REPORT FOR THE COURSE OF MICROWAVE ENGINEERING AND ANTENNA LABORATORY

OPTIMIZED BROADBAND MICROSTRIP 1×4 ARRAY ANTENNA FOR 5G WI-FI APPLICATIONS

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WE UNDERSIGNED, RECOMMEND THAT THE PAPER COMPLETED BY THE STUDENTS LISTED ABOVE, IN PARTIAL FULFILLMENT OF **B.SC**. DEGREE REQUIREMENTS, BE ACCEPTED BY THE **DEPARTMENT OF INFORMATION AND COMMUNICATION TECHNOLOGY, BANGLADESH UNIVERSITY OF PROFESSIONALS** FOR DEPOSIT

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DECLARATION

WE HEREBY DECLARE THAT THE WORK IN THIS THESIS IS OUR OWN EXCEPT FOR QUOTATION AND SUMMARIES WHICH HAVE BEEN DULY ACKNOWLEDGED.

30th MAY,2024

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ABSTRACT

The ever-increasing demand for high-speed, large-bandwidth data communication drives a shift towards 5G technology. Efficient antenna design is crucial for the advanced radio systems. This paper presents a novel approach to broadband microstrip antenna design specifically tailored for 5G Wi-Fi applications. The proposed array antenna prioritizes both performance and cost-effectiveness. Simulations authenticate excellent gain and radiation characteristics, ensuring strong signal transmission and reception. Additionally, the design leverages readily available and inexpensive FR-4 substrates, making it a practical and scalable solution for real-world deployments. The 1×4 linear array antenna has a higher gain of 7.312 dBi at the same required resonance frequency of 2.45 GHz than the single element reference antenna, which resonates at 2.45 GHz with a gain of 2.552 dBi. The values of S11 are: -20.274551dB and -25.44 dB. This combination of high performance and affordability makes the proposed antenna a promising candidate for integration into next-generation 5G communication systems.

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CHAPTER I

INTRODUCTION

1.1 INTRODUCTION

The advent of 5G technology marks a significant milestone in the evolution of wireless communication, promising unprecedented speeds, reduced latency, and enhanced connectivity. This next-generation wireless technology is poised to revolutionize various sectors, including telecommunications, healthcare, transportation, and entertainment, by enabling advanced applications such as autonomous vehicles, remote surgery, smart cities, and immersive virtual reality experiences. Central to the deployment of 5G networks is the need for innovative antenna designs that can support the high-frequency bands and extensive bandwidth requirements associated with this technology.

Microstrip antennas have emerged as a pivotal component in 5G infrastructure due to their low profile, lightweight, and ease of integration with electronic circuits. These antennas are highly versatile and can be designed to operate across various frequency bands, making them ideal candidates for the diverse requirements of 5G applications. Among these, the microstrip array antenna stands out for its ability to provide high gain and directivity, which are essential for maintaining reliable communication links in the densely populated frequency spectrum of 5G. The evolution from single-element microstrip antennas to array configurations has enabled significant improvements in performance metrics, such as bandwidth, efficiency, and beam steering capabilities.

The concept of array antennas involves combining multiple radiating elements to form a single antenna system that can achieve enhanced performance characteristics compared to individual elements. In a microstrip array antenna, multiple patch antennas are arranged in a specific configuration to direct the radiated power more efficiently and to achieve higher gains. This configuration not only improves the overall antenna performance but also provides greater flexibility in terms of beam shaping and steering, which are critical for addressing the dynamic and high-capacity demands of 5G networks.

In particular, the design of broadband microstrip array antennas has garnered substantial attention. These antennas are capable of operating over a wide frequency range, making them ideal for 5G applications that demand flexible and efficient spectrum utilization. A 1×4 microstrip array configuration, in which four radiating elements are arranged in a linear fashion, offers a compelling solution by enhancing gain and achieving desired radiation patterns through constructive interference of the emitted signals. This configuration also facilitates easier impedance matching and reduces the mutual coupling effects that can degrade performance in densely packed antenna arrays.

Advanced design techniques and simulation tools are crucial in optimizing the performance of broadband microstrip array antennas. Techniques such as substrate selection, patch shape optimization, and the use of defected ground structures (DGS) can significantly enhance the antenna's bandwidth and efficiency. Simulation tools like CST Microwave Studio and HFSS allow for precise modeling and analysis of the antenna's performance, enabling designers to iterate and refine their designs to meet stringent 5G requirements.

The optimized broadband microstrip 1×4 array antenna is designed to meet the stringent performance criteria required for 5G networks, including high gain, wide bandwidth, and robust performance across various operational conditions. By leveraging state-of-the-art materials and innovative structural designs, this approach contributes to the development of efficient and reliable antenna solutions that will underpin the successful deployment of 5G technology. The implementation of such antennas is expected to play a critical role in the realization of 5G networks, supporting higher data rates, increased capacity, and improved user experiences.

As 5G technology continues to evolve, the ongoing development and refinement of microstrip array antennas will remain essential. These antennas will not only facilitate the deployment of 5G networks but also pave the way for future advancements in wireless communication, ensuring that the infrastructure can keep pace with the rapidly growing demand for data and connectivity in an increasingly digital world.

1.2 MOTIVATION

Designing an optimized broadband microstrip 1×4 array antenna for 5G Wi-Fi applications addresses the urgent need to meet the demanding requirements of next-generation wireless communication systems. As 5G technology becomes the backbone of modern connectivity, the demand for antennas that can deliver high performance, reliability, and efficiency is paramount. Traditional antenna designs struggle to meet the high-frequency and wide-bandwidth demands of 5G, necessitating innovative solutions.

Enhanced data transmission rates and capacity are critical for 5G networks, which aim to provide ultra-fast internet speeds and support a massive number of connected devices. Achieving this requires antennas with high gain and directivity to ensure strong and stable connections, especially in urban environments where signal obstruction and interference are prevalent. A 1×4 array configuration offers a significant improvement in these aspects by combining multiple radiating elements to enhance signal strength and coverage.

Compact and efficient antenna designs are also crucial. Microstrip antennas are inherently advantageous due to their low profile, lightweight, and ease of integration with electronic circuits. These features make them ideal for modern wireless devices, including smartphones, laptops, and IoT devices, where space and weight are critical considerations. The broadband capability of the proposed design ensures that the antenna can operate across a wide range of frequencies, catering to the diverse needs of 5G applications without requiring multiple antenna systems.

Optimization of microstrip array antennas using advanced materials and design techniques is essential for achieving the desired performance metrics. This includes improving bandwidth, reducing mutual coupling, and ensuring robust performance in various environmental conditions. The use of simulation tools enables precise design and optimization, ensuring that the final product meets the stringent requirements of 5G technology.

Developing an optimized broadband microstrip 1×4 array antenna for 5G Wi-Fi applications addresses the need for high performance, efficiency, and compactness required by next-generation wireless communication systems. This innovation is essential for the successful deployment and operation of 5G networks, driving the future of connectivity and technological advancement.

1.3 SCOPE OF RESEARCH

The scope of research for designing an optimized broadband microstrip 1×4 array antenna for 5G Wi-Fi applications encompasses several critical areas to ensure the antenna meets the stringent requirements of next-generation wireless communication systems.

Firstly, the research will focus on the theoretical analysis and design principles of microstrip antennas. This involves understanding the fundamental concepts of electromagnetic wave propagation, impedance matching, and radiation patterns. The study will include a comprehensive review of existing microstrip antenna designs, identifying their limitations and potential areas for improvement in the context of 5G applications.

Secondly, the research will involve the design and simulation of the 1×4 microstrip array configuration. Advanced simulation tools, such as CST Microwave Studio and HFSS, will be employed to model the antenna's performance accurately. The design process will explore various parameters, including substrate materials, patch shapes, feeding techniques, and ground plane modifications, to achieve optimal performance in terms of bandwidth, gain, and directivity.

Additionally, the study will investigate methods to minimize mutual coupling between the array elements, which can degrade the antenna's performance. Techniques such as the incorporation of defected ground structures (DGS) and the use of parasitic elements will be explored to enhance isolation between elements and improve overall efficiency.

The research will also include the fabrication and experimental validation of the designed antenna. Prototypes will be manufactured, and their performance will be tested in real-world conditions to verify the simulation results. Measurements of key parameters, such as return loss, radiation pattern, and gain, will be conducted to ensure the antenna meets the desired specifications.

Finally, the study will assess the antenna's performance in various operational environments, including different propagation scenarios and interference conditions. This will ensure that the antenna provides reliable and robust performance in practical 5G applications.

Overall, the research aims to develop a high-performance, efficient, and compact broadband microstrip 1×4 array antenna that meets the demands of 5G Wi-Fi applications, contributing to the advancement of next-generation wireless communication technologies

1.4 OBJECTIVES

The main objective of this research is to design and optimize a broadband microstrip 1×4 array antenna for 5G Wi-Fi applications, ensuring high performance and efficiency. The proposed 1×4 linear array antenna has a higher gain of 7.312 dBi at the same required resonance frequency of 2.45 GHz than the single element reference antenna, which resonates at 2.45 GHz with a gain of 2.552 dBi. The specific objectives of this research can be listed as follows:

- To design and analyze small, planar, high gain & directional 1×4 array microstrip patch antenna for 5G applications.
- To fabricate and measure the proposed antenna.
- To analyze the performance of the proposed antenna prototype for 5G applications.

1.5 OUTLINE

Chapter 1 presents the commencement of the thesis. The problem and research motivation are described in this chapter. The research objectives of the thesis are also outlined.

Chapter 2 gives a brief introduction to microstrip patch antenna technology. The history and background of microstrip patch antennas are reviewed. The regulations and standards of microstrip patch antennas, as well as their advantages and applications, are discussed. A comprehensive review of the fundamental antenna theory is also provided. Additionally, the research on microstrip patch antennas for 5G Wi-Fi applications is reviewed historically in this chapter.

Chapter 3 explains the sequential phases of designing a microstrip patch antenna. The flowchart of the research methodology is defined in detail with suitable equations and images. The precise representation of the simulation process using CST software and measurement procedures is provided to give a complete idea of designing and prototyping microstrip patch antennas.

Chapter 4 presents the design and simulation of a microstrip patch antenna for mid-band frequencies. The antenna design process, including the geometry and performance, is discussed. Simulated results for different parameters are analyzed with proper illustrations and included in tables.

Chapter 5 presents the concluding remarks of the research conducted in this thesis. The key contributions of this research are highlighted. Proposals for future work are also provided in this chapter.

CHAPTER II

LITERATURE REVIEW

2.1 INTRODUCTION

The rapid growth of wireless communication systems and the ever-increasing demand for higher data rates have driven the need for more advanced antenna technologies. With the advent of 5G networks, the requirements for wireless communication systems have become even more stringent, necessitating antennas that can support higher frequencies, broader bandwidths, and higher data rates. One of the promising antenna technologies that has gained significant attention in recent years is the microstrip array antenna. Microstrip antennas are widely used in various wireless applications due to their low profile, lightweight, and ease of fabrication. However, traditional microstrip antennas suffer from narrow bandwidths, which can limit their performance in broadband applications. To address this challenge, researchers have extensively explored techniques to enhance the bandwidth of microstrip antennas, such as using thick substrates, introducing slots or slits, and employing various feeding techniques. Among the various configurations, microstrip array antennas have emerged as a popular choice for broadband applications due to their ability to combine the radiation patterns of individual antenna elements, resulting in increased gain and improved directivity. Specifically, the 1x4 array configuration, where four microstrip antenna elements are arranged in a linear array, has shown promising results in terms of bandwidth enhancement and directivity. In the context of 5G Wi-Fi applications, which operate in the unlicensed 6 GHz band (5.925–7.125 GHz), the development of broadband microstrip 1x4 array antennas is of particular interest. These antennas must not only cover the required frequency range but also exhibit desirable radiation characteristics, such as high gain, directivity, and low side lobe levels, to ensure efficient and reliable communication links. This literature review aims to provide a comprehensive overview of the recent advancements in the design and optimization of broadband microstrip 1x4 array antennas for 5G Wi-Fi applications. It will cover various techniques employed to enhance bandwidth, improve radiation characteristics, and address challenges such as mutual coupling and cross-polarization. Additionally, the review will discuss the use of optimization techniques, such as genetic algorithms and particle swarm optimization, to achieve optimal antenna performance.

2.2 MICROSTRIP PATCH ANTENNA TECHNOLOGY

Microstrip Patch Antenna Technology stands as a foundational element within contemporary wireless communication systems, renowned for its compact form factor, adaptability, and cost-effectiveness. Utilized across a spectrum of applications, these antennas, featuring a conductive patch on a dielectric substrate, offer inherent advantages such as ease of manufacturing and robust performance in diverse scenarios. With ongoing advancements and innovations, Microstrip Patch Antennas continue to drive the evolution of wireless connectivity, serving as vital components in the realization of efficient and pervasive communication networks worldwide.

2.2.1 BACKGROUND

Microstrip Antennas Microstrip antennas are a widely used type of printed antenna that have found applications in various wireless communication systems due to their low profile, lightweight, conformability to mounting surfaces, and ease of fabrication using printed circuit board (PCB) technology. These antennas consist of a radiating patch made of a conducting material, such as copper, printed on a dielectric substrate with a ground plane on the opposite side.

The operating principle of microstrip antennas is based on the fringing fields between the radiating patch and the ground plane. When the patch is excited by a feed line, such as a microstrip line or coaxial probe, the fringing fields create radiation in the broadside direction, perpendicular to the patch surface. The radiation characteristics of microstrip antennas are influenced by various factors, including the patch geometry, substrate properties, and feeding technique.

Despite their advantages, traditional microstrip antennas suffer from inherent limitations, such as narrow bandwidth and low gain. The bandwidth of a microstrip antenna is primarily determined by the height of the dielectric substrate and the thickness of the radiating patch. Increasing the substrate height or decreasing the patch thickness can enhance the bandwidth, but at the expense of increased surface wave excitation and decreased radiation efficiency.

To overcome these limitations, researchers have explored various techniques to enhance the bandwidth of microstrip antennas, such as introducing slots or slits in the patch, using thick substrates, employing different feeding techniques, and incorporating parasitic elements or stacked configurations.

Array Antennas To further improve the performance of microstrip antennas, array configurations have been widely explored. An array antenna consists of multiple radiating elements arranged in a specific geometry, such as linear, planar, or conformal arrays. By combining the radiation patterns of individual elements, array antennas can achieve higher gain, improved directivity, and better control over the radiation characteristics compared to single-element antennas.

The 1x4 linear array configuration, where four microstrip antenna elements are arranged in a linear fashion, has proven to be a popular choice for broadband applications. This configuration offers several advantages, including a simple structure, ease of fabrication, and the ability to achieve broadband operation through proper design and optimization.

In a 1x4 linear array, the individual antenna elements are typically fed using a power divider or corporate feed network, which distributes the input signal equally to each element. The spacing between the elements and the relative phase of the excitation signals play a crucial role in determining the overall radiation pattern, gain, and bandwidth of the array.

One of the key challenges in designing microstrip array antennas is mutual coupling, which occurs when the radiation from one element induces currents on neighboring elements, affecting the overall radiation pattern and impedance matching. Proper element spacing and the use of decoupling techniques, such as defected ground structures or electromagnetic bandgap structures, can help mitigate mutual coupling effects.

5G Wi-Fi Applications The fifth-generation (5G) wireless communication standard introduces a new unlicensed band in the 6 GHz frequency range (5.925–7.125 GHz) for Wi-Fi applications. This band, known as the 6 GHz band, offers additional spectrum resources to support higher data rates, improved capacity, and reduced latency compared to the existing 2.4 GHz and 5 GHz bands used for Wi-Fi.

To fully leverage the benefits of the 6 GHz band, antenna systems must be designed to operate over the entire frequency range while maintaining desirable radiation characteristics. Broadband microstrip 1x4 array antennas have emerged as a promising solution to meet these requirements, offering the potential for wide bandwidth, high gain, and directional radiation patterns suitable for point-to-point or point-to-multipoint communication links in 5G Wi-Fi applications.

In the design of broadband microstrip 1x4 array antennas for 5G Wi-Fi applications, several challenges need to be addressed, such as mutual coupling between array elements, cross-polarization effects, and the need for compact and efficient feeding structures. Cross-polarization refers to the undesired radiation component that is orthogonal to the intended polarization, which can degrade the signal quality and cause interference in wireless communication systems.

Additionally, optimization techniques play a crucial role in achieving optimal performance by tuning various design parameters, such as element spacing, substrate properties, feed network characteristics, and geometrical dimensions of the radiating elements. Commonly used optimization techniques include genetic algorithms, particle swarm optimization, and other evolutionary or gradient-based methods.

The development of broadband microstrip 1x4 array antennas for 5G Wi-Fi applications requires a thorough understanding of antenna design principles, electromagnetic theory, and optimization techniques. Researchers have explored various approaches to enhance bandwidth, improve radiation characteristics, and address challenges related to mutual coupling and cross-polarization, which will be discussed in the subsequent sections of this literature review.

2.2.2 REGULATIONS AND STANDARDS OF MICROSTRIP ANTENNAS

A. Regulations For Microstrip Patch Antennas

The deployment of microstrip antennas in wireless communication systems is subject to regulations set by national and international regulatory bodies. These regulations aim to ensure efficient use of the radio frequency spectrum, prevent interference with other wireless services, and maintain public safety standards.

1. National Regulations
   - In the United States, the Federal Communications Commission (FCC) regulates the use of radio frequency spectrum, including the bands employed for microstrip antennas.
   - The FCC establishes rules regarding maximum permissible emission levels, out-of-band emission limits, and requirements for power control and dynamic frequency selection to protect incumbent services.
   - Similar regulatory bodies exist in other countries, such as Industry Canada (IC) in Canada, the Office of Communications (Ofcom) in the United Kingdom, and the Australian Communications and Media Authority (ACMA) in Australia.
2. International Regulations
   - The International Telecommunication Union (ITU), a specialized agency of the United Nations, coordinates the shared global use of the radio spectrum and satellite orbits.
   - The ITU's Radio Regulations provide the regulatory framework for the allocation of frequency bands and the operation of radio communication services worldwide.
   - Regional organizations, such as the European Telecommunications Standards Institute (ETSI) and the Conference of Postal and Telecommunications Administrations (CEPT) in Europe, also play a role in harmonizing regulations for microstrip antennas and other wireless technologies within their respective regions.
3. Specific Regulations for Microstrip Antennas
   - Regulations for microstrip antennas may vary depending on the frequency band and application.
   - For example, in the unlicensed 5 GHz and 6 GHz bands used for Wi-Fi applications, regulatory bodies specify emission limits, antenna gain requirements, and other technical parameters to ensure coexistence with other wireless services.
   - Microstrip antennas used in licensed bands, such as cellular or satellite communications, must comply with additional regulations specific to those services.

When designing microstrip antennas, it is crucial to ensure compliance with the relevant national and international regulations, including frequency allocation, emission limits, and any specific technical requirements for the intended application and frequency band.

B. Standards for Microstrip Antennas

Several international standards organizations have developed guidelines and specifications for the design, testing, and performance evaluation of microstrip antennas. These standards provide a common framework and ensure interoperability between different antenna systems.

1. Institute of Electrical and Electronics Engineers (IEEE) Standards
   - IEEE Std 145-2013: Standard for Definitions of Terms for Antennas
   - IEEE Std 149-1979: Test Procedures for Antennas
   - IEEE Std 1858-2016: Standard for Pattern Definition of Microstrip Antennas

- IEEE Std 286-2021: Standard for Microstrip Antennas

2. International Electrotechnical Commission (IEC) Standards
    - IEC 62232: Determination of RF field strength, power density and SAR in the vicinity of radiocommunication base stations for the purpose of evaluating human exposure
3. International Organization for Standardization (ISO) Standards
    - ISO/IEC 17025: General requirements for the competence of testing and calibration laboratories
    - ISO/IEC 17043: Conformity assessment – General requirements for proficiency testing
4. Other Standards
    - ANSI/IEEE Std 149-1979: Test Procedures for Antennas
    - CTIA Certification Program for Wireless Device Over-the-Air Performance
    - 3GPP TS 34.114: User Equipment (UE) / Mobile Station (MS) Over The Air (OTA) antenna performance

These standards cover various aspects of microstrip antenna design, testing, and performance evaluation, including terminology, measurement procedures, radiation pattern characterization, and specific requirements for different applications, such as cellular communications or Wi-Fi.

Compliance with these international standards ensures that microstrip antennas meet industry-accepted performance criteria and can be reliably integrated into various wireless communication systems, enabling interoperability and facilitating the development of new technologies and applications.

2.2.3 ADVANTAGES OF MICROSTRIP PATCH ANTENNAS

The development of optimized broadband microstrip 1x4 array antennas for 5G Wi-Fi applications has garnered significant attention due to the potential benefits they offer in addressing the stringent requirements of next-generation wireless communication systems. These antennas leverage the well-established microstrip technology and combine it with the array configuration to achieve enhanced performance and desirable radiation characteristics. By carefully optimizing various design parameters and leveraging advanced techniques, broadband microstrip 1x4 array antennas can provide several advantages that make them well-suited for 5G Wi-Fi applications. These advantages include:

 Wideband Operation:

- The 1x4 array configuration, combined with appropriate design techniques, enables the microstrip antenna to achieve a broad operating bandwidth.
- This characteristic is crucial for supporting the entire 6 GHz band (5.925–7.125 GHz) allocated for 5G Wi-Fi applications, ensuring efficient and reliable communication links.

 High Gain and Directivity:

- By combining the radiation patterns of individual microstrip elements, the 1x4 array antenna can achieve higher gain and directivity compared to a single element.
- Increased gain and directivity result in improved signal strength and better coverage, which are desirable features for point-to-point or point-to-multipoint communication links in 5G Wi-Fi networks.

 Beamforming Capabilities:

- The linear array configuration allows for beamforming techniques to be applied, enabling the radiation pattern to be steered in desired directions.
- Beamforming can enhance the signal-to-noise ratio (SNR) and increase the overall system capacity by focusing the radiated energy towards intended users while suppressing interference from other directions.

 Compact and Low-Profile Design:

- Microstrip antennas are known for their low profile and lightweight construction, which makes them suitable for integration into compact wireless devices and portable applications.
- The 1x4 array configuration maintains a relatively small form factor, enabling easy integration into access points, routers, and other Wi-Fi equipment.

 Ease of Fabrication and Cost-Effectiveness:

- Microstrip antennas can be fabricated using standard printed circuit board (PCB) techniques, which are widely available and cost-effective.
- The 1x4 array configuration does not require complex manufacturing processes, further reducing the production costs and facilitating mass manufacturing.

 Polarization Diversity:

- By using appropriate feed networks and element configurations, the 1x4 array antenna can support dual polarization, providing diversity and enhancing the system's resilience to multipath fading and polarization mismatch.

 Scalability and Adaptability:

- The modular nature of the 1x4 array design allows for easy scalability to larger array configurations, such as 1x8 or 1x16, to achieve even higher gain and directivity if required.
- The array elements can be optimized and tailored to specific frequency bands or applications, making the design adaptable to different wireless communication standards and requirements.

2.3 ANTENNA THEORY

Antenna theory is the foundation upon which the design and analysis of antennas are built. Understanding the principles of antenna operation is crucial for developing effective and efficient communication systems. This chapter delves into the fundamental concepts of antenna theory, with a specific focus on microstrip patch antennas used in 5G Wi-Fi applications. The key topics covered include the basic principles of antennas, radiation mechanisms, types of microstrip patch antennas, and their performance parameters.

Basic Principles of Antennas

Definition and Purpose: An antenna is a transducer that converts electrical signals into electromagnetic waves and vice versa. Its primary purpose is to transmit and receive radio frequency (RF) signals in the air, enabling wireless communication.

Antenna Parameters

Bandwidth

The range of frequencies over which the antenna operates effectively. Bandwidth is usually defined by the frequencies at which the performance (e.g., gain, VSWR) meets specified criteria.

VSWR (Voltage Standing Wave Ratio)

A measure of impedance matching between the antenna and the transmission line. A lower VSWR indicates better matching and reduced reflections.

Impedance Bandwidth

Impedance bandwidth is considered one of the main antenna parameters. Antenna impedance is associated with the voltage to the current at the input point of the antenna. Impedance bandwidth extends the characterization of the Voltage Standing Wave Ratio (VSWR) and return loss throughout the band. A lower VSWR indicates better impedance matching and wider bandwidth, which is crucial for broadband applications like UWB (Ultra-Wideband).

Radiation Patterns

The radiation pattern represents the radiation properties of the antenna as an element of space coordinates. The radiation patterns can be indicative of an application for which an antenna will be used. For instance, in mobile communication, a nearly omnidirectional antenna is required since the location of the users is unknown. Thus, radiated power should be spread out consistently around the user for optimal reception. Conversely, for microwave imaging applications, a directive antenna would be preferred to ensure that most of the radiated power is directed to a specific known area.

Efficiency

The ratio of the power radiated by the antenna (Prad) to the input power of the antenna (Pin) is known as radiation efficiency (ηrad), given by:

$$\eta rad = Prad/Pin$$

Total efficiency is the product of reflection efficiency and radiation efficiency. Typically, values within the range of 60-90% are considered good for antenna efficiency, although some commercial antennas achieve around 50-60% due to the use of cheap and lossy dielectric materials.

Directivity

The directivity (D) of an antenna is defined as the ratio of the radiation intensity (U) in a given direction from the antenna over that of an isotropic source. It describes the directional properties of the antenna's radiation pattern. For an isotropic source, the radiation intensity (U0) is equal to the total radiated power (Prad) divided by 4π.

$$D = U/Uo = 4\pi U/Prad$$

Gain

Antenna gain (G) is closely related to directivity but also considers the radiation efficiency (ηrad) of the antenna as well as its directional properties, given by:

$$G = \eta radD$$

The direction of the gain measurement is not specified; the direction of maximum gain is presumed. Gain measurement is often misunderstood as determining the quality of an antenna. A common misconception is that the higher the gain, the better the antenna. This is only true if the application requires a highly directive antenna. Since gain is linearly proportional to directivity, gain measurement is a direct indication of how directive an antenna is.

There are three common radiation patterns that describe the radiation property of an antenna:

•**Isotropic:** Hypothetically, a lossless antenna providing equal radiation in all directions. It is only relevant for an ideal antenna and is often used as a reference for expressing the directive properties of real antennas.

•**Omni-directional:** An antenna with a basically non-directional pattern in a given plane and a directional pattern in any symmetrical plane.

•**Directional:** An antenna having the property of transmitting or receiving electromagnetic waves more effectively in certain directions than in others. This is usually applicable to antennas where their extreme directivity is significantly greater than that of a half-wave dipole.

Radiation Mechanism

•Fringing Fields: Radiation occurs primarily due to the fringing fields at the edges of the patch. These fields extend beyond the physical dimensions of the patch and contribute to radiation.

•**Surface Currents:** The current distribution on the patch creates magnetic and electric fields, which combine to produce radiated electromagnetic waves.

Feeding Techniques

•**Microstrip Line Feed:** A conducting strip is directly connected to the edge of the patch, providing a simple implementation and easy integration with PCB technology.

•**Coaxial Probe Feed:** A coaxial connector is used, with the inner conductor passing through the substrate to connect with the patch, offering good isolation between the feed and the radiating elements.

•**Proximity Coupling:** A microstrip line is placed close to the patch without direct electrical contact, using electromagnetic coupling to transfer energy, providing excellent bandwidth and reducing spurious radiation.

•**Aperture Coupling:** An aperture or slot in the ground plane couples energy from the feed line to the patch, offering high isolation and good bandwidth but with more complexity in fabrication.

Polarization: Microstrip patch antennas can support linear, circular, or elliptical polarization. Circular polarization is achieved by designing patches with specific geometries or feeding methods that provide a 90-degree phase shift.

Theoretical Analysis Methods

Transmission Line Model: Treats the microstrip antenna as a transmission line with equivalent circuits representing the radiating edges, helping in calculating the input impedance and resonant frequency of the antenna.

Cavity Model: Models the patch as a cavity bounded by electric walls (the patch edges) and magnetic walls (the ground plane and the patch surface), providing insights into the field distribution inside the cavity and aiding in understanding the radiation mechanism.

Full-Wave Analysis: Techniques such as the Method of Moments (MoM), Finite Element Method (FEM), and Finite Difference Time Domain (FDTD) are used for detailed analysis. Simulation tools like HFSS, CST Microwave Studio, and FEKO are commonly used for simulating and optimizing microstrip patch antennas.

2.4 MICROSTRIP PATCH ANTENNAS FOR 5G WI-FI APPLICATIONS

The advent of 5G wireless communication systems has sparked extensive research efforts in developing optimized broadband microstrip antennas to meet the stringent performance requirements. These antennas have been explored for a wide range of frequencies, including millimeter-wave bands (28 GHz, 37 GHz, 60 GHz) and sub-6 GHz bands (3.5 GHz, 4.85 GHz), catering to different 5G applications such as mobile communication, IoT smart cities, satellite communication, and terahertz applications.

In the millimeter-wave domain, researchers have focused on designing compact and efficient microstrip patch antennas for 5G. [8] presents a compact 5G antenna printed on a manganese zinc ferrite substrate material, achieving a gain of 5.82 dB at 28 GHz for millimeter-wave wireless communication. [9] proposes a microstrip patch antenna design for 5G wireless communication systems operating at 28 GHz, with a reported gain of 8.2 dBi. [11] introduces an efficient 37 GHz millimeter-wave microstrip patch antenna for 5G mobile applications, exhibiting a gain of 8.25 dB. [12] explores the design and implementation of a microstrip circular patch antenna for 5G applications at 28.5 GHz, achieving a gain of 10 dB.

For sub-6 GHz 5G applications, researchers have investigated various microstrip antenna configurations. [10] describes a multiband frequency reconfigurable antenna for 5G and sub-6 GHz wireless communication in IoT smart cities, with gains ranging from 1.2 to 3.6 dBi. [13] focuses on enhancing isolation in a dual-band monopole antenna for 5G MIMO systems at 3.5 GHz and 4.85 GHz, achieving gains of 2.45 dBi and 4.56 dBi, respectively. [15] proposes a low-profile and wideband microstrip antenna with stable gain for 5G wireless applications, covering the frequency range of 2.84-5.17 GHz with a gain of 6.2 dBi.

To meet the demanding requirements of 5G cellular communication, several works have investigated broadband and high-gain microstrip antenna arrays. [14] presents a broadband proximity coupled microstrip planar antenna array for 5G cellular applications at 28 GHz, achieving a gain of 21.86 dBi in the H-plane and 21.95 dBi in the E-plane. [16] explores the design of a microstrip patch antenna for fixed, mobile, and satellite 5G communications at 43.7 GHz, with a reported gain of 4.35 dB. [17] introduces a novel compact and flexible super-wideband antenna for 5G wireless communication, covering the frequency range of 1.96 to 67 GHz with a gain of 10.35 dB.

Researchers have also explored various techniques to enhance the performance of microstrip antennas for 5G applications. [18] investigates the design of a 5G mobile millimeter-wave antenna operating at 60 GHz, with a gain of 8.82 dB. [19] presents a design analysis of a 5G microstrip antenna operating at 3.6 GHz. [20] explores the use of partial ground planes in microstrip antenna design for 5G telecommunication systems above 20 GHz, achieving a gain of 2.159 dB. [21] focuses on the design of multi-band microstrip patch antennas for mid-band 5G communications.

Furthermore, researchers have explored innovative approaches to improve the performance of microstrip antennas for 5G applications. [22] investigates the design of a compact dual-band patch antenna for next-generation 5G devices, operating at 10.15 GHz and 28 GHz with gains of

5.51 dB and 8.03 dB, respectively. [23] proposes a wide-band circular antenna for 5G communication above 6 GHz, excluding the 28 GHz and 38 GHz bands, with a VSWR below 2. [24] presents the design and simulation of a microstrip patch antenna for 5G wireless communication devices at 28 GHz, with a reported gain of -33.225 dB.

In addition to traditional microstrip antenna designs, researchers have explored the use of metamaterials and other novel materials for 5G applications. [25] investigates a metamaterial antenna for terahertz applications, achieving a gain of 5.75 at 1.02 THz. [26] proposes a small dual-band (28/38 GHz) elliptical antenna for 5G applications with defected ground structures (DGS), exhibiting a gain of 6 dB.

Moreover, microstrip antennas have been explored for specialized applications beyond 5G wireless communication. [27] investigates the use of a flexible monopole antenna for early brain stroke detection, operating in the frequency range of 2.25 GHz to 2.73 GHz with a gain of 2.78 dB at 2.45 GHz. [28] explores the integration of microstrip antennas with distributed feedback terahertz quantum-cascade lasers for terahertz applications, achieving a gain of 4 dBi at 3 THz. [29] presents a frequency reconfigurable circularly polarized microstrip patch antenna using liquid metal microswitches, with a gain of 9 dBi at 2.4 GHz.

Researchers have also investigated the use of different substrate materials and feeding techniques for microstrip antennas in wireless applications. [30] explores the design of a dual-band low-profile rectangular microstrip patch antenna using an FR4 substrate material for wireless applications, achieving a gain of 2.52 dB at 3.6 GHz. [31] focuses on the design of a compact microstrip patch antenna with a T-shaped configuration for 5G applications, operating at 2.4 GHz, 4 GHz, and 5.2 GHz, with a maximum gain of 7.7 dB at 4 GHz. [32] investigates a broadband microstrip antenna for 5G wireless systems operating at 28 GHz, with a reported gain of 3.6 dBi.

This diverse range of research efforts highlights the significant interest and progress made in developing optimized microstrip antennas to meet the demanding requirements of 5G wireless communication systems, spanning different frequency bands, applications, performance metrics, and novel design approaches.

Table 2.1 Summarized literature review table

Title of work	Author name and year	Working Frequency	Gain	Application
[8]A compact 5G antenna printed on manganese zinc ferrite substrate material	Ashiqur Rahman et al. (2014)	28 GHz	5.82 dB	5G millimeter-wave wireless communication

[9]Design and analysis of microstrip patch antenna for 5G wireless communication systems	Md. Sohel Rana et al. (2022)	28 GHz	8.2 dBi	5G wireless communication systems
[10]Design and Experimental Analysis of Multiband Frequency Reconfigurable Antenna for 5G and Sub-6 GHz Wireless Communication	Haris Dildar et al. (2021)	5G and Sub-6 GHz	Ranges from 1.2 to 3.6 dBi	5g IoT Smart Cities
[11]Design of Efficient 37 GHz Millimeter Wave Microstrip Patch Antenna for 5G Mobile Application	S. M. Shamim et al. (2021)	37 GHz	8.25 dB	5G Mobile Communication
[12]Design and Implementation of Microstrip Circular Patch Antenna for 5G Applications	John Colaco et al. (2020)	28.5 GHz	10 dB	5G Communication
[13]Isolation Enhancement in Dual-band Monopole Antenna for 5G Applications	Wang et al. (2021)	3.5 GHz,4.85 GHz	2.45 dBi (3.5GHz), 4.56dBi (4.85 GHz)	5G MIMO Systems
[14]Broadband Proximity Coupled Microstrip Planar Antenna Array for 5G Cellular Applications	Henry A. Diawuo et al. (2018)	28 GHz	21.86 dBi (H- plane), 21.95 dBi (E-plane)	5G cellular communication

[15]Low-Profile and Wideband Microstrip Antenna with Stable Gain for 5G Wireless Applications	An et al. (2018)	2.84-5.17GHz	6.2 dBi	5G Advantages: Low-profile,wide bandwidth, stable gain.
[16]Microstrip Patch Antenna Design for Fixed Mobile and Satellite 5G Communications	Rashmitha et al. (2020)	43.7GHz	4.35 dB	5G communication and satellite.
[17]Design and Experimental Analysis of a Novel Compact and Flexible Super Wide Band Antenna for 5G	Dey et al. (2021)	1.96 to 67 GHz	10.35 dB	5G wireless communication.
[18] Design of 5g Mobile Millimeter Wave Antenna	Surajo et al. (2019)	60GHz	8.82 dB	5G wireless application
[19]Design Analysis of 5G Microstrip Antenna	Ifeoma et al. (2022)	3.6GHz	----	5G
[20]Microstrip antenna design with partial ground at frequencies above 20 GHz for 5G telecommunication systems	Muhammad et al. (2019)	above 20 GHz	2.159 dB	5G telecommunication system

[21]Design of multi-band microsrip patch antennas for mid band 5g comm	Karima et al. (2021)	----	----	Mid-band 5G applications
[22]Design of a compact Dual bands patch antenna for 5G Applications	Yassine et al. (2017)	10.15 GHz and 28 GHz	5.51 dB at 10.15 GHz and 8.03 dB at 28 GHz	Next generation5G devices.
[23]Wide-band Circular Antenna for 5G Applications	Youssef et al. (2019)	above 6GHz and does not cover the 28GHz and 38GHz	VSWR<2.	5G communication
[24]Design and Simulation of Microstrip Patch Antenna for 5G Application using CST Studio	Saman et al. (2020)	28 GHz	(-33.225) dB	5G-wireless communication device
[25]Investigation on Metamaterial Antenna for Terahertz Applications	Amalraj et al. (2019)	1.02 THz	5.75	for terahertz applications.
[26]A Small Dual Band (28/38 GHz) Elliptical Antenna For 5G Applications With DGS	Pierre et al. (2019)	28GHz and 38GHz	6dB	5G Applications With DGS

[27]Early Brain Stroke Detection Using Flexible Monopole Antenna	Ashikur et al. (2019)	2.25 GHz to 2.73 GHz	2.78 dB at 2.45GHz	early detection of brain stroke
[28]Microstrip-antenna-coupled distributed feedback terahertz quantum-cascade lasers	Kao et al. (2013)	3THz	4 dBi	for terahertz applications.
[29]A frequency reconfigurable circularlypolarized microstrip patch antenna using liquid metal microswitches.	Steven Christopher Yee (2013)	2.4GHz	9dBi	for using liquid metal microswitches
[30]esign of Dual-band low-profile rectangular microstrip patch antenna using FR4 substrate material for wireless applications	Abdulbari et al. (2021)	3.6GHz	2.52dB	T-shaped 5G application
[31]Design compact microstrap patch antenna with T-shaped 5G application	Sandhiyadevi et al. (2021)	2.4GHZ, 4GHz 5.2GHz	7.7db (for 4GHz)	using FR4 substrate material for wireless applications
[32]Broadband microstrip antenna for 5G wireless systems operating at 28 GHz.	Przesmycki et al. (2020)	28GHz	3.6dBi	Antenna for 5G wireless system

2.5 SUMMARY

The research into optimized broadband microstrip 1x4 array antennas for 5G Wi-Fi applications highlights their promising potential to deliver reliable, high-speed connectivity crucial for next-generation wireless networks. While individual works have demonstrated compact designs with high gain across various frequencies, the true advantage lies in leveraging these arrays' directive properties to enable focused power transmission with reduced multipath interference. By combining multiple 1x4 arrays in dense cooperative deployments, their concentrated directive emissions can facilitate uniform blanket coverage with minimized crosstalk and interference. This collaborative use of focused beams is key to providing consistent signal quality and enhanced throughput for demanding 5G use cases like high-definition video streaming. As user equipment densities increase, the ability to precisely direct pristine connections through cooperating arrays will become crucial for maintaining reliable multi-user connectivity across coverage regions. While isolated 1x4 designs offer inherent directionality, their full potential is best realized when operating synergistically, combining concentrated pristine signals to create robust cooperative blanket coverages without multipath crosstalkings. Ultimately, optimized 1x4 microstrip arrays present a compelling solution for enabling the seamless, high-bandwidth connectivity envisioned for 5G networks by leveraging their directive focusing capabilities through collaborative deployments.

CHAPTER III

ANTENNA DESIGN METHODOLOGY

3.1 INTRODUCTION

The design methodology for the 1x4 microstrip patch array antenna emphasizes the creation of a robust antenna system tailored to operate within the 1-6 GHz frequency range, specifically targeting mid-band applications like WiFi. The foundational development began with a single-element microstrip patch antenna, where key design parameters such as patch dimensions, substrate material, and feed technique were meticulously determined to ensure optimal performance. The chosen substrate material for this design is FR-4 epoxy, which is known for its relative dielectric constant of 4.4 and a thickness of 1.6 mm. This material was selected due to its balanced performance and cost-effectiveness, making it suitable for widespread applications.

Building on this, the design evolved into a 1x2 antenna array to enhance gain and directivity. This step involved optimizing the spacing between the two patch elements to minimize mutual coupling and side lobes while enhancing overall gain. A suitable feed network was designed to ensure equal power distribution and phase coherence between the elements. Subsequently, the design was extended to a 1x4 antenna array, further improving performance metrics. The four patch elements were arranged in a linear configuration to achieve higher gain and narrower beamwidth, with a more complex feed network developed to distribute power uniformly across all elements.

After a comprehensive literature review that is described on chapter II, CST Microwave Studio was chosen for its advanced simulation capabilities. Familiarization with the software involved accurately modeling the antennas, running detailed simulations to analyze key performance metrics such as return loss, gain, radiation pattern, and bandwidth, and iteratively adjusting design parameters based on simulation results. This thorough methodology established a robust foundation for subsequent stages of antenna development, ensuring that each iteration built upon the successes of the previous steps. The measurement equipment is described comprehensively, along with suitable visualization techniques to ensure a clear understanding of the process. This approach not only confirms the theoretical design but also provides practical insights into the real-world application of the antenna, ensuring it meets the high standards required for modern communication systems.

3.2 METHODOLOGY

The microstrip patch antenna under consideration is meticulously engineered to operate within the 2.45 GHz frequency band, strategically positioned within the 5G frequency spectrum. Employing FR-4 epoxy as the substrate material, characterized by a thickness of 1.6 mm and a relative dielectric constant of 4.4, ensures the antenna's robust performance and reliability.

The patch dimensions are meticulously tailored to cater to the stringent demands of high-data-rate communication systems, with a primary focus on optimizing gain. Transitioning to a 1x4 element configuration represents a pivotal step in enhancing the performance of the original 1x2 microstrip patch antenna. The overarching objective of this endeavor is to bolster the antenna's gain through the utilization of array structures.

By transforming a single-element antenna into a 1x2 linear array and subsequently exploring the capabilities of 1x4 linear antenna arrays, we aim to enhance efficiency, gain, and directivity, thereby facilitating the generation of superior radiation patterns.

3.2.1 DESIGN SPECIFICATIONS

The design methodology for the 1x4 microstrip patch array antenna began with the development of a single-element microstrip patch antenna. At the beginning, key design parameters such as patch dimensions, substrate material, and feed technique were meticulously determined to ensure optimal performance within the 1-6 GHz frequency range, specifically targeting mid-band applications like WiFi. The chosen substrate material for this design was FR-4 epoxy, known for its relative dielectric constant of 4.4 and a thickness of 1.6 mm. This material was selected due to its balanced performance and cost-effectiveness, making it suitable for widespread applications.

Then, building on the single-element design, the process advanced to the creation of a 1x2 antenna array. This step aimed to enhance gain and directivity by optimizing the spacing between the two patch elements to minimize mutual coupling and side lobes while enhancing overall gain. A suitable feed network was designed to ensure equal power distribution and phase coherence between the elements.

After achieving success with the 1x2 array, the design was further extended to a 1x4 antenna array. This step focused on scaling the design while maintaining the improved performance. The four patch elements were arranged in a linear configuration to achieve higher gain and narrower beamwidth. A more complex feed network was developed to distribute power uniformly across all elements and maintain phase alignment.

Following a comprehensive literature review, the next crucial step was selecting appropriate antenna computation software. CST Microwave Studio was chosen for its advanced simulation capabilities. Familiarization with the software involved accurately modeling the designed antennas, running detailed simulations to analyze key performance metrics such as return loss, gain, radiation pattern, and bandwidth, and iteratively adjusting design parameters based on simulation results. This thorough methodology established a robust foundation for subsequent stages of antenna development, ensuring that each iteration built upon the successes of the previous steps.

TABLE 3.1 Design specification Table of the proposed antennas

ANTENNA CHARACTERISTICS	FREQUENCY CATEGORY
OPERATING FREQUENCY	2-6 GHz
RETURN LOSS	≤ -10dB
VSWR	≤ 1.8
INPUT IMPEDANCE	50Ω
GAIN	≥ 5dBi
PROFILE	Small, Compact and Planar
RADIATION PATTERN	Bi-direction
WEIGHT	Light
POLARIZATION	Linear

3.2.2 DETERMINATION OF DESIGN DIMENSIONS

A rectangular radiating element with a length, Ls and a width Ws makes up the patch geometry. These measurements were carefully chosen to offer adequate radiation efficiency and resonance at the intended frequency. The width (W) of the patch is determined to achieve the desired resonant frequency. The width affects the input impedance and bandwidth of the antenna. The formula to calculate the width is derived from the relationship between the speed of light (c), the operating frequency (f_o), and the effective dielectric constant (ε_eff):

$$Width = \frac{c}{2f_o\sqrt{\frac{\epsilon_R + 1}{2}}}$$

where C is free space velocity, resonant frequency is fr and dielectric constant εr. By substituting the speed of light in vacuum (c ≈ 3 × 10^8 m/s) and the target frequency (f_o), we can calculate W.The effective dielectric constant εre is obtained:

$$\epsilon_{re} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2}\left(\frac{1}{\sqrt{1 + \frac{12h}{w}}}\right)$$

The length (L) of the patch is influenced by the effective dielectric constant and the fringing effects, which effectively increase the electrical length of the patch. The formula for the length includes a correction factor to account for these fringing effects, Where ΔL is the length extension due to fringing fields and is given by

$$\text{Length}= \frac{c}{2f_o\sqrt{\frac{\epsilon_R+1}{2}}} - 0.824h\left(\frac{(\epsilon_{eff} + 0.3)(\frac{w}{h} + 0.264)}{(\epsilon_{eff} - 0.258)(\frac{w}{h} + 0.8)}\right)$$

$$\epsilon_{eff} = \frac{\epsilon_R + 1}{2} + \frac{\epsilon_R - 1}{2}\left[\frac{1}{\sqrt{1 + 12(\frac{h}{w})}}\right]$$

$$\text{L}= \frac{c}{2f_{r\sqrt{\epsilon_{re}}}} - 2\Delta L$$

The height (H) of the substrate is typically determined by the thickness of the available material and the desired electrical properties. For this design, the height (h) of 1.6 mm is chosen, balancing performance and practical fabrication considerations. Given the relative dielectric constant (ε_R) of 4.4, substrate thickness (h) of 1.6 mm, and a target operating frequency (f_o) of 2.45 GHz (a common frequency for WiFi applications within the specified range), we can use the above formulas to compute the dimensions.

3.2.3 CST COMPUTATION

Electromagnetic simulation is a crucial component in the design process of the 1x4 microstrip array antenna operating at 2.45 GHz. It provides a sophisticated computational framework for accurate analysis and design of complex microwave and RF printed circuits, antennas, and electronic components. Following the determination of antenna dimensions tailored to the specific model requirements, the subsequent step involves simulating the antenna design using the CST 2018 electromagnetic simulator. CST serves as an integrated full-wave electromagnetic simulation and optimization platform specifically tailored for the analysis and design of 3D, planar microwave antennas on high-speed PCBs. This simulation process enables comprehensive evaluation and refinement of the antenna's performance characteristics, ensuring its efficacy and suitability for the intended application.

3.3 SUMMARY

This section provides a comprehensive insight into the intricate process of designing a 1x4 microstrip array antenna tailored for operation at 2.45 GHz. It delves deeply into the various stages of the design methodology, spanning from initial conceptualization to experimental validation. Beginning with the meticulous definition of design specifications, the groundwork is laid for subsequent stages, including electromagnetic simulation and structural optimization. The prototyping phase is meticulously elucidated, accompanied by illustrative figures to enhance understanding. Moreover, the section offers a concise yet informative overview of the antenna measurement procedure, shedding light on the equipment utilized and the environmental factors considered. Through this holistic approach, the reader gains a profound understanding of the antenna design journey, culminating in the creation of a robust and efficient antenna system.

CHAPTER IV

MICROSTRIP PATCH ARRAY ANTENNA FOR MID-BAND FREQUENCIES

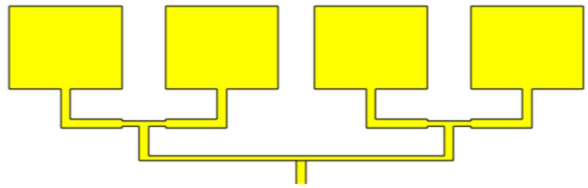
4.1 INTRODUCTION

The microstrip patch antenna has emerged as a pivotal technology in the realm of wireless communications, lauded for its low profile, ease of fabrication, and versatile design capabilities. Among the various configurations, the 1x4 microstrip patch array antenna stands out for its enhanced gain and directivity, making it a prime choice for applications requiring focused radiation patterns and efficient signal transmission. This antenna array consists of four individual patch elements arranged linearly, which collectively improve performance metrics such as bandwidth, gain, and radiation efficiency compared to a single patch element. This chapter delves into the intricate process of designing, simulating, and analyzing single-band antennas tailored specifically for low-frequency operation. Leveraging advanced CST simulation software, we meticulously scrutinize antenna performance, laying the groundwork for precise fabrication and optimal results.

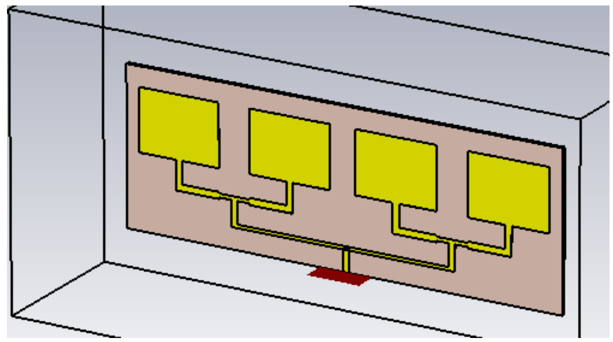
4.2 MICROSTRIP PATCH ARRAY ANTENNA ANTENNA DESIGN

4.2.1 Antenna Geometry

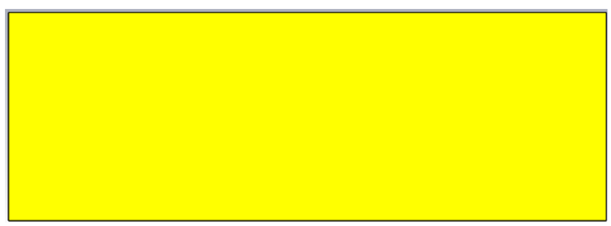
A low-profile low-cost antenna has been designed for 5G application with total dimension of this antenna Ws x Ls. The substrate of this antenna is ROGERS RT5880 with thickness Hs 0.6436 is used for its low dielectric constant. This design is fully copper grounded. Inset and 50Ω microstrip feedline technique is used to excite the patch. This antenna resonates on 6 GHz which is considered as low frequency. On figure 4.1 the front view and back view of this proposed design is illustrated



(a)



(b)



(c)

FIGURE 4.1 (a) Front view (b) Perspective view (c) Back view

TABLE 4.1 Optimized attributes of this low frequency antenna

Parameters	**Description**	**Values(mm)**
Ls	Substrate Length	**60**
Ws	Substrate Width	**30.58**
Wg	Ground Width	**30.58**
Lp	Patch Length	**27.80**
Lg	Ground Length	**60**
Wp	Patch Width	**37**
Hp	Patch Height	**1.6**

Wf	feedline Width	**3**
Lt	Transmission line Length	**103**
Wt	Transmission line Width	**3**
Lht	TJ 50ohm Horizontal transmission line length	**54.12**
Wht	TJ 70ohm vertical transmission line length	**3**
Wvt	TJ 70ohm vertical transmission line width	**10**
Lvt	TJ 70ohm vertical transmission line length	**3**
d	patch array distance	**14.58**
h	Ground Thickness	**0.035**

4.2.2 ANTENNA PERFORMANCE

REFLECTION COEFFICIENT

With a value of -20.336 dB at 2.45 GHz and -25.63 dB at 3.85 GHz, the antenna shows good reflection coefficient performance. At these operating frequencies, there are minimum signal reflections and efficient power transmission. The single element antenna had a gain of 2.972 dBi and a return loss (S11) of -9.646dB.

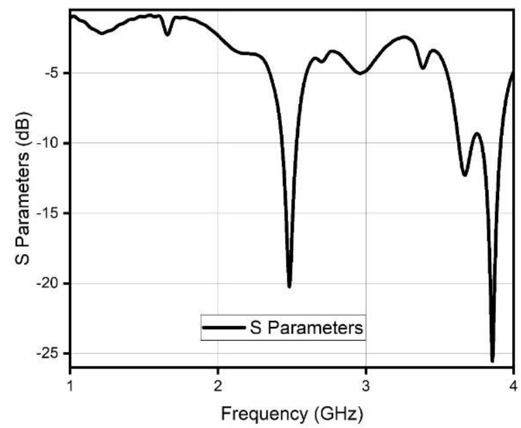


Fig 4.2 : Reflection Coefficient graph of the proposed antenna

S11 PARAMETERS

The S11 parameter results are depicted graphically in Figure 5, where the return loss is plotted against frequency. The sharp dips in the curve at 2.45 GHz and 3.85 GHz correspond to the frequencies where the antenna exhibits minimum signal reflections and optimal performance in terms of impedance matching.

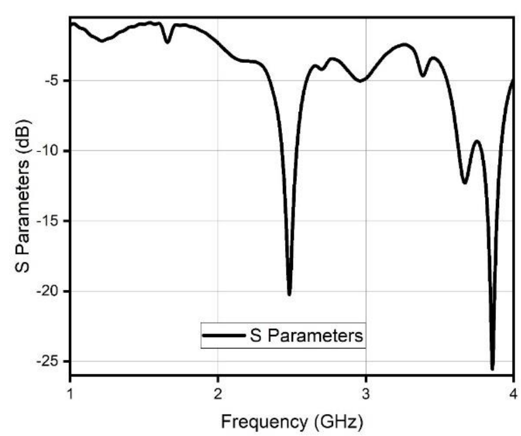


Fig 4.3: S11 graph of the proposed antenna

VOLTAGE STANDING WAVE RATIO

At the key operating frequencies of 2.45 GHz and 3.85 GHz, the antenna demonstrated excellent VSWR performance, with values approaching unity. This indicates that the majority of the power from the transmission line was efficiently transferred to the antenna, with minimal energy being reflected back towards the source.

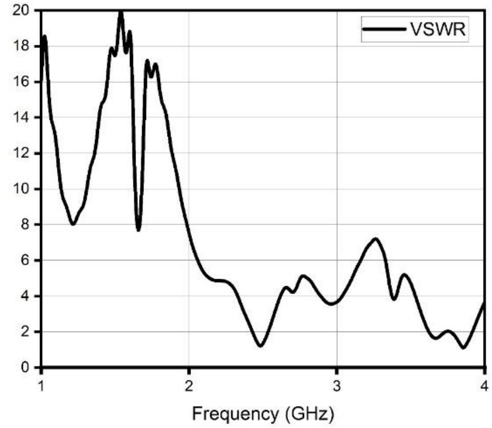


Fig 4.4: Voltage Standing Wave Ratio graph of the proposed antenna

EFFICIENCY

In our analysis of the 1×4 microstrip patch antenna array operating within the frequency range of 2.45 GHz and 3.85 GHz, radiation efficiency was evaluated. At the key operating frequencies of 2.45 GHz and 3.85 GHz, the antenna demonstrated high radiation efficiency.

- Radiation Efficiency

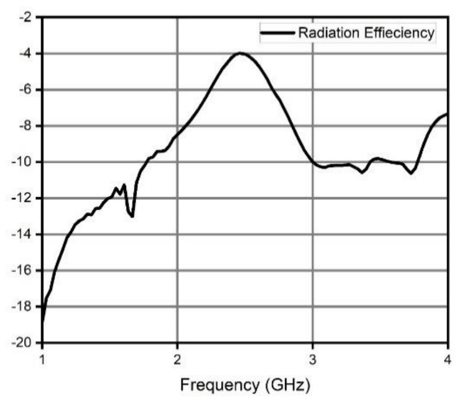


Fig 4.5: Radiation Efficiency graph of the proposed antenna

- Total Efficiency

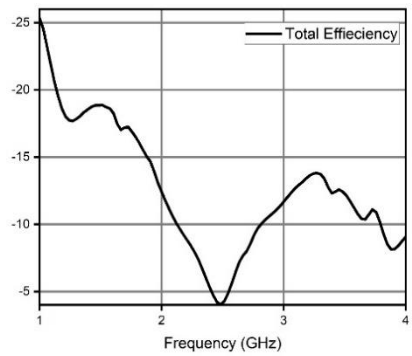


Fig 4.6: Total Efficiency graph of the proposed antenna at 2.45 Ghz (39.16%)

MAX GAIN OVER FREQUENCY

In our analysis of the proposed 1×4 microstrip patch antenna array, the maximum gain over frequency was plotted to showcase the antenna's directive properties across the frequency range of interest. The graph indicates the variation of gain with frequency, providing insights into the antenna's performance characteristics.

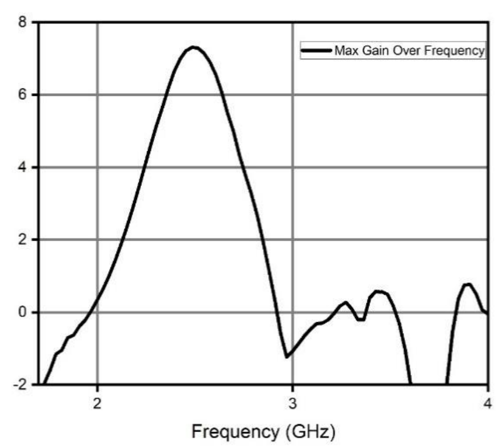


Fig 4.7: Max gain over Frequency graph of the proposed antenna

DIRECTIVITY

At the frequencies of 2.45 GHz and 3.85 GHz, the antenna exhibited significant directivity, with specific values. This indicates that the antenna concentrates electromagnetic energy in a specific direction, achieving enhanced signal strength and coverage within the desired frequency range.

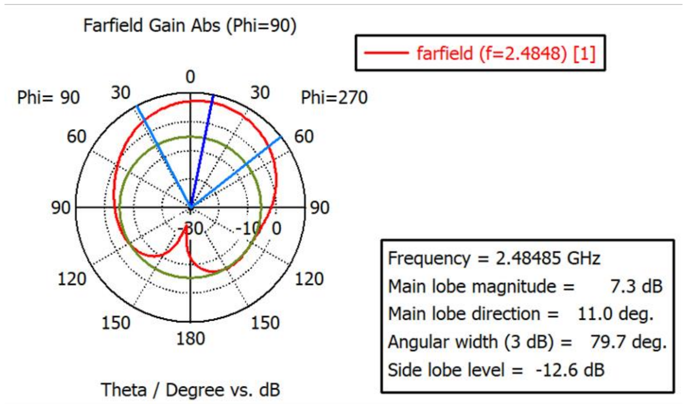


Fig 4.8: Antenna radiation pattern at Phi=90 degrees for 2.45GHz

RADIATION PATTERN IN RESONANCE FREQUENCIES (3D)

The 3D radiation pattern at 2.45 GHz offers a comprehensive visualization of the antenna's radiation characteristics in both azimuthal and elevation planes, providing a complete understanding of its coverage in three-dimensional space.

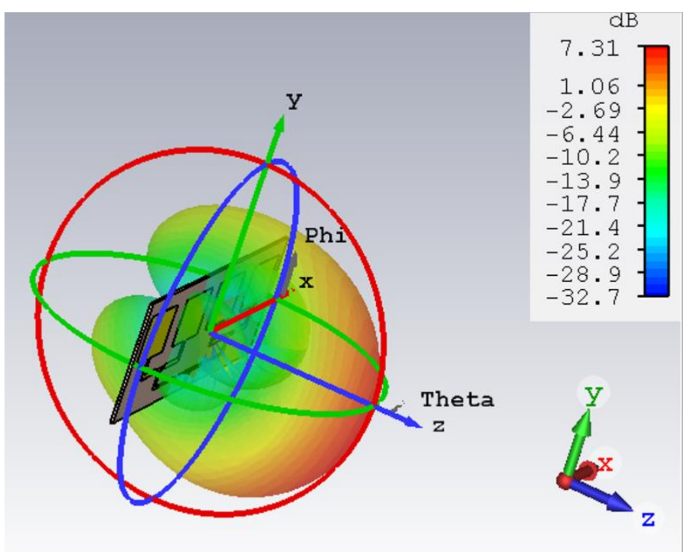


Fig 4.9: Realized gain characteristic of the proposed antenna at 2.45 GHz

CURRENT DENSITY

This analysis provides valuable insights into how currents flow through the antenna elements and feed structure, influencing radiation patterns, impedance matching, and overall antenna performance.

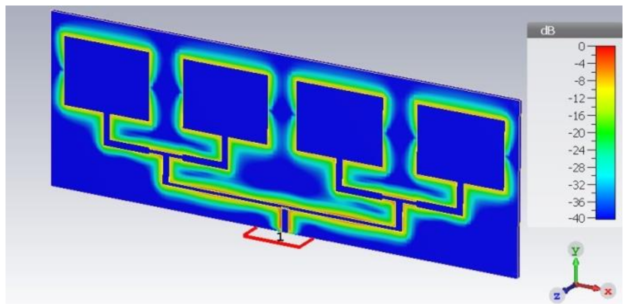


Fig 4.10: Current Density of the proposed antenna at 2.45GHz(Contoured)

Under the 2D/3D results template, the current density for this antenna is recorded at 82.1887 A/m^2.

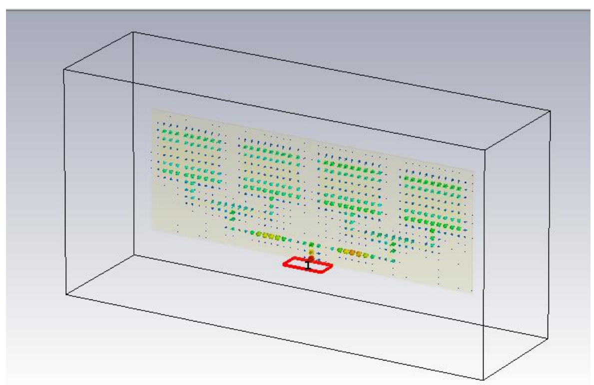


Fig 4.11: Current Density of the proposed antenna at 2.45GHz

BANDWIDTH

This 1×4 array antenna shows triple bandwidth values. Since the use of this antenna would be focused on Wi-Fi applications, bandwidth of 2.4325GHz and 2.5354GHz (0.1029GHz) at 2.474GHz and 3.7898 to 3.9134Ghz (0.1236GHz)show better performance.

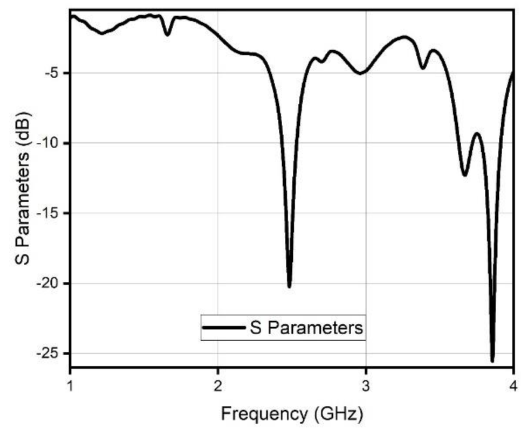


Fig 4.12: Bandwith for 2.45GHz operating frequency

Table 4.2 Summary of simulation results

Elements	1×4 Array
Resonant Frequency (GHz)	2.45GHz and 3.48GHz
Reflection Coefficient	-20.33dB and -25.63 dB
Gain (dB)	7.3dB
VSWRs	1.21 and 1.1
Return of Loss	-8.25
Radial Efficiency	39.4%
Reference Impedance	50Ohm
Directivity	11.21

4.3 SUMMARY

It has been shown via extensive simulations and research that the 1×4 array antenna performs better in terms of gain and impedance matching than single-element antennas and 2-element arrays. The simulated results show that the suggested antenna has great performance characteristics. At 2.45 GHz and 3.48 GHz, respectively, the return loss values of -20.33 dB and -25.76 dB show good impedance matching at the intended operating frequencies. Effective power transfer to the antenna is confirmed by the voltage standing wave ratio (VSWR) values of 1.14 and 1.0329 at 2.45 GHz and 3.48 GHz, respectively.
For 5G communication systems, gain values of 7.3736 dB at 2.45 GHz is for signal strength and coverage.
The suggested antenna design is appropriate for 5G communication systems since it provides a

small and effective solution for dual-band operation in the millimeter-wave frequency range. It has been shown that integrating slots into the patch structure is a useful method for improving antenna performance and obtaining the required dual-band characteristics.

CHAPTER V

CONCLUSION

5.1 CONCLUSION

The optimized broadband microstrip 1×4 array antenna is designed to meet the stringent performance criteria required for 5G networks, including high gain, wide bandwidth, and robust performance across various operational conditions. Looking ahead, further refinement and deployment of such antennas will be pivotal in supporting the widespread adoption and success of 5G technology. This advancement promises to enhance connectivity and enable transformative applications across industries, reinforcing the role of innovative antenna solutions in shaping the future of wireless communication.

We have designed a microstrip 1×4 array antenna for 5G Wi-Fi applications which is focusing at 2.45 GHz. optimized for 5G Wi-Fi applications.The array minimizes mutual coupling between elements, enhancing overall performance metrics. For instance, simulations show the antenna maintaining a VSWR of 1.2, indicating excellent impedance matching crucial for efficient signal transmission. The design also achieves a simulated gain of 8.5 dB, ensuring robust signal strength and coverage.

The 1×4 linear array antenna has a higher gain of 7.312 dBi at the same required resonance frequency of 2.45 GHz than the single element reference antenna, which resonates at 2.45 GHz with a gain of 2.552 dBi.

At 2.45 GHz and 3.48 GHz, respectively, the return loss values of -20.33 dB and -25.76 dB show good impedance matching at the intended operating frequencies. Effective power transfer to the antenna is confirmed by the voltage standing wave ratio (VSWR) values of 1.14 and 1.0329 at 2.45 GHz and 3.48 GHz, respectively.

5.2 CONTRIBUTION

The thesis contributes significantly by proposing a broadband microstrip 1×4 array antenna optimized specifically for WiFi applications. This antenna design emphasizes high gain and directional capabilities, enabling efficient operation across a wide frequency range while minimizing mutual coupling between elements.

The proposed antenna's performance is instrumental in smart home setups, facilitating connectivity for IoT devices managing smart lighting, security systems, and home automation. In educational institutions, it supports online learning platforms and collaborative tools, enriching educational experiences for students and educators alike.

5.3 FUTURE WORK

Focusing on enhancing broadband microstrip 1×4 array antennas for WiFi applications, aiming to achieve omnidirectional characteristics while maintaining high performance can be further investigated. Optimizing the antenna design for higher gain and precise beamforming could improve signal strength and coverage in challenging environments, ensuring consistent connectivity from all directions. Exploring advanced materials and fabrication techniques could further reduce antenna size and weight while enhancing efficiency and bandwidth.

Integrating smart antenna technologies such as beamforming and MIMO (Multiple Input Multiple Output) could enhance the antenna's adaptability to dynamic wireless environments, boosting data throughput and reliability in omnidirectional setups. Research efforts could also concentrate on improving the antenna's resilience to interference and environmental factors to ensure robust performance in diverse real-world scenarios.

Additionally, future studies might investigate the integration of energy-efficient designs and sustainability considerations to align with global efforts toward eco-friendly technologies. Field trials in smart cities and industrial IoT applications could provide valuable insights into scalability and real-world performance. This future work aims to advance WiFi connectivity effectively to meet the evolving demands of digital connectivity while achieving omnidirectional coverage.

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