Design of Circular and Rectangular Patch Antenna Using Teflon and Rogers Substrates For 5G Applications at 25GHz

A Project Report

Submitted to the FACULTY of ENGINEERING of

JAWAHARLAL NEHRU TECHNOLOGICAL UNIVERSITY, KAKINADA

In partial fulfillment of the requirements,

for the award of the Degree of

Bachelor of Technology

in

Electronics and Communication Engineering

By

T. Ashok

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Under the Guidance of

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Professor & Mentor (AS & A)

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(An Autonomous Institute with Permanent Affiliation to JNTUK, Kakinada)

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ANDHRA PRADESH

2023-24

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CERTIFICATE

This is to certify that the project report entitled **“Design of Circular and Rectangular Patch Antenna Using Teflon and Rogers Substrates For 5G Applications at 25GHz”** is a bonafide record of work carried out by T. Ashok (20481A04M8), G. Rajesh (20481A04J6), S. VAMSI (20481A04K2), S. SNEHA SOWJANYA (20481A04M1) under my guidance and supervision in partial fulfilment of the requirements for the award of the degree of Bachelor of Technology in **Electronics and Communication Engineering** of **Seshadri Rao Gudlavalleru Engineering** affiliated to **Jawaharlal Nehru Technological University, Kakinada**.

(Dr. Y. Rama Krishna)	(Dr. B. Rajasekhar)
Project Guide	**Head of the Department**

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ABSTRACT

This project presents a comprehensive study on the design and performance evaluation of circular and rectangular microstrip patch antennas tailored for 5G applications, operating at 25 GHz. Utilizing Teflon and Rogers substrates with superior dielectric properties, the antennas are meticulously crafted and rigorously analyzed. The study explores the design methodology, simulation outcomes and compares circular and rectangular patch antennas, focusing on their suitability for 5G systems. Through iterative simulations and optimizations, the antennas are fine-tuned to achieve optimal performance parameters, including impedance matching, radiation efficiency and bandwidth, ensuring their efficacy in high-frequency communication environments.

The design methodology involves precise calculations for optimal antenna dimensions, considering substrate material properties, dielectric constants and desired radiation characteristics. Performance metrics such as peak directivity, gain, efficiency and bandwidth are comprehensively evaluated and compared for both Teflon and Rogers substrates. This investigation contributes to advancing microstrip patch antenna design for 5G, elucidating the interplay between substrate materials, antenna geometries, and performance characteristics. The findings not only enhance our understanding of antenna design principles but also lay the groundwork for further optimization and refinement of microstrip patch antennas for future high-frequency communication systems.

Keywords:

5G technology, Circular and Rectangular microstrip patch antennas, Teflon, Roger's substrates, HFSS (High Frequency Structure Simulator),wireless communication.

CHAPTER 1

INTRODUCTION

The evolution of wireless communication technologies has revolutionized how we connect and interact with the world around us. From the early days of radio waves to the advent of 4G LTE, each generation has brought unprecedented advancements, driving innovation and shaping the way we communicate, collaborate and access information. Now, with the emergence of the fifth generation of wireless technology, 5G, we stand on the brink of yet another transformative era in telecommunications.

5G promises to deliver unparalleled speed, reliability and connectivity, ushering in a new era of connectivity where the Internet of Things (IoT), smart cities, autonomous vehicles, and augmented reality become not just possibilities, but realities. At the heart of this technological revolution lies the need for high-performance antennas capable of supporting the demands of 5G networks.

1.1 Background

In the rapidly evolving landscape of wireless communication, patch antennas play a pivotal role due to their compact size, ease of integration and suitability for various applications. With the advent of 5G technology, there's a pressing need for high-frequency antennas capable of operating efficiently at frequencies such as 25GHz. The demand for reliable and high-performance antennas has led to extensive research and development in the field.

1.2 Objective

The primary objective of this project is to design circular and rectangular patch antennas utilizing Teflon and Rogers substrates specifically tailored for 5G applications operating at 25GHz. This endeavour aims to achieve optimal performance in terms of bandwidth, gain and efficiency, thereby contributing to the advancement of wireless communication technology.

1.3 Methodology

The methodology employed in this project encompasses a systematic approach to antenna design, simulation, fabrication and testing. Leveraging state-of-the-art electromagnetic simulation software, rigorous analysis will be conducted to refine the antenna designs. Substrate selection criteria will be meticulously evaluated to ensure compatibility with the desired frequency range. Fabrication techniques will adhere to industry standards and comprehensive testing protocols will be employed to validate the performance of the antennas.

1.4 Significance of this Work

The significance of this work lies in its potential to address the growing demand for high-frequency antennas in 5G applications. By developing efficient patch antennas optimized for operation at 25GHz, this project aims to facilitate faster data rates, increased bandwidth and enhanced connectivity in wireless communication systems. The outcomes of this research endeavor hold promise for various sectors, including telecommunications, IoT and autonomous vehicles.

1.5 Outline

The document is structured as follows:

- Section 1 provides an introduction to the project, including background information, objectives, methodology and significance.
- Section 2 delves into the theoretical framework and design considerations for circular and rectangular patch antennas.
- Section 3 details the simulation process and analyses the performance of the designed antennas.
- Section 4 presents the experimental setup and results obtained from testing the antennas.
- Finally, Section 5 offers concluding remarks summarizing the key insights and contributions of the research.

CHAPTER 2

THEORETICAL FRAMEWORK AND DESIGN CONSIDERATIONS

2.1 Patch Antenna Fundamentals

Patch antennas, also known as microstrip antennas, are popular choices in wireless communication systems due to their compact size, low profile, and ease of integration into various devices and systems. They typically consist of a radiating patch, usually made of conducting material such as copper, printed on one side of a dielectric substrate, with a ground plane on the other side. The geometry and dimensions of the patch, as well as the properties of the substrate material, collectively determine the antenna's operating frequency, bandwidth, radiation pattern, and impedance characteristics.

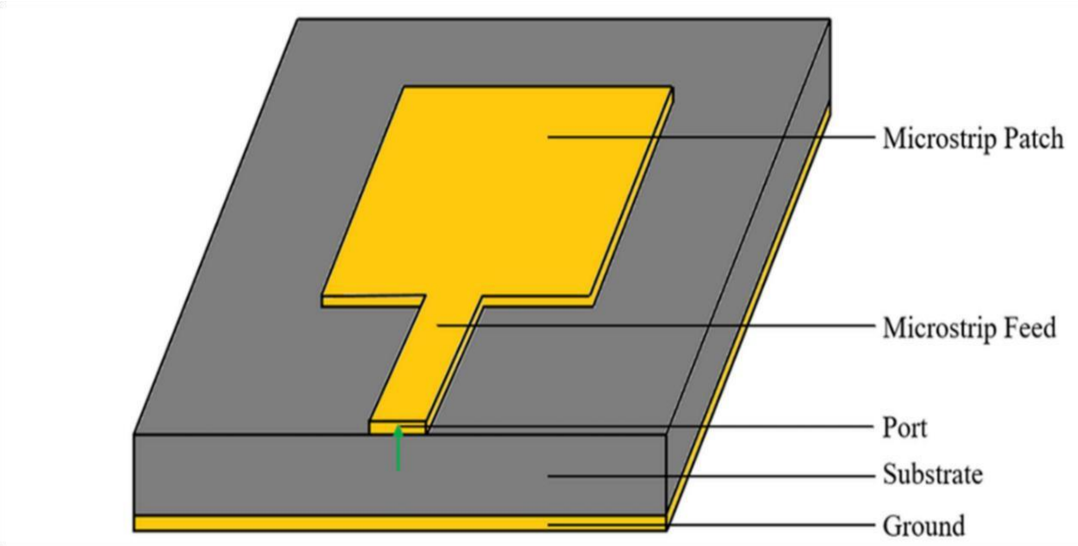


Fig. 2.1: General diagram of Micro Strip Patch Antenna

A microstrip patch antenna typically consists of the following components:

1. Substrate:

- The substrate is the base material on which the antenna is fabricated.
- It is usually a dielectric material with a specific dielectric constant (εr).
- Common substrate materials include FR-4, Rogers, and Teflon.
- The substrate thickness affects the antenna's bandwidth and efficiency.

2. Patch:

- The patch is a conductive element that radiates electromagnetic waves.
- It is typically made of a metallic material such as copper and is etched or printed on one side of the substrate.

- The patch can have various shapes, including square, rectangular, circular, or other geometries.
- The dimensions of the patch (length and width) determine its resonant frequency and radiation characteristics.

Different Shapes as Patches:

Microstrip patch antennas can have various shapes, each offering unique advantages and characteristics. Some common patch shapes include:

- Square Patch: Square patches are simple to design and fabricate, making them popular choices for microstrip patch antennas. They offer symmetric radiation patterns and are suitable for applications requiring uniform coverage.
- Rectangular Patch: Rectangular patches provide flexibility in adjusting the antenna's resonant frequency and bandwidth. They offer higher gain and improved impedance matching compared to square patches.

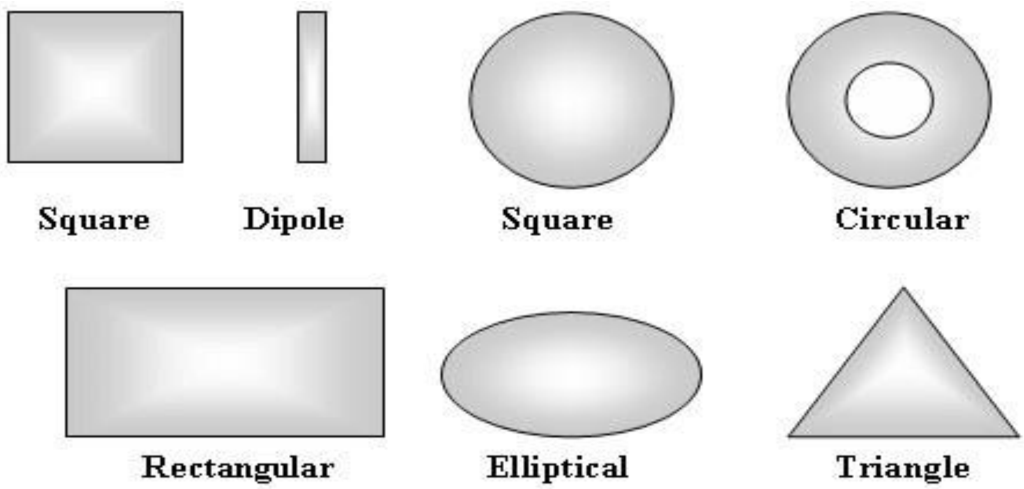


Fig. 2.2: Different Shapes as patches

- Circular Patch: Circular patches offer omnidirectional radiation patterns, making them suitable for applications requiring 360-degree coverage. They are often used in wireless communication systems where uniform radiation in all directions is desired.
- Triangular Patch: Triangular patches offer compact and lightweight designs, making them suitable for portable and mobile communication devices. They can achieve wideband performance and exhibit low cross-polarization characteristics.
- Elliptical Patch: Elliptical patches offer a combination of wide bandwidth and compact size. They can achieve circularly polarized radiation patterns, making them suitable for satellite communication and radar applications.

Each patch shape has its advantages and limitations, and the choice depends on specific application requirements, such as frequency range, radiation pattern, polarization, and size constraints.

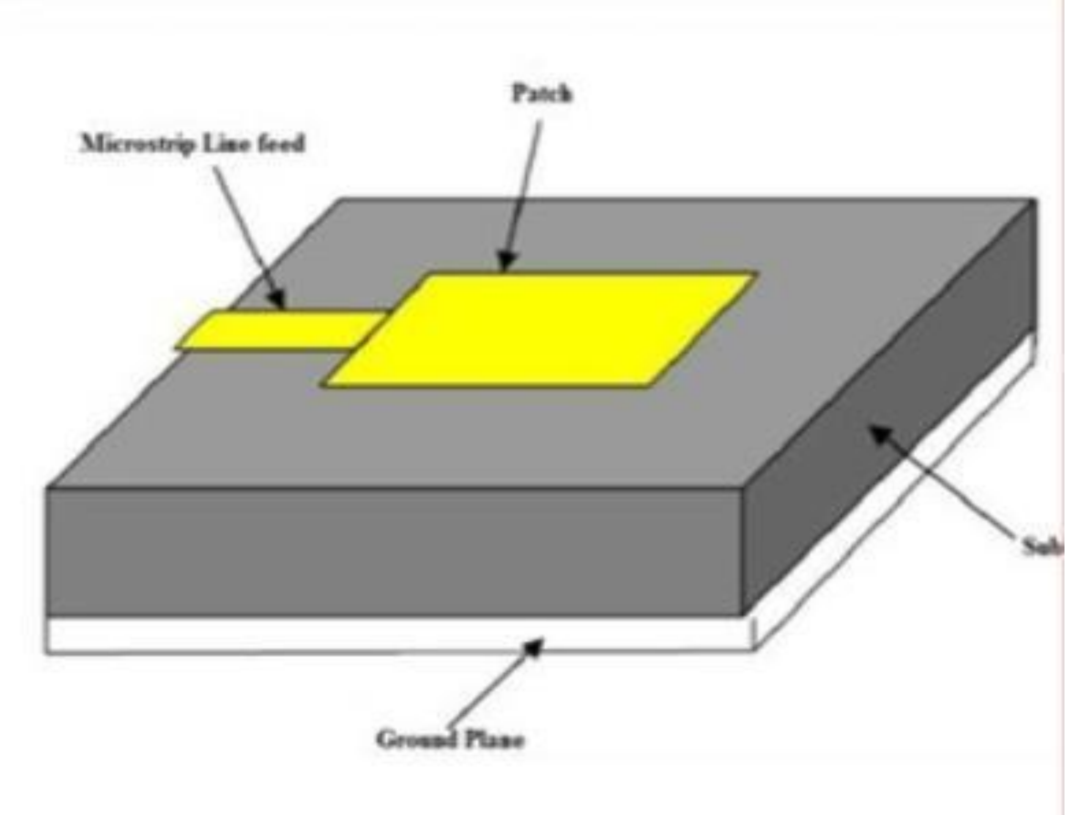
3. Ground Plane:

- The ground plane is a conductive layer on the opposite side of the substrate from the patch.
- It acts as a reference plane and provides a return path for the antenna's current.
- The ground plane dimensions are usually larger than the patch to minimize edge effects and improve antenna performance.

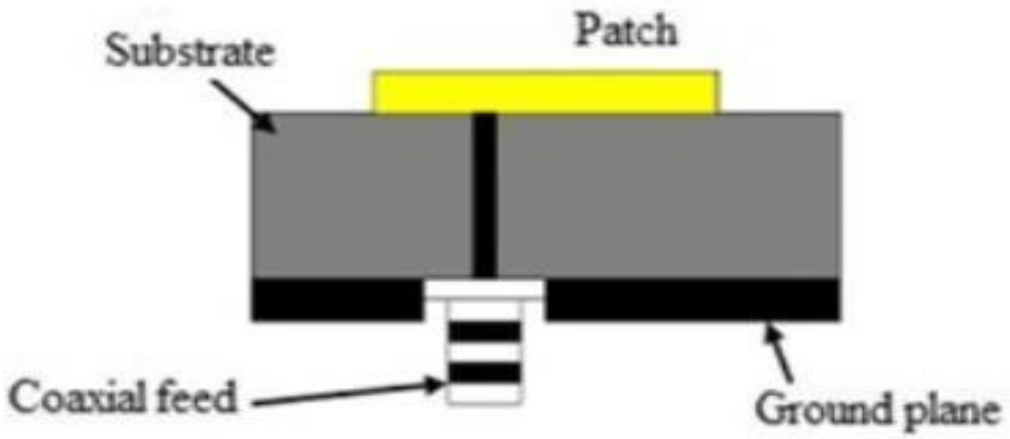
4. Feed Mechanism:

- The feed mechanism is used to couple the RF signal from the transmission line to the patch.
- Common feeding techniques include microstrip feedlines, coaxial probes, and aperture coupling.
- The feed point is the location where the RF energy is coupled to the patch.

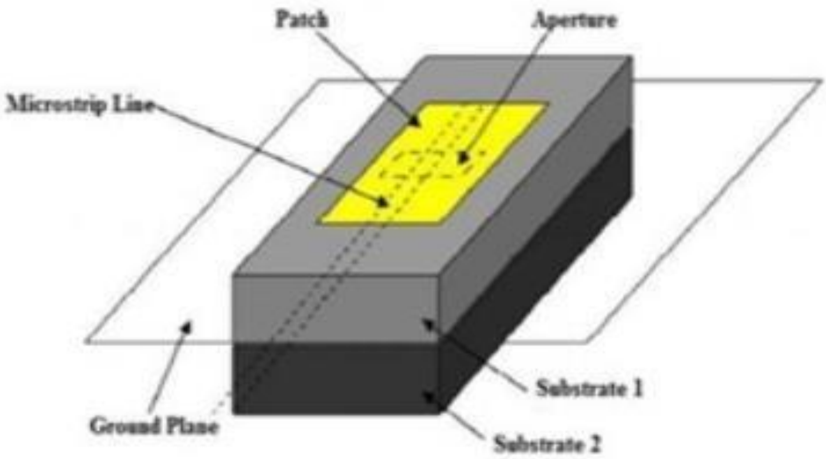
The feed mechanism is a crucial element of a microstrip patch antenna responsible for coupling the radio frequency (RF) signal from the transmission line to the patch. This coupling ensures efficient energy transfer to the radiating element, enabling the antenna to transmit or receive electromagnetic waves effectively. Common feeding techniques include:



(A) Microstrip line feed



(B) Probe feed



(C) Aperture Coupled Feed

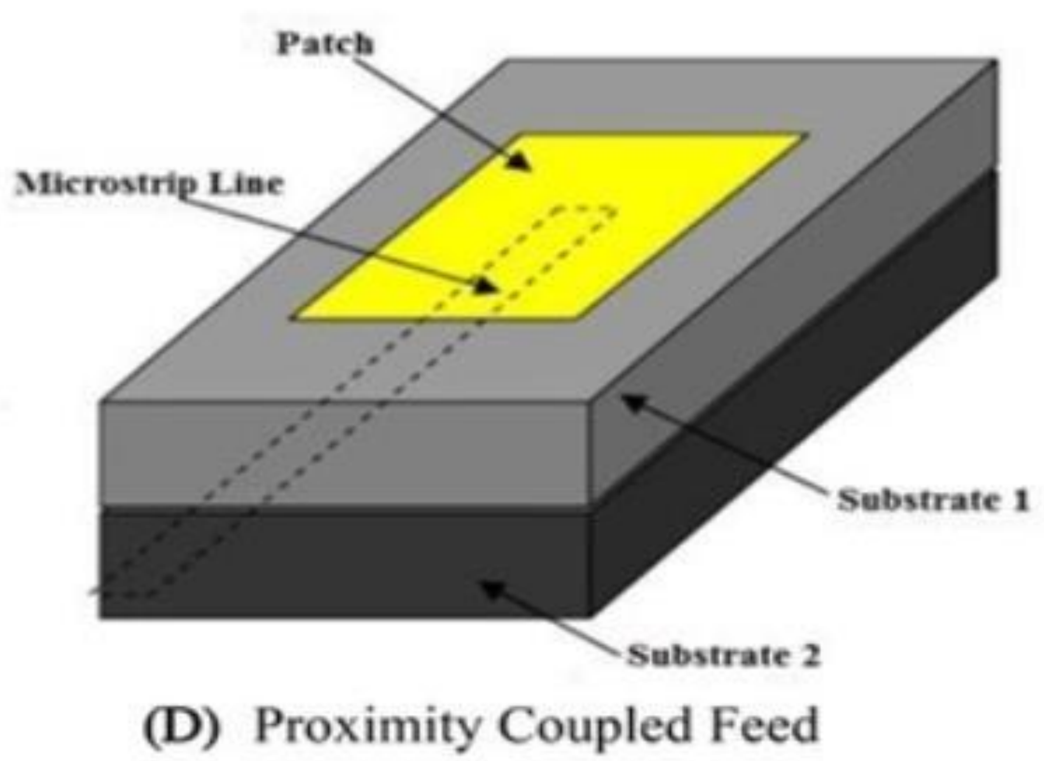


Fig. 2.3: (A), (B), (C) & (D) are the Various Feeding Techniques In Microstrip Patch Antenna Design

- Microstrip Feedlines: Microstrip feedlines are widely used for feeding microstrip patch antennas. They consist of a narrow strip of conductor routed on the same side of the substrate as the patch. The feedline is typically designed to have a characteristic impedance matching that of the transmission line. The RF signal is coupled from the feedline to the patch at a specific point known as the feed point. Microstrip feedlines offer simplicity, ease of fabrication, and precise impedance control.

- Coaxial Probes: Coaxial probes involve inserting a coaxial cable through the substrate to feed the patch. The inner conductor of the coaxial cable is connected to the patch, while the outer conductor serves as the ground reference. Coaxial probes provide good impedance matching and low radiation losses, making them suitable for high- frequency applications. However, they require careful alignment and assembly to minimize signal distortion and impedance mismatches.

- Aperture Coupling: Aperture coupling involves creating a slot or aperture in the ground plane beneath the patch. The RF signal is coupled from the transmission line through the aperture to the patch. This technique offers good impedance matching and isolation between the feedline and the patch. Aperture coupling is advantageous for applications requiring compact antenna designs and improved radiation efficiency.

- Proximity coupled feeding : Proximity coupled feeding is a technique employed in microstrip patch antennas to efficiently transfer RF energy from the transmission line to the radiating patch without physical contact. This method relies on the electric or magnetic field coupling between the transmission line and the patch, offering benefits such as excellent isolation, tunable impedance matching, broadband performance, compact size, and ease of fabrication.

By adjusting the coupling distance and optimizing the design of the transmission line and radiating patch, designers can achieve precise impedance matching and enhance antenna performance over a wide frequency range

2.2 Design Considerations for 5G Applications

Designing patch antennas for 5G applications at 25GHz requires careful consideration of several factors. The high frequency of operation necessitates compact antenna designs, which can be achieved through proper optimization of patch dimensions and substrate properties. Wideband performance is crucial to support the multiple frequency bands used in 5G networks. Furthermore, 5G applications often require antennas with specific polarization properties and beamforming capabilities to optimize signal transmission and reception in diverse environments.

Microstrip Patch Antenna Design Flow

Requirements Analysis:

- Identify the application requirements, including frequency of operation, bandwidth, radiation pattern, and size constraints.
- Determine the environmental conditions such as temperature, humidity, and interference levels.
- Define performance metrics and design goals for the MSP antenna.

Substrate Selection:

- Choose a suitable dielectric substrate material based on the application requirements and desired electrical properties.
- Consider factors such as dielectric constant (εr), loss tangent, thermal stability, and cost.

Patch Geometry Design:

- Select the shape and dimensions of the patch antenna based on the operating frequency and desired radiation characteristics.
- Common patch shapes include square, rectangular, circular, or elliptical.
- Optimize the patch dimensions to achieve the desired resonant frequency, bandwidth, and radiation efficiency.

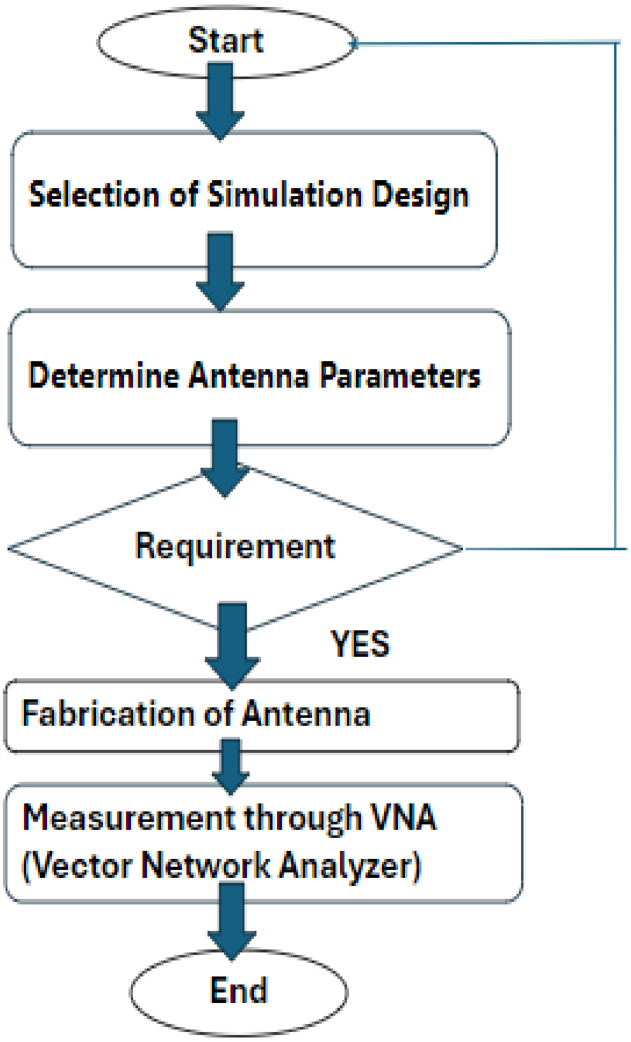


Fig. 2.4: Flowchart for Microstrip Patch Antenna Design

Feeding Mechanism Design:

- Determine the feeding mechanism for coupling the RF signal from the transmission line to the patch antenna.
- Evaluate different feeding techniques such as microstrip feedlines, coaxial probes, or aperture coupling.
- Choose the feeding mechanism that offers efficient energy transfer and impedance matching.

Impedance Matching:

- Design matching networks or tuning elements to achieve impedance matching between the feedline and the patch antenna.
- Use simulation tools to optimize the matching network components for maximum power transfer and minimum reflection losses.

Advanced Design Techniques:

- Explore advanced design techniques such as aperture-coupled designs or metamaterial structures to enhance antenna performance.
- Consider incorporating features like multi-layer configurations or frequency-selective surfaces for improved bandwidth and efficiency.

Simulation and Optimization:

- Use electromagnetic simulation software such as HFSS (Ansys) or CST Microwave Studio to analyze and optimize the antenna design.
- Perform simulations to evaluate key performance parameters such as return loss, radiation pattern, and gain.
- Iteratively refine the design based on simulation results to meet the specified requirements.

Prototype Fabrication and Testing:

- Fabricate a prototype of the MSP antenna based on the optimized design parameters.
- Conduct experimental testing to validate the antenna's performance under real-world conditions.
- Measure and analyze key performance metrics to ensure alignment with the design specifications.

Iterative Refinement:

- Iterate on the design based on prototype testing results and feedback.
- Fine-tune the antenna parameters to address any performance discrepancies or optimization opportunities.
- Continuously refine the design to achieve optimal performance and reliability.

Documentation and Reporting:

- Document the entire design process, including design specifications, simulation results, fabrication details, and testing outcomes.
- Generate a comprehensive report summarizing the MSP antenna design, optimization steps, and performance evaluation.
- Provide recommendations for future improvements or iterations based on lessons learned during the design process.

2.3 ANTENNA DIMENSIONS

2.3.1 Rectangular patch antenna

Rectangular patch antennas are commonly employed in 5G applications due to their ability to achieve wideband performance and compact form factor. The design process includes determining the length and width of the patch, as well as selecting the substrate material and feeding mechanism. Advanced techniques such as aperture coupling and impedance matching networks are utilized to enhance antenna performance and ensure compatibility with 5G frequency bands. Rectangular patch antennas offer advantages such as higher gain and improved impedance matching over their circular counterparts, making them suitable for applications requiring higher directive gain or specific radiation patterns.

(a) Determination of patch Width: The width of the patch is crucial as it affects the resonant frequency and impedance matching of the antenna. Calculating the patch width ensures that the antenna operates at the desired frequency and exhibits optimal performance.

The width of the patch is calculated using the formula given as [5]

$$W = \frac{C}{2F0\sqrt{(€r+1)/2}} \qquad (1)$$

where F0 =Operating Frequency

€r=Dielectric Constant

C=3*10^8 m/s

(b) Determination of effective dielectric constant: Accurate calculation of the effective dielectric constant accounts for fringing fields, ensuring precise tuning of the antenna for resonance at the operating frequency.

It is calculated using the equation is given as [6]

$$€erff = \frac{(€r+1)}{2} + \frac{(€r-1)}{2}\left[1 + \frac{1}{\sqrt{((1)+12\frac{H}{W})}}\right] \qquad (2)$$

(c) Determination of Effective Length (Leff): The effective length accounts for electrical lengthening due to fringing fields, enabling precise adjustment of the patch dimensions for resonance.

It is calculated using the formula given as [5,6]

$$Leff = \frac{C}{2F0\sqrt{€erff}} \qquad (3)$$

(d) Normalized Extension in Length: This parameter ensures accurate adjustment of the patch length to achieve optimal resonance and radiation characteristics.

It is calculated using the formula given as [6]

$$\Delta L = 0.412H \cdot \frac{(€erff+0.3)\cdot(\frac{W}{H}+0.264)}{(c-0.258)\cdot(\frac{W}{H}+0.8)} \qquad (4)$$

(e) Length of the patch: Calculating the patch length ensures proper resonance and determines radiation characteristics such as beamwidth and directivity [2].

The length of the patch is given as

$$L = Leff - 2\Delta L \qquad (5)$$

(f) Determination of Substrate Length and Width: Proper substrate dimensions ensure optimal alignment and mounting of the patch antenna, accounting for substrate effects on performance.

Substrate length and width are given by the formulae [14]

$$Lg = L + 6h \quad (6)$$

$$Wg = W + 6h \quad (7)$$

h: here h is not the height of the substrate

$$h = \frac{0.0606\lambda}{\sqrt{€r}} \quad (8)$$

(g) Feed Line Length: Determining the feed line length ensures efficient impedance matching and power transfer between the transmission line and the antenna.

The length of the feed line is determined using formulae [14]

$$Lf = \frac{\lambda g}{4} \quad (9)$$

$$\lambda g = \frac{\lambda}{\sqrt{\mathcal{E}reff}} \quad (10)$$

2. 3. 2 Circular Patch Antenna Design

Circular patch antennas offer several advantages for 5G applications, including their omnidirectional radiation patterns, ease of manufacturing, and compact size. The design process involves determining the radius of the circular patch, the substrate material, and the feeding mechanism. Optimization techniques, such as adjusting the patch dimensions and tuning the feeding structure, are employed to achieve desired performance metrics such as bandwidth and radiation efficiency. Circular patch antennas are well-suited for applications requiring uniform coverage and minimal antenna orientation dependence.

(a) Physical Radius of Patch (a): The physical radius determines the overall size and shape of the circular patch antenna. It influences the resonant frequency, bandwidth, and radiation characteristics of the antenna [9].

$$a = \frac{F}{\sqrt{(1+\frac{2h}{\pi \cdot \epsilon r \cdot F} \cdot \ln[(\frac{\pi \cdot F}{2h}+1.7726)])}} \quad (11)$$

$$\text{Here, } F = \frac{8.791e9}{fr\sqrt{\epsilon r}} \quad (12)$$

(b) Effective Radius (a_e): The effective radius accounts for the fringing fields and substrate effects, providing a more accurate representation of the patch size. It ensures precise tuning of the antenna for optimal performance and resonance at the operating frequency [9].

$$ae = a \cdot \sqrt{(1 + \frac{2h}{\pi \cdot \epsilon r \cdot a} \cdot \ln[(\frac{\pi \cdot a}{2h} + 1.7726)])} \qquad (13)$$

2.4 Substrate Selection Criteria

The choice of substrate material significantly influences the performance and characteristics of patch antennas in 5G applications. Teflon (PTFE) and Rogers substrates are commonly used due to their low dielectric loss, high thermal stability, and compatibility with high-frequency operation. Teflon substrates typically have lower dielectric constants, resulting in larger antenna dimensions and wider bandwidths, while Rogers substrates offer a balance between dielectric constant, loss tangent, and cost-effectiveness. Substrate selection criteria include dielectric constant, loss tangent, thermal stability, surface roughness, and cost considerations, all of which impact antenna performance and overall system design.

2.5 Advanced Design Techniques

Advanced design techniques are employed to further enhance the performance and capabilities of patch antennas for 5G applications. These techniques include metamaterial-based structures, multi-layer configurations, and aperture-coupled designs. Metamaterial structures enable precise control over electromagnetic properties, allowing for novel antenna designs with enhanced performance characteristics such as increased bandwidth, reduced side lobes, and improved radiation efficiency. Multi-layer configurations, consisting of stacked dielectric substrates and conducting layers, offer increased design flexibility and bandwidth enhancement. Aperture-coupled designs utilize coupling apertures between the patch and feedline to improve impedance matching and radiation efficiency, particularly in applications requiring high isolation and compact size.

2.6 Simulation Tools and Methods

Electromagnetic simulation tools play a crucial role in the design and analysis of patch antennas for 5G applications. Software packages such as CST Microwave Studio, HFSS (Ansys), and ADS (Keysight) provide comprehensive simulation capabilities for predicting antenna performance metrics such as return loss, radiation pattern, and impedance matching. Advanced simulation techniques, including finite element method (FEM) and method of moments (MoM), enable accurate modeling of antenna structures and interactions with surrounding environments. Parameter sweeps and optimization algorithms are employed to fine-tune antenna designs and ensure compliance with 5G specifications, enabling efficient and reliable antenna development processes.

Fig. 2. 5: Interfaces of Different Simulator Tools

CHAPTER 3

SIMULATION

Simulation is a pivotal stage in the design process of microstrip patch antennas, offering insights into their performance characteristics and aiding in design refinement before fabrication. This section delineates the simulation methodology:

Software Selection:

Choose appropriate electromagnetic simulation software, such as CST Microwave Studio, HFSS (Ansys), or ADS (Keysight), based on proficiency, feature-set, and compatibility with design requirements.

Model Development:

Construct a comprehensive model of the antenna within the chosen simulation software, encompassing substrate properties (dielectric constant, thickness), geometric parameters (patch dimensions, feedline structure), and environmental conditions.

The model development phase involves creating detailed simulations of the microstrip patch antennas using electromagnetic simulation software. The following table outlines the antenna design parameters and specifications for the different antenna types considered:

Table 3.1: Antenna Design Parameters and Specifications

Antenna Type	Permittivity	Operating Frequency (GHz)	Patch Dimensions (mm)	Feed Dimensions (mm)	Substrate Dimensions (mm)
Rectangular (Rogers 4003)	3.55	34.5	2.76 x 3.97 x 0	3 x 0.3	6 x 6 x 0.8
Rectangular (Teflon)	2.1	23.8	3.57 x 4.82 x 0	3 x 0.3	6 x 6 x 0.8
Circular (Teflon)	2.1	21.85	Radius: 2.4	5 x 0.4	10 x 10 x 0.8
Circular (Rogers RT/Duroid 5880)	2.2	20.85	Radius: 2.4	5 x 0.4	10 x 10 x 0.8

These parameters include the relative permittivity (dielectric constant) of the substrate material, the operating frequency of the antenna, dimensions of the patch, feed, and substrate. The substrate dimensions specify the length, width, and thickness of the dielectric material used. These parameters are essential for accurately modeling the antennas within the electromagnetic simulation software. Through precise modeling, the simulation results can be validated against theoretical calculations and design specifications, enabling informed decision-making during the antenna design process.

Simulation Setup:

Configure simulation parameters including frequency range, meshing density, solver settings, and boundary conditions to accurately capture antenna behavior.

Define simulation goals to analyze resonance frequency, bandwidth, radiation pattern, impedance matching, and efficiency.

Simulation results demonstrate the performance of circular and rectangular patch antennas on Teflon and Rogers substrates at 25 GHz. Comparative analysis evaluates the impact of substrate material and patch geometry on antenna characteristics. The study sheds light on the strengths and limitations of each design, providing valuable insights for antenna engineers and researchers. As illustrated in Figure 3a and Figure 3b, the simulation designs depict the performance characteristics of the rectangular and circular patch antennas, respectively.

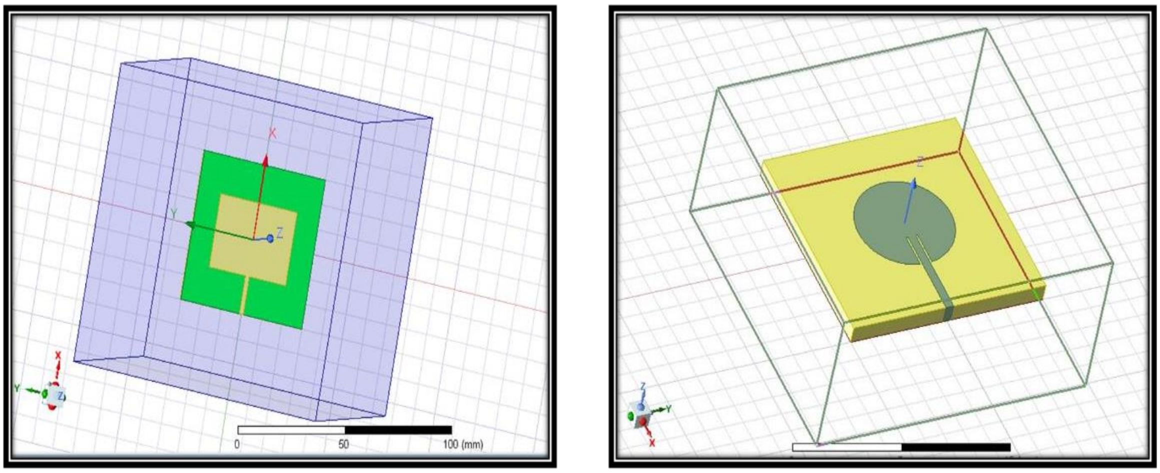


Fig 3a: Rectangular Patch Design **Fig 3b:** Circular Patch Design

Fig 3: Microstrip Patch Antenna View

Analysis and Optimization:

- Execute simulations to assess antenna performance metrics.
- Evaluate resonance frequency, return loss, Voltage Standing Wave Ratio (VSWR), radiation pattern, and gain.

- Identify optimization opportunities based on simulation outcomes, such as adjusting patch dimensions or refining feeding structures.

Validation

- Validate simulation results against theoretical calculations and design specifications.
- Ensure coherence between simulated performance metrics and desired antenna characteristics.
- Address any disparities by refining the simulation model and iteratively adjusting design parameters.

Parameter Sensitivity Analysis:

- Conduct sensitivity analysis to ascertain the influence of key design parameters on antenna performance.
- Identify critical parameters that significantly affect antenna behavior and performance, guiding optimization efforts.

Verification:

- Verify simulation accuracy through comparison with experimental measurements obtained during testing and characterization.
- Confirm the reliability of the simulation model in predicting antenna behavior under real-world operating conditions.

Documentation:

- Document simulation setup, parameters, and results comprehensively for future reference and replication.
- Generate detailed reports summarizing simulation findings, optimizations performed, and validation against design requirements.
- Simulation serves as a pivotal tool in the iterative design process of microstrip patch antennas, facilitating informed decision-making and ensuring the attainment of desired performance specifications for 5G applications at 25GH

CHAPTER 4
RESULTS AND DISCUSSION

Section 4 of the document presents a detailed analysis of the experimental results obtained from testing the microstrip patch antennas at an operating frequency of 25 GHz. The comparison of antenna parameters across different antenna types and substrate materials provides valuable insights into their performance characteristics and implications for antenna design and optimization.

4.1. Performance Evaluation:

Rectangular Patch Antennas

The rectangular patch antenna fabricated on Rogers 4003 substrate exhibits a peak directivity of 0.565728, gain of 0.5642, total efficiency of 0.927480, and radiation efficiency of 0.997434. It operates at 34.5 GHz with an S-parameter of -12.8 dB and a VSWR of 1.54. The antenna achieves a bandwidth of 2.3 GHz.

Table 2 summarizes the characteristics of distinct types of antennas fabricated with various materials, along with their corresponding peak directivity, peak gain, total efficiency, radiation efficiency, and bandwidth.

Table 2: Comparison Antenna Parameters at 25 GHZ

Antenna Type	S-parameter (dB)	VSWR	Peak Directivity	Peak Gain	Total Efficiency	Radiation Efficiency	Bandwidth
Circular (Teflon)	-14.06	1.487	5.569213	5.443	0.939920	0.977501	1.25 GHz
Circular (Rogers RT/Duroid)	-19.03	1.25	5.579727	5.4776	0.969431	0.981699	1.05 GHz
Rectangular (Teflon)	-13.9	1.58	4.491314	4.6183	0.882649	1.028291	1.0 GHz
Rectangular (Rogers 4003)	-12.8	1.54	0.565728	0.5642	0.927480	0.997434	2.3 GHz

The rectangular patch antenna fabricated on Teflon substrate demonstrates a peak directivity of 4.491314, gain of 4.6183, total efficiency of 0.882649, and radiation efficiency of 1.028291. It operates at 23.8 GHz with an S-parameter of -13.9 dB and a VSWR of 1.58. The antenna achieves a bandwidth of 1.0 GHz.

Circular Patch Antennas

The circular patch antenna fabricated on Teflon substrate exhibits a peak directivity of 5.569213, gain of 5.443, total efficiency of 0.939920, and radiation efficiency of 0.977501. It operates at 21.85 GHz with an S-parameter of -14.06 dB and a VSWR of 1.487. The antenna achieves a bandwidth of 1.25 GHz.

The circular patch antenna fabricated on Rogers RT/Duroid 588 substrate demonstrates a peak directivity of 5.579727, gain of 5.4776, total efficiency of 0.969431, and radiation efficiency of 0.981699. It operates at 20.85 GHz with an S-parameter of -19.03 dB and a VSWR of 1.25. The antenna achieves a bandwidth of 1.05 GHz.

4.2 Discussion:

4.2.1 Return Loss and Impedance Matching:

- The S-parameter (dB) values represent the return loss of the antennas, indicating the amount of reflected power. Lower S-parameter values indicate better impedance matching between the antenna and the transmission line, resulting in reduced signal loss.

Return Loss:

- Definition: Return loss measures the amount of power reflected back from an antenna due to impedance mismatches along the transmission line. It's expressed in decibels (dB) and indicates the efficiency of power transfer.

- Calculation: Return loss (RL) is calculated as the ratio of the power of the incident wave to the power of the reflected wave, expressed in dB:

$$RL = -10 \log_{10}\left(\frac{P_{reflected}}{P_{incident}}\right)$$

Interpretation:

- Higher return loss values (closer to 0 dB) indicate better impedance matching and less power reflection.

- A return loss of 0 dB indicates perfect impedance matching, where all power is absorbed by the load with no reflections.
- Importance in Antenna Design:

- High return loss signifies efficient power transfer and optimal antenna performance.
- Antennas with low return loss may suffer from reduced signal strength, interference, and decreased communication range.

Measurement:

- Return loss is typically measured using a network analyzer or reflectometer.
- The measurement is conducted across the operating frequency range to assess antenna performance under various conditions.
- Impedance Matching:
- Definition: Impedance matching ensures that the impedance of the antenna matches that of the transmission line and source, minimizing reflections and maximizing power transfer.

Techniques:

- Impedance matching techniques include using matching networks (such as baluns or quarter-wave transformers) and adjusting antenna dimensions.
- Matching networks are designed to transform the antenna's impedance to match that of the transmission line and source.

Importance in Antenna Design:

- Proper impedance matching results in reduced signal loss, broader bandwidth, and improved antenna performance.
- Antennas with mismatched impedance may experience signal reflections, leading to decreased efficiency and performance degradation.

Measurement:

- Impedance matching is assessed by measuring parameters like VSWR and return loss across the operating frequency range.
- Engineers use tools like network analyzers and Smith charts to design and evaluate impedance matching networks for antennas.

- Antennas with lower S-parameter values, such as the circular antenna fabricated on Rogers RT/Duroid substrate (-19.03 dB), exhibit superior impedance matching compared to others, indicating better overall performance in terms of signal transmission efficiency.

1. S Parameter (Return Loss)

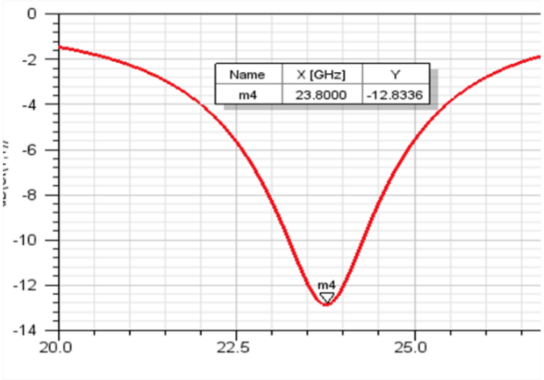


Fig 4a: S Parameter (Teflon) of Rectangular Patch Design

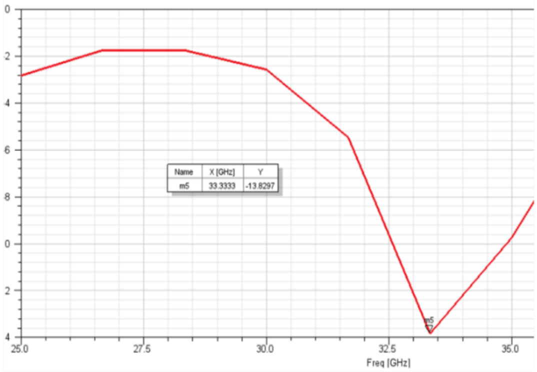


Fig 4b : S Parameter (Rogers 4003) of Rectangular Patch Design

Fig 4.1: S-Parameters of Rectangular patch antennas

Fig. (4a, 4b) depicts the S-parameter graphs of the Teflon and Rogers RT/Duroid antennas for rectangular patch antennas. The S-parameter values for the Teflon antenna and Rogers RT/Duroid antenna are -13.9 dB and -13.6 dB, respectively.

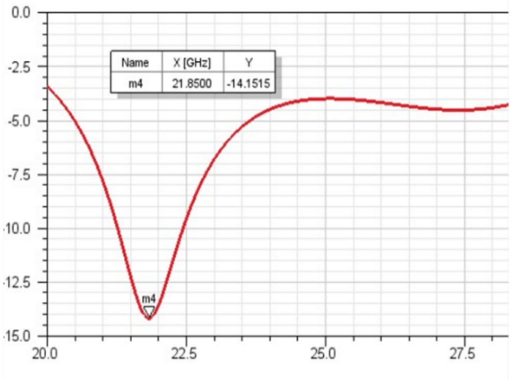


Fig 5a: S Parameter (Teflon) of Circular Patch Design

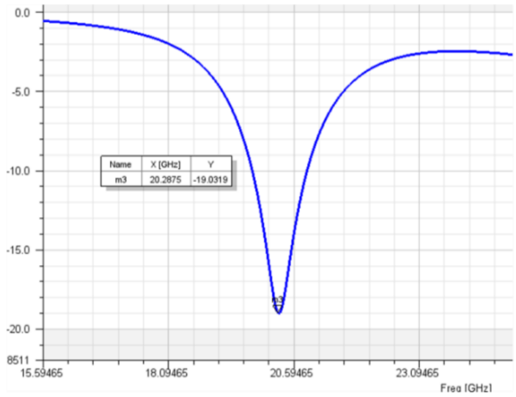


Fig 5b: S Parameter (Rogers RT/Duroid 5880) of Circular Patch Design

Fig 4.2: S-Parameters of Circular patch antennas

Fig. (5a, 5b) illustrates the S-parameter graphs of the Teflon and Rogers RT/Duroid antennas for circular patch antennas. The S-parameter values for the Teflon antenna and Rogers RT/Duroid antenna are -14.06 dB and -19.03 dB, respectively.

4.2.2 Voltage Standing Wave Ratio (VSWR):

The Voltage Standing Wave Ratio (VSWR) is a measure of the impedance mismatch between a transmission line and its load, such as an antenna. It quantifies the efficiency of power transfer along the transmission line, indicating the level of signal reflection at the interface between the transmission line and the load.

How VSWR is Calculated:

VSWR is calculated as the ratio of the maximum voltage to the minimum voltage along the transmission line. Mathematically, it is expressed as:

$$\boldsymbol{VSWR = V_{max}/V_{min}}$$

Where:

- Vmax is the maximum voltage amplitude along the transmission line.
- Vmin is the minimum voltage amplitude along the transmission line.

Interpretation of VSWR:

- A VSWR value of 1 indicates perfect impedance matching, where all the power is transferred from the source to the load without any reflections. This corresponds to no standing waves on the transmission line.
- As the VSWR value increases, it indicates greater impedance mismatch and increased signal reflection. Higher VSWR values imply lower efficiency in power transfer and increased signal loss due to reflections.
- VSWR values above 2 typically indicate significant power loss due to signal reflections, leading to reduced antenna performance and communication range.

Importance of VSWR in Antenna Design:

- In antenna design, achieving low VSWR is essential to maximize the efficiency of signal transmission and reception. It ensures that the antenna operates at its optimal performance and delivers maximum power to the load.
- Antennas with low VSWR values exhibit minimal signal reflection, resulting in improved signal strength, coverage, and overall communication performance.
- VSWR is a critical parameter in antenna testing and characterization, as it provides insights into the antenna's impedance characteristics and performance under real-world operating conditions.

Measurement of VSWR:

- VSWR can be measured using various techniques, including network analyzers, reflectometers, and directional couplers. These instruments measure the amplitude of forward and reflected waves along the transmission line and calculate the VSWR accordingly.

- VSWR measurements are typically performed across the operating frequency range of the antenna to assess its performance over different frequency bands and environmental conditions.

2. Voltage Standing Wave Ratio (VSWR)

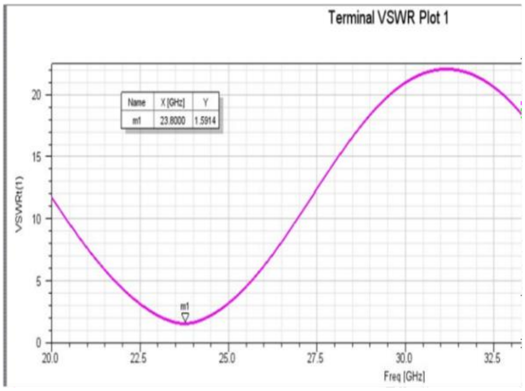


Fig 6a: VSWR (Teflon) of Rectangular Patch Antenna Design

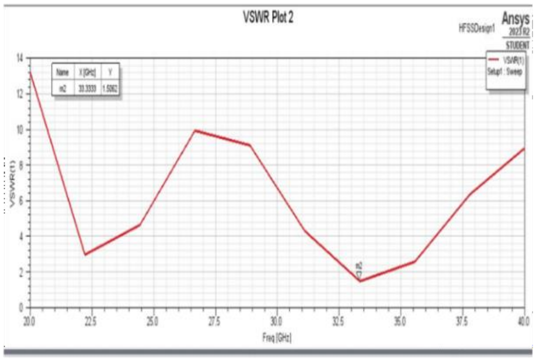


Fig 6b: VSWR (Rogers 4003) of Rectangular Patch Antenna Design

Fig 4.3: VSWR plots of Rectangular patch antennas

Fig. (6a, 6b) illustrates the VSWR graphs of the Teflon and Rogers RT/Duroid antennas for rectangular patch antennas. The VSWR values for the Teflon antenna and Rogers RT/Duroid antenna are 1.58 and 1.54, respectively.

- VSWR values close to 1 indicate excellent impedance matching and minimal signal reflection. Antennas with lower VSWR values, such as the circular antenna fabricated on Rogers RT/Duroid substrate (1.25), demonstrate superior impedance matching and signal transmission efficiency.

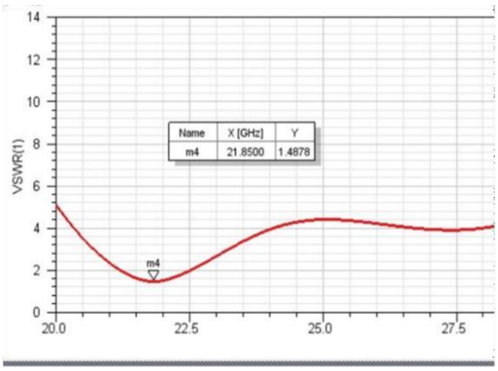


Fig 7a: VSWR (Teflon) of Circular Patch Antenna Design

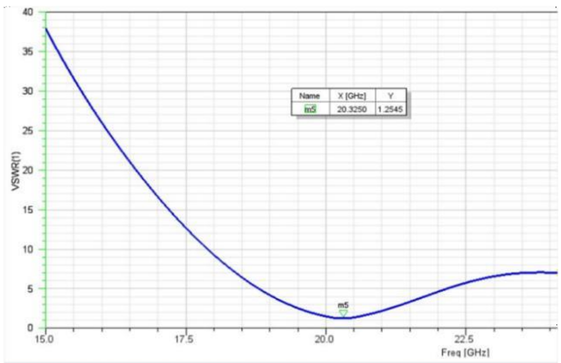


Fig 7b: VSWR (Rogers RT/Duroid 5880) of Circular Patch Antenna Design

Fig 4.4: VSWR plots of Circular patch antennas

Fig. (7a, 7b) displays the VSWR graphs of the Teflon and Rogers RT/Duroid antennas for circular patch antennas. The VSWR values for the Teflon antenna and Rogers RT/Duroid antenna are 1.487 and 1.25, respectively.

4.2.3 Gain Analysis:

Gain is a crucial parameter that quantifies the ability of an antenna to focus electromagnetic energy in a specific direction compared to an isotropic radiator. Higher gain values indicate increased radiation efficiency and signal strength in the desired direction.
Gain, in the context of antennas, refers to the measure of how well an antenna converts input power into radio waves in a particular direction. It quantifies the antenna's ability to focus or direct electromagnetic radiation in a specific direction compared to an isotropic radiator, which emits energy equally in all directions.

The gain of an antenna is usually expressed in decibels (dB) and is calculated as the ratio of the intensity of radiation in a particular direction to the intensity of radiation produced by an isotropic radiator under the same conditions. The formula for calculating gain in dB is:

$$G = 10 * \log_{10}(\frac{P_{out}}{P_{in}})$$

Where:

- **G** is the Gain(in dB).

- P_{out} is the output power in the desired direction.

- P_{in} is the total input power.

Gain is an essential parameter in antenna design and performance evaluation, as it determines the antenna's coverage area, signal strength, and overall efficiency. Antennas with higher gain are capable of transmitting or receiving signals over longer distances and are often preferred for applications requiring extended range or improved signal reception.

In practical applications, antennas with higher gain are commonly used in long-range communication systems, satellite communication, radar systems, and wireless networking to achieve better signal propagation and coverage.
Here's a breakdown of the gain analysis based on the provided comparison:

Rectangular (Teflon) Antenna:

- Peak Gain: 4.6183 dB
- The rectangular antenna fabricated on Teflon substrate achieves a peak gain of approximately 4.6183 dB. While lower than the circular counterparts, this gain value still indicates satisfactory radiation efficiency and signal strength in the desired direction.

Rectangular (Rogers 4003) Antenna:

- Peak Gain: 0.5642 dB
- The rectangular antenna fabricated on Rogers 4003 substrate demonstrates a peak gain of approximately 0.5642 dB. This lower gain value suggests reduced radiation efficiency and signal strength compared to the circular antennas, indicating potential design optimizations for improved performance.
- The analysis of gain provides valuable insights into the radiation characteristics of the microstrip patch antennas at 25 GHz. Antennas with higher gain values exhibit improved radiation efficiency and signal strength, making them suitable for long-range communication and high-demand applications where reliable signal transmission is paramount.

3. Gain Plots

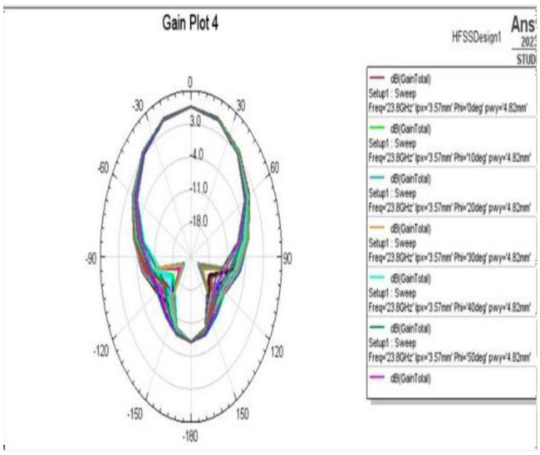


Fig 8a: Gain Plot of Teflon Rectangular Patch Antenna Design

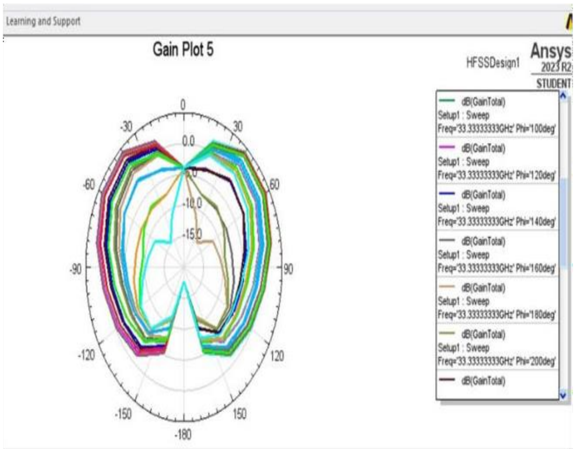


Fig 8b: Gain plot of Rogers 4003 Rectangular Patch Antenna Design

Fig 4.5: Gain plots of Rectangular patch antennas

Fig. (8a, 8b) shows the Gain graphs of the Teflon and Rogers RT/Duroid antennas for rectangular patch antennas. The gain values for the Teflon antenna and Rogers RT/Duroid antenna are 4.6183 and 0.5642, respectively.

Circular (Teflon) Antenna:

- Peak Gain: 5.443 dB
- The circular antenna fabricated on Teflon substrate exhibits a peak gain of approximately 5.443 dB. This indicates that the antenna can radiate electromagnetic energy more effectively in a specific direction compared to an isotropic radiator.

Circular (Rogers RT/Duroid) Antenna:

- Peak Gain: 5.4776 dB
- The circular antenna fabricated on Rogers RT/Duroid substrate demonstrates a peak gain of approximately 5.4776 dB. This higher gain value suggests that the antenna has improved radiation efficiency and signal strength, making it suitable for long-range communication applications.

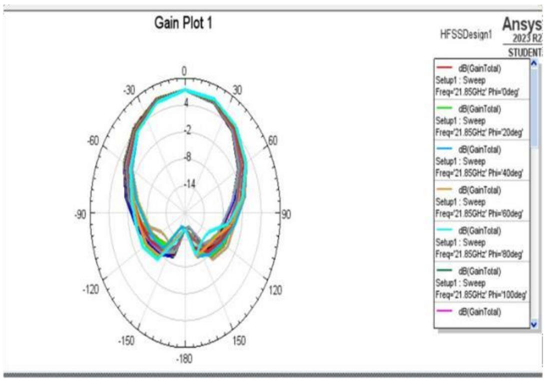


Fig 9a: Gain Plot of Teflon Circular Patch Antenna Design

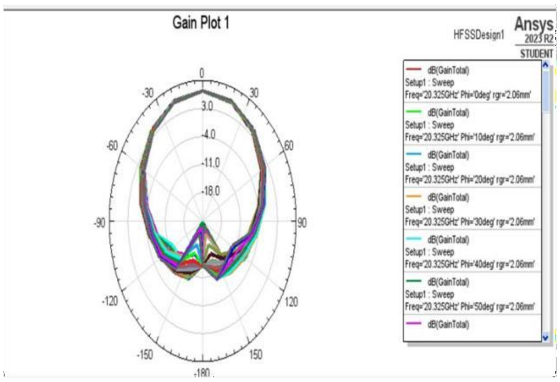


Fig 9b: Gain plot of Rogers RT/Duroid 5880 Circular Patch Antenna Design

Fig 4.6: Gain plots of Circular patch antennas

Fig. (9a, 9b) showcases the Gain graphs of the Teflon and Rogers RT/Duroid antennas for circular patch antennas. The gain values for the Teflon antenna and Rogers RT/Duroid antenna are 5.443 and 5.4776, respectively.

4.2.4 Directivity

Directivity is a fundamental parameter in antenna engineering that measures the ability of an antenna to focus electromagnetic radiation in a specific direction. It quantifies the concentration of radiated power in a particular direction relative to an isotropic radiator, which radiates power uniformly in all directions. Higher directivity values indicate more concentrated radiation in the desired direction, while lower values imply a broader radiation pattern.

Directivity is typically expressed in decibels (dB) and is calculated using the formula:

$$D = 10 * \log_{10}\left(\frac{4\pi * P_{total}}{P\_rad}\right)$$

Where:

- **D** is the directivity (in dB).

- P_{rad} is the radiated power in the desired direction.

- P_{total} is the total radiated power.

In antenna design and analysis, directivity provides valuable insights into the antenna's ability to concentrate radiation in a specific direction, making it crucial for applications such as long-distance communication, radar systems, and satellite communication. By optimizing directivity, engineers can enhance signal strength and coverage in targeted areas while minimizing interference in other directions.

Directivity quantifies the ability of an antenna to focus electromagnetic energy in a particular direction. Higher directivity values indicate increased radiation efficiency and signal concentration in the desired direction. Here's an analysis of directivity based on the comparison provided:

Rectangular (Teflon) Antenna:

- Peak Directivity: 4.491314
- The rectangular antenna fabricated on Teflon substrate achieves a peak directivity of approximately 4.491314. While slightly lower than the circular counterparts, this directivity value still signifies effective signal concentration and radiation efficiency in the desired direction.

Rectangular (Rogers 4003) Antenna:

- Peak Directivity: 0.565728
- The rectangular antenna fabricated on Rogers 4003 substrate demonstrates a peak directivity of approximately 0.565728. This lower directivity value indicates reduced radiation efficiency and signal concentration compared to the circular antennas, suggesting potential design optimizations for improved performance.

4. Directivity Plots

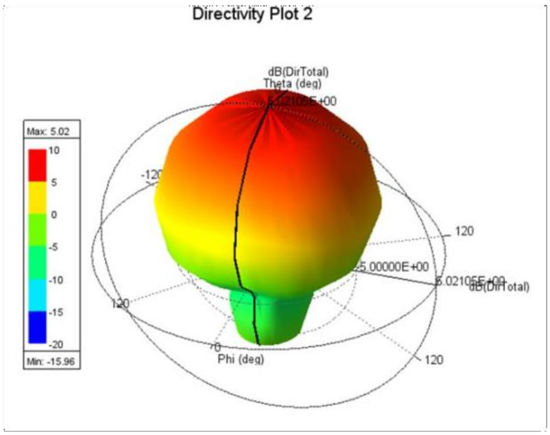


Fig 10a: Directivity Plot of Teflon Rectangular Patch Antenna Design

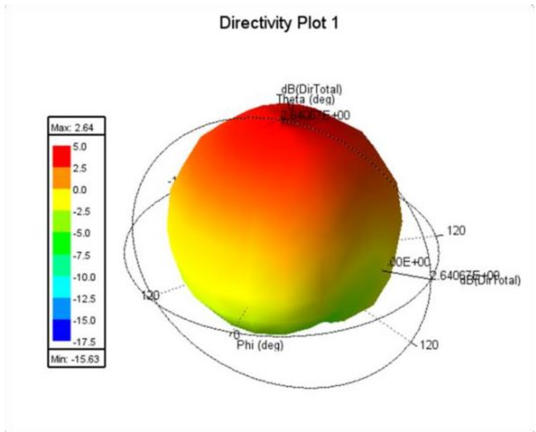


Fig 10b: Directivity Plot of Rogers 4003 Rectangular Patch Antenna Design

Fig 4.7: Directivity plots of Rectangular patch antennas

Fig. (10a, 10b) exhibits the Directivity graphs of the Teflon and Rogers RT/Duroid antennas for rectangular patch antennas. The directivity values for the Teflon antenna and Rogers RT/Duroid antenna are 4.491314 and 0.565728, respectively.

Circular (Teflon) Antenna:

- Peak Directivity: 5.569213
- The circular antenna fabricated on Teflon substrate demonstrates a peak directivity of approximately 5.569213. This indicates the antenna's ability to concentrate electromagnetic energy efficiently in a specific direction, contributing to improved signal strength and coverage.

Circular (Rogers RT/Duroid) Antenna:

- Peak Directivity: 5.579727
- The circular antenna fabricated on Rogers RT/Duroid substrate exhibits a peak directivity of approximately 5.579727. This higher directivity value suggests

enhanced radiation efficiency and signal concentration, making the antenna suitable for long-range communication applications.

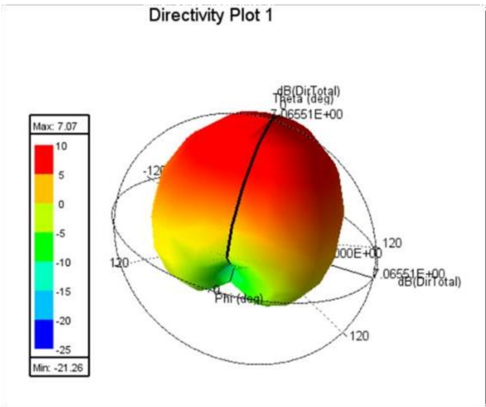


Fig 11a: Directivity Plot of Teflon Circular Patch Antenna Design

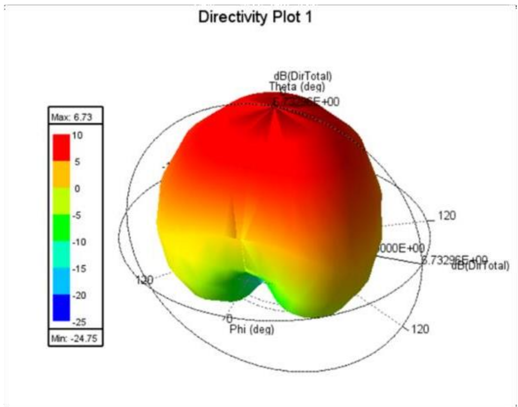


Fig 11b: Directivity Plot of Teflon Circular Patch Antenna Design

Fig 4.8: Directivity plots of Circular patch antennas

Fig. (11a, 11b) exhibits the Directivity graphs of the Teflon and Rogers RT/Duroid antennas for circular patch antennas. The directivity values for the Teflon antenna and Rogers RT/Duroid antenna are 5.569213 and 5.579727, respectively.

The analysis of directivity provides valuable insights into the radiation characteristics of the microstrip patch antennas at 25 GHz. Antennas with higher directivity values exhibit improved signal concentration and radiation efficiency, contributing to enhanced performance in long-range communication and high-demand applications.

CHAPTER 5
CONCLUSION

5.1 Summary

The project focuses on designing and testing patch antennas for 5G applications operating at 25 GHz. It begins by introducing the background and objectives, highlighting the importance of efficient antennas for 5G networks. Theoretical aspects of patch antenna design, substrate selection, and advanced techniques are explored.

Simulation tools are used to analyze antenna performance, considering factors like resonance frequency and radiation pattern. Practical experiments validate the simulated results, confirming the antennas' effectiveness.

Looking ahead, future research could explore advanced materials, AI-driven optimization, interdisciplinary collaboration, and next-generation communication technologies beyond 5G. Overall, the project lays a foundation for innovative advancements in wireless communication.

5.2 Conclusion

In conclusion, this project has investigated the design, simulation, and experimental validation of circular and rectangular patch antennas for 5G applications at 25 GHz. Through comprehensive literature review and theoretical analysis in Section 2, fundamental concepts of patch antennas were explored, including design considerations for optimizing performance in 5G communication systems. The selection of appropriate substrate materials, antenna dimensions, and advanced techniques for antenna enhancement were discussed to achieve the desired specifications for 5G patch antennas.

Section 3 delved into the simulation process using advanced tools and methodologies to analyze the performance of the designed antennas. By leveraging electromagnetic simulation software, the resonance frequency, bandwidth, radiation pattern, and impedance matching of the antennas were evaluated. The simulation results provided valuable insights into the expected performance characteristics of the antennas, guiding the design process and parameter optimization.

The experimental setup and results presented in Section 4 validated the simulated performance of the antennas through practical testing. Performance evaluation metrics such as return loss, VSWR, directivity, and gain were measured to assess the antennas' effectiveness in real-world scenarios. The comparison of experimental results with simulation data confirmed the accuracy of the design and simulation methodologies employed in this project.

Moving forward, the insights gained from this research can be leveraged to further optimize the design of patch antennas for 5G applications, considering factors such as antenna size, bandwidth, and efficiency. Future work may focus on exploring novel materials, advanced fabrication techniques, and innovative antenna configurations to push the boundaries of performance and meet the evolving demands of 5G communication systems.

In conclusion, this project contributes to the advancement of antenna technology for 5G networks, laying the foundation for enhanced wireless connectivity and enabling the realization of next-generation communication systems.

5.3 Future Scope

The project on designing and validating patch antennas for 5G applications at 25 GHz marks a crucial step towards next-generation wireless communication. Looking ahead, the project presents a myriad of opportunities for innovative research and development, paving the way for groundbreaking advancements in antenna technology.

One avenue for future exploration lies in the realm of metamaterials and advanced fabrication techniques. By harnessing the unique electromagnetic properties of metamaterials and leveraging state-of-the-art fabrication methods such as 3D printing and nanotechnology, researchers can push the boundaries of antenna performance. This could lead to the development of ultra-compact, high-efficiency antennas capable of supporting unprecedented data rates and connectivity in 5G networks.

Furthermore, the project opens doors for the integration of artificial intelligence (AI) and machine learning (ML) techniques in antenna design and optimization. By employing AI algorithms to autonomously explore vast design spaces and ML models to predict antenna performance under different operating conditions, researchers can accelerate the design process and unlock new insights into antenna behavior. This fusion of AI and antenna engineering has the potential to revolutionize how antennas are conceptualized, designed, and deployed in future communication systems.

Moreover, the project serves as a catalyst for interdisciplinary collaboration, bringing together experts from diverse fields such as materials science, signal processing, and network architecture. By fostering interdisciplinary partnerships, future research endeavors can tackle complex challenges at the intersection of technology and society, such as ensuring equitable access to high-speed connectivity, mitigating electromagnetic interference, and addressing environmental sustainability concerns in wireless infrastructure deployment.

In addition, the project lays the groundwork for exploring beyond-5G (B5G) and 6G communication technologies, which are poised to redefine the future of wireless connectivity. Future research could focus on developing innovative antenna architectures capable of supporting B5G and 6G requirements, including ultra-massive MIMO, terahertz communication, and quantum communication-enabled antennas. These cutting-edge technologies promise to unlock unprecedented levels of data throughput, ultra-low latency, and seamless connectivity, revolutionizing how we interact with the digital world.

5.4 Applications

The patch antennas designed for 5G applications at 25 GHz have a wide range of practical uses across different fields. Here's a simple and concise overview of their applications:

1. High-Speed Wireless Networks: These antennas enable fast and reliable data transmission in 5G networks, supporting applications like video streaming and online gaming.
2. Mobile Devices: They ensure strong connectivity in smartphones and tablets, allowing users to access high-speed internet on the go.
3. Automotive Communication: Used in cars for features like GPS navigation and emergency communication, enhancing road safety.
4. Satellite Communication: Facilitating long-distance communication for global internet access, weather monitoring, and navigation services.
5. Defense Systems: Utilized in military vehicles and aircraft for communication and surveillance purposes.
6. Healthcare Devices: Integrated into medical devices for remote patient monitoring and telemedicine applications.
7. Smart Infrastructure: Supporting smart grid systems, environmental monitoring, and industrial automation.
8. Industrial IoT: Enabling wireless sensor networks for asset tracking and predictive maintenance in factories and warehouses.

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Appendix

1. Technical Specifications:

1.1 Circular Patch Antenna (Teflon Substrate):

- Dimensions: Radius = 2.4 mm
- Substrate Material: Teflon (εr = 2.1)
- Operating Frequency: 21.85 GHz
- Feed Dimensions: 5 x 0.4 mm
- Substrate Dimensions: 10 x 10 x 0.8 mm

1.2 Circular Patch Antenna (Rogers RT/Duroid 5880 Substrate):

- Dimensions: Radius = 2.4 mm
- Substrate Material: Rogers RT/Duroid 5880 (εr = 2.2)
- Operating Frequency: 20.85 GHz
- Feed Dimensions: 5 x 0.4 mm
- Substrate Dimensions: 10 x 10 x 0.8 mm

1.3 Rectangular Patch Antenna (Teflon Substrate):

- Dimensions: 3.57 x 4.82 mm
- Substrate Material: Teflon (εr = 2.1)
- Operating Frequency: 23.8 GHz
- Feed Dimensions: 3 x 0.3 mm
- Substrate Dimensions: 6 x 6 x 0.8 mm

1.4 Rectangular Patch Antenna (Rogers 4003 Substrate):

- Dimensions: 2.76 x 3.97 mm
- Substrate Material: Rogers 4003 (εr = 3.55)
- Operating Frequency: 34.5 GHz
- Feed Dimensions: 3 x 0.3 mm
- Substrate Dimensions: 6 x 6 x 0.8 mm

2. Simulation Setup:

2.1 Software: ANSYS HFSS (High-Frequency Structural Simulator) 2.2 Simulation Parameters:

- Frequency Range: 20 GHz to 35 GHz
- Mesh Density: Fine
- Solver Type: Finite Element Method (FEM)
- Boundary Conditions: Perfect Electric Conductor (PEC)

3. Experimental Procedures:

3.1 Experimental Setup:

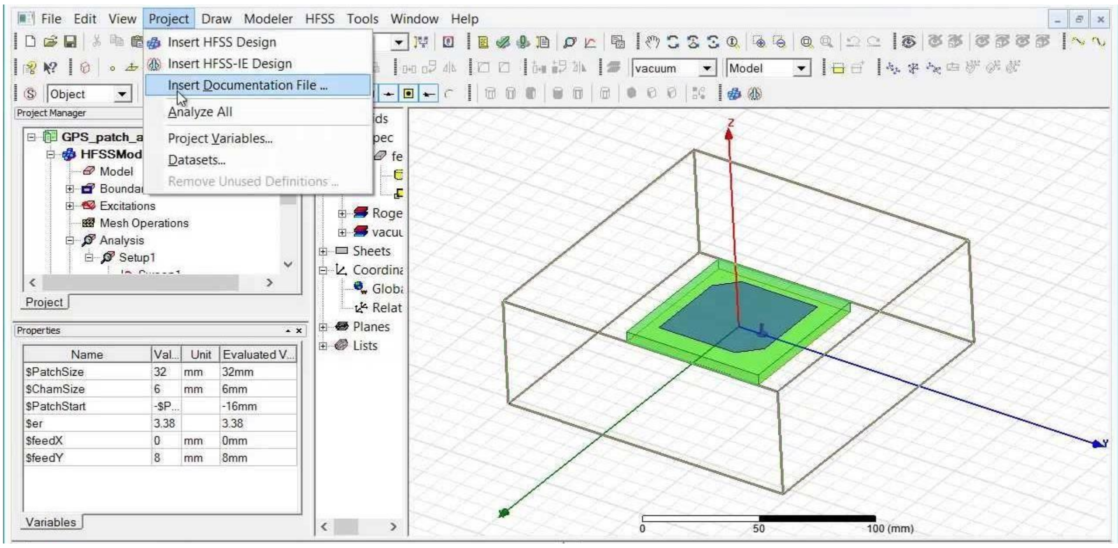
- Vector Network Analyzer (VNA) used for measurements
- Anechoic chamber for RF measurements

- Coaxial cables and adapters for connecting antennas to VNA

3.2 Measurement Techniques:

- Return loss and VSWR measured using VNA
- Radiation patterns measured using an anechoic chamber
- Directivity and gain calculations based on measured data

4. Additional Figures:



4.1 Figure 1: Simulation Setup in ANSYS HFSS

PROJECT OUTCOMES MAPPED WITH PROGRAMME SPECIFIC OUTCOMES (PSOs) AND PROGRAMME OUTCOMES (POs)

	Application	Product	Research	Review
Classification of Project	✓		✓	

PROJECT OUTCOMES

1. Successfully designed and simulated of circular and rectangular microstrip patch antennas using Teflon & Rogers substrates for 5g applications at 25ghz.

PROGRAMME SPECIFIC OUTCOMES (PSOs)

The ECE Graduates will be able to

1. Analyzing specific engineering problem relevant to Electronics and Communication Engineering by applying the knowledge of basic sciences, engineering mathematics.
2. Designing electrical, electronics and communication systems in the domains of VLSI, embedded systems, signal processing and RF communications and applying modern tools.

PROGRAMME OUTCOMES (POs)

The ECE Graduates will be able to

1. **Engineering Knowledge:** Apply the knowledge of mathematics, science, engineering fundamentals, and an engineering specialization to the solution of complex engineering problems.
2. **Problem Analysis:** Identify, formulate, review research literature, and analyze complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences and engineering sciences.
3. **Design/development of solutions:** Design solutions for complex engineering problems and design system components or processes that meet the specified needs with appropriate consideration for the public health and safety, and the cultural, societal, and environmental consideration.

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4. **Conduct investigations of complex problems:** Use research-based knowledge and research methods including design of experiments, analysis and interpretation of data, and synthesis of the information to provide valid conclusions.
5. **Modern tool Usage:** Create, Select, and apply appropriate techniques, resources, and modern engineering and IT tools including prediction and modelling to complex engineering activities with an understanding of the limitations.
6. **The engineer and society:** Apply reasoning informed by the contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to the professional engineering practice.
7. **Environment and sustainability:** Understand the impact of the professional engineering solutions in societal and environmental contexts, and demonstrate the knowledge of, and need for sustainable development.
8. **Ethics:** Apply ethical principles and commit to professional ethics and responsibilities and norms of the engineering practice.
9. **Individual and team work:** Function effectively as an individual, and as a member or leader in diverse teams, and in multidisciplinary settings.
10. **Communication:** Communicate effectively on complex engineering activities with the engineering community and with the society at large, such as, being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions.
11. **Project management and finance:** Demonstrate knowledge and understanding of the engineering and management principles and apply these to one's own work, as a member and leader in a team, to manage projects and in multidisciplinary environments.
12. **Life-long learning:** Recognize the need for, and have the preparation and ability to engage in independent and life-long learning in the broadest context of technological change.

Mapping Table

Project Outcomes	**Programme Outcomes(POs)**												**PSOs**	
	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2
Outcome 1		1	3	2	3	1			2	3	2	3	2	3
Outcome 2	2				3		1	1				2		2

1-Slightly (Low) mapped 2-Moderately (Medium) mapped 3-Substantially (High)