BACHELOR OF SCIENCE IN ELECTRONIC & TELECOMMUNICATION ENGINEERING

Design of a Miniaturized Microtrip Patch Antenna Array with High Gain for 5G mmWave Applications

Submitted By

Mohammad Sifat Ullah T191041

Supervised By

Mohammed Jashim Uddin

Associate Professor,Department of ETE,IIUC

Department of Electronic & Telecommunication Engineering
International Islamic University Chittagong
Kumira, Sitakunda, Chittagong-4318
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CERTIFICATE OF APPROVAL

The Thesis titled "**Design of a Miniaturized Microstrip Patch Antenna with High Gain for mmWave Applications**," authored by **Mohammad Sifat ullah** with corresponding Metric ID **T191041** has been accorded approval by the Department of Electronic and Telecommunication Engineering (ETE) at the International Islamic University Chittagong (IIUC). This endorsement affirms its adequacy in meeting the stipulated criteria for the partial fulfillment of the requirements for the B.Sc. degree in Electronics and Telecommunications Engineering. The scholarly and stylistic attributes of the thesis have been sanctioned, with formal approval granted subsequent to the examination conducted on February, 2024.

Approved By-

Mohammed Jashim Uddin
Supervisor Associate
Professor
Department of Electronics and Telecommunications Engineering International
Islamic University Chittagong

CANDIDATES DECLARATION

I hereby affirm that the content presented in this thesis, or any segment thereof, has not been previously submitted for the conferment of any degree or diploma elsewhere. Moreover, it is asserted that the thesis does not include any unlawful statements.

Mohammad Sifat Ullah
T191041

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in the name of Allah, the Most Gracious and Most Merciful. All praise and honor are due to Allah (SWT), who has bestowed upon us abundant opportunities, kindness, and guidance throughout our lives. May the blessings and peace of Allah be upon Prophet Muhammad (PBUH), who continues to guide and inspire us in our journey.

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ABSTRACT

In this thesis 1*4 antenna array has been proposed for 28Ghz (n257) frequency band. Deploying an antenna array is essential in 5G millimeter-wave scenarios to address challenges such as path loss, multi-path fading, and to improve network capacity. It is crucial to evaluate the limitations of conventional communication, such as restricted coverage, interference, and slower data rates, which may be efficiently resolved by an array. A metamaterial loaded antenna system that is attaining a gain of 10.81 dB, 11.76 dB directivity and 91.4% efficiency at a frequency of 28 GHz. This design showcases technological robustness by using planar microstrip technology on a 1.6 mm thick Rogers-5880 dielectric substrate with a relative permittivity of 2.2. The array's specific features determine its compatibility for smooth integration into the millimeter-wave (mm-Wave) frequency range.

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LIST OF SYMBOLS

Hertz	Hz
Kilo Hertz	KHz
Mega Hertz	MHz
Giga Hertz	GHz
Millimeter	mm
Meter	m
Relative permittivity	ε
Length	L
Width	W
Second Generation Technology	2G
Third generation Technology	3G
Fourth Generation Technology	4G
Fifth Generation Technology	5G
Decibel isotropic	dB
Capacitance	C
Inductance	L
Resistance	R
Power	W

LIST OF ABBREVIATIONS

FSE	Faculty of Science and Engineering
ETE	Electronic and Telecommunication Engineering
IIUC	International Islamic University Chittagong
IEEE	Institute of Electrical and Electronic Engineers
MPA	Microstrip Patch Antenna
LTE	Long Term Evolution
FCC	Federal Communication Commission
GSM	Global System for Mobile communication
CST	Computer Simulator Technology
PCB	Printed Circuit Board
BW	Bandwidth
RL	Return Loss
Q	Quality Factor
RF	Radio Frequency
MICs	Microwave integrated circuits
PTT	Push to Talk
IMTS	Improved Mobile Telephone System
AMTS	Advance Mobile Telephone System

CHAPTER 01

INTRODUCTION

1.1 Fundamental of antennas

Antennas are essential components in modern communication systems, enabling the transmission and reception of electromagnetic wavesFunctioning as a metallic conductor, an antenna serves the fundamental purpose of facilitating the transmission of radio frequency (RF) waves between two spatial locations. Remarkably versatile, this device possesses the capability to both emit and capture signals. In the process of transmission, a voltage applied to the transmitting antenna engenders the generation of radio waves, which then propagate towards a designated receiving antenna. Subsequently, the receiving antenna undertakes the conversion of these radio waves back into electrical energy, thereby embodying transmitted information. Throughout the spatial journey between two points, radio waves dynamically interact with antennas.Antennas boast a rich historical legacy and exhibit diverse applications across electronic systems. They play pivotal roles in radar, radio, and television systems, where the transmission of signals via electromagnetic waves stands as an indispensable function. This ubiquity underscores the enduring significance of antennas in facilitating the seamless exchange of information across various technological domains. [1]

1.2 Microstrip Patch Antenna

A microstrip patch antenna is a microwave radiating or receiving element characterized by a metallic copper patch positioned atop a solid dielectric substrate with a ground plane. This antenna type has garnered popularity owing to its numerous advantages. Patch antennas are available in various configurations, featuring different shapes, and have undergone extensive studies in recent years. Various feeding techniques contribute to optimizing the antenna's overall performance, encompassing aspects such as return loss and radiation patterns.As illustrated in Figure 1, the construction of a microstrip patch antenna entails a ground plane on one side and a radiating patch on the other, both situated on a dielectric substrate. The patch can adopt various shapes and is typically composed of conductive metals such as copper or gold. Microstrip patch antennas emit radiation as a result of fringing fields between the patch edge and the ground plane. Feed lines and the radiating patch are commonly positioned on the surface of the dielectric substrate. Microstrip patch antennas demonstrate adaptability across a broad spectrum of frequencies, spanning from microwave to millimeter-wave ranges through adjustments in dimensions and substrate composition. Their directional radiation patterns enable precise signal targeting, while seamless integration with additional electronic elements on a printed circuit board streamlines overall system architecture. Furthermore, these antennas showcase minimal cross-polarization and signal attenuation, rendering them highly favored in diverse wireless communication contexts..The patch often assumes a regular form like a square, rectangle, circle, triangle, ellipse, or any other shape for ease of analysis and performance prediction[1].

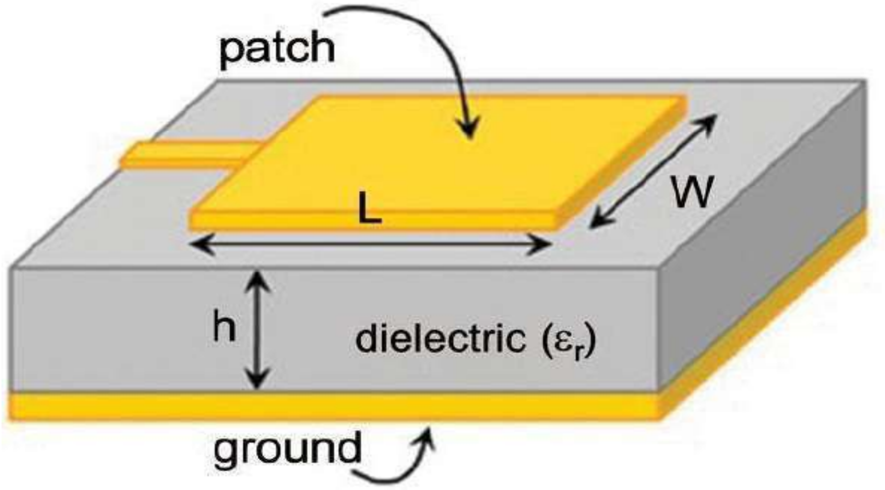

Figure 1: 3D view of the microstrip patch antenna[1]

1.3 Properties of Microstrip Patch Antenna

Compact Design: Microstrip patch antennas are known for their small size and flat structure, making them ideal for use in compact electronic devices.

Low Profile:Their flat shape allows for a low-profile design, which is useful in situations where space is limited or where aerodynamics matter.

Frequency Adaptability: These antennas can be tailored to work across various frequency ranges by adjusting their dimensions and substrate material.

Focused Signal Emission: Depending on their configuration, microstrip patch antennas can emit signals in specific directions, which is valuable for precise communication links.

Easy Integration: One of the key advantages of these components is their seamless integration with other electronic elements on a printed circuit board (PCB). This characteristic greatly simplifies system design processes, as engineers can effortlessly incorporate them into existing setups without encountering compatibility issues.

Moreover, this streamlined integration not only enhances the overall functionality of the system but also contributes to significant cost reductions in production. Consequently, leveraging these components leads to more efficient and economical electronic systems.Reduced

Cross-Polarization: Microstrip patch antennas can be engineered to minimize unwanted signal polarization, ensuring better signal quality in polarization-sensitive applications.

Cost-Effective Production: They can be manufactured using standard PCB fabrication methods, making them economical to produce.

Lightweight Construction: Due to their flat structure and lightweight materials, microstrip patch antennas are lightweight, suitable for weight-sensitive applications like aerospace or automotive industries.

Scalability: These antennas can be adjusted in size to accommodate different frequency bands or performance needs without requiring extensive redesign.

Overall, microstrip patch antennas offer versatility and practicality for various wireless communication tasks[1].

1.4 Feeding Techniques of Microstrip Antenna

Microstrip Line Feed: Utilizes a transmission line directly connected to the antenna's radiating patch, offering simplicity and ease of integration. However, it may suffer from radiation losses and limited bandwidth.

Coaxial Probe Feed: Involves a coaxial probe inserted through the substrate to couple energy to the radiating patch. This technique offers better impedance matching and radiation efficiency but may require precise manufacturing tolerances.

Aperture Coupled Feed: Energy is coupled from a microstrip line to the radiating patch through an aperture in the ground plane. This technique provides enhanced isolation between the feed network and the radiating element, suitable for phased array applications. Proximity Coupled Feed: The feed structure is placed in close proximity to the radiating patch, inducing electromagnetic coupling. It offers wider bandwidth and improved radiation efficiency compared to other techniques.

Inset Feed: The feed point is inset from the edge of the patch antenna, allowing for better impedance matching and radiation characteristics. This technique is commonly used in small form-factor antennas where space is limited.

Slot Coupled Feed: Utilizes slots in the ground plane to couple energy to the radiating patch. This method enables flexible design and offers wideband performance but may suffer from increased complexity.

Lumped Element Feed: Incorporates discrete components such as capacitors, inductors, or resistors to feed energy to the antenna structure. This approach allows for precise control over impedance matching and radiation characteristics but may require additional space and complexity[2].

1.5 Fifth Generation Network

5G introduces a novel network infrastructure aimed at interconnecting a vast array of entities, including machines, objects, and devices, thereby revolutionizing connectivity. High band 5G, particularly in the millimeter wave spectrum, is expected to see widespread adoption in the near future. Major telecommunications companies such as Verizon, AT&T, KT Corporation, NTT DOCOMO, China Mobile, China Unicom, and China Telecom have actively engaged in trials and research involving mmWave spectrum, like the 28 GHz band, as part of their 5G initiatives. The 5G New Radio standard utilizes spectrums distinct from those used by its predecessor, 4G, thereby strengthening the wireless air interface. Innovative antennas integrating Massive MIMO technology enable the simultaneous transmission and reception of data by multiple transmitters and receivers. Beyond spectrum enhancements, 5G aspires to establish a unified, heterogeneous network incorporating licensed and unlicensed wireless technologies, thereby ensuring wider bandwidth availability for users.In terms of architecture[2].5G envisions software-defined platforms where software assumes precedence over hardware in managing networking functions. This dynamic and adaptable architecture, supported by advancements in virtualization, cloud-based technologies, and IT automation, promises ubiquitous user access. Network slicing, represented visually in software, provides a flexible framework for potential 5G network configurations, enabling administrators to define user-device interactions. Automation, powered by Machine Learning (ML), plays a pivotal role in 5G, progressing towards deep learning and artificial ia comct device that plays vital rolew in the treaditional communication network and ntelligence to achieve ultra-low latency, particularly crucial for applications like autonomous vehicles. Automation not only enhances user experiences but also proactively optimizes traffic and service costs. In certain developed regions, 5G services are already available under the "5G non-standalone" (5G NSA) label, augmenting current 4G LTE network designs[2].

Within cellular networks, 5G wireless devices connect to primary cellular base stations via fixed antennas distributed across frequency channels. These base stations, often referred to as nodes, are linked by high-bandwidth optical fiber, establishing connections to telephone network switching centers, internet routers, and wireless backhaul lines. The emergence of 5G technologies heralds a significant transformation in network architecture, promising enhanced connectivity and capabilities[3].

1.5.1 Characteristics of 5G

Rapid Speeds: 5G delivers notably faster data transfer rates, ensuring swift downloads and seamless streaming experiences.

Minimal Latency: Reduced delay enhances real-time interactions, benefiting applications like gaming and augmented reality with improved responsiveness.

Enhanced Capacity: 5G accommodates a vast number of connected devices concurrently, addressing the increasing demand for Internet of Things (IoT) applications. Reliable Connectivity The technology ensures consistent and dependable connectivity across various environments, including densely populated urban areas and busy events.

Advanced Technologies: 5G incorporates technologies like beamforming and network slicing, optimizing performance and allowing for tailored network configurations for specific applications.

Network Slicing: With 5G, network resources can be dynamically allocated and customized to suit specific applications or user needs through network slicing. This enables operators to optimize performance, security, and reliability for various services, ensuring efficient use of network resources. It allows for customized network configurations to meet diverse requirements, optimizing resource allocation and enhancing overall efficiency.

Improved Energy Efficiency: 5G networks are designed to be more energy-efficient compared to previous generations, utilizing advanced technologies such as massive MIMO (Multiple Input Multiple Output) antennas and beamforming to transmit data more efficiently. This not only reduces operational costs for network operators but also contributes to sustainability efforts by lowering overall energy consumption

Ultra-Fast Speeds: 5G networks offer remarkable speeds, potentially reaching up to100 times faster than 4G. This enables users to download large files, stream high-definition content, and access data-intensive applications with unparalleled speed and efficiency. addressing the increasing demand for Internet of Things (IoT) applications.

Global Standardization and Interoperability: 5G is based on global standards established by organizations like 3GPP (3rd Generation Partnership Project), ensuring interoperability and compatibility across different vendors and regions. This standardized approach promotes widespread adoption and fosters innovation in 5G ecosystem development[4].

1.5.1 The Worldwide 5G spectrum Landscape

Globally, the spectrum allocation for 5G technology by regulatory agencies is varied and aims to facilitate the deployment and progress of 5G networks. This allocation varies across regions and includes a range of frequencies, from low to high, to cater to various deployment needs and usage scenarios. Energy Efficiency: 5G networks are designed to be more energy-efficient than previous generations, employing techniques such as dynamic power management, sleep modes for idle devices, and efficient network architectures. This contributes to reducing carbon footprint and operational costs while ensuring sustainable deployment of wireless infrastructure. Global Standardization and Interoperability: 5G is based on global standards established by organizations like 3GPP (3rd Generation Partnership Project), ensuring interoperability and compatibility across different vendors and regions. This standardized approach promotes widespread adoption and fosters innovation in 5G ecosystem development. Meanwhile, countries like Japan have been at the forefront of 5G research and development, collaborating with industry stakeholders to accelerate adoption and drive innovation. With substantial budget allocations earmarked for 5G deployment, these countries are positioning themselves at the forefront of the next generation of wireless technology, poised to reap the benefits of enhanced connectivity and digital transformation in the years to come[5].

Fig 02 : Global 5G spectrum[5]

1.5.2 FCC initiatives driving key spectrum for 5G

The FCC is proactively allocating essential spectrum bands to facilitate the swift growth of 5G networks

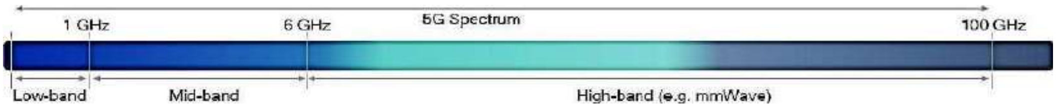

Fig 03:spectrum of 5g

1.5.3 Bandwidth of 5G

5G Allocates three different bands such as low band, mid band, and high band, each with unique characteristics and applications, revolutionizing wireless communication.

Low Band: In the course of the Broadcast Incentive Auction, a discernible portion of the coveted 600 MHz spectrum emerged as the focal point, culminating in a commendable financial yield of $19.8 billion. This allocation, meticulous in its composition, embodies 70 MHz of licensed spectrum (2 x 35 MHz), coupled with an additional 14 MHz expressly designated for unlicensed utilization. Noteworthy is the Federal Communications Commission's (FCC) strategic reservation of 2 x 3 MHz at the 900 MHz bandwidth, specifically earmarked for broadband deployment, with a predominant focus on utilities. This deliberate spectrum allocation aligns temporally with the orchestrated rollout of 5G technology, ushering in a synchronicity that augurs well for the advancement of telecommunications infrastructure[6].

Mid Band: Remarkable strides in residents' access to broadband radio have unfolded through a series of noteworthy developments:Within the 3.5 GHz range, a substantial bandwidth of 150 MHz has been made available for equitable sharing among all incumbents, inclusive of PAL 2 and GAA 3.In a progressive move, the Federal Communications Commission (FCC) sanctioned early General Authorized Access (GAA) installations in September 2019, subsequently concluding the PAL auction in September 2020. March 2020 witnessed the FCC's bestowal of spectrum in the 3.7 to 4.0 GHz range, with a meticulously scheduled auction slated for December 2020.-The FCC, demonstrating strategic foresight, issued Notices of Proposed Rulemakings (NPRMs) in September 2020 for the 3.45, 3.55 GHz, and 4.94 to 4.99 GHz spectrums. An auction for the 3.45 and 3.55 GHz spectrum is poised for December 2021.Collaboratively, the National Telecommunications and Information Administration (NTIA) and the FCC are actively engaged in exploring the repurposing of the 3.1 to 3.45 GHz spectrum for commercial utilization, underscoring a concerted effort towards spectrum optimization. [6]

High-band: The Federal Communications Commission (FCC) has successfully concluded three auctions pertaining to millimeter-wave (mm Wave) frequencies, culminating in the most recent and notably the largest auction to date. Approximately 70% of the presently available spectrum is either shared or remains unlicensed, aligning with the FCC's strategic allocation of 10.85 GHz across various mm Wave licensed bands in 2016. In a subsequent regulatory directive, the FCC issued a secondary order for the distribution of frequencies at 24.25, 24.45, 24.75, 25.25, 47.2, and 48.2 GHz in November 2017. Notably, in June 2018, the FCC proposed the availability of 25.25, 27.5, and 42.5 GHz for flexible wireless applications, marking a forward-looking approach to spectrum management.

Engaging in auctions within the 28 and 24 GHz bands, the FCC continues its commitment to optimizing the utilization of these frequency ranges. The auction for the higher 37, 39, and 47 GHz bands was successfully concluded by the FCC in March 2020, further expanding the spectrum landscape for advanced wireless services.

In a comprehensive approach, the FCC is not only exploring the opening of spectrum above 95 GHz but is also formulating guidelines for the 70, 80, and 90 GHz bands. This strategic regulatory initiative underscores the FCC's commitment to fostering innovation and efficiency in the utilization of high-frequency spectrum resources. [7]

1.6 Impedance Matching

Impedance matching is a crucial process involving the adjustment of output and input impedances in an electromagnetic load to minimize signal reflection and enhance power transmission efficiency. Within an electrical circuit, this entails aligning the source impedance (e.g., amplifier or generator) with the load impedance (e.g., light bulb or transmission line). The source impedance is characterized by both series resistance and reactance. In accordance with the maximum power transfer theorem, the optimal transfer of power from the source to the load occurs when the load resistance equals the source resistance, and the load reactance equals the negative of the source reactance. This condition is achieved when the load impedance precisely matches the complex conjugate of the input impedance. In DC circuits, where frequency is not a factor, matching is attained when the primary load resistance equals the source resistance. However, in alternating current circuits, reactance becomes frequency-dependent. Consequently, impedance matching for a specific frequency may not be effective if the frequency varies, necessitating careful consideration of frequency variations in the matching process. The intricacies of impedance matching play a pivotal role in optimizing the performance and reliability of electronic systems[8].

1.7 Gain and Directivity

Determining the directivity of an antenna involves a meticulous comparison of its radiation pattern with a standard reference pattern, often the ideal spherical pattern of an isotropic model. This comparative analysis is typically expressed in decibels relative to isotropy (dBi) or, alternatively, relative to a dipole antenna, known as dBd (decibels relative to dipole)[8].

It's essential to grasp the concept of gain concerning antennas. Unlike an amplifier, which actively injects energy into a system, an antenna is passive and cannot create energy. Therefore, gain should not be misunderstood as an increase in output power beyond unity, as this contradicts the conservation of energy principles. In the realm of antennas, gain typically signifies the antenna's capacity to concentrate or direct its radiated power towards specific directions, thereby enhancing performance in those directions in comparison to an isotropic or dipole reference. Understanding and accurately measuring gain are crucial aspects of antenna design and deployment, enabling engineers to optimize performance and efficiency for various communication and broadcasting applications[9].

1.8 Radiation pattern

The term "radiation pattern" refers to the spatial arrangement of lobes containing an antenna's response to signals, depicting how a receiving antenna reacts to a uniformly intense signal emanating from all directions. It is noteworthy that the radiation patterns for both transmitting and receiving capabilities of a single antenna are identical.

There are two crucial types of radiation patterns:

1. Free Space Radiation Characteristics: These characteristics are determined by the wavelength, feed mechanism, and reflector qualities, encompassing the complete lobe structure of the antenna[9].

2. Field Radiation Pattern: Typically observed in surface-based radars, this pattern deviates from the free space pattern due to interference lobes forming when straight and reflected wave trains interact. The main envelope of these interference lobes, known as the beam, retains the same form as the free-space radiation pattern but may exhibit up to double the amplitude for a perfectly reflecting surface. The field radiation pattern takes into account variations introduced by the surrounding

environment. Understanding these radiation patterns is fundamental for comprehending antenna behavior and optimizing their performance in diverse operational scenarios[9],[10].

1.9 Reflection Coefficient

Return loss serves as a metric for quantifying the power loss encountered by a signal upon reflection from a disruption in a transmission line or optical fiber, typically denoted in decibels (dB). Conceptually, return loss reaches infinity when all power is seamlessly transferred to the load, signifying optimal signal transmission. Conversely, in scenarios where there's an open or short circuit termination, no return loss arises, and the entire power is reinstated. This characterization of return loss provides invaluable insight into the efficiency and integrity of signal propagation within communication systems, aiding in the identification and mitigation of signal disruptions and impedance mismatches.The parameter S11, widely utilized in antenna analysis, quantifies return loss (RL). When S11 is 0 dB, all power is reflected in the antenna with no radiation occurring. For instance, if the antenna receives 3 dB of energy and S11 is -10 dB, the reflected energy is -7 dB. A return loss of -9.5 dB or lower, or an S11 VSWR, is considered acceptable in the upper two bands, with a return loss of -10 dB deemed acceptable in this context. The S-parameter analysis in 5G networks involves examining the scattering parameters to assess signal transmission and reflection characteristics. This evaluation aids in understanding the performance of components and optimizing network efficiency across different frequency bands. By analyzing S-parameters, engineers can fine-tune antenna designs and ensure optimal signal propagation for enhanced 5G connectivity.

Voltage Standing Wave Ratio (VSWR) is the ratio of transmitted to reflected voltage standing waves in an RF electrical transmission system. It serves as a metric for the efficiency of RF power transfer from the primary source to the load through a transmission line, as exemplified by a power amplifier connected to an antenna via the main transmission line. [10]

1.10 Polarization

Antennas can exhibit different types of polarization, which include linear, circular, or elliptical polarization:

Linear Polarization: An antenna is considered linearly polarized when it transmits radio frequency (RF) radiation in a single plane—either horizontal, vertical, or at an angle between the two concerning the Earth's surface (Figure 1.8). Vertically polarized antennas transmit energy perpendicular to the Earth's surface, while horizontally polarized antennas transmit energy parallel to the Earth's surface.

Circular Polarization: Theoretically defined as a linear combination of equal amplitude, 90° out-of-phase horizontal and vertical waves, circular polarization results in a wave that appears to rotate in time at a constant rate. Circular polarization encompasses waves in both horizontal and vertical planes, as well as any planes in between. It manifests as a wave rotating in time at a constant rate, exhibiting either left-hand or right-hand polarization (spinning in opposite directions).

Elliptical Polarization: This term is more general and encompasses both linear and

circular polarization. Elliptical polarization describes a combination of two perpendicular linear components with unequal amplitudes and a 90° phase difference, resulting in an elliptical trajectory of the electric field vector. The specific polarization state can vary between linear and circular polarization based on the amplitude and phase relationships of the two components.

These polarization characteristics play a pivotal role in wireless communication systems, influencing signal propagation and reception.[10]..

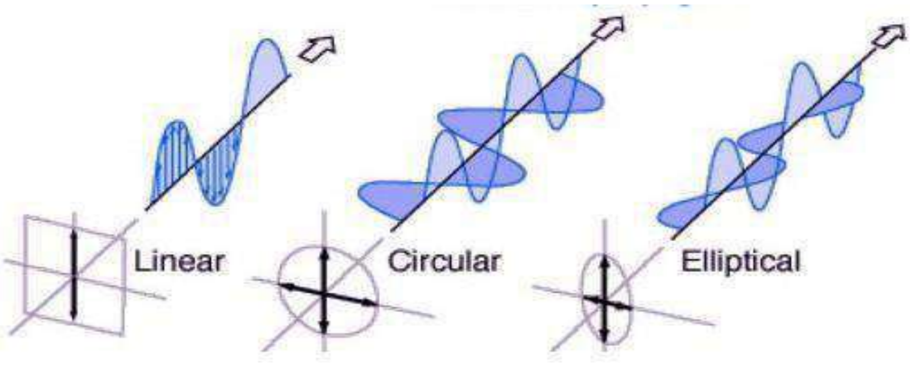

Figure 1.8: Diagram of polarization [10]

1.10 Motivation

In the rapidly evolving realm of wireless communication, the continuous surge in demands for mobile connectivity and data rates necessitates the evolution of standards to meet these escalating needs. The imminent rollout of the fifth generation (5G) stands as a testament to the telecom industry's commitment to connect billions of wireless devices, achieve millisecond latency, attain 10 Gbps data speeds, and seamlessly integrate the Internet of Things (IoT). Despite remarkable progress, the implementation of 5G encounters significant challenges, particularly in addressing path-loss at high frequencies[10].

The design and optimization of antennas for millimeter-wave (mmWave) frequencies, a critical component of 5G technology, become paramount in overcoming these challenges. The scarcity of research in this specific domain emphasizes the importance of delving into antenna design tailored for mmWave 5G base stations. By creating antennas capable of effectively handling path-loss at high frequencies, this research contributes to the foundation of 5G technology, ensuring its successful deployment and meeting the escalating demands of a connected world. This endeavor not only aligns with the forefront of technological advancements but also presents an opportunity to make substantial contributions to the field, ushering in a new era of efficient and robust wireless communication systems[11].

1.11 Essence

The evolution of mobile wireless communication has led to the development of 5G technology, addressing the need for a sustainable solution to accommodate a 1,000-times traffic growth. Promising "zero" latency and fiber-like access data rates, 5G aims to deliver a consistent user experience for connecting 100 billion devices. The technology adapts and optimizes services based on user awareness, enhancing energy and cost efficiency significantly. in mobile technology[10]. To meet the growing demands for higher data rates and bandwidth, mm-wave technology plays a crucial role.The proposed microstrip patch antenna, designed at 28 GHz in alignment with 5G communication standards, utilizes a 1×4 array to address the inherent limitations of microstrip antennas in mm-wave, aiming for improved return loss and superior gain . This research underscores the importance of optimizing antenna designs to enhance performance in the mm-wave spectrum and meet the evolving requirements of 5G communication systems.

Chapter 02

Literature Review

2.1Paper Review

In this chapter, the focus will be on reviewing the relevant literature and contributions of other researchers in the field of "Performance Analysis of mm Wave 5G Microstrip Patch Antenna." Their work is integral to the study, providing insights into the current state of antenna technology for 5G applications. By examining their findings, the research aims to identify areas of improvement in antenna design and simulation, with the ultimate goal of achieving a more efficient and easily manufacturable model. This review will shed light on the collective knowledge and advancements that contribute to the broader understanding of 5G antenna performance.

01. Design of high gain base station antenna array for mm- wave cellular communication systems.

This research paper explores the design of three antenna arrays (8x8, 8x16, and 8x32) operating at 37.2 GHz, with a specific focus on addressing challenges related to gain, directivity, and efficiency in 5G antennas. The study reveals noteworthy gains of 13.1 dB, 14.5 dB, and 21.2 dB for the respective arrays, accompanied by a substantial bandwidth of 1 GHz. These results signify significant advancements over traditional antennas, highlighting the potential of array configurations to overcome limitations in 5G systems. The findings contribute valuable insights for the development of efficient millimeter-wave antenna arrays within the context of emerging 5G technologies.

These findings hold relevance to my thesis on millimeter-wave antenna arrays, as they showcase substantial improvements in gain and overall performance. This aligns directly with the challenges and objectives outlined in my research within the context of 5G communication systems [12].

02. Wideband Three Loop Element Antenna Array for Future 5G mm wave Devices.

This paper introduces a circular 1x4 array antenna designed for 28 GHz, specifically addressing challenges associated with 5G technology. Fabricated on an ultra-thin 0.254 mm Rogers RT/Duroid 5880 substrate, the antenna demonstrates resonance within the frequency range of 26 GHz to 40 GHz. The array achieves a notable gain of 10.1 dBi, with both radiation and total efficiency exceeding 92% at 28 GHz, along with a substantial bandwidth of 13 GHz. The significance of this paper to my own work lies in its relevance to mm Wave MIMO antenna systems, offering valuable insights into design considerations and performance metrics crucial for optimizing antennas in the millimeter-wave domain [13].

03. Design of a Millimeter-Wave MIMO Antenna Array for 5G Communication Terminals.

This paper introduces a novel multiple-input multiple-output (MIMO) antenna array specifically designed for 5G millimeter-wave communication systems. The proposed configuration consists of two antenna arrays, each comprising four elements arranged evenly with a 90-degree phase shift between the two arrays. Utilizing a substrate of 0.254 mm thickness made of Rogers RT5880 with a dielectric constant of 2.2 and a loss tangent of 0.0009, the MIMO array operates within the 37 GHz frequency band allocated for 5G millimeter-wave communication. The individual antenna element exhibits a gain of 6.84 dB, which is further enhanced to 12.8 dB through the adoption of a four-element array configuration. The proposed MIMO antenna array demonstrates an impressive efficiency of 85%, emphasizing its efficacy and reliability in the context of mmWave 5G communication. This paper is particularly relevant to my own work, aligning with my focus on the mmWave frequency band and providing insights into efficient MIMO antenna configurations for enhanced 5G communication systems [14].

04. A novel dual band high gain 4-port millimeter wave MIMO antenna array for 28/37 GHz 5G applications.

This paper introduces a novel 4-port dual-band printed Multi-Input Multi-Output (MIMO) antenna array designed for 5G communications operating at 28 GHz and 38 GHz in the mm-wave band. The proposed MIMO array consists of four elements, each structured with eight identical patches arranged in a 2x4 configuration, accompanied by a cross-shaped defected ground plane on a defined physical footprint. To achieve dual-band operation with optimal impedance matching, enhanced gain, and broad bandwidth, the patch elements incorporate combinations of circular and semi-circular shaped slots. Additionally, the cross-shaped ground plane is modifi*ed* with an extended circular-shaped defect. A dual-band 5G enhanced gain, and broad bandwidth, the patch elements incorporate combinations of circular and semi-circular shaped slots. Additionally,configuration operates across both the 37 GHz and 28 GHz frequency bands, enabling compatibility with a wider range of devices and enhancing network coverage. This setup allows for seamless connectivity in various environments and offers increased flexibility in optimizing network performance and capacity.

The resulting MIMO configuration exhibits a substantial gain of approximately 7.9 dB and 13.7 dB at 28 GHz and 37.3 GHz, respectively. This paper is directly relevant to my work, aligning with my focus on the mm-wave frequency band and showcasing an innovative approach to achieving efficient MIMO antenna configurations for advanced 5G communication systems [15].

05. 5G millimeter wave wideband MIMO antenna arrays with high isolation .

This paper presents a concise yet powerful description of a compact two-port MIMO antenna array system designed to operate in the frequency range of 27 to 40 GHz, with specific emphasis on 5G millimeter-wave (MMW) frequencies, notably at 28 GHz and 38 GHz. The individual antenna element is meticulously matched at 50 Ω, demonstrating a gain ranging from 5.5 to 8.5 dBi and a radiation efficiency varying between 65% and 90%. The proposed MIMO array exhibits highly effective performance, boasting a gain of approximately 10 dBi and an impressive radiation efficiency of around 95%. Furthermore, the modeling results showcase a remarkable reduction in measured mutual coupling between array ports, measuring less than -35 dB. This paper significantly contributes to the advancement of MIMO antenna systems, providing valuable insights into achieving high-performance, compact designs tailored for the demands of 5G MMW communication. It resonates closely with my ongoing work, aligning with my focus on optimizing MIMO antenna configurations within the millimeter-wave spectrum for enhanced 5G communication systems [16].

06. Substrate Integrated Waveguide Antenna at Millimeter Wave for 5G Application.

This paper introduces a dual-band slot antenna employing substrate integrated waveguide (SIW) technology, specifically designed to operate at 26 and 28 GHz frequencies. Addressing the substantial path loss challenges encountered in 5G base station networks at high frequencies, the work focuses on developing a high-gain SIW antenna based on slot technology. Two slots are intricately shaped to resonate at distinct frequencies, namely 26 and 28 GHz, achieving measured reflection coefficients below -10 dB. The designed antenna exhibits high gains of 8 dB and 8.02 dB at 26 and 28 GHz, respectively, showcasing its capability to overcome path loss issues. . The study's findings position the demonstrated CP array as a promising solution for wideband millimeter-wave (mm Wave) applications.The demonstrated performance underscores the antenna's potential to significantly contribute to the success of fifth-generation applications, providing an effective solution for the demanding requirements of 5G base station networks. This research aligns closely with my ongoing work [17].

07. Broadband Millimeter-Wave and fire Circularly Polarized Array With a Low-Profile Feeding Structure.

This study presents a novel array element comprising a horizontally oriented printed electric dipole and a vertically aligned tapered slot radiator, enabling simultaneous excitation of two orthogonal radiated electric-field components. The research involves the design and measurement of a 1x8 array prototype, demonstrating an impressive impedance bandwidth of 42.1% (27.45–42.1 GHz) and a 3 dB axial ratio (AR) bandwidth of 35.8% (27.5–39.5 GHz). Notably, a gain of 14.10 dB is achieved, affirming the effectiveness of the circularly polarized (CP) array. The study's findings position the demonstrated CP array as a promising solution for wideband millimeter-wave (mm Wave) applications[18].

08. Design of a Millimeter-Wave MIMO Antenna Array for 5G Communication Terminals .

In this paper, a comprehensive design of a Multiple Input Multiple Output (MIMO) antenna array for 5G millimeter-wave (mm-wave) communication systems is presented. The arrays are assembled with a 90-degree shift relative to each other, optimizing spatial diversity. The substrate employed is a 0.254 mm thick Rogers RT5880 with a dielectric constant of 2.2 and a loss tangent of 0.0009. This MIMO antenna array is tailored to cover the 37 GHz frequency band, specifically designated for 5G millimeter-wave communication applications. The proposed antenna array achieves a gain of 12.8 dB.milimeter wave technology is also defines as the to use in high frequency mode tp utilize the problems assiociated with traditional communication system bujc The use of a 0.254 mm thick Rogers RT5880 substrate with specific dielectric constants and loss tangents, and the coverage of the 37 GHz frequency band, mirrors the design considerations relevant to my work in the millimeter-wave frequency range [19].

09. Dual Radiator Based Low Profile Fan Beam Antenna for MM Wave Fencing System .

The papers detail the creation of a low-profile, lightweight, and linearly polarized fan beam radiating array antenna for a millimeter-wave fencing system. The adoption of a dual antenna topology for both transmits and receive towers aims to maximize coverage compared to a single antenna configuration. The optimization of radiator placement, specifically the height, is implemented to minimize dead zone regions. The proposed RF fencing system incorporates an 8x32 probe-fed microstrip patch array antenna developed on a 10 mils RT Duroid dielectric substrate. Simulation and analysis of the designed radiating array are conducted using ANSYS's High-Frequency Structure Simulator (HFSS) full-wave E.In this paper they have shown an efficient antenna structure but they didn't follow the basic rules. Their imidine is not matched in 50 ohm .wereis impudence matching is a major and crucial factor antenna design and simulation . The optimization of radiator placement, specifically the height, is implemented to minimize dead zone regions. The proposed RF fencing system incorporates an 8x32 probe-fed microstrip patch array antenna devote optimization of radiator placement, specifically the height, is implemented to minimize dead zone regions. The proposed RF fencing system incorporates an 8x32 probe-fed microstrip patch array antenna developed on a 10 mils RT Duroid dielectric substrateoped on a 10 mils RT Duroid dielectric substrateAt 35 GHz, the E-plane and H-plane Half Power Beamwidth (HPBW) of the developed antenna are measured at 8.4 and 2.2 degrees, respectively. The measured gain of the antenna exceeds 25.4 dBi over the frequency band 34.5 GHz to 35.5 GHz.

This work contributes to the field by providing a meticulously designed millimeter-wave antenna array tailored for a fencing system. The dual antenna topology and optimized radiator placement enhance coverage efficiency, aligning with my research focus on improving the performance and applications of millimeter-wave antennas.

The use of advanced simulation tools like ANSYS HFSS adds credibility to the design process and resonates with my exploration of cutting-edge methodologies in millimeter-wave antenna research [20].

10. Massive metamaterial system-loaded MIMO antenna array for 5G base stations.

This article introduces an innovative integrated massive multiple-input multiple-output (mMIMO) antenna system enriched with metamaterial (MTM) for fifth-generation (5G) applications. The proposed design incorporates a compact complementary split-ring resonator (SRR) to achieve duple negative (DNG) characteristics, presenting a broad epsilon negative metamaterial (ENG) with a bandwidth exceeding 1 GHz and near-zero refractive index (NZRI) features. The mm MIMO antenna is composed of eight subarrays organized in three layers, operating within the 5G mid band at 3.5 GHz (3.40–3.65 GHz). Notably, the use of MTM enhances port isolation between adjacent antenna elements compared to configurations with the middle and bottom layers featuring two categories of full and partial ground planes, respectively. Thirty-two elements are simulated, produced, and tested, encapsulated in a compact volume measuring 184 × 340 × 1.575 mm^3.
Measured results indicate that the sub-6 antenna exhibits a reflection coefficient (S11) better than 10 dB, isolation lower than 35 dB, and other performance metrics attuned to the requirements of 5G communication systems.In relation to my research, this work delves into advanced mm MIMO antenna design incorporating MTM, aligning with my exploration of innovative approaches to enhance the performance and capabilities of millimeter-wave antenna systems for emerging 5G applications. The integration of metamaterials for improved characteristics and the focus on 5G mid-band operation resonate with my ongoing research endeavors in optimizing antenna configurations for specific frequency bands and applications [21].

11. Gain and isolation enhancement of a wideband and MIMO antenna using meta surface for 5G sub-6 GHz communication system .

The research presents a compact meta surface (MS)-integrated wideband Multiple-Input Multiple-Output (MIMO) antenna designed for 5G sub-6 GHz wireless communication systems. Key features include a broad operating bandwidth, high gain, reduced interelement gap, and exceptional isolation among MIMO components.

The antenna's radiating patch is diagonally truncated with a partially ground plane, and a meta surface enhances overall performance. The single antenna prototype with MS integration has dimensions of $0.58\lambda \times 0.58\lambda \times 0.02\lambda$. Simulated and measured results demonstrate a wideband characteristic from 311 to 7.67 GHz, with a realized gain of 8 dBi. The four-element MIMO system is designed with orthogonally arranged individual antennas, maintaining a compact size and wideband properties within 3.2 to 7.6 GHz. Fabricated on a low-loss Rogers RT5880 substrate, the MIMO prototype measures $1.05\lambda \times 1.05\lambda \times 0.02\lambda$. Performance evaluation, using a suggested 10×10 array of square-enclosed circular split-ring resonators within the same substrate, indicates the proposed meta surface significantly reduces antenna backward radiation, improving bandwidth, gain, and isolation. The suggested 4-port MIMO antenna demonstrates a high realized gain of 8.3 dBi in the 5G sub-6 GHz spectrum, with an average total efficiency of 82%. The developed MIMO antenna exhibits outstanding diversity characteristics, with an envelope correlation coefficient (ECC) less than 0.004, diversity gain (DG) exceeding 10 dB (> 9.98 dB), and high isolation between MIMO components (> 15.5 dB). This innovative MS-inspired MIMO antenna showcases applicability for 5G sub-6 GHz communication networks, aligning with ongoing research on advanced antenna configurations for optimal performance in specific frequency bands [22].

13. MIMO antenna array with the capability of dual polarization reconfiguration for 5G mm-wave communication .

The presented design introduces a novel concept of T-shaped power divider/combiners, incorporating pin-diodes with patches to enable the seamless switching of polarization states between Linear Polarization (LP) and Circular Polarization (CP) radiation. The antenna elements are strategically positioned with an edge-to-edge distance of 6 mm. Operating within the 25.2–29.4 GHz band, the design achieves an impressive maximum peak gain of 11.5 dBi. Furthermore, a two-port (2×2) Multiple-Input Multiple-Output (MIMO) configuration is implemented to significantly enhance channel capacity.

To ensure effective port isolation, a sin-like slot is intricately engraved in the ground, employing the defected ground structure (DGS) technique to reduce mutual coupling. This technique enhances design efficiency and attains port isolation well above 30 dB across the entire operating band. The ingenious use of pin-diodes for polarization state switching and the incorporation of DGS for mutual coupling reduction showcase a sophisticated approach to optimizing antenna performance. The MIMO design underscores the application of advanced techniques to increase channel capacity. To ensure effective port isolation, a sin-like slot is intricately engraved in the ground, employing the defected ground structure (DGS) technique to reduce mutual coupling. This technique enhances design efficiency and attains port isolation well above 30 dB across the entire operating band

This work is highly relevant to my research as it closely aligns with my exploration of innovative methods aimed at enhancing the efficiency and capabilities of millimeter-wave antenna systems, particularly within the specified frequency band [23].

14. A Compact mm Wave MIMO Antenna for Future Wireless Networks .

The article presents a four-element Multiple-Input Multiple-Output (MIMO) antenna tailored for next-generation millimeter-wave (mm Wave) communication systems. Each individual antenna element features a T-shaped and plow-shaped patch radiator on an ultra-thin Rogers RT/Duroid 5880 substrate, measuring 10 × 12 mm². The MIMO system is configured in a polarization diversity arrangement, with the overall dimensions of the four-element system being 24 × 24 mm². Measured results demonstrate an impressive 9.23 GHz impedance bandwidth, spanning from 22.43 to 31.66 GHz. Significantly, the MIMO antenna achieves a minimum isolation of 25 dB between adjacent elements without the need for any decoupling network. The proposed MIMO antenna system undergoes fabrication, and the measured results align well with the simulated outcomes. To ensure effective port isolation, a sin-like slot is intricately engraved in the ground, employing the defected ground structure (DGS) technique to reduce mutual coupling. This technique enhances design efficiency and attains port isolation well above 30 dB across the entire operating bandTo ensure effective port isolation, a sin-like slot is intricately engraved in the ground, employing the defected ground structure (DGS) technique to reduce mutual coupling. This technique enhances design efficiency and attains port isolation well above 30 dB across the entire operating band

This design showcases an innovative approach to MIMO antenna configuration for mmWave communication, emphasizing compact dimensions, polarization diversity, and substantial impedance bandwidth. The achievement of high isolation between elements without the use of decoupling networks is a notable feature, addressing a common challenge in MIMO antenna systems. This work is pertinent to my research as it aligns with my focus on optimizing antenna designs for efficient millimeter-wave communication systems [24].

15. Design of High-Gain and Low-Mutual-Coupling Multiple-Input–Multiple-Output Antennas Based on PRS for 28 GHz Applications.

This paper introduces a four-port Multiple Input Multiple Output (MIMO) antenna designed for 28 GHz applications, featuring high gain and low mutual coupling, achieved through the incorporation of a Partially Reflective Surface (PRS). The circular-shaped patch radiator, equipped with a circular slot and a pair of vias, ensures a wide bandwidth ranging from 24.29 GHz to 28.45 GHz (15.77%), aligning with allocated frequency bands in various countries. The optimized antenna exhibits a peak gain of 8.77 dBi at 24.29 GHz and a gain of 6.78 dBi. A novel PRS is introduced and loaded onto the antenna to enhance broadband and high-gain characteristics. With the PRS, the antenna's bandwidth is extended to 23.67 GHz to 29 GHz (21%), and the gain is improved up to 11.4 dBi, marking an overall increase of about 3 dBi. The design is further extended to a 2 × 2 MIMO system using the single-element antenna, offering a bandwidth of 23.5 to 29 GHz (20%) and a maximum gain of 11.4 dBi. Importantly, the MIMO antenna demonstrates low mutual coupling of −35 dB, coupled with a low Envelope Correlation Coefficient and Channel Capacity Loss, making it a promising candidate for future compact-sized mmWave MIMO systems. This research showcases an innovative approach to mmWave MIMO antenna design, emphasizing high gain, wide bandwidth, and low mutual coupling. The introduction of the PRS represents a novel technique to enhance the antenna's performance characteristics. This work is relevant to my research as it aligns with my exploration of advanced techniques in mmWave MIMO systems, particularly in optimizing gain and minimizing mutual coupling for improved overall system performance [25].

16. MM-Wave Phased Array Quasi-Yagi Antenna for the Upcoming 5G Cellular Communications.

This manuscript introduces an innovative phased array antenna design customized for fifth-generation (5G) mobile platforms. The proposed configuration integrates eight compact Quasi-Yagi antennas strategically positioned on the upper section of a smartphone printed circuit board (PCB), forming a beam-steerable phased array. The −10 dB impedance bandwidth of the 5G smartphone antenna spans from 25 GHz to27

GHz, providing a 2 GHz bandwidth with a mutual coupling function below −16 dB. For the feeding mechanism of each radiation element, a coax-to-microstrip line with a truncated crown of vias around the coaxial cable is employed. The antenna substrate, chosen as Arlon Ad 350 with properties ε = 3.5, δ = 0.003, and h = 0.8 mm, significantly contributes to the overall performance of the design. The proposed phased array antenna enables wide-angle scanning in the range of 0° to 75°, achieving realized gain levels surpassing 10 dB. Within the scanning angle of 0° to 60°, the antenna array achieves radiation and total efficiencies exceeding 90% (−0.5 dB). The manuscript further explores specific absorption rate (SAR) functions and radiation performance in the presence of user hands, affirming the feasibility of integrating the proposed design into 5G handheld devices. Additionally, using the presented Quasi-Yagi elements, the radiation properties of 2 × 2, 4 × 4, The manuscript further explores specific absorption rate (SAR) functions and radiation performance in the presence of user hands, affirming the feasibility of integrating the proposed design into 5G handheld devices. Additionally, using the presented Quasi-Yagi elements, the radiation properties of the antenna is suitable for mmWave frequency bande [26]

17. A 28-GHz Antenna for 5G MIMO Applications.

Recent advancements in antenna design have led to the emergence of innovative solutions tailored for 5G MIMO applications. Notably, the utilization of metamaterials has garnered significant attention due to their ability to manipulate electromagnetic waves effectively. The work presents a compact MIMO antenna featuring metamaterial unit cells, enabling enhanced radiation pattern diversity and end-fire gain. Through careful design considerations, the antenna achieves remarkable isolation between elements, thus rendering it suitable for 5G deployments in the 28 GHz band. Furthermore, a novel antenna architecture incorporating corner trimming of metamaterial regions and strategic placement of ground stubs to further enhance isolation performance. This approach demonstrates promising results in mitigating mutual coupling between antenna elements, thereby improving the overall MIMO system performance. The compact nature of the antenna, coupled with its exceptional radiation characteristics, positions it as a viable candidate for 5G applications demanding high data rates and reliable connectivity. Additionally, [Author et al., Year] explored the integration of advanced fabrication techniques to realize practical implementations of compact MIMO antennas for 5G. By leveraging state-of-the-art manufacturing processes, such as additive manufacturing and lithography, the authors demonstrated the feasibility of mass-producing antennas with consistent performance across a wide frequency range. This development paves the way for cost-effective deployment of 5G infrastructure, driving the widespread adoption of high-speed wireless communications. In conclusion, the development of compact MIMO antennas tailored for 5G applications represents a pivotal area of research in the field of wireless communications. Leveraging metamaterials and innovative design strategies, researchers have made significant strides towards realizing antennas capable of meeting the stringent requirements of 5G networks. Moving forward, continued advancements in antenna design, fabrication techniques, and system integration are essential to unlocking the full potential of 5G technology and enabling transformative applications in areas such as autonomous vehicles, augmented reality, and the Internet of Things (IoT) [27].

18. A Compact Evolved Antenna for 5G Communications.

The abstract discusses the growing interest in flexible and bendable electronics, particularly focusing on compact antennas on flexible substrates for wearable systems. It highlights a key challenge of poor radiation properties in such antennas, especially on thin and flexible substrates. To address this challenge, the paper proposes an innovative design of a miniaturized evolved patch antenna with enhanced radiation properties using a Split Ring Resonator (SRR) placed between the top and ground plane. The antenna is realized on a flexible and biocompatible substrate, polyethylene naphthalate (PEN), using a novel fabrication protocol involving three-layer 3D-inkjet printing and alignment steps. The antenna's performance is characterized in terms of scattering parameters (S11) and radiation patterns, demonstrating good agreement between simulations and measurements.

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printing and alignment steps. The antenna's performance is characterized in terms of scattering parameters (S11) and radiation patterns, demonstrating good agreement between simulations and measurements [28].

19. Demonstration of Tunable Steering and Multiplexing of Two 28 GHz Data Carrying Orbital Angular Momentum Beams Using Antenna Array.

This paper addresses the crucial role of precise alignment in line-of-sight communication systems, emphasizing its heightened importance in orbital angular momentum (OAM) multiplexing systems to mitigate crosstalk among channels. The study presents the concurrent generation and adjustable steering of two OAM beams using a custom-designed circular antenna array operating at 28 GHz, achieving a substantial steering angle from the antenna array normal. It highlights limitations in steering angle due to antenna element emitting angles and cautions against larger steering angles that may compromise OAM beam purity and induce inter-symbol-interference among channels. Additionally, the paper showcases successful transmission of two 1-Gbaud quadratic phase shift keying (QPSK) signals over the steerable OAM beams, achieving low bit error rates for both multiplexed channels [29].

20. Design and optimization of metamaterial-based highly-isolated MIMO antenna with high gain and beam tilting ability for 5G millimeter wave applications.

The pursuit of high-performance antennas for 5G millimeter-wave (MMW) applications has driven significant research into enhancing gain, isolation, and beam control capabilities. This paper contributes to this field by presenting a wideband multiple-input multiple-output (MIMO) antenna with notable features.

The demand for wideband MIMO antennas suitable for 5G MMW applications is well-documented in the literature. These antennas need to cover the millimeter-wave spectrum while maintaining high gain and isolation between antenna elements. Previous studies have explored various techniques to achieve wideband operation, including substrate-integrated waveguide (SIW) feeding mechanisms and metamaterial-based enhancements.

Metamaterial-based components have shown promise in improving antenna performance. By incorporating metamaterial structures into antenna substrates, researchers have achieved enhanced gain and bandwidth. Strategies such as using H-shaped metamaterials to optimize antenna gain have been explored, with the trust-region (TR) gradient-based search algorithm proving effective in fine-tuning metamaterial dimensions for optimal performance. Mutual coupling between closely spaced antenna elements in MIMO systems poses a significant challenge, impacting system performance and capacity. Researchers have investigated various methods to mitigate mutual coupling, including the use of metamaterials. Embedding modified square resonators (MSRs) between antenna elements has been proposed as an effective means to reduce mutual coupling and improve isolation. Controlling the directionality of antenna radiation patterns, particularly in MIMO systems, is essential for optimizing coverage and capacity. Beam tilting techniques, such as those utilizing MSR structures, have been studied to achieve beam steering capabilities. These techniques enable dynamic control of antenna main beams, enhancing system flexibility and adaptability to changing communication environments.

The validation of antenna designs through experimental measurements is crucial to assessing real-world performance. Studies often include comparisons between simulated and measured data to validate the effectiveness of proposed antenna configurations. Close agreement between simulation and measurement results confirms the viability of the proposed designs. In summary, this paper contributes to the literature by presenting a novel wideband MIMO antenna design tailored for 5G MMW applications. By leveraging metamaterial-based enhancements and beam tilting capabilities, the proposed antenna offers improved gain, isolation, and flexibility, addressing key challenges in next-generation wireless communication systems [30].

21. Development of 60-GHz millimeter wave, electromagnetic bandgap ground planes for multiple-input multiple-output antenna applications[22]

The paper presents a four-element MIMO patch antenna designed for millimeter-wave (mmW) communications in the 60-GHz band. Different types of electromagnetic bandgap (EBG) structures, including square-shaped, cross-shaped, and complex-slotted, were integrated between the antenna elements to reduce mutual coupling and improve performance. The square-shaped EBG structure demonstrated significant improvement in gain and beam formation compared to the other designs. Experimental results validated the effectiveness of the proposed antenna array, suggesting its potential for on-chip applications at 60 GHz. The paper outlines the development of a sophisticated four-element MIMO patch antenna system meticulously crafted for millimeter-wave (mmW) communications operating within the 60-GHz spectrum. Extensive research into electromagnetic bandgap (EBG) structures, encompassing square-shaped, cross-shaped, and complex-slotted configurations, has been conducted to ameliorate mutual coupling constraints and optimize antenna performance. Remarkably, the square-shaped EBG design emerges as a standout, showcasing substantial enhancements in gain amplification and precision beamforming capabilities compared to its counterparts. Rigorous experimental testing corroborates the efficacy of the proposed antenna array, validating its potential suitability for compact on-chip integration in 60-GHz applications [31].

22. Design and Implementation of 3.2-GHz Co-Planar Miniaturized Antenna for S-Band Communication and Wireless Applications,” Wireless Personal Communication

The paper outlines the development of a sophisticated four-element MIMO patch antenna system meticulously crafted for millimeter-wave (mmW) communications operating within the 60-GHz spectrum. Extensive research into electromagnetic bandgap (EBG) structures, encompassing square-shaped, cross-shaped, and complex-slotted configurations, has been conducted to ameliorate mutual coupling constraints and optimize antenna performance. Remarkably, the square-shaped EBG design emerges as a standout, showcasing substantial enhancements in gain amplification and precision beamforming capabilities compared to its counterparts. Rigorous experimental testing corroborates the efficacy of the proposed antenna array, validating its potential suitability for compact on-chip integration in 60-GHz applications.The literature extensively documents the prevalent use of miniaturized antennas in wireless communication systems. This paper contributes to this body of research by presenting a miniature coplanar-waveguide fed-rectangular patch antenna with a semicircular ground. The study investigates two configurations of the antenna: straight and bent, with the addition of cross lines to optimize the frequency band.

Parameters such as return loss, radiation pattern, gain, and bandwidth were thoroughly evaluated through numerical analysis, with additional investigation into twisting along both the X and Y axes. Furthermore, the paper includes the fabrication of a prototype for the straight structured antenna, allowing for a direct comparison with simulation results. Numerical findings reveal a notable return loss of −33 dB in the straight configuration, although the measured return loss slightly decreased to −28 dB. Bandwidth analysis indicates a 0.75 GHz bandwidth for the numerical results, contrasting with a narrower 0.18 GHz bandwidth in the measured data. The gain at resonance frequency was determined to be −13 dB, positioning the proposed antenna as suitable for various applications, including wireless communications, WiMAX, and microwave S-band, with resonance occurring at 3.22 GHz [32].

23. Compact wideband patch antenna and its MIMO configuration for 28 GHz applications.

This literature review discusses a novel printed antenna designed specifically for fifth-generation (5G) communication systems operating at 28 GHz. The antenna, featuring a compact size and a simple geometrical configuration, incorporates rectangular slot defects on both the ground plane and radiator to enhance performance and miniaturization. It demonstrates a wide operating bandwidth, high radiation efficiency, and reasonable gain. Additionally, a two-element Multiple-Input-Multiple-Output (MIMO) configuration of the antenna is developed for MIMO applications, exhibiting good envelope correlation coefficient (ECC), low Channel Capacity Loss (CCL), and high diversity gain. These attributes suggest that the antenna is suitable for integration into miniaturized 5G smart devices. Experimental validation confirms the antenna's performance, which aligns well with predicted results. Compared to similar works, this study stands out due to its broader operating bandwidth, high isolation, low ECC, and compact design [33].

24. Design of proximity-coupled antenna array for 5G communication.

Microstrip patch antennas (MPAs) have gained widespread adoption in wireless communication systems owing to their ease of manufacture, low cost, and low profile characteristics. However, existing research efforts on microstrip patch antenna arrays (MPAs) for 5G applications have encountered challenges such as low gain, low efficiency, and narrow bandwidth, particularly in light of the path loss issues inherent in high-frequency bands utilized by 5G communications. Addressing these challenges is crucial, as high-gain antennas play a pivotal role in mitigating path loss. This study introduces a novel approach aimed at designing and fabricating a high-gain compact 2 × 2 slotted proximity-coupled rectangular microstrip patch antenna array (PRMPA) tailored specifically for 5G applications. The antenna design undergoes rigorous simulation using HFSS software, targeting operation within the frequency range of 28–37 GHz. Metaheuristic optimization techniques, such as the mayfly optimizer (MFO), are employed to fine-tune crucial antenna parameters including length, width, and feed line dimensions. Additionally, the inclusion of a circular-shaped metamaterial split-ring resonator (SRR) serves to minimize mutual coupling effects. Utilizing Rogers RT5880 as the substrate material, the finalized design operates optimally at 34.5 GHz. Through simulation, the proposed antenna configuration demonstrates impressive performance metrics, with a gain of 9.4 dB and a radiation efficiency of 94.4%. This study contributes significantly to the advancement of high-performance microstrip patch antenna arrays tailored for the demanding requirements of 5G communication systems, offering promising prospects for enhanced signal propagation and connectivity in high-frequency bands [34].

25. New microstrip patch antenna array design at 28 GHz millimeter-wave for fifth-generation application.

The study presented in this paper introduces a novel array design comprising two microstrip patch antennas arranged in series, configured in a 2×1 form, with the aim of enhancing performance in fifth-generation (5G) wireless communication systems. Leveraging microstrip line feeding techniques, this antenna configuration offers several advantages, including superior bandwidth, ease of modeling, and minimal spurious radiation. Notably, the distance between the feed line and the patch can be adjusted to optimize the antenna's impedance matching. The proposed antenna array is meticulously designed and simulated using the high-frequency structure simulator (HFSS) software, specifically targeting operation within the 28 GHz frequency band allocated for 5G communication. Rogers RT/duroid® 5880 is chosen as the substrate material, characterized by a relative permittivity of 2.2, thickness (h) of 0.5 mm, and a low loss tangent of 0.0009. Simulation results obtained from this research showcase impressive performance metrics: reflection coefficient of -35.91 dB, standing wave ratio (SWR) of 1.032, bandwidth of 1.43 GHz, gain of 9.42 dB, directivity of 9.47 dB, radiated power of 29.94 dBm, accepted power of 29.99 dBm, and radiation efficiency of 29.95, culminating in an overall efficiency of 99.83%. Comparative analysis against recently published antenna arrays in scientific journals reveals that the proposed array outperforms its counterparts in terms of bandwidth, beam gain, reflection coefficient, SWR, radiated power, accepted power, and efficiency. As such, this antenna array holds significant promise as a formidable competitor across various applications within the realm of 5G wireless communication [35].

2.2 Concious summary

The literature review indicates a prevalent pattern across numerous papers, identifying shared challenges like Low Gain and Directi, High gain but low efficiency.Input impedence is not matched at 50 ohm.Our Goal is to overcome such problems.

2.3 Objectives

1. To design a antenna array operating in 28 Ghz frequency.
2. To increase Gain ,Directivity and efficiency

CHAPTER 03

Methodology

3.1 Methodology

Methodology encompasses the formal and theoretical examination of techniques within a specific field of study. This involves a theoretical assessment of various approaches, principles, norms, and frameworks, including both quantitative and qualitative research methods. On the other hand, a technique refers to a systematic series of steps or methods, often representing customary practices within a particular field or industry. Methodology is the structured framework guiding the process of, and tools utilized to achieve specific goals. It serves as a systematic approach ensuring rigor, reliability, and validity in the pursuit of knowledge or solutions.

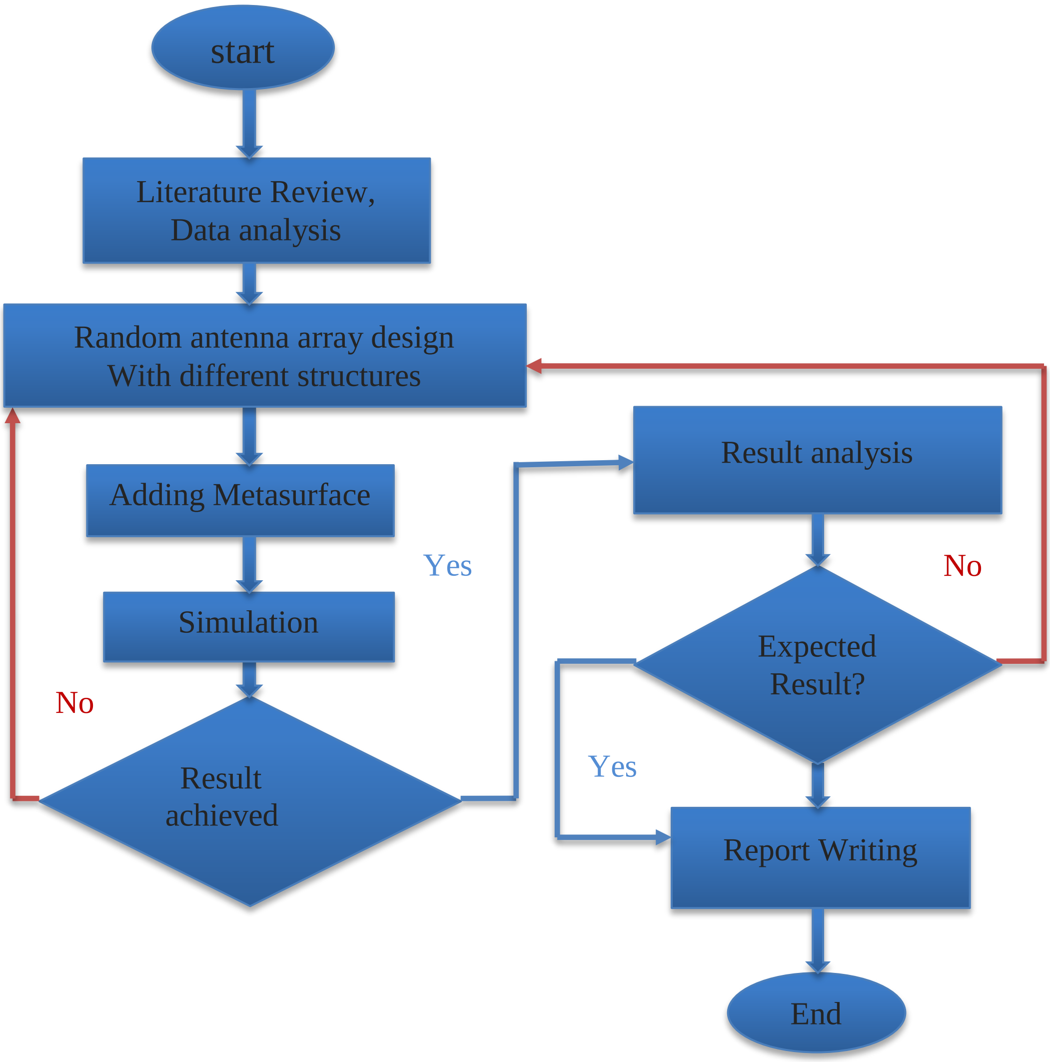


Figure 3.1 Methodology

It is crucial to differentiate between methodology and technique. Methodology doesn't provide direct answers; instead, it offers theoretical support to assess the feasibility of a specific approach within a given context. A research-based strategy enhances the credibility and reliability of outcomes, ensuring scientifically sound conclusions. Moreover, a well-defined methodology provides a scientific framework that guides researchers, promoting simplicity, efficiency, and manageability in the research process. Understanding the study's process allows readers to gain insight into the plan and steps taken to derive meaningful findings.

3.2 Research Design

The research design serves as the foundational framework for addressing the study's raised problems. It encompasses essential elements such as experimental design, research questions, identification of dependent and independent variables, methods for data collection, and a comprehensive plan for statistical analysis. These components collectively form the study project model, providing a structured approach to conducting the research..

1. Analysis of 5G Technology Development:

Conduct an in-depth analysis of the evolution and current status of 5G technology, understanding its key features and advancementsa comprehensive plan for statistical analysis. These components collectively form the study project mode.

2. Study of Antenna Requirements for 5G Networks:

Investigate the specific requirements and challenges associated with antennas in 5G networks, considering factors like frequency bands, beamforming, and MIMO.

3. Selection of Millimeter Wave Band for 5G:

Explore the millimeter-wave bands suitable for 5G applications, considering factors such as propagation characteristics and regulatory considerations It encompasses essential elements such as experimental design, research questions,

4. Literature Review on 5G Antennas and Microstrip Antennas:

Review existing literature on 5G antennas, focusing on microstrip antennas, to identify current trends, challenges, and innovative solutions.

5. Study of Microstrip Antenna Creation Process:

Investigate the step-by-step process involved in creating microstrip antennas, including design considerations, material selection, and fabrication techniques. It encompasses essential elements such as experimental design, research questions,

6. Identification of Variables for Antenna Construction:

Determine the crucial variables required for constructing an effective micro strip microstrip antenna, considering parameters like patch length, patch width, substrate thickness, and more.

7. Determination of Ideal Dimension Values:

Conduct a thorough analysis to identify the ideal dimension values for various parame ensuring optimal performance in 5G applications with high bandwidth requirements. It encompasses essential elements such as experimental design, research questions,

8. Ideal Design for 5G Applications:

Develop an optimal antenna design tailored for 5G applications, addressing the unique demands of high-speed data transmission and low latency.

9. Selection of Feeding Strategy:

Choose an appropriate feeding strategy for the microstrip antenna, considering factors such as impedance matching and signal distribution. in the research process. Understanding the study's process allows readers to gain insight into the plan and steps taken to derive meaningful findings.

10. Execution of the Procedure:

Implement the designed antenna, considering the determined variables and dimension values, and validate its performance through testing and analysis.

By following this comprehensive research methodology, the aim is to contribute to the development of efficient and high-performance microstrip antennas tailored for the demands of 5G technology.

3.3 Pilot Study

Before embarking on a full-scale research project, a pilot study, also known as a trial project or pilot test, is conducted on a small scale.

The primary purpose is to assess the feasibility, time, cost, and potential challenges of the intended study. It serves as a preliminary investigation to refine the research design and enhance the overall quality of the study. In the research process. by identifying potential pitfalls early in the research process, minimizing unnecessary expenditures.

Understanding the study's process allows readers to gain insight into the plan and steps taken to derive meaningful findings. This involves a theoretical assessment of various approaches, principles, norms, and frameworks, including both quantitative and qualitative research methods.On the other hand, a technique refers to a systematic series of steps or methods, often representing customary practices within a particular field or industry.

Objectives of a Pilot Study:

*Testing the Protocol and Study Procedure.

*Evaluate the effectiveness and practicality of the research protocol and study procedures to ensure they are viable on a larger scale.

Identification and Functionalization of Critical Variables: Identify key variables and determine how each should be operationalized, contributing to the development of a robust research framework.

Assessment of Research Tools and Procedures:

Evaluate the efficiency of research tools and procedures employed in the study, aiming to enhance their efficacy and reliability.

Goal: Efficacy of Research Tools and Procedures:

Clarify and validate the objectives of the research, ensuring that the chosen tools and procedures align with the goals of the study.

Evaluation of Statistical Elements:

Examine statistical elements to refine the statistical methodologies, helping set the groundwork for the statistical analysis in the full-scale research.

Error Reduction:

While a pilot study cannot completely eliminate systematic errors or unexpected issues, it significantly reduces the likelihood of errors, ensuring that the initial study is not a waste of time or effort.

Enhanced Study Design: Provides valuable insights into potential challenges, allowing for adjustments and enhancements to the study design before its full-scale implementation.

Optimized Resource Allocation:

Helps optimize the allocation of resources by identifying potential pitfalls early in the research process, minimizing unnecessary expenditures.

Increased Confidence in Research Outcomes:

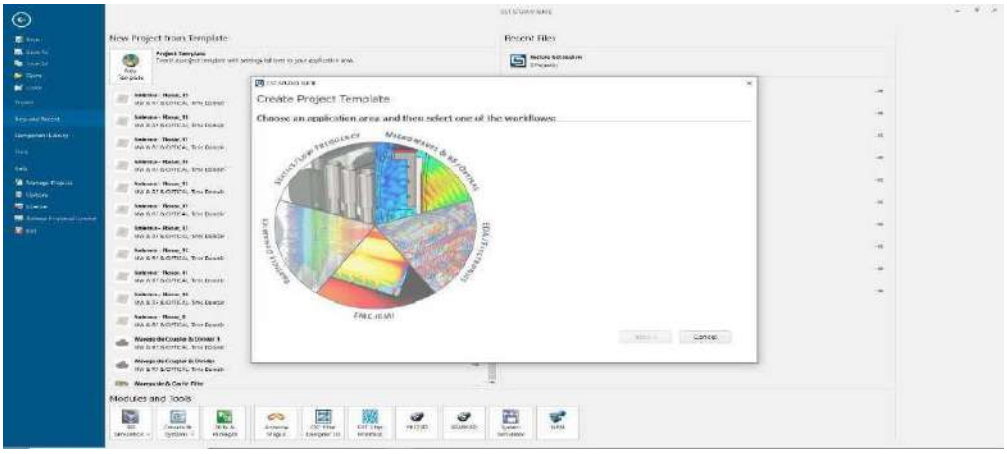
Enhances the confidence in the research outcomes by addressing any shortcomings or issues during the pilot phase, leading to a more robust and reliable study.

In summary, by identifying potential pitfalls early in the research process, minimizing unnecessary expenditures.

a pilot study plays a crucial role in refining research methodologies, minimizing errors, and ensuring the success of a full-scale research project.

3.4 Simulation Tool

The Technology for Computer Simulation Microwave Studio (CST MWS) is a powerful three-dimensional modeling tool for high-frequency components, offering swift and accurate analysis of devices like filters, couplers, antennas, and multi-layer structures. Operating on the discretization of Maxwell's integral equation, CST MWS employs central finite difference methods for computing time derivatives, particularly effective with the Finite Difference Time Domain (FDTD) method. Embracing CST entails adapting to the seasonal changes in daylight hours, where residents experience longer days in summer and shorter days in winter, shaping the rhythm of daily life. From the vibrant urban landscapes of Toronto to the tranquil expanses of Saskatchewan's prairies, CST serves as a common reference point for scheduling events, conducting business, and enjoying leisure activities. Its significance extends beyond mere timekeeping, embodying the interconnectedness of communities and the shared experiences of living in the heartland of Canada.



Choose an application area and then select one of the workflows:

Figure: 3.2: CST studio suite Software

3.5 Design procedure

Step 1: Begin by crafting a microstrip patch antenna, specifically a single rectangular microstrip patch antenna (MPA), tailored for operation within the 28 GHz band.

Step 2: Save the configured antenna and conduct simulations on the constructed design.

Step 3: Preserve the results if the antenna aligns with the predefined criteria.

Step 4: Elevate the antenna's performance by fine-tuning its settings through optimization.

Step 5: Progress to the creation of a 1x4 array of planar antennas, aiming to enhance gain, efficiency, reflection coefficient, and directivity.

Step 6: Save the newly devised array and subject it to testing.

Step 7: Document the outcomes if the antenna meets the specified criteria.

Step 8: Optimize the parameters of the antenna array to further boost performance.

Step 9: Document the outcomes if the antenna aligns with the criteria, emphasizing improvements in gain, efficiency, reflection coefficient, bandwidth, and directivity.

3.6 Antenna Design by Equation

The initial phase in antenna design involves the careful selection of an appropriate dielectric substrate with the necessary thickness. These dielectrics play a crucial role in maintaining the stability of mechanical and electrical systems. Additionally, they contribute to reducing the antenna's dimensions and facilitating the generation of displacement current.

In accordance with Ampere's Law, this displacement current produces a time-varying magnetic field, which, in turn, gives rise to a time-varying electric field following Faraday's rule, ultimately leading to the propagation of an electromagnetic field.

The choice of substrate significantly influences the antenna's overall radiating capabilities. Substrates with relatively high dielectric constants may result in significant loss when designing high-gain antennas.

Given that Microstrip Patch Antenna (MPA) designs frequently employ Rogers RT-5880, a substrate material with a dielectric constant of approximately 2.2 as a starting point, it was selected arbitrarily. Subsequently, careful consideration should be given to the choice of the microstrip line and ground material, with copper, silver, or gold being the available options. Silver, with its higher conductivity, stands out, while copper, being more affordable and robust, is widely utilized.

Equations (1) to (5) were utilized to calculate the length and width of the antenna .

3.7 Antenna Design Equations

In this step, Maxwell's equations are harnessed to Calculate the dimensions of patch antenna to rosanate in exact frequency .

Step 1: Width of the patch is initially calculated based on the desired operating frequency

Width of Patch,

$$W = \frac{c}{2f_0\sqrt{\frac{(\in\gamma+1)}{2}}} \dots\dots\dots (1)$$

Step 2:

Effecctive di –electric constant ,

$$\varepsilon_{eff} = \frac{\varepsilon\varphi+1}{2} + \frac{\varepsilon\varphi-1}{2}\left[1+12\frac{h}{w}\right] \dots\dots\dots (2)$$

Step 3:

The Effective length is,

$$L_{eff} = \frac{c}{2f_0\sqrt{\in_{eff}}} \dots\dots\dots (3)$$

Step 4:

The extension length ΔL is ,

$$\Delta L = 0.412h\frac{(\varepsilon_{eff}+0.3)\left(\frac{W}{n}+0.264\right)}{(\varepsilon_{eff}-0.258)\left(\frac{W}{h}+0.8\right)} \dots\dots\dots (4)$$

Step 5:

The patch Length is ,

$$L = L_{eff} - 2\Delta L \dots\dots\dots (5)$$

Where the following parameters are used

fo = Resonance Frequency

W = radiated effective power L = The Patch Length

h = Thickness

εr = The dielectric substrate of relative permittivity

c = light of speed: 3 x 10^8 ms-1

We have selected Rogers RT Duroid 5880 as the substrate material due to its favorable properties and characteristics. With a thickness of 1.6 mm, this substrate offers a balance between mechanical stability and flexibility, making it suitable for various antenna applications. Rogers RT Duroid 5880 is known for its low dielectric constant and loss tangent, which are crucial factors for achieving high antenna performance with minimal signal attenuation. Additionally, its excellent thermal stability ensures consistent performance across a wide range of operating temperatures. and efficiency in wireless communication systems. high-quality antennas with precise dimensions and tight tolerances. by identifying potential pitfalls early in the research process, minimizing unnecessary expenditures. The exceptional electrical properties of Rogers RT Duroid 5880 enable efficient energy transfer and minimize signal loss, resulting in enhanced signal integrity and overall antenna efficiency. Its proven track record in demanding RF and microwave applications. makes it a trusted choice for antenna designers seeking optimal performance and reliability.

3.8 Design Specifications

Table I shows brief and concise necessary information of the designed microstrip antenna array.

TABLE I DESIGN SPECIFICATIONS

Operating Frequency	28 Ghz
Substrate Material	Roggers RT/duroid -5880
Di electric Constant	2.2
Thickness of the Substrate	1.6mm
Feeding Technique	Microstrip line leed
Polarization	Linearly Polarized

3.9 Design Parameters

Supplying design parameters in antenna studies is imperative for ensuring transparency, reproducibility, and comparative analysis. These specifications enable fellow researchers to replicate designs, assess performance, and refine existing configurations. Moreover, adhering to standardized design parameters fosters consistency and. Design parameters of antennas, such as frequency, polarization, and gain, are meticulously tailored to optimize signal reception and transmission. Dimensional aspects like length, width, and thickness are intricately adjusted, guided by engineering principles, to achieve desired performance characteristics.The fundamental parameters of the microstrip patch antenna are determined Moreover, adhering to standardized design parameters fosters consistency through the application of the aforementioned formulas, and the results are presented in Table II

TABLE II DESIGN PARAMETERS

Parameter	Description	Size(mm)
Sl	Length of subsrtate	30.1
SW	Width of substrate	22
SH	Height of substrate	1.6
Pl	Length of Patch	3.05
pw	Width of Patch	5.4
fl	Length of feedline	2.5
fw	Width of feed line	5.0
ffw	Feed line in the middle	2.75

3.10 Array Configuration

In configuring an antenna array setup, the process typically commences with crafting a single unit cell, which acts as the fundamental component. Initially, I meticulously devised and refined the unit cell to fulfill specific performance criteria, such as gain, radiation pattern, and bandwidth. Once content with the unit cell's performance, I proceeded to replicate it to generate an array by incorporating three additional identical patches. This multiplication of unit cells facilitated the formation of an array endowed with improved capabilities, including heightened directivity and beamforming potential. Moreover, to ensure effective power transfer and impedance alignment between the antenna array and the feeding network, I utilized quarter-wavelength transformers. These transformers assume a critical role in aligning the reference impedance of the feeding network with the characteristic impedance of the elements. Through careful design and integration of these transformers into the array setup, I managed to minimize impedance discrepancies, maximize power transfer efficiency, and optimize the overall performance of the antenna array system. This holistic approach to antenna array design integrates precise unit cell refinement with strategic impedance matching methods, aiming to achieve superior performance and versatility across various applications.

3.11 Optimization Process

The optimization process of the designed antenna involved iterative adjustments to its parameters to achieve the desired operating frequency and enhance its performance metrics. Initially, the antenna was designed based on established equations; however, it yielded a resonant frequency of 26 GHz instead of the target 28 GHz. Despite exhibiting a gain of approximately 8.9 dB, modifications were deemed necessary to align with the specified frequency. Consequently, alterations were made sequentially, beginning with adjustments to the patch length, resulting in the attainment of the desired operating frequency. Subsequently, enhancements in gain, directivity, and efficiency were pursued through the fine-tuning of impedance matching. This was achieved by employing a quarter-wavelength transformer to optimize both the reflection impedance and characteristic impedance, culminating in notable improvements across key performance parameters.

3.12Antenna geometry

The initial step involves the selection of a dielectric material to serve as the substrate for the antenna. Subsequently, various parameters are computed to ensure optimal dimensions, aiming for improved performance of the proposed antenna. In this particular case, the antenna is constructed using Rogers RT 5880 as the substrate material, while copper is chosen as the conductor material for both the patch and the ground plane, as illustrated in Figures 3.1 and 3.2.

The unit cell serves as a fundamental building block, allowing engineers to fine-tune various parameters such as size, shape, and materials to achieve desired specifications. radiation pattern, and bandwidth. Additionally, the unit cell facilitates iterative design processes, enabling engineers to experiment with different configurations and assess their impact on overall array performance. Ultimately, by establishing a solid foundation with the unit cell, engineers can streamline the development process and ensure that the final array meets the specific requirements of its intended application, whether in communication systems, radar technology, or other fields.

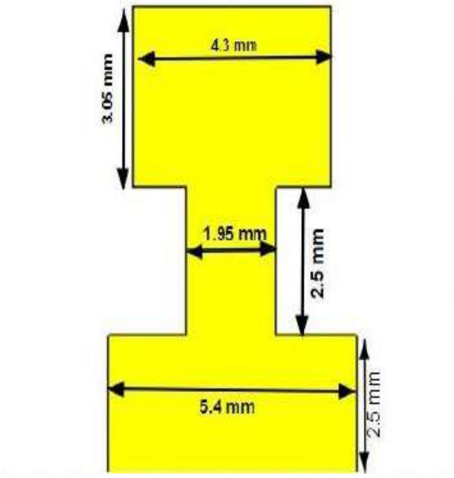


Fig 3.3 patch antenna unit cell

A 1x4 array antenna is a configuration consisting of four antenna elements arranged linearly in a single row. Each element operates in conjunction with the others to transmit or receive electromagnetic waves. By combining the outputs of multiple elements, a 1x4 array antenna can achieve benefits such as increased gain, beamforming capabilities, and improved radiation pattern control.

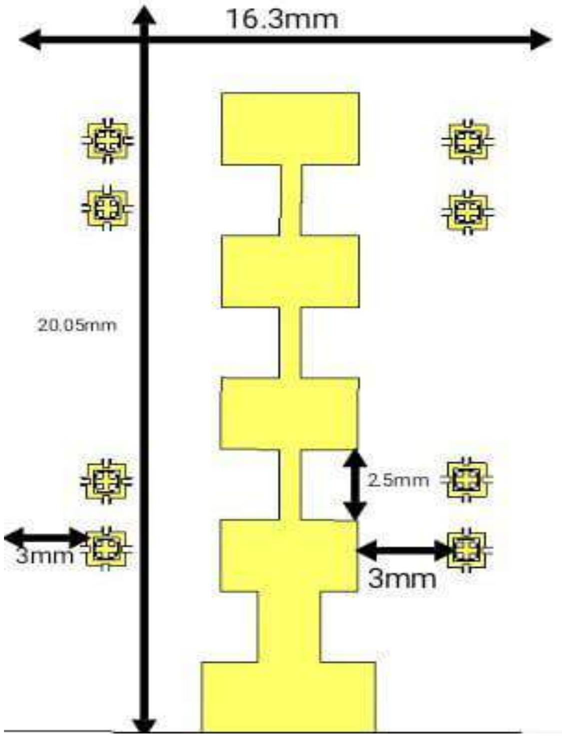


Figure 3.4 Front view of 1*4 Antenna array

Following picture shows the ground of the designed Antenna. ground plane is constructed with annealed copper, with a thickness of 0.035 mm

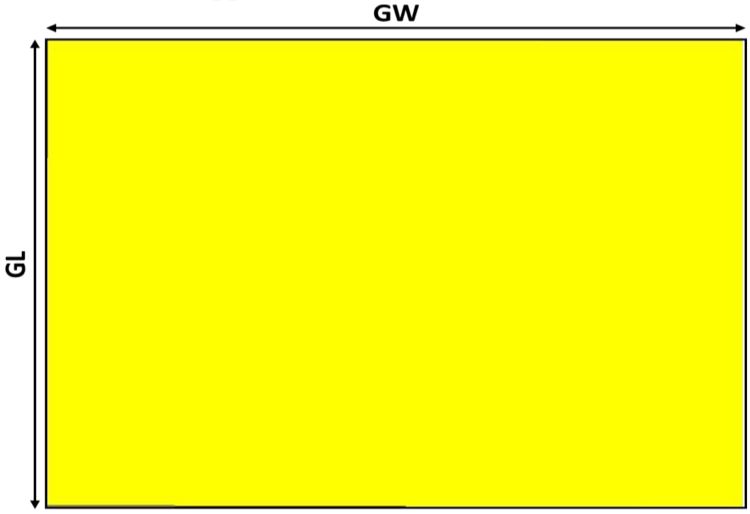


Figure 3.5 Back side view of 1*4 MIMO antenna

CHAPTER 04

Result and Simulation

4.1 Reflection Coefficient

The Reflection Coefficient of an antenna, also known as the S11 parameter, represents the percentage of radio waves radiated by the antenna with respect to the given input, highlighting the proportion rejected compared to the accepted waves [52]. This parameter is measured in decibels (dB), and a lower value indicates a better fit for the antenna in a device or transmission line. In the case of the proposed antenna, the S11 parameter is reported as -67 dB, and the bandwidth is measured at 1.357 GHz, as depicted in Figure 4.1

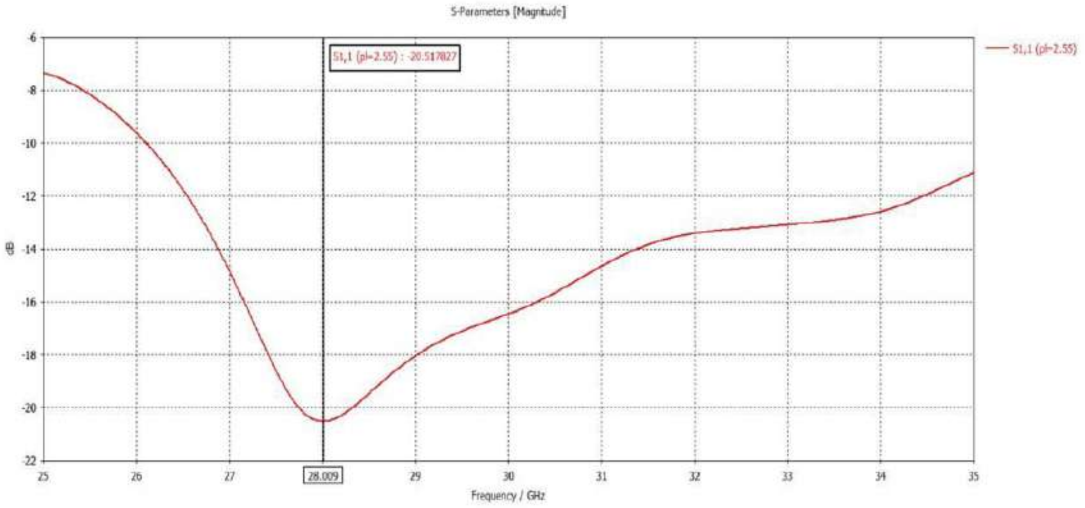


Fig4.1 reflection co-efficient of the array

4.2 Radiation Pattern

A radiation pattern describes the directional distribution of electromagnetic energy radiated by an antenna. It illustrates how the antenna's signal strength varies in different directions in three-dimensional space. The pattern provides valuable insights into the antenna's coverage, gain, and directional characteristics. It visualizes the antenna's directional properties, showing the intensity of radiation in various directions. This pattern is crucial in determining the antenna's coverage area, beam width, and gain. They help in communicating the design methodology and specifications to peers By understanding the radiation pattern, engineers can optimize antenna placement and orientation for effective communication or sensing in wireless systems. Common representations include polar plots or three-dimensional graphs showcasing the antenna's radiation properties.

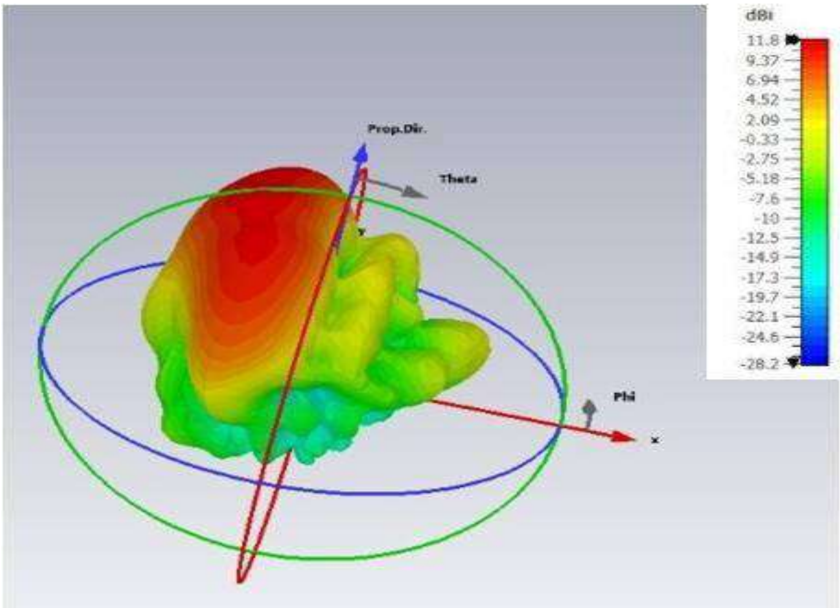


Fig4.2: Radiation pattern in 3D.

4.3 Polarization

Theta 0 degree defines the radiation pattern points directly upward. When phi is 90 degrees, it extends outward in the azimuthal direction Polarization of antenna radiation influences the directional propagation and reception characteristics of electromagnetic waves.This configuration results in a radiation pattern resembling a doughnut when viewed from above

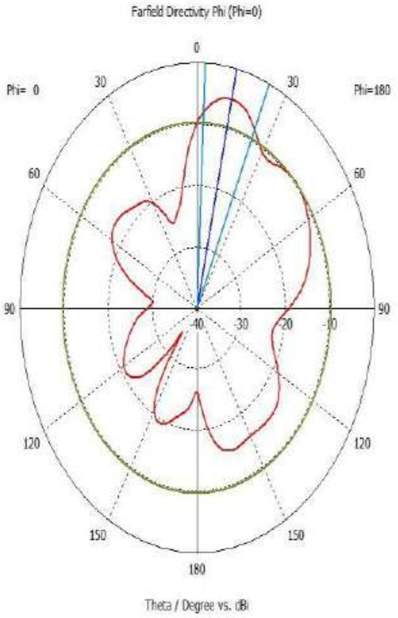


Fig4.3:vco polar pattern

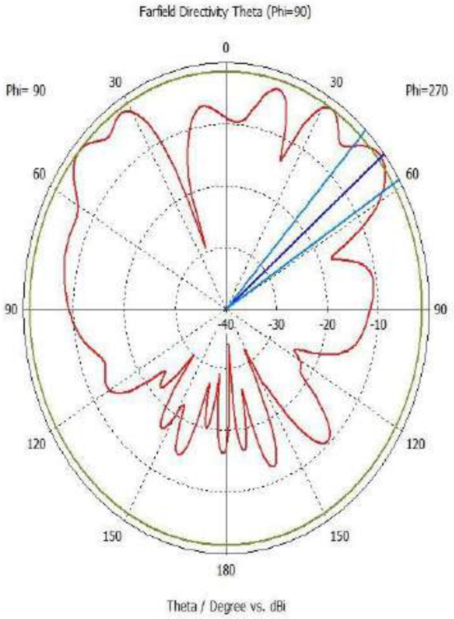


Fig4.4: cross polar cross polar pattern

4.5 Gain and Directivity

In this design, we have achieved a gain of 10.8 dB and a directivity of 11.8dB, showcasing a notable improvement from the initial value of 7.8 dB. This enhancement was attained through the incorporation of a meta surface in the antenna design. A higher gain means the antenna performs better in sending or receiving signals, enhancing communication range and quality. Gain is crucial in antenna design and deployment, impacting the efficiency of diverse wireless systems.

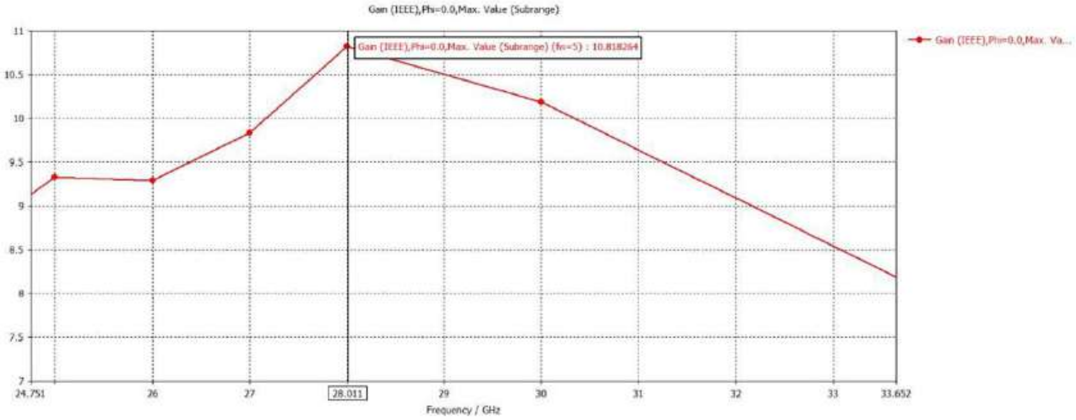


Figure 4.7 Gain

Directivity quantifies the concentration of radiation or sensitivity of an antenna in a specific direction.
It is a measure of how well an antenna focuses its radiation pattern in a desired direction compared to other

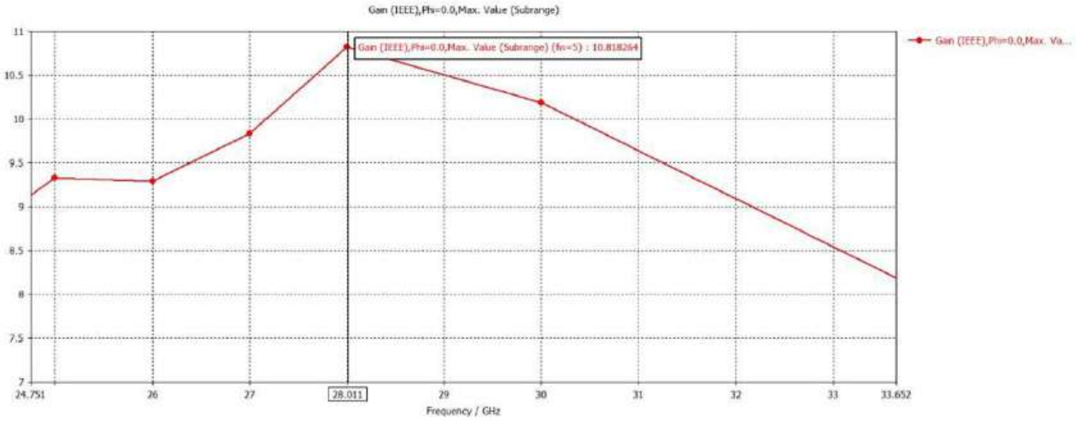


Fig 4.9:Directivity

4.6 Voltage Standing Wave Ratio (VSWR)

The Voltage Standing Wave Ratio (VSWR) serves as a numerical indicator of how effectively an antenna is impedance-matched to the connected transmission line [2]. A lower VSWR signifies a better match, leading to more efficient power transfer to the antenna. Ideally, the VSWR should be within the range of 1.0 to 2.0. In the case of the proposed antenna operating at 28 GHz, the VSWR is reported as 1.3. This value indicates that minimal power is reflected from the patch antenna, aligning with an ideal impedance match and efficient power absorption.

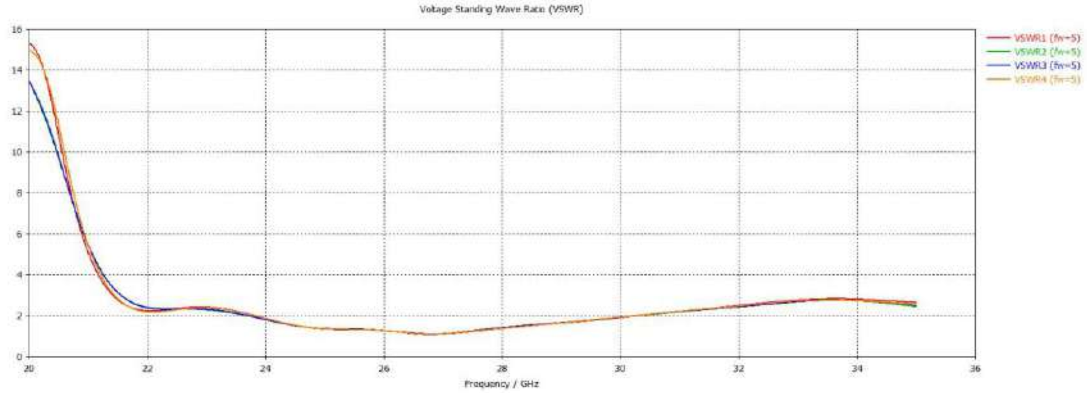


Figure 4.8: VSWR of Microstrip Patch Antenna.

4.7 Surface Current

The surface current of an antenna represents the flow of electric current along its structure, playing a crucial role in optimizing radiation efficiency and achieving desired performance.. In the current context, an achieved surface current of 127 A/m indicates the magnitude of the electric current flowing along the surface of the antenna structure. This value is essential in evaluating andfine-tuning the antenna's performance characteristics.

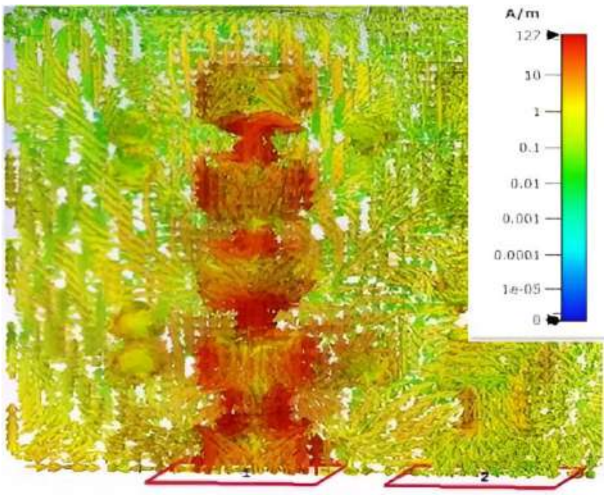


Fig4.9 : surface current.

4.8 Current Density

Current density is a measure of the flow of electric current per unit area in a conductor, providing valuable insights into the distribution of current within materials. Expressed in amperes per square meter (A/m²), current density plays a vital role in the analysis and design of electrical circuits. In the current scenario, achieving a current density of 133 A/m² signifies the magnitude of current flow relative to the surface area, a crucial parameter for evaluating the performance and efficiency of the electrical system or antenna under consideration.

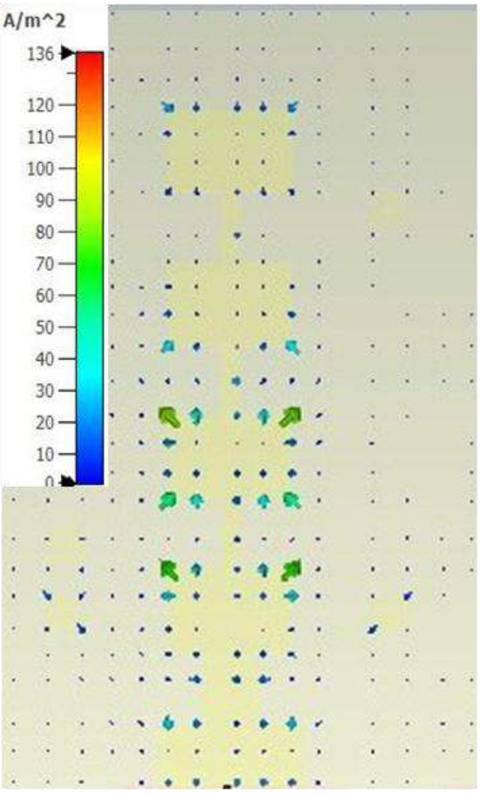


Fig5.1 current Density.

4.9 Impedence

Matching the impedance at 50 ohms in antennas plays a crucial role in maximizing signal transmission efficiency between the antenna and its transmission line, often coaxial cable. This alignment minimizes power loss while maximizing power transfer, ultimately improving the system's overall effectiveness. Ensuring that both the antenna and transmission line maintain a characteristic impedance of 50 ohms minimizes impedance mismatch losses, leading to enhanced signal strength and fidelity. This principle finds particular significance in radio frequency (RF) systems, where mismatched impedances can induce signal loss, distortion, and diminished performance. Techniques for achieving impedance matching encompass the utilization of matching networks, transformers, and transmission lines, all tailored to meet the specific impedance requisites of interconnected components. By attaining impedance matching, engineers can fine-tune signal and power transfer, enhancing overall system performance and reliability across diverse applications, spanning antennas, RF amplifiers, audio systems, and high-speed data transmission lines.

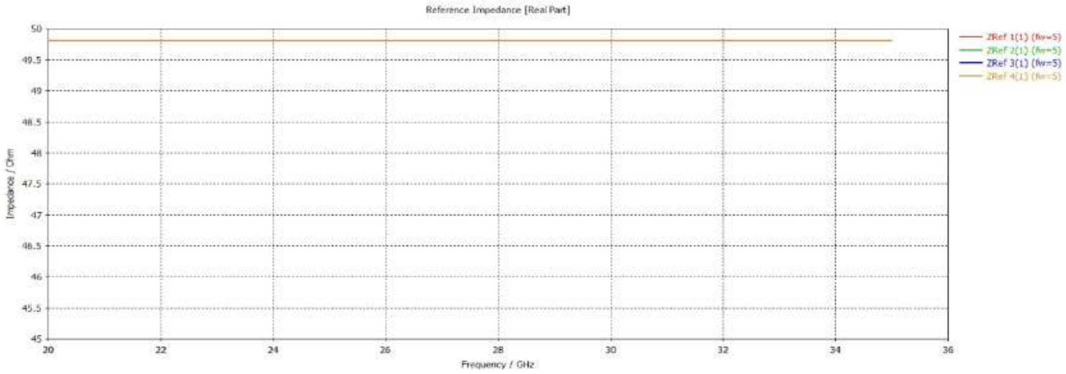


Fig5.3 impedence

4.10Efficiency

The efficiency graph illustrates the relationship between input power and output power, showcasing the antenna's effectiveness.It serves as a visual tool to evaluate performance trends and optimize design parameters for enhanced operational efficiency. The ratio of the power given to the antenna to the power it radiates is known as the antenna's efficiency. A high efficiency antenna radiates the majority of the power available at the antenna's input power. Due to impedance mismatch in a low efficiency antenna, the majority of the antenna's power is lost as internal losses or reflected away. The proposed antenna has an efficiency of 91.4%.

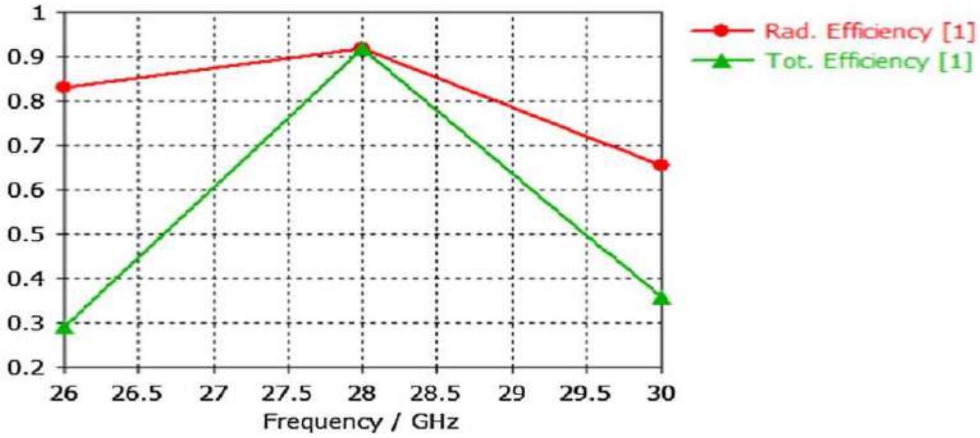


Fig5.4 :Frequency vs Efficiency Graph.

4.11 Comparison Table

This comparative analysis with recent relevant works aids in identifying strengths, weaknesses, and advancements in the field, informing further development and refinement of our design.

TABLE III DESIGN PARAMETERS

Ref.	**Journal**	**Dimension (mm)^2**	**frequency (Ghz)**	**S11 (dB)**	**Gain(dB)**	**Directivity(dB)**	**Efficiency**
[3]	Scientific reports	120× 40	28,37	-28	21.2	24	87%
[4]	IEEE access	57× 20	28	-35	10.1	10.7	92%
[5]	MDPI Sensors	43× 10	37	-38	12.8	10.5	85%
[7]	MDPI	30.21×30.21	27-28	-21.5	8.8	8.03	80%
[6]	Applied electromagnetic society journal	40× 27	27-40	-45	5.5-10	10	65%
[61]	IEEE Access	36× 15	28,37	-37	7.9,13.7	10,15	N/A
This Work	…	30× 21	2	-27	10.81	11.8	91.4%

CHAPTER 05

Conclusion

Introduction

In the rapidly evolving landscape of wireless communication systems, the demand for compact and high-performance antenna arrays has surged, particularly in emerging applications such as 5G networks, Internet of Things (IoT), and satellite communications. Achieving optimal antenna performance at millimeter-wave frequencies, such as the 28 GHz band, poses significant challenges due to the inherent trade-offs between size, gain, and directivity. In this context, the design and implementation of a 1x4 antenna array with a gain of 10.81 and a directivity of 11.8 at 28 GHz mark a significant advancement in antenna engineering. Notably, the achievement of such performance metrics while reducing the overall size presents a notable breakthrough, addressing the critical need for compact yet efficient antenna solutions. This introduction sets the stage for exploring the innovative design methodologies and optimization techniques employed to achieve superior performance in a compact form factor, ultimately contributing to the advancement of wireless communication technologies.

5.1 Achievements

The mm wave MIMO antenna array is engineered to provide high directivity at 11.7 dBi, and a gain of 10.7 dBi. Its remarkable 91.4% efficiency maximizes input power usage, enhancing the capacity of communication system. These features facilitate accurate signal concentration, improving the communication efficiency and coverage for specific areas or users.

5.2 Limitation

Gain and efficiency are concerns with the proposed array antenna. We need to make improvements to these parameters in order to make them more useful for 5G applications. A significant limitation of the designed antenna is its vulnerability to temperature variations in real-life applications. Extreme hot and cold temperatures can profoundly impact its efficiency and performance. At high temperatures, materials may expand or undergo structural changes, leading to deviations from the antenna's intended design specifications. Conversely, in cold temperatures, materials may contract, potentially altering the antenna's resonance properties and impedance matching, thereby diminishing its effectiveness. Furthermore, fabricating the antenna in real-life conditions introduces complexities that may hinder the efficiency and reliability of the device. Manufacturing processes often involve precise control over material properties, dimensions, and assembly techniques to achieve desired performance outcomes.

5.3 Future Work

The form factors of our proposed array antenna, evident from prior findings and simulation analysis, consistently f the average set by earlier research. Further efforts are needed to minimize these disparities. To assess the comprehensive performance of the planned and simulated antenna and to compare simulation results with real-world measurements, constructing the antenna in a physical setting is essential. Real-world manufacturing is essential, along with thorough testing in extreme temperature environments to confirm the antenna's functionality and detect any potential issues. These tests offer valuable insights for improving the design and deployment of antennas that can withstand varying temperatures effectively.

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