dual-band microstrip patch antenna incorporating the Defected Ground Structure (DGS) technique. The DGS approach involves deliberate geometric modifications in the ground plane to enhance the antenna's performance metrics, particularly at the operational frequencies of 28 GHz and 38 GHz. This innovative design leverages advanced simulation tools to optimize key parameters such as reflection coefficient, impedance matching, and gain, ensuring superior performance across both bands.

Key Features of the Proposed Solution:

1. **Defected Ground Structure (DGS):**
   By introducing geometric alterations in the ground plane (dimensions: 6 mm × 7 mm × 0.035 mm), the DGS enhances the electromagnetic behavior of the antenna. This improves the bandwidth, reduces unwanted higher-order modes, and strengthens impedance matching.
2. **Dual-Band Functionality:**
   The design achieves seamless operation at both 28 GHz and 38 GHz, catering to the demands of 5G and other mmWave communication systems.

3. **Compact Design:**
   The antenna’s compact ground plane and patch dimensions make it ideal for integration into space-constrained devices while maintaining high performance.
4. **Bandwidth**:
   To support diverse communication standards and frequency allocations, the antenna aims for a 2.44 GHz bandwidth at 28 GHz and a 3.39 GHz bandwidth at 38 GHz, providing comprehensive coverage and flexibility.
5. **Directivity and Gain**:
   With directional radiation patterns and high gain, the antenna enhances communication range and reliability, making it particularly effective in dense urban environments.

1.3Objective of the Project

The primary objective of this project is to design and develop a dual-band microstrip patch antenna operating at 28 GHz and 38 GHz to meet the high-frequency requirements of 5G communication systems. The antenna aims to achieve the following:

1. Dual-Band Resonance:
   To enable efficient operation at two critical 5G mmWave frequency bands, 28 GHz and 38 GHz, by integrating a primary patch and a parasitic patch.
2. Compact Design:
   To create a lightweight and compact antenna structure with minimal dimensions suitable for modern miniaturized devices and systems.
3. Enhanced Bandwidth and Impedance Matching:
   To improve the antenna's bandwidth and ensure excellent impedance matching at both frequency bands through the use of a defected ground structure (DGS) and innovative patch modifications.
4. Radiation Pattern Optimization:
   To produce an omnidirectional radiation pattern at 28 GHz and suppress higher-order mode side lobes at 38 GHz, achieving reliable and efficient signal transmission.
5. High Efficiency and Gain:
   To utilize high-performance substrate materials (Rogers RT5880 Lossy) with a low dielectric constant (ε_r = 2.2) and low loss tangent to maximize efficiency and minimize power loss.
6. Sustainability and Practicality:
   To design an antenna that is both energy-efficient and easy to fabricate, making it feasible for real-world applications in IoT, 5G small cells, and satellite communication systems.

1.4 Motivation Of our topics

1.Developing Networking System in Bangladesh

The millimeter-wave (mmWave) bands, which are the current high-band frequencies of 5G, are normally between 24 GHz and 100 GHz. These bands are perfect for sophisticated applications because they offer extremely fast data speeds and low latency.

But in our country, there are only available mid-band spectrum (sub – 6GHz) of 5 GHz. For commercial 5G rollout, telecom operators have been granted mid-band spectrum (e.g., 2.3 GHz, 2.6 GHz, and 3.5 GHz) by the Bangladesh Telecommunication Regulatory Commission (BTRC). There are still trials and rollouts going on. 5G services are being tested and deployed by providers such as Grameenphone, Robi, Banglalink, and Tele talk, with an initial focus on industrial zones and densely populated urban regions. But high-band spectrums provide ultra-high data rates and low latency, making them ideal for advanced applications.

2.Main Focus of our project

We were focused to an antenna design which had the following characteristic:

- A compact, lightweight, and low-profile antenna.
- Multiband or wideband operation for systems like 5G, Wi-Fi, or IoT.
- Integration with modern electronic circuits on PCBs.
- High gain with the option for array-based designs.
- Cost-effective, mass-producible solutions.

1.5 Our Project Justification

Depending on the main focus of project, A Microstrip patch antenna may be preferred over other antenna types. The main justifications for why a microstrip patch antenna would be the best option are listed below:

1. Compact Size and Low Profile

- Why Important: Modern wireless devices require compact and lightweight components.
- Microstrip Patch Advantage: Microstrip antennas are perfect for small devices like wearables, tablets, and smartphones because they are naturally thin, small, and planar.

2. Ease of Integration

- Why Important: Integration with circuits is important for modern RF systems.
- Microstrip Patch Advantage: In order to ensure smooth integration with RF circuits, filters, these antennas can be readily built on the same printed circuit board (PCB) as other components.

3. Multiband and Wideband Capabilities

- Why Important: Devices often need to operate on multiple frequency bands (e.g., 28/38 GHz for 5G).
- Microstrip Patch Advantage: These antennas can operate in multiband or wideband without the need for additional antennas by utilizing slots, stubs, or stacked patches.

4. Directional Radiation Patterns

- Why Important: Many applications (e.g., 5G, satellite, radar) require antennas with high gain and focused beams.
- Microstrip Patch Advantage: Arrays of microstrip patches can create directional radiation patterns suitable for beamforming and high-gain applications.

5. Cost-Effective Manufacturing

- Why Important: Large-scale deployment requires cost-effective solutions.
- Microstrip Patch Advantage: Fabrication using standard PCB or low-cost materials (e.g., FR4, RT/Duroid) makes these antennas economical for mass production.

6. Versatility in Design

- Why Important: Different applications have unique requirements like gain, polarization, or size.
- Microstrip Patch Advantage: Microstrip antennas can be easily customized for:
    - Linear or circular polarization for MIMO systems or satellite communication.
    - Dual-band or multi-band operation for 5G or Wi-Fi.
    - Conformal designs for curved surfaces like drones or aircraft.

7. Lightweight and Conformal

- Why Important: Aerospace, automotive, and wearable applications require lightweight solutions.
- Microstrip Patch Advantage: These antennas are lightweight and can be designed to conform to curved surfaces without compromising performance.

8. Suitability for Millimeter-Wave (mmWave) Applications

- Why Important: 5G and other modern systems operate in mmWave bands (e.g., 28 GHz, 38 GHz).
- Microstrip Patch Advantage: At higher frequencies, their small size and high gain performance make microstrip antennas a natural fit.

9. High Reliability

- Why Important: Antennas in harsh environments require robust designs.
- Microstrip Patch Advantage: They are reliable under environmental stress, especially when using durable substrates like RT/Duroid or ceramics.

10. Low Electromagnetic Interference (EMI)

- Why Important: Reducing interference is crucial in dense wireless environments.
- Microstrip Patch Advantage: The planar design allows for lower EMI and easy integration with shielding techniques.

1.6 Technology Procedure:

The project follows a **"Design-Simulate-Optimize"** approach, an iterative development model tailored for designing the dual-band microstrip patch antenna. This methodology is ideal for antenna design projects due to its structured and efficient process:

1. **Efficient Exploration**: Various design configurations are explored through simulation before physical fabrication, reducing reliance on prototypes and streamlining development.
2. **Performance Evaluation**: Simulations help assess key antenna characteristics, such as return loss, bandwidth, gain, and radiation patterns, across the target frequency bands.
3. **Targeted Optimization**: Based on simulation results, the design is iteratively refined to meet performance objectives, ensuring precision and efficiency.

The methodology consists of three core stages, which form a continuous loop:

- **Design**: The process begins with creating an initial antenna design, guided by theoretical calculations, design principles, and specific application requirements.
- **Simulate**: The design is modeled and simulated using software like CST Studio Suite, providing a detailed analysis of the antenna's electrical behavior at operating frequencies.
- **Optimize**: The simulation results are analyzed, and the design parameters—such as dimensions, substrate properties, and feeding mechanisms—are modified. The refined design undergoes another round of simulation and evaluation.

This cycle repeats until the final design achieves the desired performance standards. The iterative nature of this process ensures continuous improvement, resulting in an antenna optimized for its intended application.

1.7 Summary Of this Paper

Chapter-1

This project develops a dual-band microstrip patch antenna for 5G mmWave applications at 28 GHz and 38 GHz, addressing challenges like bandwidth limitations and impedance mismatches. Advanced techniques, including parasitic patches and Defected Ground Structure (DGS), were employed to improve reflection coefficients, gain, and radiation efficiency. Using Rogers RT5880 as the substrate, the antenna achieved compact design, high performance, and suitability for IoT, satellite communication, and 5G networks. The iterative "Design-Simulate-Optimize" approach ensured precise and efficient results.

Chapter-2

This chapter examines advancements in dual-band antenna designs for 5G applications, emphasizing the importance of the 28 GHz and 38 GHz bands within the mmWave spectrum. Key challenges, such as gain, bandwidth, compactness, and manufacturability, are addressed using innovative techniques like Defected Ground Structures (DGS) and Substrate Integrated Waveguides (SIW). The review highlights the superior performance of the proposed DGS-based design, including excellent reflection coefficients, high gain, and compact size. Challenges like limited bandwidth, complexity, and material cost remain research gaps. Future directions include hybrid techniques, low-cost materials, and integration with MIMO systems for scalable and high-performance designs.

Chapter-3

Chapter 3 focuses on the design, working principles, and characteristics of **microstrip patch antennas**, emphasizing their importance in modern communication systems. These antennas are compact, lightweight, cost-effective, and suitable for a wide frequency range. Their construction involves etching a conductive patch on a dielectric substrate mounted on a ground plane, using materials such as FR4, Rogers, and Teflon.

The chapter explains the **working principle** of microstrip patch antennas, highlighting the role of fringing fields, resonance, and electromagnetic radiation. It also outlines the **design techniques**, such as selecting appropriate materials, calculating patch dimensions, choosing feeding techniques, and optimizing impedance matching. Techniques like using defected ground structures (DGS) and slot designs enhance bandwidth and radiation efficiency.

Key **parameters** like gain, directivity, bandwidth, radiation pattern, polarization, and impedance are detailed, along with methods to optimize them for high-frequency applications like 5G. The chapter also provides mathematical formulas for designing patch dimensions and feed lines, ensuring precise resonance and performance. Overall, the chapter highlights microstrip patch antennas as essential components in compact and efficient wireless communication systems.

Chapter-4

The chapter describes the design and evolution of a dual-band 5G antenna capable of operating at 28 GHz and 38 GHz. Key stages of the design are as follows:

1. **Primary Patch Antenna**: Initial design aimed to resonate at both frequencies but showed poor impedance matching and limited performance.
2. **Improvements in Stage 2**: A circular patch antenna was designed, yielding better gain and efficiency but still failing to achieve optimal impedance matching.
3. **Parasitic Patch Addition**: To address impedance mismatch, a parasitic patch was incorporated, significantly enhancing return loss and impedance matching. This led to improved gain and radiation efficiency.
4. **Defected Ground Structure (DGS)**: To further enhance performance, intentional modifications in the ground plane were made. This resulted in better reflection coefficients, bandwidth, and overall radiation properties.

Chapter-5

The chapter explores the evolution of a dual-band 5G antenna designed to operate at 28 GHz and 38 GHz, detailing its development stages and performance enhancements. The initial design focused on achieving dual-band operation using a primary patch, but limitations such as impedance mismatch and low efficiency necessitated modifications. A parasitic patch was then added to improve impedance matching, gain, and efficiency. Finally, a Defected Ground Structure (DGS) was introduced, which significantly enhanced reflection coefficients, bandwidth, and radiation patterns. The optimized antenna, compact and efficient, demonstrates strong potential for applications in 5G, IoT, satellite communication, and medical imaging.

Chapter-6

This chapter outlines the systematic project management plan for developing a microstrip patch antenna. It divides the project into structured tasks, including initial research, design and simulation, prototyping, testing and validation, and deployment. Each stage ensures thorough progress, from material selection and design optimization to performance evaluation for dual-band operation at 28 GHz and 38 GHz. The plan incorporates an organized schedule with milestones and emphasizes effective tracking to ensure timely delivery. The project concludes with environmental and health impact analysis, detailed documentation, and deployment of the antenna for applications like communication systems.

Chapter-7

This chapter concludes the project on the dual-band microstrip patch antenna designed for 5G mmWave applications. The project successfully demonstrated a compact and efficient antenna capable of dual-band operation at 28 GHz and 38 GHz, meeting the stringent requirements of high-speed, low-latency 5G networks. Innovations like the parasitic patch and defected ground structure significantly improved impedance matching, radiation efficiency, and bandwidth.

The design is well-suited for integration into IoT devices, small-cell base stations, and modern wireless systems. However, challenges like side lobes in the 38 GHz radiation pattern and lower-than-expected gain highlight areas for future improvement. Potential advancements include bandwidth enhancement, multi-band operation, radiation pattern optimization, and integration with emerging technologies like reconfigurable intelligent surfaces and energy harvesting systems. Additionally, exploring sustainable materials and AI-assisted design could further elevate the antenna’s performance and eco-friendliness.

Chapter-2
Literature Review

2.1 Introduction

The increasing penetration of fifth-generation (5G) communication technologies has been introduced in a new era of antenna design, with dual-band antennas gaining prominence due to their ability to operate at the 28 GHz and 38 GHz frequency bands. These frequencies, within the millimeter-wave (mmWave) spectrum, are critical for supporting the high data rates, low latency, and increased network capacity required by 5G applications. As a result, antenna designs are expected to meet stringent criteria, including high gain, enhanced bandwidth, compact size, efficient impedance matching, and strong isolation.

Designing dual-band antennas for 5G applications involves addressing several key challenges: achieving high gain, maintaining wide impedance bandwidth, ensuring compactness, minimizing mutual coupling in multi-antenna systems, and ensuring manufacturability at a reasonable cost.

Dual-band antennas play a pivotal role in addressing these requirements by enabling simultaneous operation across two frequency bands, thereby reducing hardware complexity and cost. However, achieving optimal performance in such antennas poses several challenges. Factors such as mutual coupling, bandwidth limitations, gain optimization, and manufacturability need to be addressed through innovative techniques like Defected Ground Structures (DGS), substrate-integrated waveguides (SIW), and advanced slotted configurations.

This chapter presents an in-depth review of state-of-the-art dual-band antenna designs operating at 28 GHz and 38 GHz. The review compares Our DGS-based results with existing studies to highlight advancements, identify research gaps, and propose future directions.

Our results exemplify the efficacy of the DGS technique, achieving remarkable performance metrics at both frequency bands, including:

- **Reflection coefficients (S11):** -32.356 dB at 28 GHz and -51.504 dB at 38 GHz, indicating excellent impedance matching.
- **Gain:** 7.903 dB at 28 GHz and 5.339 dB at 38 GHz, showcasing balanced directivity and efficiency.
- **VSWR:** Near-perfect values of 1.05 and 1.06 at 28 GHz and 38 GHz, respectively.

2.2 Related Research

Defected Ground Structure (DGS) is a widely adopted technique for enhancing antenna performance by introducing patterns or slots in the ground plane. These modifications disrupt current distributions, leading to improvements in impedance matching, reflection coefficients, and bandwidth.

Our design demonstrates the efficacy of DGS in achieving superior performance. With reflection coefficients of -32.356 dB at 28 GHz and -51.504 dB at 38 GHz, our antenna outperforms many existing designs in impedance matching and power reflection minimization. The near-perfect VSWR values (1.05 at 28 GHz and 1.06 at 38 GHz) further highlight the DGS technique's capability for ensuring efficient power transfer.

Marzouk et al. also utilized DGS in their slotted MIMO antenna, achieving isolation levels of -29.4 dB and -27.3 dB at 28 GHz and 38 GHz, respectively, with gains of 7.88 dBi and 9.49 dBi. While their design prioritized isolation, our DGS-based approach strikes a balance by achieving high gain, low reflection coefficients, and compact dimensions. [3]

Farahat and Hussein applied DGS to a wideband composite patch MIMO antenna, reporting S_{11} values of -34.5 dB at 28 GHz and -27.3 dB at 38 GHz. However, their design required additional complexity, such as composite patches and parasitic elements, compared to the simplicity and efficiency of our approach. [4]

Substrate Integrated Waveguide (SIW) technology integrates waveguide-like structures within planar substrates, offering high gain and bandwidth. SIW-based designs, such as those by Ashraf et al., have demonstrated their effectiveness in mmWave applications. Their SIW antenna array achieved gains of 11.9 dBi and 11.2 dBi at 28 GHz and 38 GHz, respectively. However, these designs typically require larger substrates, which limits their suitability for compact mobile devices.

In contrast, Our DGS-based design achieves competitive performance within a smaller footprint (6 mm × 7 mm × 0.035 mm ground plane), making it a strong contender for integration into 5G smartphones and other compact applications. [5]

Compact patch antennas remain a popular choice for dual-band designs due to their simplicity and ease of fabrication. Liu et al.'s H-shaped slot patch antenna achieved relative bandwidths of 3.2% and 5.3% with gains of 9.0 dBi and 5.9 dBi at 28 GHz and 38 GHz, respectively. Similarly, Ahmad and Khan's PIFA antenna emphasized compactness, achieving bandwidths of 3.34 GHz and 1.395 GHz with a form factor of just 1.3 mm × 1.2 mm (2)(7). [6] [7]

Our results demonstrate a balanced approach, achieving competitive gain and impedance matching without compromising compactness. Unlike Liu's design, which required additional complexity to achieve high gain, Our design benefits from the simplicity and efficiency of the DGS technique.

MIMO antenna systems are essential for 5G networks, offering enhanced channel capacity and reliability. Chu et al.'s dual-polarized phased-array MIMO antenna achieved isolation levels exceeding 20 dB, making it suitable for multi-user environments. However, the complexity of such designs often increases fabrication costs and implementation challenges (4). [8]

In comparison, Our DGS-based design achieves high isolation and gain with minimal complexity, making it more feasible for mass production and widespread adoption.

AFSL antennas, such as those by Marzouk et al., offer cost-effective solutions for 5G applications. Their design achieved bandwidths of 3.5% and 7% at 28 GHz and 38 GHz, respectively, using low-cost FR-4 substrates. While these designs prioritize manufacturability, our results highlight the ability to achieve superior impedance matching and gain without sacrificing cost-effectiveness (6). [9]

2.3 Comparative Analysis

The reviewed designs vary significantly in their methodologies and performance metrics. Table 2.1 provides a detailed comparison:

Table 2.1: Comparison proposed antenna among another antenna

Reference paper	**Resonance paper**		**Bandwidth GHz**		**Gain dB**		**Reflection coefficient dB**	
			28	**38**	**28**	**38**	**28**	**38**
Proposed Antenna 11 Nov 2024	28.055	38.138	2.444	3.397	5.87	3.74	-32.356	-51.504
3	28	38	1.0683	1.4306	7.88	9.49	-29.4	-27.3
4	28	38	1.23	1.06	6.6	5.86	−34.5	−27.3
5	28	38	0.32	1.9	11.9	11.2	-25	-37
6	28	38	3.34	1.395	3.75	5.06	42	16
7	28	38	1.02	3.69	6	4	NA	NA
8	28	38	1	1.3	5.535	4.932	-21.09	-30.36
9	28	38	0.9	2	9	5.9	-27	-24

2.4 Discussion

2.4.1 Strengths of Our DGS Design

Our DGS-based antenna demonstrates exceptional performance in key metrics such as gain, reflection coefficient, and VSWR. The balanced radiation patterns at both frequencies further enhance its suitability for real-world applications.

2.4.2 Addressing Compactness and Manufacturability

While designs like the SIW antenna excel in gain, their large size limits their applicability in compact devices. Similarly, PIFA and AFSL antennas offer compact designs but compromise on performance. Our DGS approach strikes an optimal balance, achieving high performance within a manageable size.

2.4.3 Research Gaps and Opportunities

While several studies have demonstrated the effectiveness of DGS in enhancing antenna performance, there are still several gaps in the current literature that need to be addressed:

1. **Bandwidth Optimization:**
   Although the DGS technique has proven effective in improving impedance matching and reducing mutual coupling, there is still room for improvement in achieving broader bandwidths without compromising compactness. Future research could explore hybrid approaches, such as combining DGS with reconfigurable elements, to further extend bandwidth and gain.
2. **Manufacturability:**
   While DGS enhances antenna performance, it also introduces complexity in terms of fabrication. The integration of DGS in commercial antenna designs must consider manufacturability, especially in high-volume production for mobile devices. Future studies should focus on simplifying the DGS design to facilitate easier and cost-effective production.
3. **Material Exploration:**
   Most DGS-based designs rely on high-cost substrates like Rogers 5880 for performance optimization. However, there is a need for research into low-cost, high-performance materials that can enable mass adoption of DGS-based antennas for consumer electronics without increasing the cost significantly.

2.4.4 Future Research Directions

Future work should explore hybrid approaches, such as combining DGS with reconfigurable designs or integrating metamaterials to further enhance bandwidth and gain. Investigating low-cost materials with high performance could also improve scalability for mass production.

2.4.5 Additional Considerations

In addition to the primary technical considerations, other aspects should be taken into account when designing antennas for 5G applications:

- **Polarization Diversity:** The inclusion of polarization diversity in antennas can help reduce interference in multi-user environments, improving the overall capacity of 5G networks. Research into dual-polarized DGS antennas could further enhance performance for such scenarios.
- **Integration with MIMO Systems:** As MIMO systems play a crucial role in enhancing 5G capacity, the integration of DGS-based antennas with multi-port MIMO configurations is an area for further exploration.

2.5 Summary

This literature review has explored the current state-of-the-art in dual-band antenna design for 5G, with a specific focus on the DGS technique. The review has highlighted key advancements, including the improvement of reflection coefficients, impedance matching, gain, and isolation in DGS-based antennas. While existing research has made significant strides, challenges related to bandwidth, compactness, and manufacturability remain. our DGS-based antenna design provides a promising solution to these challenges, offering a balance of performance, compactness, and cost-effectiveness. Future research should focus on optimizing bandwidth, enhancing manufacturability, and exploring new materials and hybrid techniques to further improve the performance of dual-band antennas for 5G applications.

2.7 Conclusion

The integration of DGS into dual-band antenna design highlights its potential to overcome the challenges of 5G communication systems. Our results, in comparison with existing literature, demonstrate the superiority of the DGS technique in achieving optimal performance metrics. By focusing on compactness, cost-effectiveness, and scalability, our design provides a roadmap for future advancements in 5G antenna technology.

Chapter-3
Microstrip Patch Antenna

Microstrip patch antenna has a great impact in modern communication system. It offers more features than the traditional one. These features including compact size, weight, cost, ease of fabrication, ease of integration, performance, wide frequency range etc.

Microstrip patch antenna is designed by etching out a piece of conductive material on a piece of dielectric surface which mounted at ground level. Usually, the size of the patch antenna can be rectangular, circular or square.

Nowadays communication devices keep getting smaller so are antennas. Though it has low efficiency and low radiation power, designer is used it due to its size, installation. The dielectric material increases the bandwidth of patch antenna. Nowadays manufacturer design patch antenna on metal sheet and mount them on dielectric substrate to solve the radiation problem also save manufacturing cost.

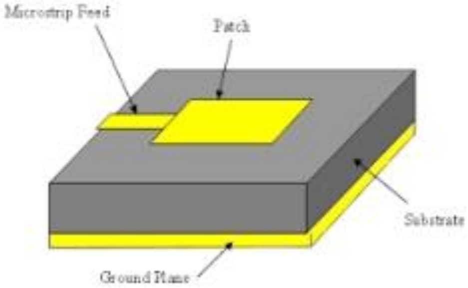


Fig 3.1: Microstrip Patch Antenna

3.1 Construction

Microstrip patch antenna is generally designed on dielectric substrate which mounted on a ground. Patch antenna and feed line are etched on substrate. There are many substrates that can be used, some are FR4, RT Duroid, Rogers RO 2300 etc. Generally, copper, aluminums are used as conducting material. Patch antenna height is smaller than the substrate height. Thick substrate provides better efficiency, greater bandwidth better efficiency. And they have higher dielectric constant and larger in size. On the contrary thin substrate minimized undesired radiation and coupling and thin substrate dielectric constant is smaller and small in size. Nowadays designer first design antenna in software then implements it. CST, HFSS are one of these software. [10]

3.2 Working Principle of patch antenna

The working principle of a microstrip patch antenna is based on electromagnetic radiation due to the fringing fields between the edges of a conductive patch and the ground plane. The patch is excited or fed with an RF (radio frequency) signal through various feeding techniques, such as microstrip line feeding, coaxial probe feeding, aperture coupling, or proximity coupling. The patch is excited or fed with an RF (radio frequency) signal through various feeding techniques, such as microstrip line feeding, coaxial probe feeding, aperture coupling, or proximity coupling. The edges of the patch antenna experience “fringing effects,” where electric fields extend beyond the patch boundaries into the surrounding air.

When the patch size is approximately half the wavelength (λ/2) of the operating frequency, it resonates, and these fringing fields effectively contribute to radiating energy. The oscillating electric and magnetic fields create electromagnetic waves that propagate from the patch. The resonant frequency depends on the patch dimensions and the dielectric properties of the substrate material. This radiation is primarily perpendicular to the patch surface and is directional. Due to the constructive and destructive interference of the waves from opposite edges of the patch, a specific radiation pattern is formed. Typically, patch antennas have a broad, directional radiation pattern focused in the forward direction (above the patch). The radiation efficiency depends on factors like substrate material, thickness, and losses in the feed and patch materials. The radiation efficiency depends on factors like substrate material, thickness, and losses in the feed and patch materials. [11]

3.3 Comparison of Other Antennas

Feature	**Microstrip Patch Antenna**	**Dipole Antenna**	**Horn Antenna**	**Parabolic Reflector**
Size	Compact	Larger	Bulky	Very Large
Weight	Lightweight	Moderate	Heavy	Heavy
Directionality	Moderate to High (Array)	Omnidirectional	Very High	Very High
Integration with PCB	Excellent	Difficult	Not feasible	Not feasible
Cost	Low	Low	High	High
Multiband Capability	Easy to Design	Challenging	Difficult	Difficult
Gain	Medium to High	Low	High	Very High

3.4 Design Technique of Microstrip Patch Antenna

When designing a patch antenna, suitable materials and dimensions must be chosen in order to desired requirements for polarization, gain, bandwidth, and resonant frequency. The following are the primary methods and procedures used in patch antenna design:

1.Define Operating Frequency and Dielectric Material: Operating frequency of the antenna need to be determined which will specify the antenna physical size. Dielectric substrate material should be chosen with an appropriate dielectric constant (ϵr) and thickness (h). Common materials include FR4, Rogers, and Teflon. This material has different characteristics. [12]

2.Calculate Patch Dimensions: The dielectric constant and resonance frequency of the substrate are used to determine the patch's width and length.

The length of the patch L can be approximated by:

$$L=\frac{c}{2f_0\sqrt{\epsilon_{eff}}}\ \ldots\ldots\ldots\ldots\ldots\ldots..(1)$$

where:

- c is the speed of light,
- f_0 is the operating frequency,
- e_{eff} is the effective dielectric constant of the substrate.

 Width **Calculation**: The width W of the patch is typically given by:

$$W=\frac{c}{2f_0}\sqrt{\frac{2}{\epsilon_r+1}}\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(2)$$

3. Determine Feeding Technique

Feeding techniques in microstrip patch antennas are critical for determining their impedance matching, bandwidth, and overall performance. These techniques can be categorized into **contacting** and **non-contacting methods**, each with specific applications and advantages:

i. **Contacting Feeding Techniques**
   a) **Microstrip Line Feed:**
      - A conducting strip (microstrip line) is connected directly to the radiating patch.
      - **Advantages:**
        Simple design and easy to fabricate.
        Impedance matching can be adjusted by varying the inset length.
      - **Disadvantages:**
        High spurious radiation, especially at higher frequencies.

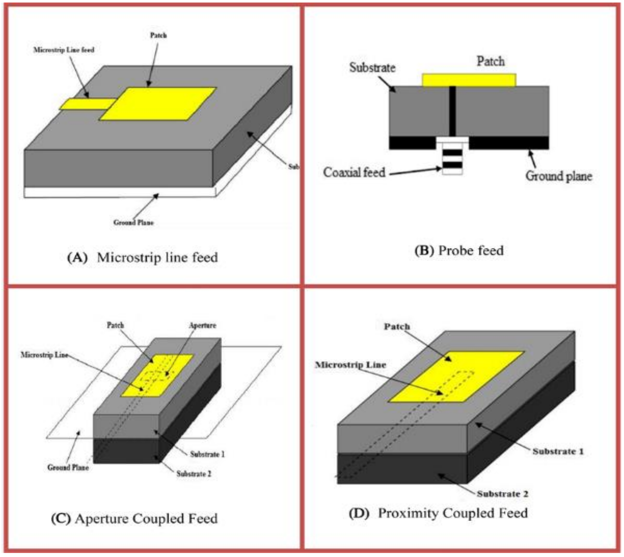
   b) **Coaxial/Probe Feed:**
      - A coaxial cable is fed through the ground plane and connected to the radiating patch.
      - **Advantages:**
        Easy to implement.
        Suitable for compact designs.
      - **Disadvantages:**
        Can cause limited bandwidth and complexity in multi-layer designs.

ii. **Non-Contacting Feeding Techniques**
   a. **Proximity Coupling:**

- Uses a feed line underneath the patch separated by a dielectric layer.
- Advantages:
  Improved bandwidth.
  Reduced spurious radiation.
- Disadvantages:
  Complex fabrication due to multi-layer structure.

b. **Aperture Coupling:**

- A slot (aperture) in the ground plane couples the energy from the feed line to the radiating patch.
- Advantages:
  Better isolation between the feed and radiating element.
  Enhanced bandwidth.
- Disadvantages:
  Complex design and alignment challenges.



(A) Microstrip line feed

(B) Probe feed

(C) Aperture Coupled Feed

(D) Proximity Coupled Feed

Fig 3.2: Feeding Technique

Choosing a Feeding Technique

The selection of a feeding technique depends on the desired application. For example:

- **Simple and low-cost designs:** Microstrip line or coaxial feed is suitable.
- **High-performance designs:** Proximity or aperture coupling is preferred.

4. Impedance Matching and Optimization

Use the inset feed to adjust the feed point location for impedance matching. Simulations can help identify the optimal feed position for minimal return loss (s_{11}) at both frequencies.

5.Using Ground Structure Defects (DGS)

Introduce a defective ground structure (DGS) to increase bandwidth. This entails making gaps or patterns in the ground plane, which can alter the way current is distributed and lower the antenna's Q-factor, increasing bandwidth.

i. **Design of Slots:** Slot machine types include simple slots, circular patterns, U-shaped slots, and rectangular slots. To improve coupling for this dual-band design, two circular or rectangular slots might be positioned right underneath the patch.
ii. **Slot Dimensions:** For optimal performance, start with slots that are around λ/4 at the lower frequency (28 GHz). The bandwidth and resonance may be adjusted by adjusting the slot's width and length.
iii. **DGS positioning:** To ensure symmetric radiation characteristics, place the slots symmetrically with regard to the feed line. DGS positioning: To ensure symmetric radiation characteristics, place the slots symmetrically with regard to the feed line.

6. Simulation and Optimization

- Use electromagnetic simulation software (e.g., HFSS, CST, or ADS) to:
    - Optimize patch dimensions for resonance at 28 GHz and 38 GHz.
    - Fine-tune the feed point for impedance matching.
    - Simulate the impact of DGS on bandwidth and optimize slot dimensions and placement.
- Analyze key parameters:
    - **Return Loss (S11)**: Should be below -10 dB at both 28 GHz and 38 GHz.
    - **Bandwidth**: Check if the DGS improves bandwidth for each frequency band.
    - **Radiation Pattern**: Ensure that the pattern is consistent with mmWave communication needs (directional and high gain).

7. Fabrication and Testing

- Fabricate the antenna on a PCB with the specified substrate and defected ground structure.
- Test the antenna with a vector network analyzer (VNA) to measure return loss, gain, and bandwidth at 28 GHz and 38 GHz.
- Compare results with simulations and make necessary adjustments if required.

3.5 Parameters of Microstrip Patch Antenna

Antenna parameters are key factors that describe the performance and characteristics of an antenna [13]. Here are some important antenna parameters:

3.5.1 Gain:

An antenna's gain is a measurement of how well it concentrates energy in a certain direction in relation to a reference antenna, which is frequently a dipole antenna or an isotropic radiator. Decibels (dB) are typically used to express it [14].

An important factor that shows an antenna's capacity to concentrate energy in a particular direction and improve signal strength and quality is its gain. High gain at both 28 GHz and 38 GHz is crucial for a dual-band microstrip patch antenna intended for 5G applications.

In 5G networks, higher gain means more efficient transmission and reception, which is essential for high-speed data transport. Gain can be increased by employing strategies like array designs and patch stacking. Furthermore, by optimizing impedance matching and reducing surface wave losses, a Defected Ground Structure (DGS) can further increase gain, guaranteeing dependable and strong communication in challenging 5G conditions.

3.5.2 Directivity:

The capacity of an antenna to concentrate energy in a specific direction is known as directivity. It is a dimensionless quantity that is usually associated with the gain of the antenna.
In contrast to an isotropic radiator, which emits uniformly in all directions, directivity quantifies how concentrated an antenna's emission pattern is in a particular direction. In order to maximize signal strength and reduce interference from other directions, an antenna with higher directivity effectively concentrates energy in a certain direction. This is critical for applications where targeted signal transmission and reception are necessary, such as radar and satellite communication. Usually measured in decibels (dB), directivity is a crucial factor in antenna design that affects coverage and performance. It improves the overall quality of communication by assisting in identifying how well the antenna concentrates electricity in the required regions [15].

3.5.3 Bandwidth:

The range of frequencies that an antenna can efficiently operate over is known as its bandwidth. Usually, it is stated in Hz, MHz, or GHz. The size and design of the antenna have a direct impact on its bandwidth.

The range of frequencies that an antenna can efficiently operate over is referred to as its bandwidth. It is an important parameter that establishes how well the antenna can handle a variety of signals. The low bandwidth of a microstrip patch antenna can restrict its performance in wideband applications. Broadband can be increased by employing strategies like a Defected Ground Structure (DGS), parasitic elements, or a thicker substrate. Modern wireless systems, particularly 5G, require an antenna with a wider bandwidth in order to support more communication channels and faster data speeds. Essentially, more bandwidth means that the antenna is more versatile and performs better.

3.5.4 Radiation Pattern:

The way an antenna radiates energy in various directions is described by its radiation pattern. A polar plot, which shows the radiation strength in relation to direction, is commonly used to illustrate it.
An antenna's power distribution as a function of direction is represented by a radiation pattern. Both two-dimensional and three-dimensional graphs can be used to show how an antenna sends and receives signals in various directions. The pattern aids in visualizing the coverage area of the antenna by displaying areas of maximum and least radiation. A clearly specified radiation pattern is essential for 5G applications in order to maximize signal

strength and reduce interference. A crucial component of assessing antenna effectiveness is comprehending and developing the radiation pattern, which is necessary to guarantee effective and focused communication.

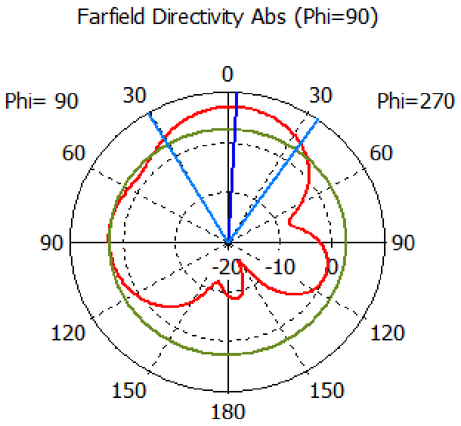


Fig 3.3: Radiation Pattern of Microstrip Patch Antenna

3.5.5 Polarization:

The orientation of the radio wave's electric field with respect to the Earth's surface is known as polarization. Antennas may be circularly polarized (left- or right-hand) or linearly polarized (horizontal or vertical).

Polarization refers to the orientation of the electric field of an electromagnetic wave. It is a critical parameter in antenna design and wireless communication. There are three main types: linear, circular, and elliptical polarization. Linear polarization has the electric field oscillating in a single plane, either horizontally or vertically. Circular polarization has the electric field rotating in a circular motion, which can be right-hand or left-hand. Elliptical polarization is a mix, with the electric field tracing out an ellipse. Proper matching of polarization between transmitting and receiving antennas ensures maximum signal strength and quality, while mismatched polarizations can lead to signal loss. Understanding polarization is vital for optimizing communication systems and reducing interference.

3.5.6 Impedance:

An antenna's resistance to alternating current flow is known as its impedance. Usually, it is stated in ohms (Ω). 50Ω and 75Ω are the most popular impedance levels for antennas. To reduce signal reflection, the antenna impedance must be equal to the transmission line impedance.

Usually measured in ohms (Ω), impedance in an antenna is a measurement of resistance to electrical current flow. It combines reactance (the hypothetical part) with resistance (the real part). The antenna's impedance, which is typically set at 50 ohms, should match the impedance of the transmission line and the associated equipment for effective power transfer. Signal reflection from mismatched impedance causes power loss and decreased performance. In order to maximize signal strength, minimize reflection (VSWR), and guarantee the best possible operation of the communication system, proper impedance matching is essential. To accomplish this match, methods like matching networks and tuners are frequently used [16].

3.5.7 Antenna Efficiency:

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3.5.8 Front-to-Back Ratio:

The antenna's radiation in its primary direction (front) divided by its radiation in the opposite direction (back) is known as the front-to-back ratio. Better directional focus is indicated by a high front-to-back ratio.

The ability of an antenna to suppress radiation in the opposite direction of its main lobe is measured by the Front-to-Back Ratio, or F/B Ratio. Power radiated in the intended direction (front) divided by power radiated in the opposite direction (back) is what it is. A greater F/B ratio, measured in decibels (dB), denotes improved performance by reducing interference and sharpening the signal's focus. In applications like satellite communication and directional antennas, where lowering back radiation is critical for enhancing overall signal quality and minimizing undesired interference, this value is essential.

3.5.9 Beam-width:

The antenna's radiation in its primary direction (front) divided by its radiation in the opposite direction (back) is known as the front-to-back ratio. Better directional focus is indicated by a high front-to-back ratio.

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3.5.10 VSWR (Voltage Standing Wave Ratio):

The antenna's radiation in its primary direction (front) divided by its radiation in the opposite direction (back) is known as the front-to-back ratio. Better directional focus is indicated by a high front-to-back ratio.

The ability of an antenna to suppress radiation in the opposite direction of its main lobe is measured by the Front-to-Back Ratio, or F/B Ratio. Power radiated in the intended direction (front) divided by power radiated in the opposite direction (back) is what it is. A greater F/B ratio, measured in decibels (dB), denotes improved performance by reducing interference and sharpening the signal's focus. In applications like satellite communication and directional antennas, where lowering back radiation is critical for enhancing overall signal quality and minimizing undesired interference, this value is essential [18].

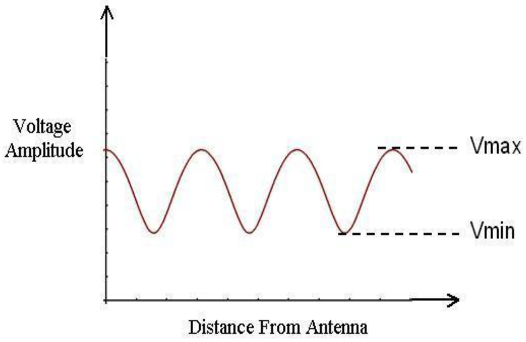

Fig 3.4: VSWR of Microstrip Patch Antenna

3.5.11 Return Loss:

Return loss is related to the VSWR and indicates the amount of power that is reflected back from the antenna due to impedance mismatch. It is expressed in dB, with higher values indicating better matching.

Return Loss is a critical parameter that indicates how effectively an antenna transmits power from a transmission line to a load, without reflecting back. It is measured in decibels (dB) and is a key indicator of impedance matching between the antenna and the transmission line. High return loss signifies that most of the power is transmitted with minimal reflection, resulting in efficient operation [19].

Mathematically, return loss is defined as:

Return Loss (dB) = 20 log_{10} ($\frac{v_{incident}}{v_{reflected}}$) ……………………(3)

Where V (incident) is the incident voltage and V (reflected) is the reflected voltage. High return loss values (e.g., 20 dB or higher) indicate good impedance matching, leading to minimal signal loss and enhanced communication quality.

Efficient antenna design aims to maximize return loss, ensuring that the power delivered to the antenna is radiated effectively. Poor return loss results in more power being reflected back, which can cause interference, reduce signal quality, and potentially damage the transmitter. Techniques such as using matching networks, adjusting antenna dimensions, and optimizing feed points are employed to achieve high return loss and ensure optimal antenna performance. Understanding and improving return loss is crucial for achieving robust and reliable wireless communication.

3.5.12 Elevation and Azimuth Angles:

Elevation and Azimuth Angles are crucial in defining the direction of an antenna's radiation or reception.

1. Elevation Angle

The Elevation Angle measures the vertical angle between the horizontal plane and the line of sight to the target. It ranges from 0° (horizontal) to 90° (vertical). In satellite communication, for instance, the elevation angle indicates how high the satellite appears in the sky from the observer’s location. A higher elevation angle generally reduces the chances of obstructions, like buildings or trees, interfering with the signal path.

2. Azimuth Angle

The horizontal angle clockwise from a reference direction (often true north) to the object's direction is measured by the azimuth angle. From 0° to 360°, it spans. Azimuth in antenna orientation indicates the path toward the target along the horizon.

Importance in Antenna Alignment

For optimal antenna alignment and signal intensity and quality, precise elevation and azimuth angles are essential. Poor transmission or reception, more interference, and decreased system performance can all result from misalignment. Setting these angles correctly guarantees the best possible connectivity for devices such as wireless communication towers, radar systems, and satellite dishes.

In order to achieve dependable and effective wireless communication, it is essential to comprehend and modify these angles, which guarantees that antennas are precisely aimed at the messages they are supposed to receive.

3.5.13 Current Distribution

The flow of electric current across an antenna's surface is referred to as its current distribution. The radiation pattern, impedance, and general performance of the antenna are all greatly influenced by this distribution. Current distribution in microstrip patch antennas usually varies along the patch and is focused close to the feed point. A number of variables, including operating frequency, substrate characteristics, and antenna design, affect the current distribution's form and intensity.

Reduced efficiency and undesired radiation modes can result from uneven current distribution. As a result, attaining the intended antenna properties requires optimizing the current distribution. Current distribution can be improved and controlled with the use of strategies including impedance matching networks, patch size modifications, and feed point placement adjustments. In order to guarantee optimal performance, it is usual practice in antenna design to analyze current distribution using simulation tools.

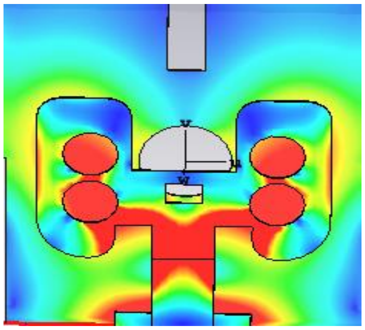

Fig 3.5: Current Distribution of Microstrip Patch Antenna

3.5.14 Surface Current

The flow of electrical current along an antenna's surface is referred to as surface current. The radiation pattern, impedance, and general performance of the antenna are all determined by this current distribution. The geometry of the antenna, the input signal's frequency, and the antenna's material characteristics all affect how surface current behaves. For instance, the surface current of a dipole antenna usually peaks in the middle and falls off toward the ends. The radiation pattern produced by this distribution is strongest perpendicular to the antenna. Understanding and improving antenna performance through surface current analysis ensures effective signal transmission and reception to analyze current distribution using simulation tools [20].

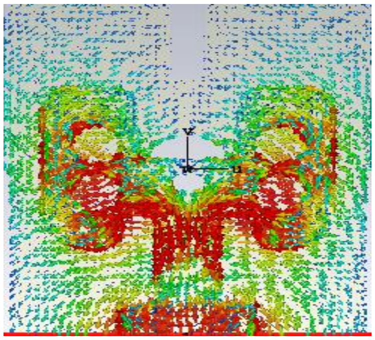

Fig 3.6: Surface current of Microstrip Patch Antenna

3.5.14 Far-Field

An antenna's far-field zone, sometimes referred to as the Fraunhofer region, is the region where the angular field distribution is independent of the distance from the antenna and the electromagnetic waves it emits look as plane waves. The magnetic (H) and electric (E) fields in this area are perpendicular to one another and to the direction in which waves are propagating. When examining the radiation pattern, gain, and directivity of an antenna, the far-field is essential. It is commonly described as the area outside of a distance of 2/λ, where λ is the wavelength and λ is the antenna's greatest dimension.

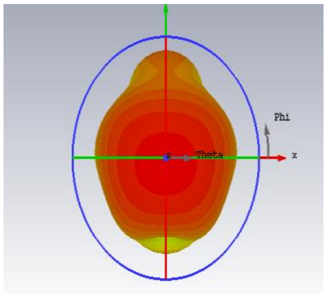

Fig 3.7: Far-field Region of Microstrip Patch Antenna

3.5.15 Impedance Matching

Impedance matching is crucial in antenna design to ensure maximum power transfer between the transmission line and the antenna. When impedances are matched, the reflection of the signal is minimized, improving efficiency and performance. Mismatched impedances can cause significant power loss and signal degradation due to reflections. Techniques for impedance matching include the use of matching networks, such as quarter-wave transformers, stubs, and impedance matching circuits like L-networks, Pi-networks, and T-networks. Additionally, adjusting the physical dimensions of the antenna or employing tun-able components can achieve better impedance matching. Proper impedance matching not only enhances signal strength and quality but also ensures the reliability and efficiency of the communication system, making it a fundamental aspect of antenna design and implementation.

3.5.16 Parasitic Patch

Parasitic patch antennas are distinctive in their design because they incorporate additional elements that aren't directly connected to the feed line. These parasitic elements, such as patches, slots, or rings, are placed near the driven element (the main patch), influencing the electromagnetic fields and improving the antenna's overall performance [21]. The unique configuration of parasitic patches allows for enhancements in several key areas:

1. **Bandwidth Improvement**: By modifying the current distribution and resonant frequencies, parasitic elements can significantly broaden the antenna's operational bandwidth. This is particularly beneficial for applications requiring wideband or multiband capabilities, such as modern wireless communication systems.

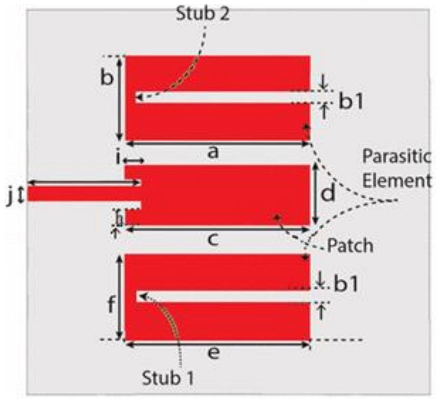

Fig 3.8: Parasitic Patch of Microstrip Patch Antenna

2. **Gain Enhancemen**t: The presence of parasitic elements can help direct more power in desired directions, thereby increasing the antenna's gain. This makes parasitic patch antennas suitable for applications where high efficiency and strong signal strength are essential.
3. **Radiation Pattern Control**: Parasitic patches can modify the radiation pattern of the antenna, providing better control over the directionality and shape of the emitted signals. This is useful in scenarios where specific coverage areas need to be targeted or interference needs to be minimized.
4. **Compact and Low-Profile Design**: Despite their enhanced performance, parasitic patch antennas maintain a compact and low-profile design, making them ideal for integration into space-constrained devices and systems.

3.5.17 Port

Port in the context of antennas typically refers to the point where the transmission line or feeder connects to the antenna, allowing for the transfer of power. This connection is crucial as it defines how efficiently the antenna can transmit or receive signals. The port impedance needs to match the transmission line impedance to ensure maximum power transfer and minimize reflections, usually set at 50 ohms. In antennas with multiple elements, each element might have its own port, and the performance can be analyzed using parameters like S-parameters (Scattering parameters). These parameters describe how the signal is split, reflected, and transmitted between the different ports, providing insights into the antenna's performance and efficiency [22].

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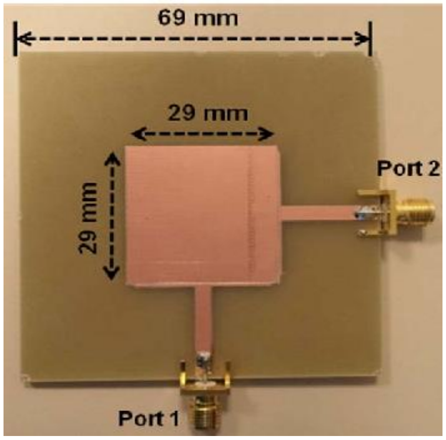


Fig 3.9; Port of Microstrip Patch Antenna

3.6 Materials of Microstrip Patch Antenna

Microstrip antennas, also known as patch antennas, are constructed using specific materials that determine their performance and characteristics. Here are the details:

i. Dielectric Substrate
ii. Ground Plane
iii. Radiating Patch

3.6 .1 Dielectric Substrate:

The substrate is a crucial component in the design and performance of microstrip antennas. It serves as the foundational layer upon which the metallic patch and ground plane are mounted. The properties of the substrate, including its dielectric constant, thickness, and loss tangent, significantly influence the antenna's characteristics such as impedance, bandwidth, and efficiency [23]**.**

Materials Type:

a) **FR4: A** common component of printed circuit boards (PCBs), FR4 is especially utilized in microstrip antennas. It has a loss tangent of around 0.02 and a dielectric constant (εr) of about 4.4. Because of these characteristics, FR4 balances cost and performance, making it appropriate for a range of electronic applications. Its cost-effectiveness is one of its main benefits, which makes it a desirable option for mass production. It works well at low to intermediate frequencies and is frequently found in commonplace gadgets like computers, smartphones, and home electronics.

b) **Rogers RT/duroid: A** popular high-performance substrate material for microstrip antenna manufacturing is Rogers RT/duroid. It has an extremely low loss tangent of less than 0.001 and a dielectric constant (εr) that ranges from 2.2 to 3.0. Because of these qualities, Rogers RT/duroid is incredibly well-suited for high-frequency applications, where superior electrical characteristics and little loss are essential for optimum performance. Even at higher frequencies, Rogers RT/duroid's ability to maintain high efficiency and low signal attenuation is one of its fundamental features. Because of this, it is the perfect option for use in sophisticated communication systems where accuracy and dependability are crucial, such as satellite communications and aircraft.

c) **Teflon:** Teflon (PTFE), a highly specialized substrate material known for its remarkable electrical and thermal resilience, is utilized in the production of microstrip antennas. It has an exceptionally low loss tangent of around 0.0002 and a dielectric constant (εr) of about 2.1. Teflon (PTFE) is the perfect material for applications that need low dielectric losses and reliable performance across a range of circumstances because of these qualities. Teflon (PTFE) is a favored material for sophisticated communication systems because of its main advantage, which is its capacity to preserve signal integrity with little attenuation, even at high frequencies. One of the best materials for high-performance microstrip antenna designs is Teflon (PTFE), which guarantees remarkable robustness and efficiency under some of the most demanding operating circumstances.

d) **Arlon:** Because of its low to moderate loss tangent and broad range of dielectric constants, Arlon is a flexible substrate material that is utilized to build microstrip antennas. The dielectric constant (εr) can range from 2.5 to 10.2 depending on the particular kind of Arlon material employed. Engineers can modify the substrate material to satisfy the unique performance needs of various antenna designs thanks to the dielectric characteristics' flexibility. Arlon's ability to provide diverse design options is one of its key advantages; it makes it possible to create antennas with optimal performance for a range of applications. Arlon's diverse range of dielectric constants and favorable loss characteristics make it a highly adaptable material for microstrip antennas, supporting a wide array of communication systems with varying performance needs.

Properties:

a) **Dielectric Constants:** Relative permittivity, another name for the dielectric constant, is a measurement of a material's electrical energy storage capacity. The dielectric constant of the substrates used in microstrip antennas usually ranges from 2.2 to 12. For high-frequency and wideband applications, lower dielectric constants (around 2.2 to 4.4) are favored because they produce lower losses and bigger bandwidths.

b) **Thickness:** The antenna's bandwidth, impedance, and efficiency are all impacted by the substrate's thickness. In general, thicker substrates (more than 0.05λ, where λ is the free-space wavelength) offer a broader bandwidth; however, they can also increase radiation into the substrate and surface wave losses, which lowers efficiency. However, thinner substrates (less than 0.01λ) have a narrower bandwidth but increase efficiency. Microstrip antennas typically have a substrate thickness of 0.003λ to 0.05λ**.**

c) **Loss Tangent:** The dielectric losses in the substrate material are measured by the loss tangent. It can be described as the complex permittivity's imaginary to real portion ratio. For high-efficiency antennas, lesser dielectric losses are shown by lower loss tangents. High-frequency applications can benefit from the low loss tangents ($\tan \delta < 0.002$) of substrate materials such as Teflon and Rogers RT/duroid. In high-performance antenna designs, materials having greater loss tangents ($\tan \delta > 0.005$) are often avoided since they are less efficient.

3.6 .2 Radiating Patch

Antenna efficiency, bandwidth, and overall performance are all directly impacted by the conductor material selection, making it a crucial design decision. Both the antenna's ground plane and radiating element (such as a patch or dipole) are made of conductive materials. Here are the detailed aspects of the conductor material and its properties:

Material type:

a) **Copper:** The remarkable electrical conductivity of copper (Cu), which is roughly 5.8 x 10^7 S/m, makes it a highly preferred material in antenna construction. By drastically lowering resistive losses, this high conductivity level raises the antenna's overall efficiency. The availability and affordability of copper, which make it suitable for a variety of uses, are two of its main benefits. The use of copper in antenna design emphasizes how crucial it is to creating effective and high-performing antennas, which support the smooth operation of contemporary communication networks.

b) **Silver:** Since silver (Ag) has the highest electrical conductivity of any metal (about 6.3 x 10^7 S/m), it stands out as a premier material in antenna design. Silver is a great option for reducing resistive losses and increasing efficiency because of its greater conductivity, which is essential in high-frequency applications where performance is vital. Silver's exceptional conductive qualities, which guarantee little signal attenuation and peak performance, are one of its benefits. Silver continues to be a useful component in antenna design, helping to create cutting-edge communication systems that demand the best possible performance and efficiency.

c) **Gold:** Due to its remarkable resistance to oxidation and corrosion, gold (Au) is a unique substance utilized in antenna design. With a conductivity of roughly 4.1 x 10^7 S/m, gold has a lesser electrical conductivity than copper; nonetheless, its chemical stability provides substantial benefits for long-term dependability and performance, particularly under challenging conditions. Because of this, gold is the best option for high-reliability applications where longevity is essential. In space and military applications, when the necessity for reliable and long-lasting materials surpasses the increased cost, gold is widely used. All things considered, gold's special qualities make it a useful material for designing antennas for the most demanding and high-stakes situations.

Properties:

a) **Conductivity:** To ensure effective current flow and reduce resistive losses, high conductivity is necessary. Maintaining the antenna's performance, particularly at high frequencies, depends on this.

b) **Measurement of thickness:** Particularly at high frequencies where the skin effect causes current to flow largely on the surface, the thickness of the conductive material affects the skin depth. Sufficient thickness reduces losses and guarantees effective conduction.

c) **Roughness of Surface:** The performance of the antenna can be impacted by surface roughness, particularly at high frequencies. Efficiency is increased and resistive losses are decreased on a smoother surface.

d) **Stability of the Environment:** Long-term dependability and performance in challenging conditions are offered by materials like gold, which have a high resistance to oxidation and corrosion. Applications in military and aerospace systems depend on this.

3.6.3 Ground Plane

The ground plane is a vital component of an antenna system, particularly in microstrip and monopole antennas. It serves as the reference point for the radiating element and influences the antenna's performance in various ways. Here are the detailed aspects of the ground plane material and its properties:

Material type:

a) **Copper: Because** of its excellent electrical conductivity (around 5.8 x 10^7 S/m) and affordable price, copper is the most often used material for ground planes. Copper ground planes work well to reduce resistive losses, which raises the antenna's overall efficiency. Utilized in bigger ground planes for monopole and dipole antennas and printed circuit boards (PCBs) for microstrip antennas.

Aluminum

While not as high as copper, aluminum has a decent conductivity (around 3.5 x 10^7 S/m). Additionally, it is less costly and lighter than copper, which makes it a common option for bigger ground planes like those found in radar and satellite systems. Often used in larger installations where weight and cost are considerations, such as in satellite dishes and radar antennas.

Gold

Despite having a lesser conductivity than copper (about 4.1 x 10^7 S/m), gold has superior resistance to oxidation and corrosion. Utilized in vital systems where dependability and endurance are crucial, like military and space applications.

Properties:

Conductivity

To guarantee effective current flow and minimum resistive losses, the ground plane needs to have a high electrical conductivity. Maintaining the antenna's performance, particularly at high frequencies, depends on this.

Measurement of thickness:

The ground plane's conductivity and effectiveness as a reflector are influenced by its thickness. Although it can increase speed, a thicker ground plane is more expensive and heavier. A thin sheet of metal laminated onto a dielectric substrate usually serves as the ground plane for microstrip antennas.

Roughness of Surface:

The antenna's performance may be affected by the ground plane's surface roughness, especially at high frequencies when the skin effect induces current to flow on the surface. Efficiency is increased and resistive losses are decreased on a smoother surface.

Mechanical and Thermal Properties:

The ground plane needs to be resilient enough to endure the mechanical and thermal strains that the antenna will experience while in use. Good thermal conductivity, found in materials like copper and aluminum, aids in the dissipation of heat produced by the antenna

3.7 Equation used for Microstrip Patch Antenna

Microstrip patch antennas are widely used in modern wireless communication systems due to their compact size, ease of fabrication, and suitability for planar configurations [24]. Here are the primary equations for designing a rectangular microstrip patch antenna:

i. Resonant Frequency f_0 : 28 GHz (common frequency for High-Speed Data Transmission)

ii. Dielectric Constant ε_r: 2.2 (typical for FR4 substrate)

iii. Speed of Light c: 3×10^8 m/s

3.7.1 Formula for Patch Width, $W=\frac{c}{2f_0}\sqrt{\frac{2}{\varepsilon_r+1}}$

Plugging in the Values:

Substitute c: 3×10^8 m/s, f_0 : 28 GHz and Constant ε_r: 2.2

$$W=\frac{3\times10^8}{2\times28\times10^9}\sqrt{\frac{2}{2.2+1}}$$

$$=\frac{3}{560}\times0.79$$

=0.00423 m

=4.23 mm

3.7.2 Formula for Patch Length

Step 1: Calculate the Effective Dielectric Constant (ε_{eff})

The effective dielectric constant accounts for the fringing effect around the patch edges.

$\varepsilon_{eff} = \frac{\varepsilon_{r+1}}{2} + \frac{\varepsilon_{r-1}}{2}\,(1 + 12\,\frac{h}{W})^{-\frac{1}{2}}$ ……………………………(4)

Since the substrate height h was not specified, assume a common value for high-frequency applications, such as h = 0.254 mm (often used in millimeter-wave designs). If the actual h value differs, we can adjust the calculation accordingly.

Substituting Values:

- ε_r= 2.2
- W = 4.23 mm= 0.00423 m
- h = 0.254 mm = 0.000254 m

$\varepsilon_{eff} = \frac{\varepsilon_{r+1}}{2} + \frac{\varepsilon_{r-1}}{2}\,(1 + 12\,\frac{0.000254}{0.00423})^{-\frac{1}{2}}$

ε_{eff} = 1.6 +0.505 = 2.105

Step 2: Calculate Effective Length (L_{eff})

The effective length accounts for the fringing fields at the edges of the patch.

$L_{eff} = \frac{c}{2f_0\sqrt{\varepsilon_{eff}}}$

Substitute c = 3 × 10^8 m/s, f_0 = 28× 10^9 Hz, and ε_{eff} = 2.105

$L_{eff} = \frac{c}{2\times 28\times 10^9\,\sqrt{2.105}}$

Step 3: Calculate Length Extension (ΔL)

The fringing fields extend the effective length slightly beyond the physical length.

$\Delta L = 0.412h\,\frac{(\varepsilon_{eff} + 0.3)\,(\frac{W}{h} + 0.264)}{(\varepsilon_{eff} - 0.258)\,(\frac{W}{h} + 0.8)}$ ………………………(5)

Substitute h =0.000254 m, ε_{eff} = 2.105, and W = 0.00423 m

1. **Width to height ratio:** $\frac{W}{h} = \frac{0.00423}{0.000254} \approx 16.65$

2. Substitute values into the formula:

$\Delta L = 0.412 \times 0.000254 \times \frac{(2.105+0.3)(16.65+0.264)}{(2.105-0.258)(16.65+0.8)}$

$\Delta L = 0.123$ mm

Step 4: Calculate Patch Length L

Finally, we calculate the actual patch length L by adjusting the effective length:

$$L = L_{eff} - 2\Delta L \text{ ………………….(6)}$$

Substitute $L_{eff} = 3.695$ mm and ΔL = 0.123mm

L = 3.695 - 2 × 0.123 = 3.695 - 0.246 =3.449 mm

3.7.3 Feed Line Calculation

Formula for Microstrip Feed Line Width:

$$Z_0 = \frac{60}{\sqrt{\varepsilon_r}} ln\left(\frac{8h}{W} + \frac{W}{4h}\right) \text{ …………………(7)}$$

Where:

- Z_0: Characteristic impedance of the feed line (in ohms, typically 50 ohms for most designs)
- h: Height of the substrate (in meters)
- W_f: Width of the microstrip feed line (in meters)
- ε_r : Relative dielectric constant of the substrate material (a dimensionless quantity)

Rearranged Formula for
For practical purposes, solving for W_f requires numerical methods or approximation, but for wide
microstrip lines (when W_f /h is large, typically W_f > h), you can use an approximation for
simplicity:

$$W_f \approx \frac{8h}{\sqrt{\varepsilon_r}}\left(\frac{Z}{60}\right)^{-1} \text{ …………………………(8)}$$

This is a simpler formula that is often used for the typical case when the feed line width is much

greater than the substrate height.

3.7.4 Formula for Port Extension Coefficient

The port extension coefficient (also known as the length extension factor) is given by the

following formula: $\beta = \frac{L_{eff}}{L}$ …………………………..(9)

Where:

- L_{eff} is the effective length of the microstrip patch or feed line, which accounts for the fringing effects at the edges.
- L is the physical length of the patch or feed line without considering the fringing effects.

Chapter-4

Proposed 28-38 Dual Band 5G Antenna Design & Steps

The dual-band composite patch antenna design presented in this study is shown in Fig 4.11. It consists of two patches: the primary patch, which is fed by a direct microstrip line with an inset feed, and the secondary patch, which is coupled to the primary patch via its edge and acts as an indirect feed. Initially, a primary circular patch is designed to resonate at 28-38 GHz. After the initial design, parts of the patch with minimal current density are removed, and the dimensions are adjusted to maintain resonance at 28-38 GHz. But impedance did not match with Reference 50 Ohm. A secondary parasitic patch is capacitively coupled to the primary patch to provide impedance matching at a resonance frequency of 28-38 GHz. The composite patch antenna design is illustrated in Fig. 1, along with its dimensional parameters. The substrate material used is Rogers RT5880 Lossy, with a dielectric constant (ε_r) of 2.2, a height of 0.787 mm, and a loss tangent of 0.003. The final printed antenna dimensions are 4.732 mm × 3.344 mm × 0.035 mm. To improve the antenna's bandwidth, a defect is incorporated into the ground plane, as shown by the dotted red line in Fig 22. The entire design aims to improve radiation properties, increase bandwidth by modifying the ground plane, and achieve dual-band operation (28 GHz and 38 GHz). Further details of the design's dimensional parameters are provided in Table

Table 4.1: Parameter List

Parameter Name	Expression	Value (mm)
Ground Width	GW	6
Ground length	GL	7
Ground Height	GH	0.035
Substrate Width	SW	6
Substrate Length	SL	7
Substrate Height	SH	0.787
Patch Width	PW	4.732
Patch Length	PL	3.344
Patch Height	PH	0.035

4.1 Design stage-1: Primary patch Antenna with Feed Line

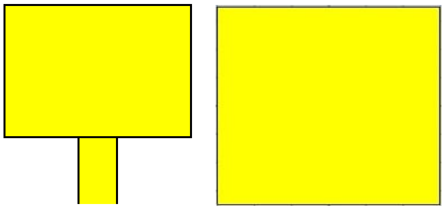


Fig 4.1: Primary Patch Antenna

Design Configuration

Primary antenna was designed to resonate at 28-38 GHz frequency. It is the initial stage. The geometry of this antenna shown in Fig 4.1. The goal is to find resonance in 28 and 38 GHz frequency. The size of the antenna is 4.732 x 3.344 x 0.035 mm. At this initial stage, this Antenna doesn't show a promising performance. At 28 GHz as well as, the patch is not matched to a 50-ohm feed line, resulting in no significant surface current spread over a large portion of the patch, as illustrated in Fig. 4.3. The reflection coefficient (|S11|) as a function of frequency is presented in Fig. X3. At this primary stage antennas bandwidth is not showed satisfactory performance. The gain pattern shows main lobe magnitude is 7.39 dBi at at $\theta = 7°$ at lower band 28 GHz on the other hand main lobe magnitude is 3.13 dBi at $\theta = 7°$ at upper band 38GHz. Though the gain of the initial antenna is satisfactory. The gain of the lower band is 5.009 dBi at 28 GHz and at higher band of 38 GHz the gain is 4.11 dBi. Al this result and performance can be improved by further modification.

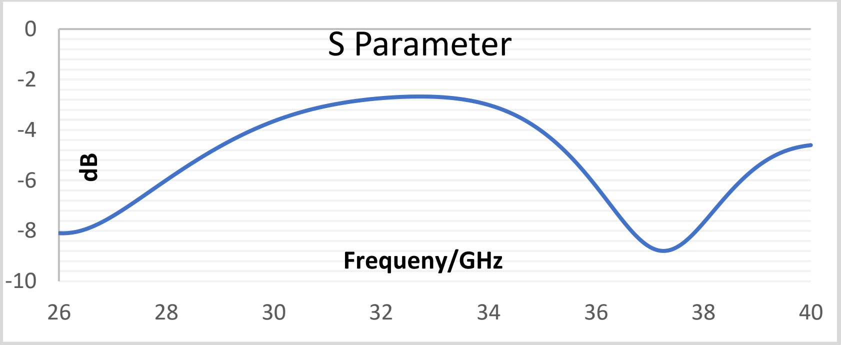
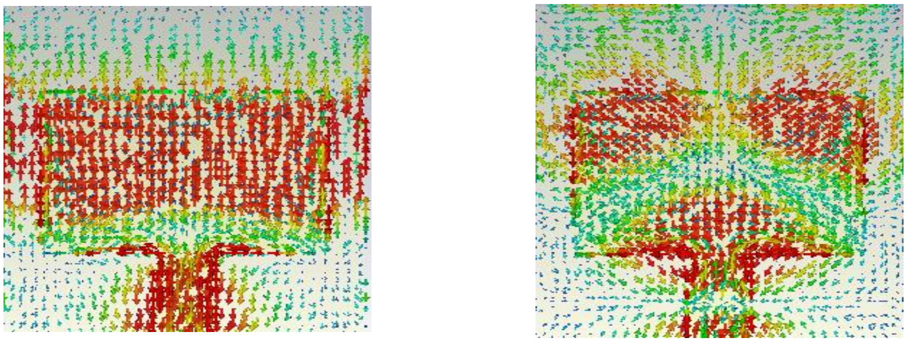


Fig 4.2: Reflection Coefficient of primary antenna



(a) **(b)**

Fig 4.3: Current distribution at (a) 28GHz & (b) 38GHz

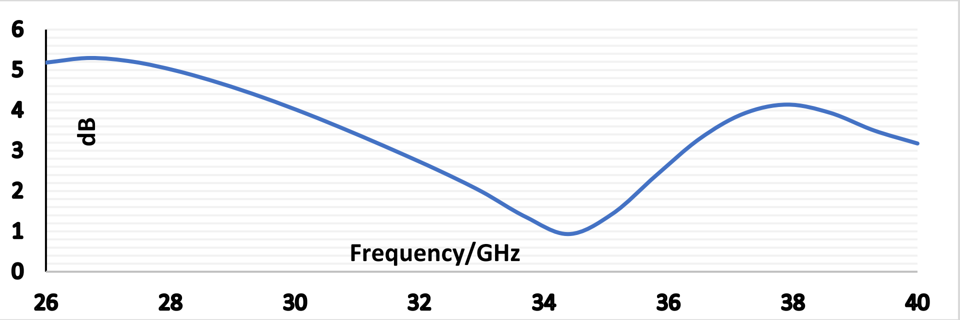


Fig 4.4: Realized Gain of Primary Antenna

4.2 Design Stage 2: Improvements of Parameter

A circular patch antenna is shown in Fig 4.5 which resonate at 28GHz and 38GHz. The patch antenna is not matched to impedance at 28 GHz and 38 GHz. The return loss at 28 DB was – 22.388 and at 38GHz was – 18.314 dB which is shown in Fig 4.6. The impedance at 28 GHz was 80.92 Ohm and 38 GHz was 64.199 Ohm. The gain of the primary antenna is 5.676 dB at 28 GHz also 3.93 dB at 38 GHz which shows in Fig 4.10 .The farfield direction shown in Fig 4.9 (a) the main lobe magnitude is 7.39 dBi in forward direction at 28 GHz (theta=1)and in fig 4.9 (b) shown the main lob magnitude is 0.413 dBi in forward direction at 38 GHz (theta=18.0degree).The surface current distribution shown in Fig 4.8(a) as impedance was not matched and the surface current area at 38GHz was narrow as compared to 28 GHz was shown in Fig 4.8(b) .The VSWR value is 1.36 at 28 GHz and 1.28 at 38 GHz.The radiation efficiency of the antenna is 69.33% at 28 GHz and 68.38% at 38 GHz. After all, comparing it can be decided that the 28GHz is much active than 38 GHz in Primary stage. The geometrical size of the antenna is to find 4.732 x 3.344 x 0.035 mm.

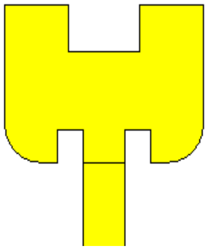


Fig.4.5: Modified Patch Antenna

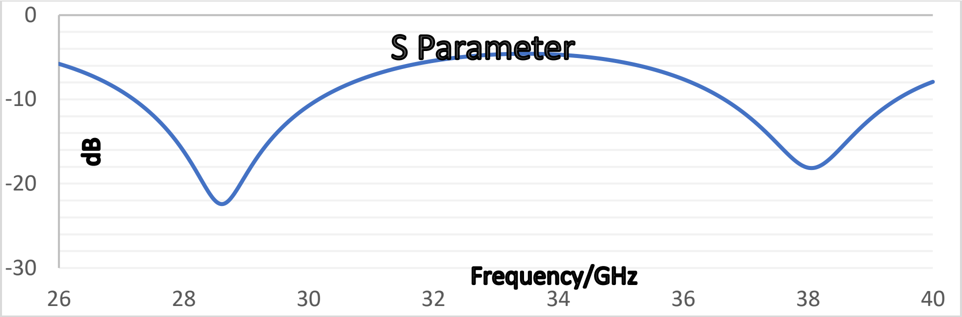


Fig 4.6: Reflection Coefficient of modified Antenna

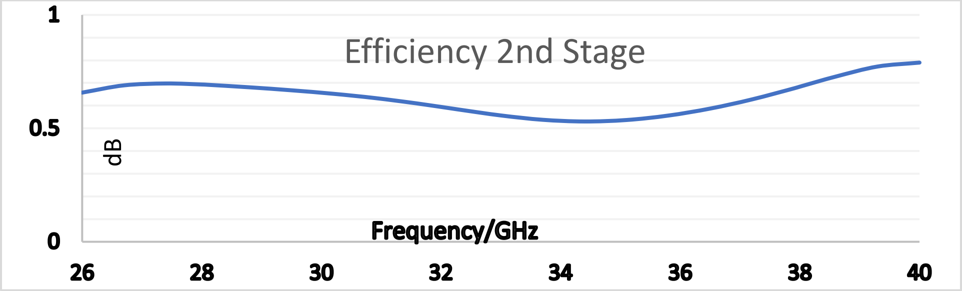
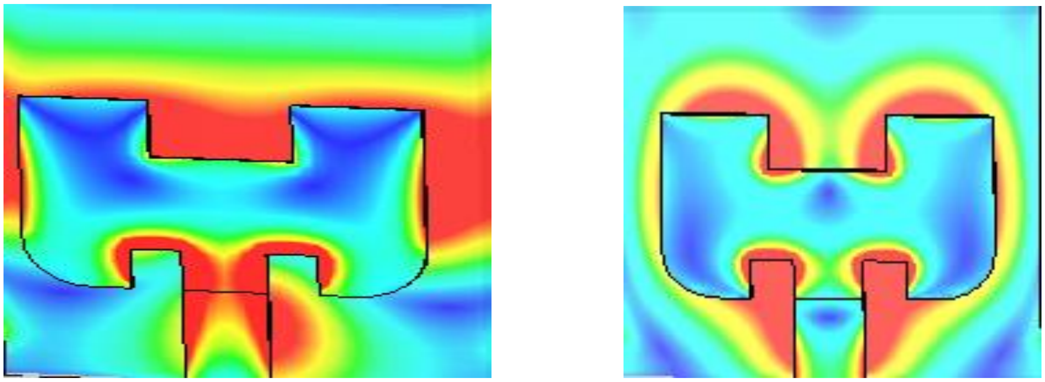
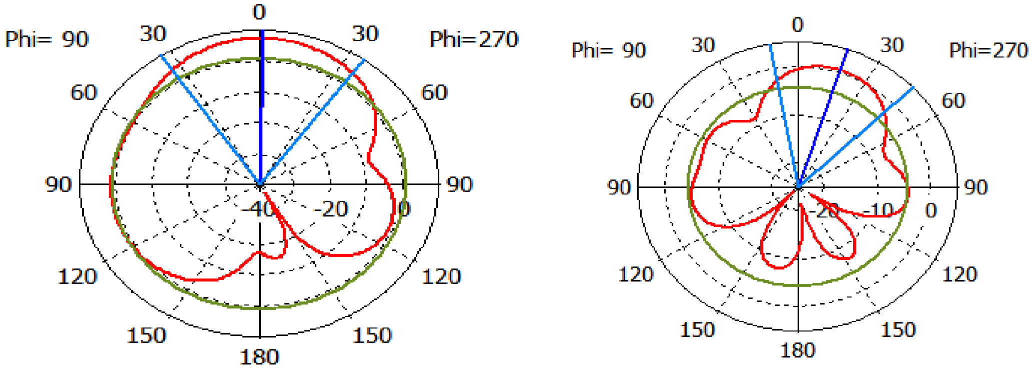


Fig 4.7: Efficiency of the antenna shows 69.33% at 28 GHz and 68.38% at 38 GHz



(a) **(b)**

Fig 4.8: Surface Current Distribution of 28 GHz of antenna



(a) **(b)**

Fig 4.9: Simulated Farfield Radiation Pattern of 28 GHz ($\theta = 1$)& 8 GHz ($\theta = 18$)

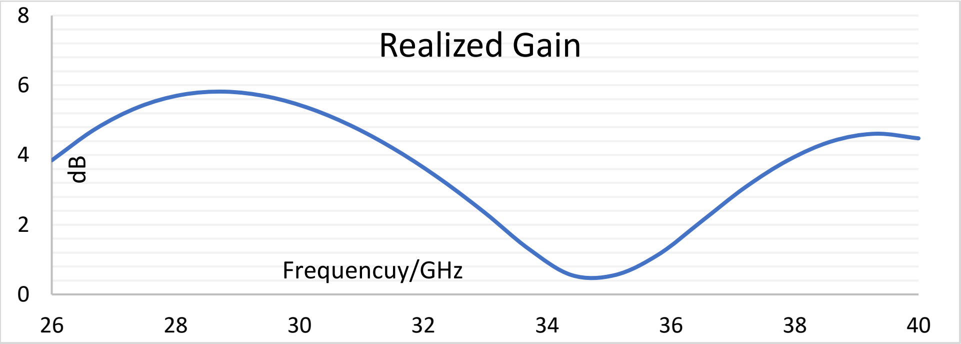


Fig 4.10: Gain Pattern Of 28 GHz (G=5.676) and 38 GHz (G=3.93)

4.3 Design stage 3-Parasitic patch for Matching Impedance at 28-38 GHz

At this stage, the objective was to achieve impedance matching for the proposed antenna. To address this, a parasitic patch was added to the feed line, aiding in impedance matching by coupling capacitively or inductively with the main patch. This approach improves return loss and minimizes mismatch losses, effectively matching the antenna's impedance to the feed line or source at the desired frequencies.

The impedance matching for the patch antenna was enhanced at 28 GHz and 38 GHz, relative to a 50 Ohm reference. The impedance at 28 GHz was measured at 53.30 Ohms and at 38 GHz, it was 53.79 Ohms. The S-parameter results indicate that the return loss was -25.474 dB at 28 GHz and -20.993 dB at 38 GHz, as depicted in Fig. 4.11. The primary antenna gain was observed to be 5.83 dB at 28 GHz and 4.20 dB at 38 GHz, as shown in Fig. 4.17.

The far-field radiation patterns are presented in Fig. 4.14 and Fig. 4.15. At 28 GHz, the main lobe magnitude was 7.86 dB in the forward direction (θ = 1.0°), whereas at 38 GHz, the main lobe magnitude was 0.637 dB in the forward direction (θ theta = 18.0°). The surface current distribution, shown in Fig. 4.16 (a), highlights the matched impedance and a wider surface current area at both 28 GHz and 38 GHz compared to the previous design stage (Stage-2), as illustrated in Fig. 4.16 (b).

The VSWR values were 1.29 at 28 GHz and 1.66 at 38 GHz, indicating good impedance matching. The radiation efficiency was measured at 64% for 28 GHz and 74% for 38 GHz. Upon comparison, it was determined that the antenna's performance at 28 GHz is slightly less effective than at 38 GHz in this design stage (Stage-3).

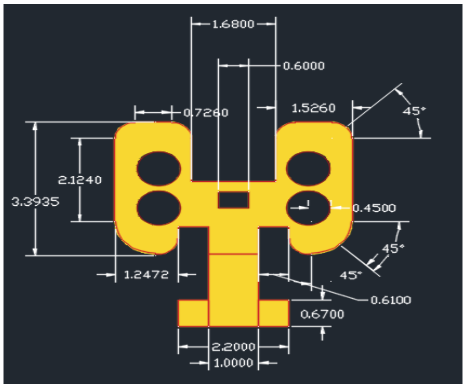


Fig 4.11: Parasitic Patch Antenna for Impedance Matching

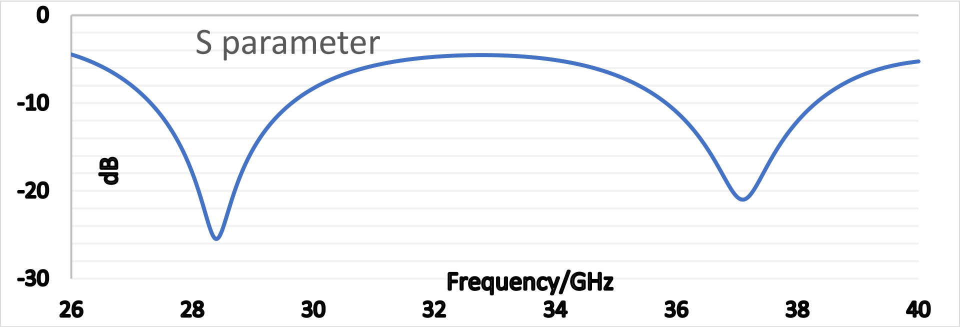


Fig 4.12: Reflection Coefficient of 28 GHz Antenna is -25.463 dB and 38 GHz Antenna is -20.994 dB.

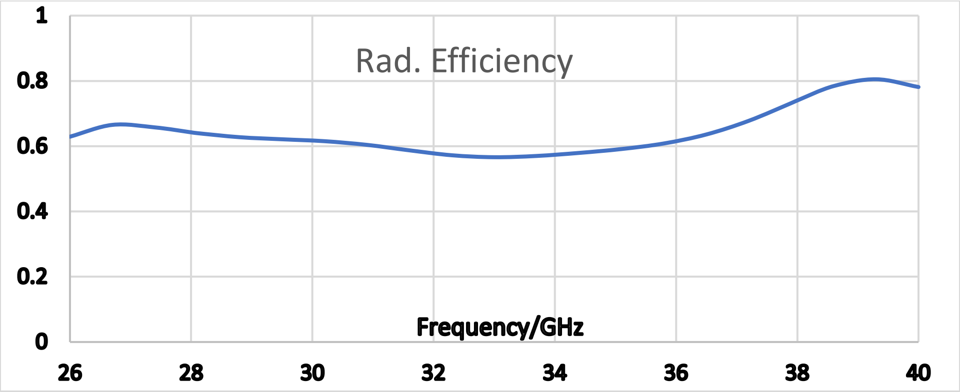
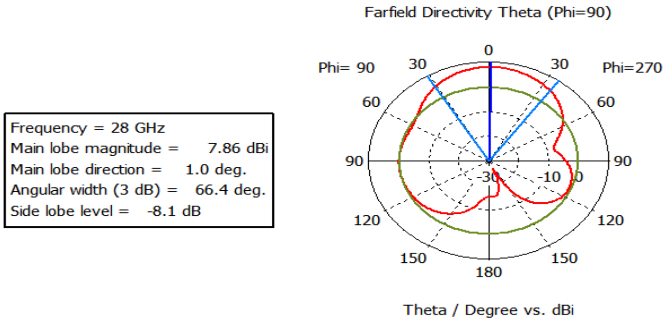
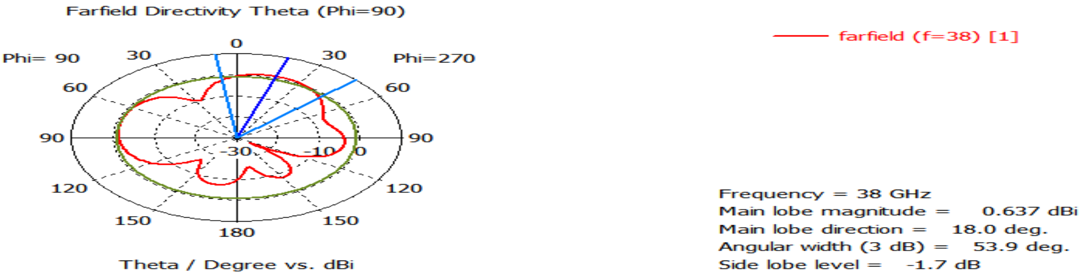


Fig 4.13: Radiation Efficiency of Parasitic Patch Antenna



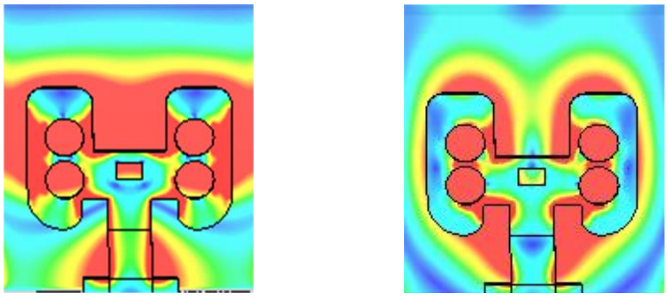
Frequency = 28 GHz
Main lobe magnitude = 7.86 dBi
Main lobe direction = 1.0 deg.
Angular width (3 dB) = 66.4 deg.
Side lobe level = -8.1 dB

Fig 4.14: Farfield Direction of 28 GHz parasitic Patch Antenna



Frequency = 38 GHz
Main lobe magnitude = 0.637 dBi
Main lobe direction = 18.0 deg.
Angular width (3 dB) = 53.9 deg.
Side lobe level = -1.7 dB

Fig 4.15: Farfield Direction of 38 GHz Parasitic Patch Antenna



(a) (b)

Fig 4.16: Radiation Pattern Of (a) 28 GHz and (b) 38 GHz of Parasitic Patch Antenna

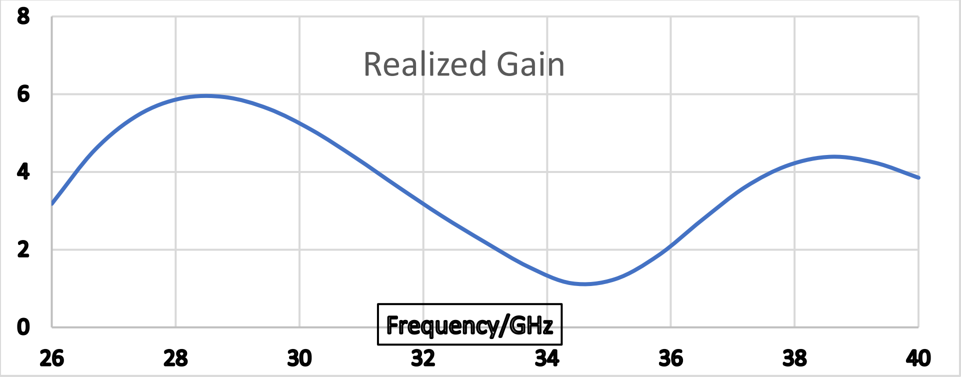


Fig 4.17: Realized Gain of Parasitic Patch Antenna

4.4 Design Stage: Defected Ground Structure (Final)

In this stage, the aim was to enhance the performance of the microstrip patch antenna by applying specific modifications to its ground plane geometry. The ground structure dimensions were 6 x 7 x 0.035 mm, and alterations were made to optimize the surface current distribution. Two rectangular slots were introduced in areas with minimal surface current, while a circular slot was added in a region of significant current concentration. These adjustments facilitated the antenna's operation at frequencies of 28 GHz and 38 GHz. The reflection coefficient of the antenna was measured as -32.356 dB at the lower band (28 GHz) and -51.504 dB at the upper band (38 GHz), demonstrating excellent impedance matching. The bandwidth was found to be 2.444 GHz at 28 GHz and 3.397 GHz at 38 GHz. The antenna achieved a gain of 5.875 dB at 28 GHz and 3.74 dB at 38 GHz. The VSWR values were 1.05 for the lower band and 1.06 for the higher band, indicating minimal reflection and efficient power transfer.

The surface current distribution extended across the patch length, with maxima near the edges at both operating bands. The radiation pattern at 28 GHz exhibited an omnidirectional behavior, with a visible peak in the forward direction ($\theta = 0°$), achieving a maximum gain of 7.903 dB, indicating high directivity in this direction. At 38 GHz, the radiation pattern was quasi-omnidirectional, with a moderate maximum gain of 5.339 dB, suggesting a balance between omnidirectional characteristics and directivity.

These results highlight the effectiveness of the design adjustments in achieving robust performance across both frequency bands.

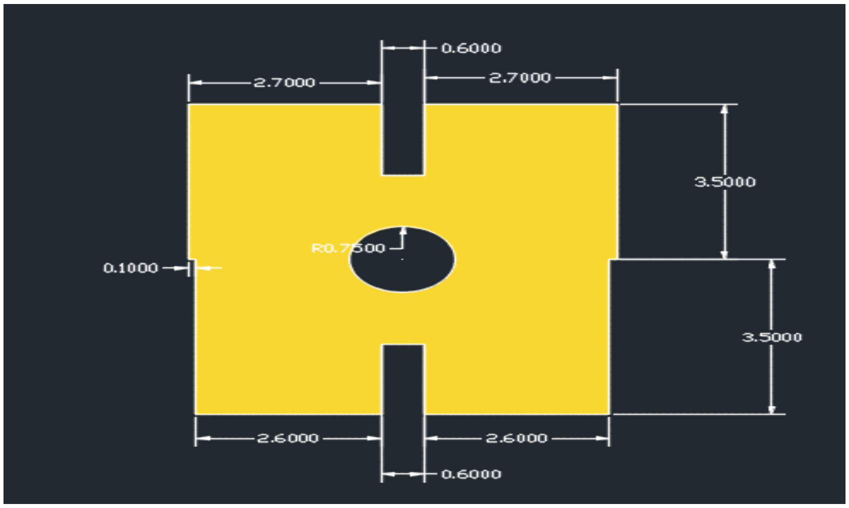


Fig4.18: Defected Ground Structure

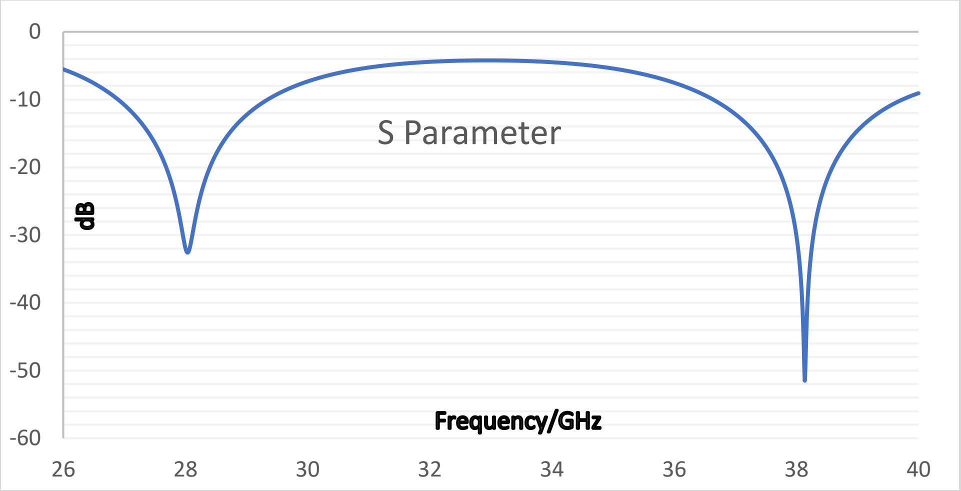


Fig 4.19: Reflection Coefficient of DGS Antenna

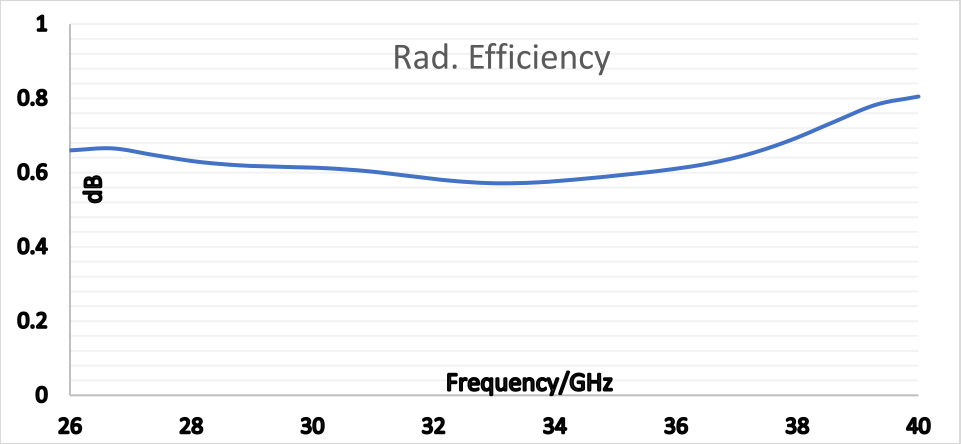


Fig 4.20: Radiation Efficiency of DGS Antenna

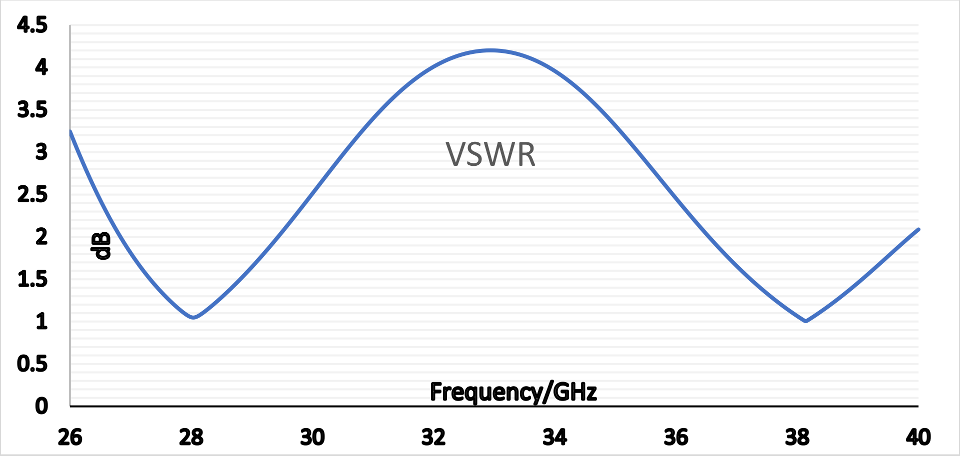
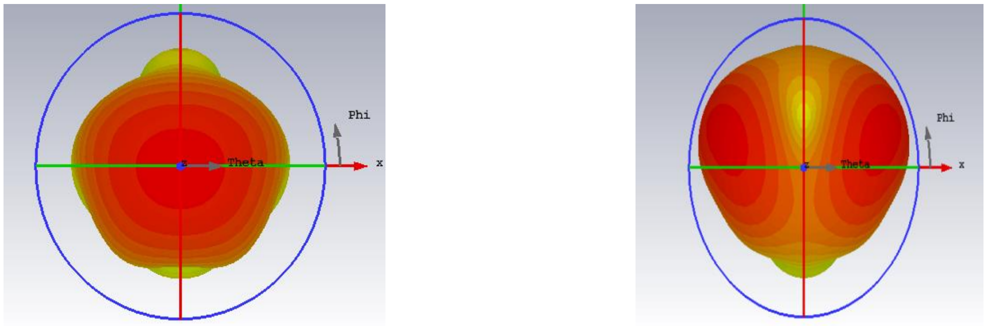
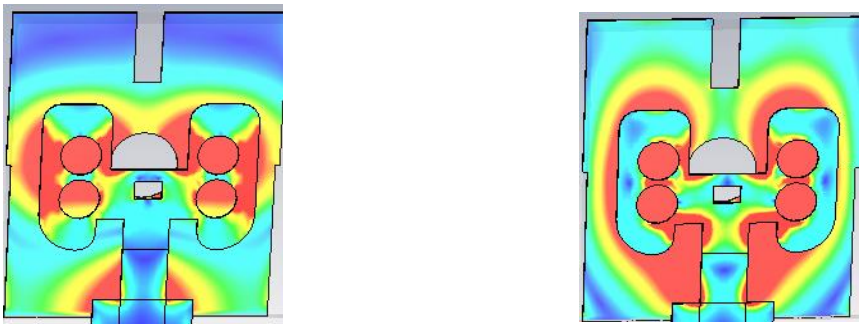


Fig 4.21: VSWR of DGS Antenna



(a) **(b)**

Fig 4.22: Simulated Far-field Radiation Pattern of (a) 28 GHz and (b) 38 GHz of DGS Antenna



(a) **(b)**

Fig 4.23: Current Distribution at (a) 28 GHz and (b)38 GHz of DGS Antenna

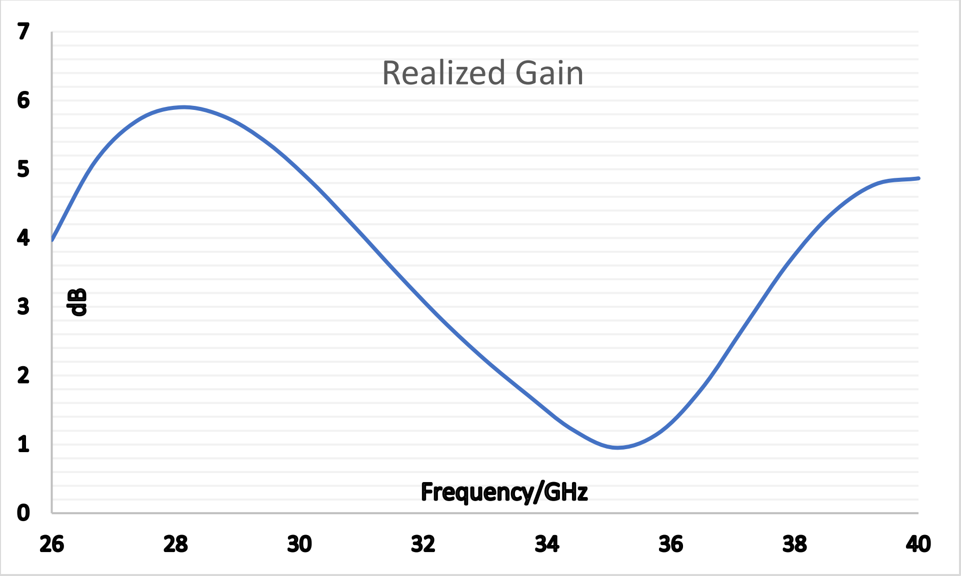


Fig 4.24: Realized Gain of Parasitic Patch Antenna of DGS Antenna

Chapter – 5
Result and Discussion

5.1 Result

The Defected Ground Structure (DGS) technique is used to enhance the performance of a microstrip patch antenna by deliberately introducing geometric modifications in the ground plane. In this design stage, the DGS approach aims to achieve improved reflection coefficients, impedance matching, and gain at the operational frequencies of 28 GHz and 38 GHz.

Ground Geometry

- The ground plane has dimensions of 6 mm × 7 mm × 0.035 mm.

Performance Metrics

1. **Reflection Coefficient (S11):**
    - At 28 GHz: -32.356 dB, indicating strong impedance matching and minimal power reflection.
    - At 38 GHz: -51.504 dB, demonstrating excellent return loss.

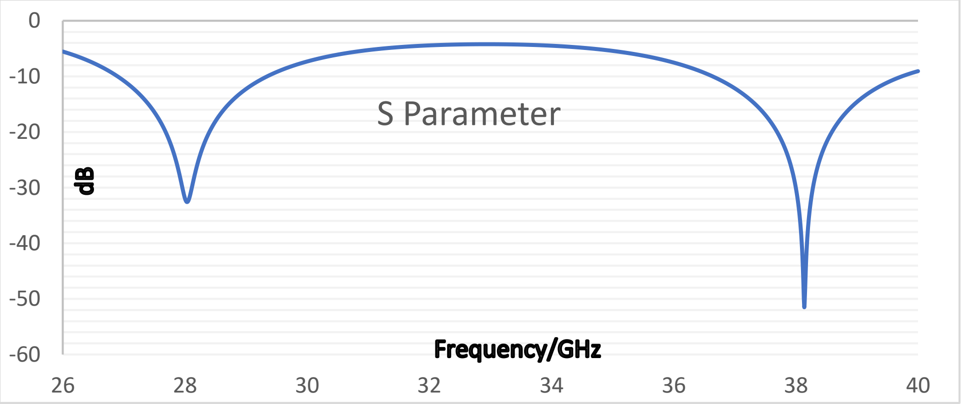


Fig 5.1: Reflection Coefficient of DGS Antenna at 28/38 GHz

2. **Gain:**
    - At 28 GHz: 5.875 dB.
    - At 38 GHz: 3.74 dB.

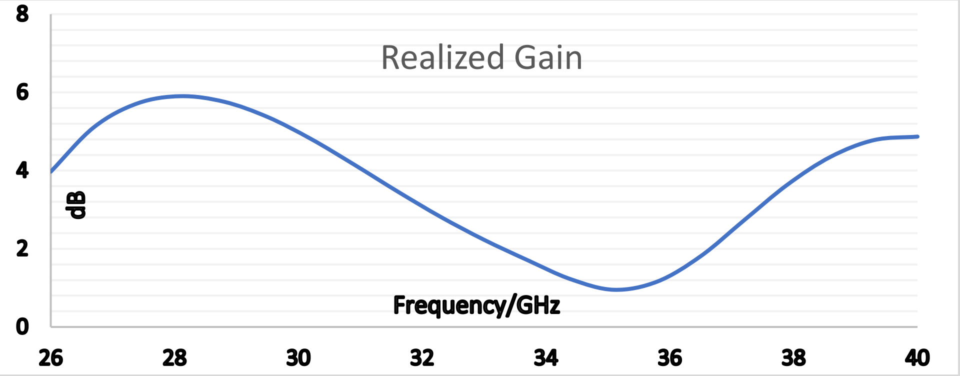


Fig 5.2: Realized Gain of Parasitic Patch Antenna of DGS Antenna

3. **VSWR:**
    - At 28 GHz: 1.05, representing nearly perfect impedance matching.
    - At 38 GHz: 1.06, also indicating strong matching.
4. **Surface Current Distribution:**

    Surface current spreads across the patch's length, with the highest concentration near the edges at both frequencies**.**

5. **Radiation Patterns**

I. Lower Band (28 GHz):

- **Radiation Pattern**: The pattern exhibits a directional characteristic with a prominent peak in the forward direction (θ = 1°), indicating enhanced directivity.
- **Maximum Gain**: The main lobe magnitude is 5.9 dB, and the direction is at 1° (close to the central axis of the plot).

ii. Upper Band (38 GHz):

- The radiation pattern is quasi-omnidirectional, displaying moderate directivity and some asymmetry.
- **Maximum Gain:** 5.339 dB, reflecting a balanced trade-off between directivity and omnidirectional behavior.

Comparison without DGS AND with DGS

Parameter	4.3 Parasitic Patch (Stage-3)	4.4 Defected Ground Structure (Stage-4)
Objective	Impedance matching using a parasitic patch.	Performance enhancement through defected ground structure.
Frequency Bands	28 GHz and 38 GHz	28 GHz and 38 GHz
Impedance	53.30 Ω (28 GHz), 53.79 Ω (38 GHz)	53.30 Ω (28 GHz), 53.79 Ω (38 GHz)
Return Loss (S11)	-25.474 dB (28 GHz), -20.993 dB (38 GHz)	-32.356 dB (28 GHz), -51.504 dB (38 GHz)
Bandwidth	2.312 GHz (28 GHz) 2.434 GHz (38 GHz)	2.444 GHz (28 GHz), 3.397 GHz (38 GHz)
Gain	5.83 dB (28 GHz), 4.20 dB (38 GHz)	5.875 dB (28 GHz), 3.74 dB (38 GHz)
Main Lobe Magnitude	7.86 dB (28 GHz, θ = 1.0°), 0.637 dB (38 GHz, θ = 18.0°)	7.903 dB (28 GHz, θ = 0°), 5.339 dB (38 GHz, quasi-omnidirectional)
VSWR	1.29 (28 GHz), 1.66 (38 GHz)	1.05 (28 GHz), 1.06 (38 GHz)

Radiation Efficiency	64% (28 GHz), 74% (38 GHz)	N/A
Radiation Pattern	Directional (28 GHz), quasi-omnidirectional (38 GHz).	Omnidirectional (28 GHz), quasi-omnidirectional (38 GHz).
Surface Current Distribution	Wider current area than Stage-2, matched impedance.	Improved current distribution with maximum near edges.
Performance Observation	Better performance at 28 GHz than 38 GHz.	Robust performance at both frequency bands.

5.2 Application of the Antenna:

I. 5G Wireless Communication
   a) In order to guarantee smooth connectivity and capacity in high-density settings, dual-band antennas are essential to small cells [25].
   b) 5G Small Cells: In order to guarantee smooth connectivity and capacity in high-density settings, dual-band antennas are essential to small cells.
   c) Fixed Wireless Access (FWA) is a key application of the 28 GHz and 38 GHz bands, particularly in the deployment of 5G networks. Company like Verizon and T-Mobile utilize FWA to provide ultra- fast connectivity speeds over 155 Mbps.

II. Internet of Things (IoT) and Smart Devices [26]
   a) High-Speed IoT Connectivity: Bands like 28 GHz are used by Cisco and Huawei to seamlessly integrate millimeter-wave (mmWave) technologies into IoT networks.
   b) Using bands like 28 GHz for seamless communication, Cisco and Huawei have been leading the way in incorporating millimeter-wave (mmWave) technology into IoT ecosystems.
   c) Samsung SmartThings and Amazon (via Alexa-enabled devices) both employ cutting-edge mmWave antennas in their Internet of Things product lines.
   d) When it comes to implementing mmWave technologies for intelligent agricultural solutions, John Deere and Bosch are leaders.
   e) 38 GHz dual-band antennas provide for real-time machinery and system monitoring and control in industrial automation.

III. Satellite Communication [27]
   a) The Ka-band spectrum (26.5 GHz to 40 GHz), which includes the 28 GHz and 38 GHz frequency bands, is extensively utilized for satellite-based communications because of its capacity to manage high data rates and constrained beamwidths. Companies Utilizing It:

SpaceX (Starlink): Uses Ka-band frequencies for high-speed, low-latency internet.

HughesNet: Employs Ka-band for its satellite broadband offerings

ViaSat: Provides high-capacity Ka-band satellite communications.

IV. Vehicle-to-Everything (V2X) Communication

Real-Time Data Exchange: The high bandwidth and low latency offered by the 28–38 GHz spectrum is ideal for transmitting real-time data crucial for autonomous vehicle navigation, such as sensor feeds, vehicle diagnostics, and environmental mapping.

Safety Systems: V2X communication enables vehicles to exchange information about speed, position, and road conditions with other vehicles, infrastructure, and pedestrians, enhancing safety by preventing collisions and optimizing traffic flow.

V. Point-to-Point Wireless Communication

It is appropriate for line-of-sight point-to-point communications in densely populated locations due to its high-gain performance at both frequencies. Used in business and industrial settings to provide high-speed connections or link distant locations.

VI. Radar Systems

Because of their high frequency and correspondingly shorter wavelengths, the 28 GHz and 38 GHz frequency bands are ideal for short-range radar applications. In a variety of situations, these features allow for accurate resolution and detection. Company such as Infineon Technologies, Texas Instruments, NXP Semiconductors are using 28-38 GHz for operating their radar system.

VII. Medical Applications

Microwave Imaging: Because these antennas can function at high frequencies and offer superior resolution, they are utilized in early cancer detection systems (such as those for breast tumor detection).

Skin and Tissue Imaging: High-frequency bands like 28 GHz and 38 GHz allow for non-invasive imaging of skin layers and subcutaneous tissues.

Companies and Research

Medtronic and **Philips Healthcare**: Utilize advanced communication systems, including antennas, in their medical devices. Ongoing academic research focuses on integrating these dual-band antennas into portable diagnostic tools and wearable health monitors

5.3 Drawbacks of Microstrip Patch Antenna

While microstrip patch antennas are widely used in many applications, including 5G and wireless communication systems, they have some inherent drawbacks:

1. Bandwidth Limitation

Narrow bandwidth is one of the significant disadvantages of microstrip patch antennas. As noted, the antenna's performance is often limited by the bandwidth it can cover effectively. For instance, at 28 GHz, the bandwidth is narrow, which could limit the antenna’s ability to support high-frequency communication across a wide range of applications.

2. Low Gain (At Higher Frequencies)

The gain at 38 GHz is relatively low (3.74 dB) compared to the gain at 28 GHz (5.875 dB). Higher frequencies like 38 GHz typically result in lower gain due to increased path loss and the inherent properties of microstrip antenna designs. To overcome this, a larger array or more advanced beamforming techniques would be required.

3. Surface Current Concentration

The surface current distribution is concentrated near the edges of the patch at both frequencies, which can lead to inefficiencies and potential radiation losses in some configurations. This might necessitate careful design optimization to ensure maximum efficiency, particularly when dealing with higher frequencies.

4. Limited Directivity at Higher Frequencies

At 38 GHz, the antenna exhibits a quasi-omnidirectional radiation pattern with some asymmetry. This could lead to less efficient radiation compared to the 28 GHz band, where the pattern is more omnidirectional with a peak forward direction. This discrepancy in radiation patterns could affect the antenna's ability to cover all desired areas with equal efficiency, especially for applications requiring precise and directed signal propagation.

5. Temperature and Environmental Sensitivity

Microstrip patch antennas are susceptible to temperature fluctuations and humidity, which can affect the impedance and radiation characteristics. This is particularly relevant in outdoor environments and locations with extreme weather conditions, which can result in performance degradation if the antenna isn't adequately shielded.

6. Integration Complexity at High Frequencies

28 GHz and 38 GHz are both within the mmWave frequency range, where the wavelengths are very small. Integrating a microstrip patch antenna at such high frequencies requires precise fabrication techniques to ensure that the antenna operates efficiently. Any mismatch in the substrate or patch dimensions could significantly degrade the performance, making it challenging to achieve optimal impedance matching at both frequencies.

7. Size and Design Constraints

Microstrip patch antennas are relatively compact in design, but this comes at the expense of limited bandwidth and gain. Achieving a dual-band operation for 28 GHz and 38 GHz while maintaining compactness can pose challenges in terms of optimizing the physical dimensions of the antenna.

5.4 Impact Assessment of Microstrip Patch Antenna Project on Human Health and Environment

The development and deployment of microstrip patch antennas are a significant aspect of modern wireless communication systems. While these antennas offer numerous technological benefits, their potential impacts on human health and the environment must be carefully assessed to ensure safe and sustainable implementation.

5.4.1 Impact on Human Health

a. Exposure to Electromagnetic Radiation (EMR):

- **Source of EMR**: Microstrip patch antennas, used in applications like 5G, Wi-Fi, and IoT devices, emit non-ionizing electromagnetic radiation (EMR).
- **Health Implications**:
    - Prolonged exposure to high levels of EMR can potentially cause thermal effects, where body tissues are heated due to radiation absorption.
    - Non-thermal effects, such as disruption of cellular processes or neural activity, remain areas of ongoing research, with no definitive conclusions at standard communication frequencies.

b. Safety Guidelines:

- **Compliance**: These antennas are designed to comply with international standards for EMR exposure, such as limits set by the **International Commission on Non-Ionizing Radiation Protection (ICNIRP)** and **FCC guidelines**.
- **Safe Usage**: Proper placement, power regulation, and design optimizations (e.g., beam steering) help minimize health risks.

c. Benefits to Health and Safety:

- **Applications in Healthcare**: Microstrip antennas are crucial in wearable devices for health monitoring, offering early disease detection and promoting preventive care.
- **Enhanced Communication**: Their contribution to reliable communication systems can indirectly improve healthcare delivery, disaster response, and public safety.

5.4.2 Impact on the Environment

a. Material and Manufacturing Impacts:

- **Material Usage**:
    - The substrates (e.g., **Rogers RT5880**, FR4) and conductive materials (e.g., copper) used in microstrip patch antennas are generally considered environmentally safe but contribute to resource depletion during production.
    - Non-biodegradable materials in the substrate can lead to waste management issues.
- **Manufacturing Byproducts**:
    - The fabrication processes, such as etching and lamination, may produce chemical waste and emissions if not properly managed.

b. Energy Consumption:

- **Operational Energy**: Microstrip antennas are highly efficient and consume low power compared to other antenna types, contributing positively to energy savings in communication systems.
- **Sustainability Concerns**: Mass production and widespread deployment may indirectly increase the energy footprint of the overall communication infrastructure.

c. Environmental Radiation:

- **Electromagnetic Pollution**: Large-scale deployment can lead to increased EMR levels in the environment, potentially affecting wildlife, such as birds and insects, sensitive to electromagnetic fields.

- **Mitigation Strategies**: Optimizing antenna design to minimize side lobes and unnecessary emissions reduces environmental radiation impacts.

d. Recycling and Disposal:

- The components of microstrip patch antennas, particularly the substrate materials, pose challenges for recycling and safe disposal.
- **Eco-Friendly Alternatives**: Development of biodegradable substrates and energy-efficient designs can mitigate long-term environmental impacts.

5.4.3 Societal and Technological Benefits

a. Enhanced Communication:

- Microstrip antennas enable high-speed communication, essential for technological advancements in education, healthcare, transportation, and remote work.

b. Reduced Carbon Footprint:

- Their compact size and high efficiency reduce infrastructure needs, lowering the carbon footprint of wireless networks compared to older technologies.

c. Positive Environmental Impact:

- Use in renewable energy systems (e.g., solar-powered IoT devices) and smart grids enhances environmental sustainability.

5.4.4 Mitigation Measures for Minimizing Negative Impacts

1. **Material Recycling**: Implement recycling programs for antenna components, particularly substrates and metals.
2. **Green Manufacturing**: Use environmentally friendly manufacturing techniques, reducing waste and emissions.
3. **EMR Management**: Adhere to strict radiation safety standards, conduct regular environmental EMR assessments, and adopt shielding technologies.
4. **Eco-Friendly Designs**: Research biodegradable and sustainable substrates, such as those made from natural fibers or polymers.
5. **Public Awareness**: Educate stakeholders about safe antenna deployment practices and responsible usage of devices.

5.5 Discussion

Discussion

The microstrip patch antenna developed in this project represents a step forward in the evolution of modern communication technologies, particularly in the domain of high-frequency millimeter-wave (mmWave) systems, which are central to 5G networks. The project's primary focus was to design an efficient, compact, and dual-band antenna operating at 28 GHz and 38 GHz, two critical frequency bands for 5G applications. The innovative inclusion of a parasitic patch and a defected ground structure (DGS) served to overcome some of the traditional limitations of microstrip patch antennas, such as limited bandwidth and narrow radiation coverage. The **primary patch**, designed for 28 GHz resonance, was enhanced through structural modifications to ensure optimal current distribution. This adjustment ensured that the antenna could resonate effectively at the desired frequency while maintaining a compact size. The **secondary parasitic patch**, capacitively coupled to the primary patch, played a pivotal role in achieving dual-band performance. By introducing resonance at 38 GHz, it allowed the antenna to cater to multiple frequency bands without requiring separate elements, making the design more space-efficient. However, at 38 GHz, the higher-order modes introduced complexities in the radiation pattern, such as the presence of side lobes and nulls. The design addressed this by incorporating **slots and cuts** in the primary patch, which suppressed higher-order modes and enhanced first-order mode radiation. This solution ensured a more consistent and omnidirectional radiation pattern at both resonances.

The use of **Rogers RT5880 Lossy** as the substrate material was a deliberate choice, given its favorable properties, including a low dielectric constant (ε_r=2.2) and a low loss tangent. These characteristics contributed to the antenna's high radiation efficiency and reduced power losses, which are critical for mmWave applications. The substrate's thickness of 0.787 mm provided the necessary structural support while keeping the overall profile thin, enabling integration into compact communication systems. The antenna's final dimensions, **4.732 mm × 3.344 mm × 0.035 mm**, highlighted its compactness and suitability for modern miniaturized devices. A **defected ground structure (DGS)** was employed to broaden the antenna's bandwidth. By strategically introducing a defect (as seen in the red dotted line of the ground plane in Fig. 1), the current distribution on the ground plane was altered, leading to improved impedance bandwidth. This enhancement enabled the antenna to support high-speed data rates, a critical requirement for 5G systems. However, challenges persisted, such as relatively lower gain at the higher frequency band (38 GHz) and the increased sensitivity of the design to fabrication tolerances. These challenges suggest room for improvement in future iterations. The project also demonstrated the importance of computational simulation tools in antenna design. Software such as CST Microwave Studio enabled precise modeling of electromagnetic behavior, facilitating optimization of the antenna's dimensions and material properties. Simulated results revealed impressive performance metrics, such as reflection coefficient values of -32.356 dB at 28 GHz and -23.014 dB at 38 GHz, along with a nearly ideal VSWR of 1.05 at 28 GHz. These results affirmed the success of the design in meeting its performance objectives.

Chapter 6

Project Management

This project management plan ensures systematic execution of the microstrip patch antenna project by dividing it into structured tasks, setting a realistic schedule, and defining clear milestones. Effective tracking and periodic review of progress help to deliver the project on time and within scope.

6.1 Task

The project is broken into key tasks, each focusing on different stages of the microstrip patch antenna development.

a. Initial Research and Planning

- Review literature on microstrip patch antenna design, materials, and dual-band operation.
- Define project scope, objectives, and success criteria.

b. Design and Simulation

- Research and select substrate material and patch dimensions.
- Develop initial design using simulation tools (e.g., CST).
- Optimize antenna parameters for dual-band operation (28 GHz and 38 GHz).

c. Prototyping

- Procure substrate and materials (e.g., Rogers RT5880).
- Fabricate the microstrip patch antenna prototype.
- Integrate feed and parasitic patch elements.

d. Testing and Validation

- Perform S-parameter testing for return loss and bandwidth.
- Measure radiation pattern, gain, and efficiency.
- Validate dual-band operation at 28 GHz and 38 GHz.

e. Deployment and Documentation

- Analyze the environmental and health impacts of the design.
- Prepare a project report detailing design methodology, testing results, and conclusions.
- Deploy antenna for intended applications (e.g., communication systems).

6.1 Schedule

The project timeline ensures tasks are completed in an organized manner. Below is an estimated schedule:

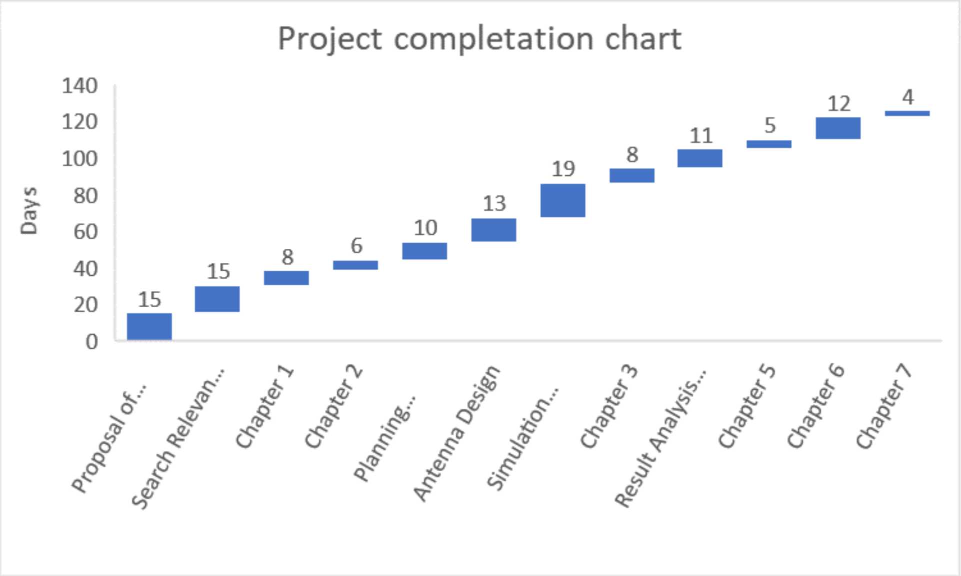


Fig 6.1: Schedule of this Project

Chapter-7
Conclusion

7.1 Future work of this project

The future work of the dual-band microstrip patch antenna operating at 28 GHz and 38 GHz can focus on further enhancements, optimizations, and expanding its applications. Here are some potential directions for future research and development:

1. Enhanced Bandwidth and Multi-Band Capability

Investigate methods to increase the operational bandwidth, allowing the antenna to support a wider range of frequencies beyond 28 GHz and 38 GHz.

Explore designs for tri-band or multi-band operation to cater to emerging communication standards like 6G or other IoT applications.

2. Improved Radiation Characteristics

Optimize the radiation pattern for specific applications, such as beamforming for 5G base stations or directional antennas for satellite communications. Investigate methods to further reduce side lobes and increase forward gain for enhanced directivity.

3. Integration with Advanced Technologies

Integrate with reconfigurable intelligent surfaces (RIS) to allow dynamic tuning of frequencies and beam directions. Develop prototypes for integration into wearable devices, drones, or smart vehicles.

4. Performance Optimization in Harsh Environments

Enhance performance under challenging conditions such as high temperatures, humidity, or mechanical stress. Develop ruggedized versions of the antenna for military or aerospace applications.

5. Energy Harvesting Applications

Investigate the antenna's capability for RF energy harvesting to power IoT devices, enabling self-sustained operation.

6. Massive MIMO Systems

Adapt the dual-band antenna design for use in massive MIMO configurations to improve spectral efficiency in 5G networks.

7. Substrate and Fabrication Innovations

Test innovative substrates with lower loss tangents and higher thermal stability for better efficiency and reliability.

Incorporate 3D printing technologies for cost-effective and rapid antenna prototyping.

8. AI-Assisted Optimization

Use machine learning algorithms for optimizing design parameters such as patch dimensions, feeding techniques, and substrate properties.

9. Real-World Testing and Application Development

Conduct field testing for specific applications like V2X communication, IoT networks, or satellite-based systems.

Collaborate with industries such as healthcare, automotive, and telecommunications to customize the antenna for specialized applications.

Future advancements in dual-band antenna designs will contribute significantly to the evolving landscape of high-frequency communication technologies, enhancing the performance and utility of devices across industries.

7.2 Conclusion

The project successfully achieved its goal of designing and implementing a dual-band microstrip patch antenna for 5G mmWave applications. The use of innovative design elements, such as the parasitic patch and the defected ground structure, enabled the antenna to resonate effectively at 28 GHz and 38 GHz. This dual-band operation meets the stringent requirements of 5G networks, supporting high-speed, low-latency communication across different bands.

The antenna’s compact size and efficient design make it ideal for integration into modern wireless devices, IoT systems, and small-cell base stations. Its performance metrics, including excellent impedance matching, high radiation efficiency, and enhanced bandwidth, highlight its potential for widespread adoption. Furthermore, the project showcases how careful material selection and structural design can overcome the inherent limitations of microstrip patch antennas, such as narrow bandwidth and higher-order mode interference.

While the project achieved its primary objectives, some challenges remain. The radiation pattern at 38 GHz displayed undesired side lobes due to higher-order modes, and the gain at this frequency was somewhat lower than expected. Future work could address these issues by exploring advanced techniques such as beamforming, the use of array configurations, or further optimization of the parasitic patch geometry. Additionally, investigating alternative substrate materials, such as biodegradable or eco-friendly substrates, could align antenna design with sustainability goals.

In conclusion, this project contributes meaningfully to the advancement of high-frequency antenna technologies, particularly for 5G and beyond. It provides a foundation for future research and development, offering a scalable and efficient solution for dual-band communication systems. The lessons learned from this project pave the way for enhanced designs that meet the growing demands of next-generation wireless networks.

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APPENDIX A

COMPLEX ENGINEERING PROBLEM SOLVING AND ENGINEERING ACTIVITIES

Table -1 Program Outcomes and Assessment

Complex Engineering Problems Solving and Engineering Activities		
	Attributes	**Statement from Students**
PO1	Apply fundamental knowledge to solve engineering problems.	The thesis applies knowledge of mathematics and engineering fundamentals to design a microstrip patch antenna using theoretical and simulation tools (e.g., CST Studio Suite). It demonstrates an understanding of concepts like reflection coefficients, bandwidth, and impedance matching.
PO2	Identify and analyze complex engineering problems	The thesis identifies the challenge of achieving efficient dual-band performance at 28 GHz and 38 GHz for 5G applications and proposes a solution using the Defected Ground Structure (DGS) technique. It analyzes problems related to gain, bandwidth, and impedance matching
PO3	Design solutions considering societal and environmental factors.	The design addresses modern telecommunication needs, aligning with societal requirements for high-speed, low-latency networks. The compact design minimizes material usage, reflecting environmental considerations.
PO4	Conduct research-based investigations and provide valid conclusions	The project uses research methods, including simulations, to optimize performance metrics like reflection coefficients and gain. It synthesizes findings to validate the proposed design.
PO5	Apply modern tools for engineering tasks	The project extensively uses CST Microwave Studio for simulation and modeling, demonstrating the application of modern IT tools to solve complex engineering problems
PO6	Assess societal, health, and safety implications.	The thesis evaluates the impact of high-frequency radiation on human health and environmental factors, reflecting professional engineering responsibilities.
PO7	Evaluate sustainability and impact in societal and environmental contexts	The use of materials like Rogers RT5880 ensures sustainable and efficient antenna designs. The compact size contributes to reduced material waste, aligning with environmental sustainability.

PO8	Commit to professional ethics and responsibilities	Ethical practices are evident in the proper acknowledgment of references and adherence to academic guidelines during research and documentation.
PO9	Function effectively as an individual and in diverse teams.	The thesis is a collaborative effort among multiple authors, showcasing teamwork and individual contributions to achieve the project's objectives
PO10	Communicate effectively in engineering contexts.	The thesis is well-structured with clear documentation of research, design, and results. It includes detailed illustrations and simulations to communicate findings effectively.
PO11	Apply engineering management principles.	The project includes a structured management plan, detailing tasks, schedules, and milestones, demonstrating effective project management skills.
PO12	Engage in life-long learning.	The use of advanced design methodologies and exploration of innovative techniques (e.g., DGS) reflects the authors' commitment to continuous learning in emerging technologies.

Table 2 Knowledge Profile

Complex Engineering Problems Solving and Engineering Activities		
	Attributes	**Statement from Students**
KO1	A systematic, theory-based understanding of the natural sciences applicable to the discipline.	The thesis demonstrates the application of electromagnetic theory and wave propagation principles in designing microstrip patch antennas. The use of fringing fields and resonance concepts illustrates a strong foundation in the natural sciences.
KO2	Conceptually based mathematics, numerical analysis, statistics, and formal aspects of computer and information science to support analysis and modeling applicable to the discipline	Mathematical formulas are used to calculate patch dimensions, resonant frequencies, and impedance. Numerical simulation tools like CST Microwave Studio were employed for analysis and performance optimization.
KO3	A systematic, theory-based formulation of engineering	The project applies engineering principles in antenna design, focusing on fundamental concepts like bandwidth, gain, reflection coefficient, and

	fundamentals required in the engineering discipline	impedance matching to solve high-frequency communication challenges.
KO4	Engineering specialist knowledge that provides theoretical frameworks and bodies of knowledge for the accepted practice areas in the engineering discipline; much is at the forefront of the discipline.	The thesis explores advanced antenna design techniques like Defected Ground Structures (DGS) and parasitic patches to improve antenna performance. It discusses cutting-edge applications in 5G communication, IoT, and satellite systems.
KO5	Knowledge that supports engineering design in a practice area.	The thesis report does not applicate this KO5.
KO6	Knowledge of engineering practice (technology) in the practice areas in the engineering discipline.	The thesis cannot fulfill this criterion as there is no accessories available to implement this project in Bangladesh.
KO7	Comprehension of the role of engineering in society and identified issues in engineering practice in the discipline, including ethics, safety, sustainability, and environmental impacts.	The thesis discusses societal and environmental aspects, such as the deployment of 5G networks and the impact of high-frequency radiation. It also emphasizes sustainable design through compact and efficient structures.
KO8	Engagement with selected knowledge in the research literature of the discipline	The thesis includes a comprehensive literature review, comparing the proposed design with existing studies, showcasing the authors' engagement with current research trends and methodologies in the field.

Table-3 Range of Complex Engineering Problem Solving

Complex Engineering Problems Solving and Engineering Activities		
	Attributes	**Statement from Students**
P1	Depth of knowledge required	The thesis demonstrates in-depth knowledge of electromagnetic theory, microstrip patch antenna design, and the Defected Ground Structure (DGS) technique, relying on first principles of engineering, physics, and advanced simulation tools (CST Microwave Studio).

P2	Range of conflicting requirements	The project addresses multiple conflicting requirements, such as achieving compact antenna dimensions while maintaining high gain, dual-band operation, and optimal impedance matching. These challenges required balancing performance and manufacturability.
P3	Depth of analysis required	The design process required abstract thinking and originality, as evident in the application of the DGS technique and the incorporation of parasitic patches to optimize reflection coefficients, bandwidth, and gain for two distinct frequency bands (28 GHz and 38 GHz).
P4	Familiarity of issues	The issues tackled in the thesis are infrequently encountered, such as designing dual-band antennas with precise performance characteristics for 5G mmWave applications. This involves advanced topics like high-frequency impedance matching and radiation pattern control.
P5	Extent of applicable codes	The thesis report does not fulfill this criterion.
P6	Extent of stakeholder involvement and conflicting requirements	The thesis report does not fulfill this criterion.
P7	Interdependence	The problem involves multiple interdependent components, including material selection (substrates), geometrical optimization (DGS and parasitic patches), and the interplay of simulation parameters to achieve targeted performance metrics. Each element's performance directly affects the overall antenna functionality.

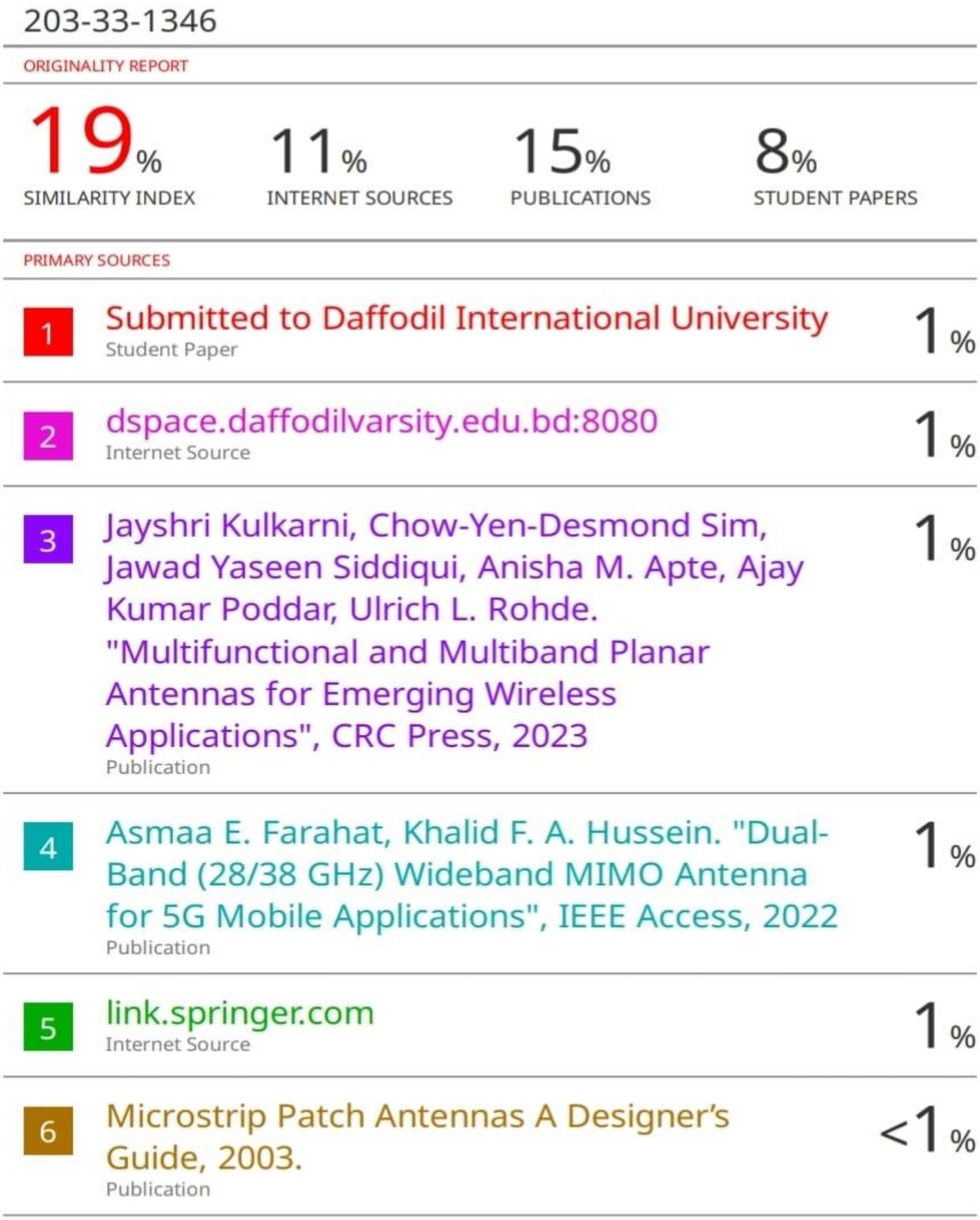
Table- 4 Range of Complex Engineering Activities

Complex Engineering Problems Solving and Engineering Activities		
	Attributes	**Statement from Students**
A1	Range of resources	The project integrates teamwork, advanced simulation tools (CST Microwave Studio), efficient materials (Rogers RT5880), and extensive research to create an innovative antenna design.
A2	Level of interaction	The thesis report does not fulfill this criterion.

A3	Innovation	The design employs creative techniques like Defected Ground Structure (DGS) and parasitic patches to enhance bandwidth, gain, and impedance matching.
A4	Consequences for society and the environment	We could not identify this as there is no room for implementation.
A5	Familiarity	The project tackles unfamiliar challenges, such as dual-band operation at 28/38 GHz, using advanced methods like DGS to optimize performance.

K-P-A Addressing (Fill up by Supervisor)																			
Knowledge Profile (K)								**Complex Engineering Problem (P)**							**Complex Engineering Activities (A)**				
K1	K2	K3	K4	K5	K6	K7	K8	P1	P2	P3	P4	P5	P6	P7	A1	A2	A3	A4	A5

APPENDIX B
Turnitin Report



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