A Study of Performance Evaluation and Improvement of Microstrip Patch Antenna for Wireless Communication in Recent Years

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Declaration by the Scholar

I at this moment declare that this thesis entitled, "A Study of Performance Evaluation and Improvement of Microstrip Patch Antenna for Wireless Communication in Recent Years," in fulfillment of requirements for the award of the degree of Doctor of Philosophy submitted in the Maharishi School of Engineering & Technology, Maharishi University of Information Technology, Lucknow, is an authentic record of my research work carried out under the supervision of Dr. Kalyan Acharjya. I also state that the work embodied in this thesis-

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Supervisor's Certificate

It is certified that Mrs. Neera Agarwal has completed the required Academic turn, and the swirl presented by her is a faithful record of a bonafide original work under my guidance and supervision. She has worked on "A Study of Performance Evaluation and Improvement of Microstrip Patch Antenna for Wireless Communication in Recent Years" under the School of Engineering & Technology, Maharishi University of Information Technology, Lucknow.

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ABSTRACT

This doctoral thesis is structured into four key chapters that help to develop a deep knowledge base regarding microstrip patch antenna technology as well as discover some new ideas about it. A microstrip patch antenna is considered the core technology in the wireless communication world, which is studied and proposed as a new system of development.

The First Chapter is meant to build the basis for further understanding of microstrip patch antennas by giving a detailed description of their essential properties. These characteristics are structural features, operational principles, and intrinsic benefits that allow them to be widely used in many wireless communication systems. The purpose of this chapter is to describe a solid foundation for further studies on the antenna, emphasizing its small size and low cost, as well as adaptability to various devices and systems.

It can be noted that after discussing preliminary ideas, the Second Chapter becomes an extensive analysis of what has already been done in the sphere of studies. Here, this literature review thoroughly reviews the range of design methodologies, material selections, and myriad configurations explored through scholarly articles. The chapter, on its part, does not only summarize major findings obtained from different research but it also critically evaluates development and evolution patterns of antenna technology research, identifying principal difficulties and prospects.

The third chapter is an elaboration of the fundamental understanding and information resources related to the history of antenna design. It goes into greater detail about how antenna design has evolved historically and technologically. Among other things, this chapter explores the changes in methodology throughout time with a particular emphasis on innovative ways that have revolutionized performance measurements. In doing so, it also discusses present-day design trends as well as tries to establish links between those trends and earlier ones while ensuring that a comprehensive picture of the field's evolution can be formed.

The main results of the thesis are found in Chapters Four and Five; this is where the shift from pure theory and literature-based research to the empirical implementation of models and their testing becomes more explicit. These value-added chapters include the extensive design, simulation, and experimental validation of the hybrid microstrip patch antenna, serving to integrate a number of bandwidth-enhancing and performance-enhancing design innovations. Advanced materials, advanced fabrication techniques, and new structural enhancements are the salient features of this hybrid design, specially intended to enhance the bandwidth and

overall efficiency of the antenna in wireless communication.

A research methodology adopted in this thesis combines theoretical analysis, simulation-based design, and empirical validation to guarantee that a study is thorough and complete. The novelty of the findings is not only in their academic significance but also in their practical value since they reveal new design paradigms that can deliver better antenna performance. It is significant to the field of antenna engineering, particularly in microstrip patch antennas. This PhD dissertation is considered a worthy contribution. The thesis has significantly contributed to the knowledge base by bringing together an extensive body of existing knowledge with novel investigation and development, pushing boundaries and revealing new dimensions for the technology. It provides insights into practical applications aimed at solving pressing needs for advanced wireless communication systems. As part of the academic quest, it is hoped that the thesis will be a valuable resource for future scholars and technicians who will guide the ongoing evolution of microstrip patch antenna technology, as well as its increasingly connected-world applications.

In this research work the value of the return loss has been graphed. The generated prototype's isolation and loss of return with the S-Parameter is the prototype's resonance frequency, and it is here because less return loss means more efficiency. HFSS has been used for all simulations after this as shown for this y-parameter for the rectangular Microstrip Patch Antenna. Radiation elements are added as the first step in building a MIMO conformal antenna and Microstrip Patch Antennas are used as radiation elements as part of the design. In microstrip circuits, there is much loss in the millimetre range and there are three ways that losses can happen: through conductors, dielectrics, and radiation. It is concluded that when using a substrate with a low dielectric constant, the characteristic impedance and overall loss of the microstrip remain largely unaffected. However, with a high dielectric constant substrate, both the characteristic impedance and the loss associated with the microstrip exhibit significant variations. Increasing the thickness of the substrate tends to heighten the chances of experiencing radiation losses as well as damage due to surface waves. This is because thicker substrates allow more surface wave interactions, leading to potential energy dissipation and interference. On the other hand, using a substrate with a reduced height is beneficial as it helps in suppressing the propagation of higher-order modes, effectively minimizing radiation losses. This suppression is particularly advantageous in applications where minimizing interference and energy loss is critical for system performance and efficiency. This characteristic makes thinner and more flexible substrates preferable for conformal antennas, which need to adapt to curved surfaces without compromising performance. This research also highlights how the physical properties of the substrate can critically influence the functionality and efficiency of microstrip antennas. As the dielectric constant of a substrate increases, there are pronounced changes in both the characteristic impedance and the microstrip's total loss. In contrast, a low dielectric constant results in negligible alterations in these properties.

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LIST OF ABBREVIATIONS

Abbreviation	Description
AC	Alternating Current
AI	Artificial Intelligence
AMPS	Advanced Mobile Phone System
AR	Augmented Reality
AWGN	Additive White Gaussian Noise
BER	Bit Error Rate
CDMA	Code Division Multiple Access
CDMA2000	Code Division Multiple Access 2000
DC	Direct Current
EM	Electromagnetic
FCC	Federal Communications Commission
FDMA	Frequency Division Multiple Access
GPS	Global-Positioning System
GSM	Global-System for Mobile Communications
IEEE	Institute of Electrical and Electronics Engineers
IoT	Internet-of-Things
ISO	International-Organization for Standardization
ITU	International Telecommunication Union
LOS	Line of Sight
LTE	Long-Term Evolution
MIMO	Multiple Input Multiple Output
mmWave	Millimeter Wave
NFC	Near Field Communication
NLOS	Non-Line of Sight
OFDM	Orthogonal Frequency Division Multiplexing
P2P	Peer to Peer
PCB	Printed Circuit Board
QoS	Quality of Service

RF	Radio Frequency
RFID	Radio Frequency Identification
SAR	Specific Absorption Rate
SMS	Short Messaging Service
SNR	Signal to Noise Ratio
TDMA	Time Division Multiple Access
THz	Terahertz
UHF	Ultra High Frequency
UMTS	Universal Mobile Telecommunications System
VHF	Very High Frequency
VR	Virtual Reality
WCDMA	Wideband Code Division Multiple Access
WiMAX	Worldwide Interoperable Microwave Access

LIST OF SYMBOLS

Symbol	Nomenclature	Unit (MKS/CGS)
B	Bandwidth	GHz
ϵ	Dielectric constant	dimensionless
d	Directivity	dBi
e	Efficiency	**%**
λ	Wavelength	nm, m
f	Frequency	Hz, s^{-1}
π	Osmotic pressure	Pa
ρ	Density	gm/cm^3
σ	Surface tension	N/m
h	Height	mm
L	Length of the patch	mm
W	Width of the patch	mm

CHAPTER – 1

INTRODUCTION OF MICROSTRIP PATCH ANTENNAS IN WIRELESS COMMUNICATION

This chapter, a part of the wireless communication world, will bring to your knowledge the microstrip patch antenna and emphasize this point, as it is also very important you should see the technical perspective. Following this is a general introduction to microstrip patch antennas, detailing their design and operation, focusing on how small, low-profile ICs can be easily integrated into electronic devices. Here we would be discussing their many configurations, materials, and design methodologies, taking more care to prove that they can be best adopted in any wireless applications, whatever their nature might be. The chapter further delves into the antenna's radiation patterns, impedance matching techniques, and bandwidth considerations, providing a comprehensive understanding of how these factors influence its performance in wireless systems. By examining recent advancements and applications in mobile communication, satellite communication, and other emerging fields, this chapter underscores the pivotal role of microstrip patch antennas in facilitating robust and efficient wireless communication networks. communication, transcending the boundaries of distance and time, and fortifying the bonds between individuals, organizations, and the ever-expanding frontiers of knowledge and innovation (AL-Amoudi et al., 2019).

1.1 Brief History of Antenna

The history of antennas traces back to the late 19th century with the pioneering work of scientists and engineers in the field of electromagnetism. In the 1860s, James Clerk Maxwell established the foundation for antenna technology with his famous equations, which mathematically explained the behavior of electromagnetic waves. Guglielmo Marconi, an Italian inventor, is credited with the practical implementation of wireless telegraphy (Al-Hiti, 2019). In the late 1890s and early 1900s, Marconi developed the first practical radio transmitters and receivers, which utilized simple antennas consisting of elevated wires. These antennas, often referred to as Marconi antennas, played a crucial role in the early days of radio communication, enabling long-distance wireless transmission. Engineers developed various antenna designs, including the dipole and loop antennas, for military applications. These antennas were essential for communication between troops, aircraft, and naval vessels (Ali et al., 2018). High-frequency antennas, such as Yagi-Uda antennas, became common for long-range communication. With the advent of television in the mid-20th century, new types of antennas emerged to support broadcast reception in households, including rooftop antennas and rabbit ears. The space age of the 1950s and 1960s brought about revolutionary advancements in antenna technology (Ali et al., 2019). The launch of artificial satellites paved the way for global communication networks. Parabolic reflector antennas, capable of focusing radio waves over long distances, became the standard for satellite communication. These antennas enabled the transmission of television signals, telephone calls, and data across continents and oceans. Horn antennas and waveguide antennas were developed for microwave communication and radar systems. These antennas played a vital role in military applications, such as air traffic control, surveillance, and missile guidance (Al-Nahiun et al., 2021; Anantha et al., 2022).

In recent decades, the rapid advancement of electronics and telecommunications has led to further evolution in antenna technology. From the humble beginnings of simple wire antennas to the sophisticated designs of modern-day phased arrays, the history of antennas is a testament to human ingenuity and the relentless pursuit of innovation in the field of electromagnetics. Antennas continue to play a critical role in enabling global communication, wireless connectivity, and the exploration of the cosmos. As technology continues to evolve, so too will the antennas that serve as the backbone of our interconnected world (Arora et al., 2018).

1.2 Purpose and Scope

Wireless communication is well supported by antennas as they are considered to be an interface that connects electronic devices with the electromagnetic spectrum. One way they help to make the signal flow efficient is by steering it toward a proper receiver, which ultimately determines the reach and scope of any wireless network. Antennas also contribute to maintaining signal quality by minimizing distortion, noise, and signal degradation during transmission and reception (Badr, & Hamad, 2018). Among recent innovations in antenna technologies are patch antennas, phased array antennas, and metamaterial antennas. These antennas demonstrate improved performance and reconfigurability to realize multifunction capability, thereby enabling many applications ranging from wireless communication systems and radar systems to sensing systems. Consequently, antennas have become the indispensable types of components for a vast range of applications, which are optional add-ons like mobile phones, IoT devices, wireless routers, base stations, satellite terminals, and even radar systems, which turn out to be flexible w.r.t. different frequencies, communication standards, and deployment scenarios. The scope of antennas encompasses design, optimization, integration, deployment, and performance evaluation, addressing parameters such as radiation patterns, gain, bandwidth, impedance matching, efficiency, and polarization characteristics. As wireless communication continues to evolve, antennas will remain indispensable in enabling reliable, efficient, and seamless connectivity across diverse technological landscapes (Bakhtiari et al., 2019).

1.3 Generation of Wireless Communication

Wireless communication has grown over multiple generations, each with substantial technology improvements and alterations in communication standards. The first wireless communication technology, which was developed in the 1980s, dealt with analog voice transmission based on 1G systems provided only 1 voice channel and were also limited in capacity and experienced interference. Hence, second-generation (2G) systems came up in the late 1990s. In turn, the technologies that contributed to 2G consisted of GSM (Global System for Mobile Communications) and CDMA (Code Division Multiple Access) allowing not only digital voice transmissions but also SMS (Short Messaging Service) and basic data services as well (Bangash et al., 2019; Bansal et al., 2020). In the early 2000s, the third generation (3G) of wireless communication was an evolution with improved data rates that supported multimedia services such as internet browsing and video calling. UMTS (Universal Mobile Telecommunications System) and CDMA2000 took wireless towards more connectivity and data focus, which revolutionized its space in a much deeper sense than ever before. With lower latency, higher spectral efficiency, and faster data speeds among other improvements, the fourth generation (4G) of wireless communication emerged during the later 2000s, making a landmark in this field. LTE (Long-Term Evolution) and WiMAX (Worldwide Inter-operable Microwave Access) technologies enabled high-definition video streaming, internet gaming, and advanced mobile apps (Barua et al., 2022; Bharathi et al., 2020). In the modern period, the fifth generation (5G) of wireless communication marks the most recent frontier, promising unparalleled levels of speed, capacity, and connectivity. Advanced technologies like massive MIMO, mmWave frequencies, and network slicing are employed by 5G networks to offer ultrafast data rates, ultralow latency, and cater to a large number of IoT (Internet of Things) devices and applications. Beyond 5G, future generations of wireless communication are likely to investigate even more revolutionary technologies, such as THz communication, quantum communication, and others, ushering in a new era of connectivity that defies the limits of imagination (Bisht, 2021).

1.3.1 The 1st Generation

It was in the 1980s that the wireless communication revolution started with the first generation (1G). Telecommunications history achieved a major milestone with this advancement. With respect to technology and voice transmission, 1G systems were mainly analog in nature, thus signifying the shift from landline telephony to mobile communication. The most remarkable of these is AMPS (Advanced Mobile Phone System). The major drawback of 1G systems was low capacity, poor voice quality, as well as vulnerability to interference which contributed to inconsistent performance and inadequate coverage. The introduction of 1G paved the way for the evolution of mobile networks, spurring innovation in technologies like digital signal processing, frequency reuse, and cellular architecture, which would later become the cornerstones of more advanced wireless standards (Bohari et al., 2021; Britto et al., 2021).

1.3.2 The 2nd Generation

The 1990s saw the advent of 2G wireless communication as a considerable upgrade to its antecedent, the first generation (1G). While enabling digital voice transmission, 2G systems demonstrated an advancement in the quality of connection, security features, and spectral efficiency. The two primary standards for 2G were GSM and CDMA. GSM, which was widely adopted in Asia, introduced capabilities such as text messaging (SMS) and enabled interoperability between networks. CDMA, which is widely used in North America and portions of Asia, provided more capacity and improved call quality thanks to enhanced modulation techniques. 2G networks also allowed wider adoption of mobile phones by providing better coverage and reliability than their analog predecessors. The advent of 2G systems cleared the way for the digital revolution in telecommunications and succeeding generations of wireless communication, laying the framework for the mobile data revolution that would come with 3G and beyond (Chinnagurusamy et al., 2021; Chourasia et al., 2020).

1.3.3 The 3rd Generation

Third-generation patch antennas are designed for catering to the advanced requirements of modern applications like 5G networks, IoT devices, and satellite communication. These designs inherently have a low-profile configuration easily integratable onto the surface of a device. In comparison to the second-generation patch antennas, there is an increase in bandwidth, improvement in radiation patterns, and heightening of efficiency in third-generation patch antennas. These improvements are realized through advanced dielectric materials and innovative design concepts, like fractals, put into use with more complex fabrication techniques. These provide the tangible benefit of faster and more reliable data transfer, critical to high-speed internet and for communication processes.

It is important to highlight that third-generation patch antennas are typically multi-band and wideband, making them significantly more versatile than their first and second-generation counterparts. As a result, they are widely used in many modern wireless communication systems. Third-generation (3G) networks were developed to provide faster internet access, enhanced multimedia capabilities, and improved voice quality, offering a more robust and diverse mobile experience. With data speeds reaching several Mbps, 3G enabled applications like video calling, mobile TV, and internet browsing on mobile devices. Moreover, 3G networks played a crucial role in the widespread adoption of smartphones, allowing users to easily access a range of data-intensive applications and services on handheld devices. Despite early challenges such as network deployment delays and limited coverage, 3G networks were pivotal in shaping the modern mobile landscape, laying the foundation for future generations of wireless communication and the data-driven world we live in today (Christina et al., 2021; Colaco et al., 2022).

1.3.4 The 4th Generation

The fourth generation (4G) of wireless communication, which debuted in the late 2000s, represents a substantial step forward in mobile connectivity, providing faster data throughput, lower latency, and improved spectral efficiency than its predecessors. The key technology driving 4G networks is Long-Term Evolution (LTE), which allows for data rates of up to several hundred megabits per second, paving the way for high-definition video streaming, online gaming, and other mobile apps. Another technology, Worldwide Interoperability for Microwave Access (WiMAX), aided the development of 4G networks, particularly in offering broadband wireless access in specific areas. 4G networks used advanced technologies such as MIMO and OFDM to improve spectrum efficiency and network capacity. Users saw considerable gains in mobile connectivity with 4G, allowing them to access data-intensive services and applications without interruption. The widespread use of 4G networks established the groundwork for the modern mobile ecosystem, enabling the development of smartphones, tablets, and other connected devices. As the demand for high-speed mobile data grows, 4G networks remain an important component of the global telecommunications infrastructure, acting as the foundation for the changing mobile landscape and preparing the way for the transition to fifth-generation (5G) networks (Das et al., 2022; Demirbas et al., 2022).

1.3.5 The 5th Generation

The fifth generation (5G) of wireless communication is the most recent advancement in telecommunications, providing unprecedented speed, capacity, and connectivity. The fifth-generation patch antenna is an advanced development in wireless communication and plays a paramount role in the technological advancement of 5G. They are designed to meet the massive demand for modern communication systems with much better competency in terms of bandwidth and efficiency simultaneously. The fifth-generation patch type antennas will be multiband, targeting applications that handle mobiles, IoTs, and high data-rate wireless devices. They apply advanced materials, available for a few years only, and advanced design methodologies, such as metamaterials and phased arrays, to meet the needed performance. One of the most essential features of these antennas is that they support beamforming and massive MIMO technologies.

Essentially, this means that 5G is now visible for high-rate data, low latency, and far higher capacity in high-speed and high-density environments whenever harnessed. The 5th generation patch antennas are also very compact and light, hence fit for integration in these small, portable device designs of today and the future. The described ability to deliver reliable and high-quality wireless capabilities prominently at the core of the demands placed on the future of connected technologies, smart cities, and autonomous vehicles. Deployed in the 2020s, 5G networks build on previous generations' foundations, offering breakthrough technology and standards to suit today's ever-increasing digital needs. Due to its versatility to cater to any type of use case or application, 5G has the capacity for changing modes of communication systems people have been using so far and thus this technology can be considered as highly transformative in creating new ways of human connection leading towards a digital era (Dubey, 2022).

1.3.6 The 6th Generation

By 2024, the sixth generation of wireless communication, or 6G, is still largely in its research and development phase but rapidly picking up steam. 6G will be a huge leap forward from today's 5G technology both in the speed and latency it will allow for—microseconds. It will take a leap forward, enabling a host of disruptive applications in the realms of telemedicine, autonomous vehicles, AR/VR-based content visualization, and the Internet of Things. Other propitious inventions are also based on 6G, assuring that very important issues will be addressed, such as digital inclusiveness, enhanced cybersecurity, and environmental sustainability. While it is not really possible to give an exact timeline for the commercial deployment of 6G, from current research and technological improvements, it may be a certainty in less than a decade. Recent studies have indicated that 6G networks will assure higher network efficiency, better spectrum management, and sustainable technologies against Gupta et al. (2024). When this eventually arrives, 6G will open a new frontier of ultra-fast, ultra-reliable, and ubiquitous wireless connectivity that will power the next phase of digital transformation.

1.4 Need for Antennas

The wireless communication systems cannot function without antennas that take part in the process of transferring and receiving electromagnetic signals between various electronic devices. The purpose of using an antenna in wireless communication is related to several essential aspects. No antennas mean no wirelessly transmitted data, voice, or any other kind of information that would make it really hard for the communication systems being utilized today to work effectively and be practical. Secondly, antennas play a crucial role in ensuring efficient signal propagation by directing electromagnetic waves towards their intended recipients. Through careful design and optimization, antennas can maximize signal strength, extend communication range, and mitigate interference, thereby enhancing the reliability and performance of wireless networks. Additionally, antennas contribute to maintaining signal quality by minimizing distortion, noise, and signal degradation during transmission and reception. Well-designed antennas can help preserve the integrity of transmitted data, ensuring clear, reliable communication even in challenging environments (Elechi & John, 2022). Furthermore, antennas are adaptable to various frequencies, communication standards, and deployment scenarios, making them versatile solutions for a wide range of applications, including mobile phones, IoT devices, wireless routers, base stations, satellite terminals, and radar systems. The ability to tailor antenna designs to specific requirements allows for optimized performance across diverse technological landscapes. Lastly, as wireless communication continues to evolve, the need for antennas remains paramount in enabling the next generation of connectivity. Emerging technologies such as 5G, IoT, and satellite communication rely heavily on advanced antenna systems to deliver high-speed data, ultra-low latency, and seamless connectivity on a global scale. In conclusion, antennas are essential components of wireless communication systems, fulfilling a variety of crucial functions that enable reliable, efficient, and seamless connectivity in today's interconnected world (Ezzulddin, & Hasan, 2022).

1.5 Types of Antennas

Wireless communication systems employ several different kinds of antennas, depending on particular performance specifications and environmental issues. A good example is the dipole antenna that consists of two conductive elements mounted in line which finds a place because of its simplicity and effectiveness in many frequency ranges. Yagi-Uda antennas, another popular choice, are directional antennas consisting of multiple elements arranged in a specific configuration, providing high gain and improved signal reception in a particular direction. Patch antennas, characterized by their flat, low-profile design, are commonly employed in applications requiring compact, lightweight antennas, such as mobile phones and wireless routers. Helical antennas, featuring a helical shape, are frequently utilized in satellite communication and GPS systems due to their circular polarization and omnidirectional radiation pattern. Phased array antennas, consisting of multiple antenna elements controlled by phase shifters, enable beamforming and electronically steerable beams, allowing for adaptive beam shaping and directional coverage. The selection depends on factors such as operating frequency, coverage requirements, space constraints, and environmental considerations. Overall, the diverse range of antenna types available provides flexibility and versatility in designing wireless communication systems tailored to specific applications and performance objectives (Fante & Gemeda, 2020; Güneş & Belen, 2018).

1.5.1 On the Basic of Radiation

1.5.1.1 Omni-Directional Antenna

Their radiation pattern resembles a three-dimensional sphere, allowing for 360-degree coverage and communication with devices located in any direction around the antenna. This characteristic makes omni-directional antennas ideal for applications where communication needs to occur with devices situated in various orientations relative to the antenna, such as Wi-Fi access points in indoor environments or cellular base stations in urban areas. The radiation pattern of omni-directional antennas typically exhibits consistent signal strength in all directions, making them suitable for providing wide-area coverage and supporting devices moving within the coverage area without the need for constant alignment. However, while omni-directional antennas offer excellent coverage and simplicity in deployment, their omnidirectional radiation pattern may lead to increased interference and reduced signal range compared to directional antennas, particularly in environments with high levels of radio frequency (RF) congestion. Therefore, the selection of omni-directional antennas for wireless communication systems involves careful consideration of factors such as coverage requirements, interference mitigation strategies, and the trade-offs between coverage area and signal strength (Guo & Pan, 2021; Gupta & Saxena, 2019).

1.5.1.2 Directional Antenna

An adequately designed directional antenna illuminates energy primarily in one direction, which enhances communication because of less interference from other directions. In direct contradiction, omnidirectional antenna radiation scatters in all directions uniformly. Directional antennas offer better range and signal strength in the desired region than their omnidirectional counterparts. Ideal applications for such antennas are point-to-point communications, broadcasting, and radar systems. Some popular types are the Yagi--Uda, parabolic, and log-periodic. They are extensively applied in radio and television reception, wireless networking, satellite communication, and many others. Therefore, the directional antennas improve efficiency and performance through signal concentration and are important to different communication technologies.

Directional antennas are a crucial component in wireless communication systems, particularly when there is a need to focus signal energy in a specific direction. These antennas emit electromagnetic waves preferentially in one direction, resulting in a concentrated radiation pattern that provides enhanced signal strength and coverage in the desired area while minimizing interference from other directions. The basic principle of radiation for directional antennas involves shaping the antenna's structure to achieve a desired radiation pattern. For example, Yagi-Uda antennas feature a linear array of elements, including a driven element and multiple parasitic elements, which are carefully sized and spaced. These directional antennas are widely used in point-to-point communication links, wireless backhaul systems, and satellite communication dishes, where precise aiming and efficient use of radio frequency spectrum are essential for achieving reliable, high-performance connectivity over long distances (Guttula et al., 2021).

1.5.2 On the Basic of Apertures

1.5.2.1 Wire Antennas

The wired antennas form an essential part of the modern communication system and are engineered to help transmit and reception electromagnetic signals. All operate in converting electric power to radio waves and vice versa. They can be found in different forms, including dipole, monopole, and loop antennas; they are helpful in applications from broadcasting systems for radios and televisions to wireless communication and radar systems. The most popular antennas are dipole antennas, simple and effective planar antennas composed of a pair of conductive elements. The monopole is half of a dipole, mounted perpendicularly on some conductive surface, and is popular due to its omnidirectional radiation pattern. Another long-time classic necessary type of antenna used predominantly for compactness is the loop antenna; it comprises a loop of wire. It is the choice of many operations in terms of reliability, installation ease, and consistent performance under most environmental conditions. Design and deployment of wired antennas have a major role to play in assuring efficient and reliable communication. Slot antennas are one of the most frequently used antenna devices since wireless communication systems rely on the apertures based on wire antennas, which have as their central working mechanism electromagnetic waves passing through conductive surfaces and out of an opening. An aperture antenna can be created by making a slit or slot in a conductive surface (e.g. metal plate or waveguide). Aperture antennas provide omnidirectional or directional radiation patterns, depending on their geometry and design, and can be tailored to meet specific performance requirements for wireless communication systems operating across a wide range of frequencies (H Patel, & D Makwana, 2021).

1.5.2.2 Aperture Antennas

These antennas utilize the principles of diffraction and radiation to achieve their functionality. When electromagnetic waves encounter the aperture, they diffract and propagate outward, effectively radiating or receiving signals. Slot antennas are particularly well-suited for applications requiring low-profile and broadband operation, such as in mobile communication devices and radar systems. Another type of aperture antenna is the waveguide horn antenna, which utilizes the aperture formed by the open end of a waveguide to radiate or collect electromagnetic waves. Aperture antennas offer advantages such as simplicity, versatility, and efficiency in various wireless communication scenarios. As wireless communication technologies continue to evolve, aperture antennas will remain essential components, providing reliable and effective means for transmitting and receiving electromagnetic signals in diverse environments (Haleem & Elwi, 2022).

1.5.2.3 Micro-Strip Antennas

This has made microstrip antennas, also known as patch antennas, very popular among wireless communication systems because of their low profile, lightweight, and simplicity of manufacture. They usually consist of a conducting patch on one side of a dielectric substrate and a ground plane on the other. The patch can be in different shape configurations like rectangular, circular, or elliptical, in configurations depending upon the requirement of applications. The main advantage of micro-strip antennas is their compatibility with PCB technology, thus allowing integration with other electronic components. They are widely used in mobile phones, satellite communications, and radar systems. On the downside, most of the time, micro-strip antennas suffer from narrow widths and lower gain as compared to other types of antennas. Engineers usually use different techniques to increase the performance and bandwidth of these antennas by using numerous patches and slots. Engineers developed micro-strip antennas as a leading design because they are flexible and versatile in practice, although limited by nature.

In view of size, weight, and integration flexibility as the main concerns, microstrip antennas having aperture components are a useful alternative for wireless communication systems in specific applications. Aperture-coupled microstrip antennas, for example, utilize slots or holes in the radiating patch to couple energy from the feed line to the radiating element, enabling efficient energy transfer and improved impedance matching (Hamad & Abdelaziz, 2021). This design approach allows for the integration of additional components, such as filters, amplifiers, or switches, directly onto the antenna substrate, offering enhanced functionality and performance in a compact footprint. Overall, microstrip antennas based on apertures represent a versatile and practical solution for wireless communication applications, offering a balance of performance, size, and cost-effectiveness that meets the demands of modern communication systems (Hasan et al., 2023).

1.5.2.4 Array Antennas

These antennas consist of multiple radiating elements arranged in a geometric pattern, such as linear, planar, or conformal configurations, to form an aperture through which electromagnetic waves propagate. A phased array antenna is another kind that employs the variables phase and amplitude as signals. Among others, one of the major advantages of using phased array antennas in wireless communication is that they allow electronically steer the antenna beam to track moving targets or adjust coverage patterns dynamically (Hussain et al., 2020). This feature is particularly useful in applications such as radar systems, satellite communication, and mobile networks, where the ability to adapt to changing environmental conditions and user requirements is essential. Additionally, array antennas based on apertures can achieve higher gain, improved directivity, and increased spatial diversity compared to single-element antennas, resulting in better signal quality, extended range, and enhanced reliability in communication links. As wireless communication technologies continue to evolve, array antennas based on apertures will play a crucial role in enabling advanced features and capabilities for next-generation wireless networks (Imran et al., 2021).

1.5.3 On the Basic of Polarization

1.5.3.1 Linearly Polarized Antenna

In linearly polarized antennas, the electric field vector of the electromagnetic wave oscillates in a specific plane, defining the orientation of polarization. Common orientations for linear polarization include horizontal, vertical, and slant polarization. Horizontal and vertical polarization are frequently used in terrestrial communication systems, such as mobile networks and Wi-Fi, with horizontal polarization often favored for long-distance communication and vertical polarization for urban and indoor environments. Slant polarization, which lies between horizontal and vertical orientations, offers advantages in mitigating multipath interference and improving signal reception in diverse propagation environments. Linearly polarized antennas are designed to generate, transmit, and receive electromagnetic waves with a consistent polarization orientation, ensuring efficient signal propagation, minimal signal distortion, and optimal communication performance. By aligning the polarization of antennas in transmitting and receiving devices, wireless communication systems can maximize signal strength, enhance link reliability, and achieve seamless connectivity in various operating conditions and deployment scenarios (Imran et al., 2018).

1.5.3.2 Circularly Polarized Antenna

Circularly polarized antennas offering advantages in terms of signal robustness, interference mitigation, and improved link reliability. Unlike linearly polarized antennas, which radiate electromagnetic waves antennas emit waves with rotating electric fields. This circular polarization enables better resistance to signal fading and multipath interference, making circularly polarized antennas particularly suitable for environments with challenging propagation conditions, such as urban areas, indoor spaces, and non-line-of-sight communication scenarios. Additionally, circularly polarized antennas exhibit better compatibility with handheld devices and mobile terminals, as the orientation of the receiving antenna relative to the transmitting antenna is less critical for maintaining signal strength and quality. Common types of circularly polarized antennas include helical antennas, crossed-dipole antennas, and quadrivial helix antennas, each offering unique advantages in terms of bandwidth, gain, and radiation characteristics (Islam et al., 2019). Overall, circularly polarized antennas play a vital role in enhancing the performance contributing to the seamless transmission of data, voice, and multimedia content across a variety of applications and deployment scenarios.

1.6 Micro-Strip Patch Antenna

These types of antennas displayed in Figure 1.1 and Figure 1.2, that have a radiator, called a patch which is usually made from a conductive material like copper or printed on dielectric substrate with a ground plane on the backside. A microstrip patch antenna is a class of low-profile antennas, which have a lot of advantages such as broad bandwidth and high radiation efficiency. Furthermore, by customizing its design, we can ensure that the antenna will radiate an omnidirectional or directional beam with respect to our specific requirements. Through adjusting its shape and size or altering other physical parameters like width or thickness of the substrate, the patch can also be made to work in preferred frequency bands, polarization, and radiation patterns, thus making it a versatile solution for modern wireless communication needs. Additionally, advancements in materials and manufacturing techniques have enabled the development of innovative designs such as dual-band, circularly polarized, and reconfigurable microstrip patch antennas, further expanding their utility and applicability in diverse communication scenarios. Overall, microstrip patch antennas continue to play a crucial role in enabling reliable, efficient, and high-performance wireless communication systems (Kannadhasan & Nagarajan, 2021; Kannadhasan & Nagarajan, 2023).

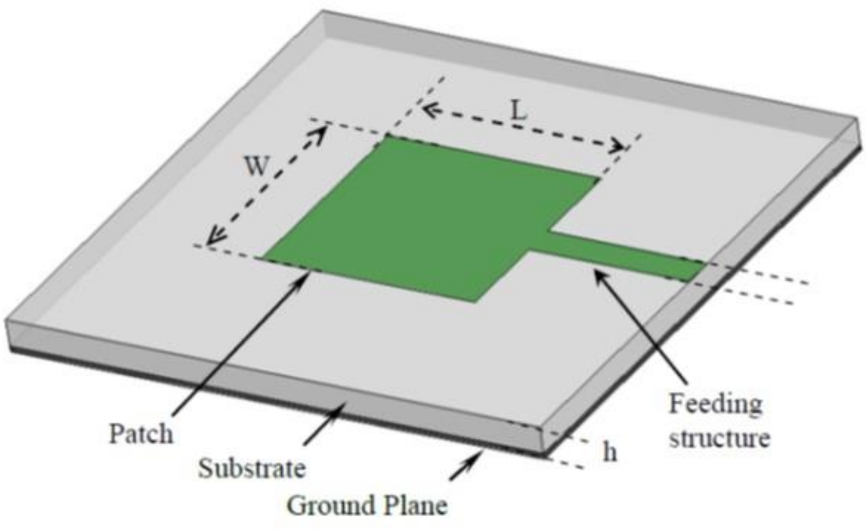

Figure 1.1: Micro-Strip Patch Antenna

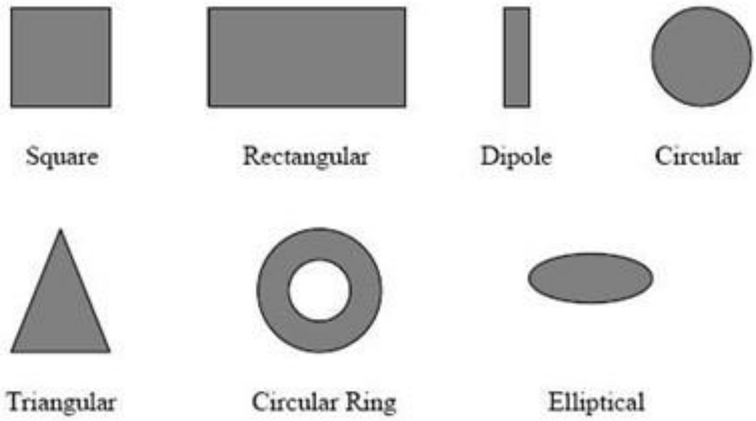

Figure 1.2 Different type of Shapes and Sizes of Patch

1.6.1 Advantages of Patch Antenna

Firstly, their size is small and they are very thin, which allows them to be easily integrated into smaller electronic gadgets like smart mobile phones, IoT-based devices, or Wi-Fi routers, which, due to the reason of portability, these small gadgets have to be much more compact than any other device. Secondly, these patches have a small footprint that makes it possible to fit them in any free space in different environments without taking into consideration how large and deep those spaces may be, thus meeting requirements for applications where they need to be confined within certain physical size limits. Also, the weight of microstrip patch antennas is quite low, and they can be made cost-effective when manufactured in large numbers because of this factor.

Using conventional printed circuit board (PCB) manufacturing methods as an added benefit, their simple structure also allows fabrication to be easily done, which, in turn, reduces production costs. In addition, microstrip patch antennas can cater to different frequencies, as the resonant frequency can be simply regulated. This flexibility allows for compatibility with a wide range of communication standards and operating frequencies, making them suitable for multi-band and broadband communication systems. Furthermore, microstrip patch antennas exhibit relatively high efficiency and gain, especially when designed with proper impedance matching and radiation pattern control techniques. Overall, the advantages of microstrip patch antennas, including their compact size, low cost, frequency agility, and high performance, make them an attractive choice for various wireless communication systems, contributing to their widespread adoption in modern telecommunications (Kaur & Nitika, 2019).

1.6.2 Disadvantages of Patch Antenna

While microstrip patch antennas offer several advantages such as compact size, low profile, ease of fabrication, and cost-effectiveness, they also come with certain disadvantages that limit their suitability for some wireless communication applications. Microstrip patch antennas typically operate over a limited frequency range, making them less versatile for applications requiring broad frequency coverage or frequency agility. The inherent narrow bandwidth of microstrip patch antennas is primarily due to their planar structure, which results in high levels of surface wave excitation and radiation losses, particularly at higher frequencies. Additionally, microstrip patch antennas are susceptible to impedance mismatches, which can further degrade their bandwidth performance. Another disadvantage of microstrip patch antennas is their relatively low radiation efficiency, especially when compared to antennas such as dipole or helical antennas. The substrate material used in microstrip patch antennas, typically dielectric materials like FR4 or RT/Duroid, introduces dielectric losses that reduce the overall efficiency of the antenna. Moreover, microstrip patch antennas may suffer from cross-polarization and higher-order mode excitation, leading to undesirable radiation characteristics and reduced antenna performance. Another limitation is their sensitivity to nearby objects and electromagnetic interference, which can cause signal degradation and reduced communication range. Additionally, microstrip patch antennas are typically limited in terms of power handling capabilities, making them less suitable for high-power applications. Overall, while microstrip patch antennas offer many advantages, their narrow bandwidth, low radiation efficiency, susceptibility to impedance mismatches, and sensitivity to environmental factors make them less ideal for certain wireless communication scenarios, particularly those requiring wideband operation, high efficiency, and robust performance in challenging environments (Kaur & Goyal, 2020).

1.6.3 Feeding Techniques for Patch Antennas

1.6.3.1 Micro-strip Line Feed

Some typical microwave engineering techniques other than micro-strip line feed are also widely applied and showed in Table 1.1. In the microstrip line feed, the feed line is formed by a conducting strip mounted on a dielectric substrate, with a ground plane on the other side.

Table 1.1 Different feed techniques for patch antennas

Characteristics	Microstrip Line Feed	Coaxial Feed	Aperture Coupled Feed	Proximity Coupled Feed
Spurious feed radiation	More	More	Less	Minimum
Reliability	Better	Poor due to Soldering	Good	Good
Ease of fabrication	Easy	Soldering and drilling Required	Alignment required	Alignment Required
Impedance Matching	Easy	Easy	Easy	Easy
Bandwidth (achieved with impedance matching)	2-5%	2-5%	2-5%	13%

The microstrip line antennas are straightforward to fabricate and cost significantly little as all the microwave components can easily be integrated. This feeding guarantees suitable matching impedance and very effective transmission of microwaves signals. The flexibility for different designs of antennas comes along because the microstrip line can take various shapes and sizes to satisfy some application specifications. Another advantage is that, due to its planar structure, fabrication using technology through printed circuit board (PCB) is much easier. Hence it is suitable for mass production. Besides, microstrip feed is relatively easy to integrate with other passive and active components in such a way that the ensuing microwave system becomes complex or composite.

Two important factors affecting the antenna's performance include the position of the feed point and the design of an impedance matching network, which result in characteristics such as impedance match, bandwidth, radiation pattern, and efficiency. Through tailoring the feeding line dimensions as well as the feed point location and by optimizing the impedance matching network, engineers are able to achieve desired antenna performance metrics that cater to specific wireless communication requirements. In general, feeding microstrip line techniques can provide a practical and efficient way of coupling RF signals to patch antennas, making them suitable for most applications related to wireless communication, especially those involving mobile phones, Wi-Fi routers, IoT devices, satellite terminals (Khraisat, 2018).

1.6.3.2 Coaxial Feed

Coaxial feed feeding techniques are commonly used to offering several advantages in terms of simplicity, versatility, and performance. One of the most straightforward coaxial feed configurations is the probe feed, where a coaxial probe is inserted through the ground plane beneath the patch antenna, coupling energy directly into the patch's radiating element. This technique allows for easy impedance matching and tuning by adjusting the probe's position and length. Coaxial line feed offers excellent impedance matching and minimal radiation losses, making it suitable for high-performance applications. Additionally, aperture-coupled feeding techniques utilize a coaxial feed connected to a microstrip line on the patch antenna's substrate, allowing for efficient power transfer and enhanced bandwidth. These coaxial feed techniques provide flexibility in designing microstrip patch antennas for various wireless communication applications, offering reliable performance, ease of integration, and compatibility with standard coaxial connectors and transmission lines (Krishna & Abdelaziz, 2018).

1.6.3.3 Aperture Coupled Feed

With this strategy, the feed structure is positioned beside the patch antenna where a small opening or a slot connects them together. This particular layout helps provide an efficient means of transferring energy from the feed line to the patch element while guaranteeing insulation between the feed line and radiating structure. Impedance improvement, spurious radiation minimization, and radiation pattern control enhancement are just some of the benefits that aperture-coupled feeding offers.

Design of the patch antenna aperture and feed structure play a vital role in optimizing the performance with such desired characteristics as enhanced bandwidth, greater gain, and radiation efficiency. Moreover, aperture-coupled feeding techniques provide more options for antenna design that can integrate additional components like filters, amplifiers, or matching networks into feed structures. This versatility makes aperture-coupled feeding an attractive choice for a wide range of wireless communication applications, including cellular networks, satellite communication, radar systems, and wireless LANs. Overall, aperture-coupled feeding techniques offer a robust and efficient method for achieving high-performance patch antennas with tailored characteristics to meet the demands of modern wireless communication systems (Kumar & Gupta, 2018).

1.6.3.4 Proximity Coupled Feed

One of the widely adopted feeding methods is the proximity-coupled feed feeding techniques for microstrip patch antennas that are used in wireless communication systems. Here, the antenna is connected to the feed line by means of a closely situated microstrip or coplanar waveguide (CPW) feedline, but with no direct physical connection between them. The electromagnetic coupling takes place because when placed in close proximity to the patch antenna substrate, this phenomenon allows an efficient energy transfer from the feed line to the radiating patch. Among the advantages of proximity coupling is its capability to have wide bandwidth and impedance matching as well as retaining compact and low-profile antenna design. This technique also offers flexibility in adjusting the feed position and impedance matching, allowing for easy integration with various antenna configurations and applications. Additionally, proximity coupling reduces radiation losses and improves the radiation efficiency of the antenna compared to other feeding methods. Overall, proximity coupled feed techniques are a versatile and effective means of feeding patch antennas for wireless communication, offering wide bandwidth, impedance matching, and compact design advantages suitable for a wide range of applications (Li et al., 2018).

1.6.4 Applications of Patch Antenna

Common applications is for use in mobile devices like smartphones, tablets, and laptops where there are space limitations or one just needs it to look good. Patch antennas integrated into these devices offer stable wireless connection for voice calls, text messaging, internet surfing, and video streaming over cellular networks, Wi-Fi, Bluetooth, and other wireless protocols. Another key application of patch antennas is in wireless local area networks (WLANs) and Wi-Fi routers, where they serve as primary radiating elements for indoor and outdoor wireless coverage. Patch antennas offer directional coverage, high gain, and ease of deployment, making them well-suited for providing reliable Wi-Fi connectivity in homes, offices, public spaces, and outdoor environments. In addition, patch antennas are commonly used in RFID (Radio Frequency Identification) systems for tracking and identification purposes in retail, logistics, inventory management, and access control applications (Mahabub et al., 2018).

Their compact size and omnidirectional radiation pattern make them ideal for embedding into RFID tags and readers for wireless data exchange. Patch antennas also find applications in satellite communication systems, where they serve as feed elements for parabolic reflector antennas, providing efficient signal transmission and reception for satellite terminals, earth stations, and satellite phones. Moreover, patch antennas are employed in microwave point-to-point links for wireless backhaul and network infrastructure, offering high data rates and long-distance connectivity for telecommunications networks (Mahbub & Islam, 2021). Overall, the compact size, low profile, and versatility of patch antennas make them indispensable components in a wide range of wireless communication applications, including mobile devices, Wi-Fi networks, RFID systems, satellite communication, microwave links, and automotive communication systems.

CHAPTER – 2

LITERATURE SURVEY ON MICROSTRIP PATCH ANTENNA FOR WIRELESS COMMUNICATION

Within this Chapter, we explore a literature overview of microstrip patch antennas in the field of wireless communication; primarily a scholarly review of published papers and journals, as well as other research works that reveal its history, development, and present status. Our survey encompasses a range of design approaches, materials employed, and cutting-edge improvements implemented at different stages to enhance microstrip patch antenna capabilities. Based on the analysis of the trends, issues, and developments reported in the current literature, this chapter offers a review of the state of the art in antenna technology, highlights areas where research is lacking, and outlines avenues that future researchers may consider. This extensive review serves as an important reference material for scientists and engineers engaged in wireless communication; at the same time, it also frames various contexts so that later chapters can explain ongoing achievements and applicability of microstrip patch antennas to the real industry scenarios.

2.1 Literature Survey

This review represents a general survey of the research progress and applications that have taken place with microstrip patch antennas. The present survey is an attempt at generalizing the key findings and trends in research on microstrip patch antennas. Various techniques used for enhancement in performance included those related to metamaterials, fractal geometry, and advanced feeding techniques. The integration of metamaterial structures, for instance, has exhibited tremendous potential in enhancing antenna performance by transforming the electromagnetic properties surrounding the antenna. There is also a growing interest in multi-band and wideband microstrip patch antennas for developing communication systems in high demand involving multiple frequencies. Researchers have explored innovative design approaches, such as the use of stacked or parasitic elements, to achieve broad frequency coverage while maintaining a compact antenna footprint. Additionally, the utilization of reconfigurable and tunable techniques has enabled dynamic adjustment of antenna parameters to adapt to changing environmental conditions and communication requirements (Mohamed et al., 2020).

The literature on improving also considered the effect of controlling radiation pattern and polarization diversity. Radiation characteristics and polarization diversity have been sought using techniques including aperture-coupled and proximity-coupled feeds, making microstrip patch antennas usable in different applications. Flexible substrates, such as polymer-based materials, have been explored to develop conformal microstrip patch antennas capable of conforming to irregular surfaces while maintaining reliable performance. In addition to design and optimization aspects, literature in this field also discusses practical considerations such as fabrication techniques, material selection, and integration challenges. Advanced manufacturing methods, including additive manufacturing and inkjet printing, have been investigated for cost-effective and scalable production of microstrip patch antennas. Overall, the literature survey highlights the continuous evolution and diversification of microstrip patch antenna research, versatile antenna solutions in modern wireless communication systems. Future research directions may include further exploration of advanced materials, integration with emerging technologies such as 5G and Internet of Things (IoT), and optimization for specific applications such as millimeter-wave communication and biomedical sensing (Mohammed & Kamal, 2019; Mudda & Gayathri, 2021).

2.2 Historical Development

In 1984, a landmark research paper titled "Microstrip Antenna for Dual-Frequency Operation" introduced a novel compact antenna design that utilized an H-shaped microstrip patch with a shorting pin. This innovative antenna design offered a significant size reduction and allowed operation at two different frequencies with a single feed, far surpassing the capabilities of the conventional rectangular patch antenna. The added flexibility in design parameters, such as frequency ratio and input impedance, allowed for improved resonance tuning. This advancement made the concept of dual-frequency operation more accessible and practical for various applications (Mukta & Rahman, 2021; Nabil & Faisal, 2021).

Further exploration of dual-band frequency operation was presented in the 1997 paper "Dual-Frequency Patch Antennas." This study showed that dual-frequency patch antennas, which support wide bandwidths, offer a viable alternative to broadband planar antennas in applications requiring operation at two distinct frequency bands. The paper provided a detailed review of methods for designing these antennas, highlighting the advantage of using a single structure to eliminate the need for separate antennas. A 2005 paper by Naji (2018) introduced the concept of defected ground structure (DGS), demonstrating its effectiveness in reducing cross-polarized radiation in microstrip patch antennas. The simplicity and compatibility of DGS with commercial microstrip substrates were validated through both simulation and experimental results, marking a significant development in antenna design (Noor et al., 2021).

A subsequent 2008 paper, "Efficiency Enhancement of Microstrip Patch Antenna with Defected Ground Structure," delved deeper into the potential of DGS for improving microwave device characteristics. In addition to enhancing antenna efficiency, DGS was shown to reduce cross-polarization and mutual coupling. The paper emphasized the wide-ranging applications of DGS in antenna miniaturization, making it an essential tool in modern antenna design (Nyunt, 2018).

DGS introduces specific modifications to the ground plane of a microwave circuit to alter its electromagnetic properties, leading to improved bandwidth, size reduction, and impedance matching. The use of patterns such as slots or gaps in the ground plane enables better current distribution, creating a stopband effect that suppresses unwanted frequencies and enhances desired ones. DGS has become a powerful and flexible tool in RF and microwave engineering, with applications in filters, antennas, and power amplifiers.

In summary, these foundational papers have significantly advanced the field of antenna design. The 1984 paper introduced a dual-frequency antenna that surpassed traditional designs, while the 1997 paper explored dual-frequency patch antennas as an alternative to broadband planar antennas. In 2005, the DGS concept provided a solution for mitigating cross-polarized radiation, and the 2008 paper expanded its applications to size reduction and efficiency enhancement. Together, these studies have contributed to the continuous evolution of antenna technology (Obot & Igwue, 2019).

In 2021, a key paper by Palanivel & Vivek offered valuable insights that formed the basis for our current research. The study focused on improving WLAN antenna performance at 5.2 GHz and 5.8 GHz through the use of two CSSRRs on the ground plane, achieving dual-band operation and size reduction. Capacitive matching via gap coupling further enhanced the design. Additionally, the 2014 AEM journal article, "Dual-Band Gap-Coupled Antenna Design with DGS for Wireless Application," explored the hybrid use of gap coupling and DGS to improve gain and reduce sidelobe levels. The strong agreement between simulation and experimental results highlighted the effectiveness of this dual-band antenna design (Pandey & Agrawal, 2021).

In recent years, particularly in 2023 and 2024, research on microstrip patch antennas has focused on the integration of advanced materials, innovative geometries, and optimization algorithms to further improve performance for emerging wireless applications like 5G, 6G, and IoT. For instance, the development of metamaterial-based antennas has gained significant attention due to their ability to manipulate electromagnetic waves, resulting in enhanced bandwidth and radiation characteristics. A 2023 study explored the use of graphene in patch antennas, demonstrating improved tunability and flexibility, which is particularly beneficial for wearable and flexible electronics. Moreover, Artificial Intelligence (AI)-driven optimization techniques, such as machine learning and genetic algorithms, have been increasingly applied to antenna design in 2024. These approaches help identify optimal configurations for factors such as shape, size, and feeding techniques to achieve superior performance metrics such as gain, efficiency, and reduced interference.

Another breakthrough in 2024 focuses on hybrid antenna designs that incorporate both dielectric resonators and microstrip patches. These designs have shown promise in addressing the bandwidth limitations of traditional antennas, making them more suitable for high-frequency applications in 6G and beyond. Additionally, researchers in 2023 successfully demonstrated the use of reconfigurable antennas with the ability to dynamically adjust operating frequencies and radiation patterns in real time, paving the way for adaptive communication systems.

These advancements in 2023 and 2024 build upon earlier innovations while addressing the challenges of modern wireless communication, ultimately pushing the boundaries of microstrip patch antenna technology.

2.3 Design Considerations

Design issues in microstrip patch antennas include a wide variation in the consideration factors: antenna geometry, substrate material selection, feeding techniques, radiation characteristics, and integration with other components. Each factor is very crucial to the antenna in respect of its efficiency, bandwidth, and functionality. Some of the designing issues include geometrical configuration, techniques of feeding, materials of the substrate, radiation characteristic, and integration aspects. Below we do an in-depth analysis of such considerations according to Parasuraman & Yogeeswaran, 2020.

2.3.1 Antenna Geometry

2.3.1.1 Patch Shape and Size

The choice of patch shape and size is crucial in microstrip patch antenna design as it directly impacts the antenna's electrical characteristics, including resonance frequency, bandwidth, and radiation pattern. Various patch geometries, such as rectangular, circular, and elliptical shapes, offer different advantages and trade-offs. They offer a wide range of design flexibility and can be easily tailored to achieve desired resonance frequencies and bandwidths by adjusting their length and width. However, rectangular patches may suffer from undesired higher-order mode excitations, leading to complex radiation patterns and potential spurious radiation. Circular patches exhibit symmetric radiation patterns and are inherently less prone to higher-order mode excitations compared to rectangular patches. Circular patches also provide broader bandwidth compared to rectangular patches with similar dimensions. However, achieving precise frequency tuning with circular patches can be more challenging due to their limited geometric adjustability. Elliptical patches combine some of the advantages of both rectangular and circular patches. They offer improved bandwidth compared to rectangular patches while maintaining a relatively simple geometry for fabrication. Elliptical patches can be optimized to achieve specific polarization characteristics and radiation patterns, making them suitable for applications requiring polarization diversity or directional antenna beams (Pathak & Singh, 2021).

2.3.1.2 Substrate Dimensions

Resonance frequency, bandwidth, and radiation efficiency are some of the electrical performance and physical characteristics of microstrip patch antennas that are affected by the dimensions of the substrate. The dimensions, in turn, are also used to select the overall size of the microstrip patch antenna. Typically, these dimensions depend on the desired operating frequency as well as radiation characteristics. Longer substrates can support larger patch sizes, which are advantageous for achieving lower resonant frequencies and broader bandwidths. Conversely, shorter substrates result in smaller patch sizes, suitable for higher resonant frequencies and compact antenna designs. Wider substrates facilitate the integration of wider patches, enabling broader bandwidth and improved radiation characteristics. Thicker substrates typically lead to higher antenna bandwidth but may result in larger antenna profiles. Thinner substrates are preferred for compact antenna designs, as they reduce the overall size and weight of the antenna. However, thin substrates may be more susceptible to bending and mechanical damage, necessitating careful consideration of mechanical support and reinforcement. The substrate thickness also affects the antenna's radiation efficiency and losses. Thicker substrates can reduce substrate losses but may introduce additional fabrication challenges and increase cost (Peddakrishna & Khan, 2018).

2.3.2 Substrate Selection

2.3.2.1 Dielectric Constant and Loss Tangent

The values of the dielectric, which are of primary importance in the determination of electrical features and general efficiency of microstrip patch antennas. The dielectric constant is a commonly designated value that determines how fast electromagnetic waves move along the substrate material. An increased value for the dielectric constant lessens the wavelength in between where these electromagnetic waves traverse within their substrate, culminating in a reduced size of the whole antenna structure. This reduction enables miniaturization resulting in smaller forms suitable for integration with small form-factor devices. The dielectric constant also plays a role in determining the antenna's resonant frequency and impedance matching, as higher dielectric constants are typically associated with lower resonant frequencies. In contrast, tan(δ), known as the loss tangent, shows how much energy is lost as heat because of dielectric losses within a substrate material. It is preferable to have a low loss tangent to prevent signal attenuation and allow the antenna to function at its optimal efficiency.

Thus, the bandwidth of an antenna is also influenced by the loss tangent where a lower loss tangent is responsible for more bandwidth. Consequently, one of the crucial factors for improving the performance of a microstrip is choosing a material whose dielectric constant is high, whereas its loss tangent remains low. This antenna, enabling efficient radiation, compact design, and wide bandwidth capabilities across various wireless communication applications (Punith & Praveenkumar, 2020).

2.3.2.2. Substrate Thickness

Electrical performance and mechanical robustness of microstrip patch antennas are determined mainly by the choice of the substrate thickness. It is generally the case that a thinner substrate will have a wider bandwidth as a result of lower substrate. However, excessively thin substrates may compromise mechanical integrity and increase fabrication complexity. On the other hand, thicker substrates offer mechanical stability but may lead to narrower bandwidth and reduced radiation efficiency due to increased dielectric losses and substrate dispersion. Therefore, substrate thickness must be carefully chosen to strike a balance between electrical performance and mechanical considerations. Additionally, with thinner substrates enabling compact designs suitable for integration into space-constrained environments. Advanced manufacturing techniques, such as additive manufacturing and thin-film deposition, allow for precise control over substrate thickness, facilitating the optimization of microstrip patch antenna performance for specific application requirements. Moreover, substrate thickness impacts the antenna's radiation characteristics, with thinner substrates favoring broader beamwidths and thicker substrates yielding narrower beamwidths. Hence, substrate thickness represents a critical design parameter that must be carefully tailored to achieve the desired electrical performance, mechanical robustness, and integration feasibility of microstrip patch antennas across various applications (Rahman & Hasan, 2022).

2.3.3 Feeding Techniques

2.3.3.1 Microstrip Feed Line

A microstrip feed line is an electrical transmission line that conveys microwave signals at microwave frequencies. It is a conducting strip on a dielectric substrate separated from a ground plane by a dielectric layer. The structure is typical for microwave circuits because of the planar form and works in good compatibility with PCBs and integrated circuits. The quasi-TEM mode, which is the wave propagation that is supported by the structure of the microstrip feed line, has both electric and magnetic fields.

One of the main advantages of microstrip feed lines is that they can be easily manufactured simply and added to other related circuit components. This could be done for instances such as antennas and band-pass filters, among other elements like amplifiers. Design parameters are outlined to realize characteristic impedance or effective dielectric constant influenced by transmission performance or effectiveness. In high-frequency electronic systems nowadays, this gives rise to the necessity for microstrip feedlines.

Several key considerations must be taken into account when designing the microstrip feed line. Firstly, the feed line geometry, including its width, length, and impedance, directly impacts the antenna's input impedance and bandwidth. Proper impedance matching between the feed line and the antenna is essential to minimize reflection losses and maximize power transfer efficiency. Various techniques, such as tapered feed lines and impedance matching networks, are employed to achieve impedance matching across the desired frequency band. Additionally, the proximity of the feed line to the patch antenna affects the coupling efficiency and radiation characteristics. Close proximity can lead to higher coupling efficiency but may also introduce unwanted radiation from the feed line. The choice of material in the feed line may also determine its electrical properties like impedance and dielectric loss, which contribute to how well the antenna system performs. In order to reduce signal loss and ensure reliable operation of the antenna, substrates with low losses and stable dielectric properties over a wide frequency range should be preferred. For instance, it is worth noting that the creation of microstrip lines can only be accomplished after studying electromagnetic theory, transmission lines, and practical factors to have better effects for characteristics match such as impedance matching, bandwidth, radiation efficiency, and integration possibility.

2.3.3.2 Impedance Matching Network

This ensures efficient transfer of RF energy without significant signal loss or reflection. Various types of impedance matching networks can be employed, including lumped element networks, distributed matching networks, and hybrid configurations. Lumped element networks, consisting of discrete components such as capacitors and inductors, are commonly used for impedance matching at specific frequencies or narrow bandwidths. Distributed matching networks, integrated into the transmission line structure or the antenna itself, offer broadband impedance matching over a wider frequency range. Hybrid matching networks combine lumped and distributed elements to achieve a balance between bandwidth, complexity, and performance. Design considerations for impedance matching networks include the desired operating frequency, bandwidth requirements, power handling capabilities, physical size constraints, and manufacturing considerations. Advanced design techniques, such as network synthesis algorithms and electromagnetic simulation tools, facilitate the optimization of impedance matching networks for various antenna configurations and application scenarios. Overall, impedance matching networks play a critical role in antenna design, ensuring optimal RF performance and system efficiency in wireless communication systems, radar systems, and other RF applications (Rana & Fahim, 2023).

2.3.4 Radiation Characteristics

2.3.4.1 Radiation Pattern

The fundamental consideration as it describes the directional properties of electromagnetic wave propagation from the antenna. Understanding and controlling the radiation pattern is essential for optimizing antenna performance. The shape and orientation of the radiation pattern depend on various factors, including antenna geometry, feed configuration, and surrounding environment. Providing 360-degree coverage ideal for applications requiring broad coverage, such as wireless networking and broadcasting. Designing the radiation pattern involves optimizing parameters such as antenna shape, size, feeding technique, and substrate properties to achieve desired coverage, gain, polarization, and sidelobe levels while minimizing losses and interference (Rana, 2022). Advanced design tools, such as electromagnetic simulation software and measurement techniques, facilitate accurate prediction and characterization of radiation patterns, enabling antenna engineers to tailor antenna designs for diverse applications, including satellite communication, cellular networks, radar systems, and wireless sensors. Moreover, antenna arrays and beamforming techniques are employed to further manipulate radiation patterns, allowing for adaptive control of signal directionality, spatial diversity, and interference mitigation in complex wireless communication scenarios. Overall, the radiation pattern serves as a critical design parameter guiding the development of efficient and reliable antenna systems for modern wireless communication systems, where performance, coverage, and interference management are paramount considerations (Rao & Vani, 2018).

2.3.4.2 Polarization

When working on antenna engineering, it is necessary to pay much attention to the design parameter of polarization because the radiation pattern, or how electromagnetic waves move and respond to their environment, depends on it. In the field of antennas, polarization is defined as the orientation of an electric field vector produced by radiated waves in relation to a reference axis – this axis can be either the antenna’s structure or ground plane. An important requirement for successful communication is the alignment of transmitting and receiving antennas by matching their polarizations, resulting in efficient energy transmission without significant signal losses caused by cross-polarization loss due to mismatching polarizations. Linear polarization can be either horizontal, vertical, slant, right-hand, or left-hand circular, while elliptical polarization is relatively uncommon. The choice of polarization depends on various factors, including the communication system's requirements, propagation characteristics, interference mitigation, and environmental conditions. For instance, linear polarization is often preferred in terrestrial communication systems due to its simplicity and compatibility with vertically polarized antennas commonly used in infrastructure. Circular polarization offers advantages in multipath propagation environments, where it mitigates fading effects and improves signal robustness. Elliptical polarization combines aspects of both linear and circular polarization, offering flexibility in adapting to diverse communication scenarios. Antenna designers must carefully consider polarization compatibility between transmitting and receiving antennas, as well as polarization diversity techniques to enhance system performance, particularly in wireless communication networks characterized by dynamic propagation conditions and interference sources. Additionally, polarization diversity techniques, such as spatial diversity and polarization switching, can be employed to improve system reliability and mitigate polarization-induced fading effects in multipath environments. Overall, polarization considerations play a critical role in antenna design, impacting system performance, interoperability, and resilience in various communication applications, including terrestrial, satellite, and mobile communication systems, as well as radar, remote sensing, and wireless sensor networks (Razali & Ngah, 2021).

2.3.5 Bandwidth and Frequency Range

2.3.5.1 Resonant Frequency

The resonant frequency is a fundamental frequency of oscillation in a system. At this frequency, the system will oscillate with higher amplitude because it is slightly losing energy. In physics and engineering, it just so happens that it is what occurs when the frequency level of the externally applied vibrations matches the object's inherent vibrational frequency in such a way that amplitude increases to an order of tenfold. Resonant systems can be exemplified by an oscillating bridge when the wind blows back and forth, the shattering of glass at a particular pitch, and the tuning of a radio station. In most applications in mechanical systems, resonance is employed through: detection of possible failures through the help of electric circuits about acoustics, filtering signals derived from any source, and enhancement of sound. The ability to understand the detected resonance frequency is convenient to design both structures and devices, thus avoiding destructive resonances while harnessing useful ones in efforts to preserve safety, efficiency, and performance in technological applications.

Resonant frequency is a major point to consider when designing an antenna as it determines the wave transmission efficiency at which electromagnetic waves are transmitted or received. Moreover, maintaining resonance stability over environmental factors such as temperature variations and substrate material changes is essential for ensuring consistent antenna performance across different operating conditions. Overall, understanding and controlling the resonant frequency are paramount in antenna design to meet performance requirements and achieve reliable operation in various communication and sensing applications (Sangwan & Panda, 2020).

2.3.5.2 Bandwidth Enhancement Techniques

The Bandwidth enhancement techniques play a crucial role in optimizing the performance of antennas, ensuring compatibility with modern communication systems' diverse frequency requirements. One commonly employed approach is the utilization of parasitic and stacked elements, which involves incorporating additional passive elements adjacent to the main radiating element. Parasitic elements, such as slots, patches, or wires, interact with the primary radiator to create multiple resonant modes, thereby broadening the antenna's operating bandwidth. Stacked configurations, where multiple radiating layers are vertically stacked with a dielectric spacer, offer increased bandwidth by exploiting the coupling between adjacent layers and introducing additional resonant modes. Moreover, frequency-selective surfaces (FSS) are employed to enhance bandwidth by selectively. FSS enabling precise control over the antenna's frequency response. Metamaterial-based approaches represent another promising avenue for bandwidth enhancement, leveraging artificially engineered materials with unique electromagnetic properties to tailor the antenna's dispersion characteristics and achieve wideband operation. By incorporating these bandwidth enhancement techniques into antenna design considerations, engineers can develop compact and efficient antenna systems capable of supporting high-speed data transmission, multi-frequency operation, and seamless integration into modern wireless communication networks (Sayem et al., 2023).

2.3.6 Integration and Packaging

2.3.6.1 Compactness and Conformality

This often requires careful optimization of antenna geometry, substrate properties, and feeding techniques. Conformality, on the other hand, pertains to the antenna's ability to conform to non-planar or irregular surfaces, enabling integration into diverse platforms such as wearable devices, IoT sensors, and unmanned aerial vehicles (UAVs). Conformal antennas offer advantages in terms of reduced aerodynamic drag, improved aesthetics, and enhanced performance in applications where traditional rigid antennas are impractical. Designing compact and conformal antennas involves a trade-off between electrical performance, mechanical flexibility, and fabrication complexity, necessitating interdisciplinary approaches that encompass antenna theory, materials science, and mechanical engineering. Advances in flexible substrate materials, additive manufacturing techniques, and conformal antenna design methodologies continue to drive innovation in this field, enabling antennas to be seamlessly integrated into a wide range of modern communication systems and emerging technologies (Shafeay & kurnaz, 2021).

2.3.6.2 Manufacturability and Cost

Manufacturability and cost considerations are integral aspects of antenna design, influencing material selection, fabrication techniques, and overall design complexity. Achieving cost-effective manufacturability involves optimizing design parameters to minimize material usage, simplify manufacturing processes, and reduce production time. Additive manufacturing techniques, such as 3D printing, offer opportunities for rapid prototyping and customization while minimizing material waste. Similarly, inkjet printing enables the deposition of conductive inks on flexible substrates, allowing for the fabrication of conformal and low-cost antennas. Substrate material selection is crucial, with preferences for low-cost, readily available materials such as FR-4 epoxy or polyester films, balancing performance requirements with affordability. Moreover, considering the scalability of production processes is essential for mass deployment, with batch fabrication methods and automated assembly processes helping to streamline manufacturing and reduce labor costs. Overall, a holistic approach that integrates manufacturability and cost considerations into the antenna design process ensures the realization of practical and economically viable antenna solutions for a wide range of applications (Sharma, 2020).

2.3.7 Environmental Considerations

2.3.7.1 Temperature Stability

The temperature stability is a crucial consideration in the design of antennas, including microstrip patch antennas, especially when they are deployed in environments where temperature variations occur. Temperature fluctuations can significantly impact the electrical properties of antenna materials, substrates, and components, leading to changes in antenna performance. Additionally, temperature-induced changes in the loss tangent can lead to variations in antenna efficiency and bandwidth. Therefore, selecting substrate materials with stable dielectric properties over a wide temperature range is essential to ensure consistent antenna performance under varying environmental conditions. Furthermore, temperature stability is critical for applications where antennas are subjected to extreme temperature conditions, such as aerospace, automotive, and outdoor wireless communication systems. By carefully considering temperature stability in the antenna design process and choosing appropriate substrate materials, engineers can mitigate the adverse effects of temperature variations and enhance the reliability and performance consistency of microstrip patch antennas (Shereen & Khattak, 2022).

2.3.7.2 Moisture and Chemical Resistance

Moisture and chemical resistance are critical considerations in antenna design, particularly for outdoor, industrial, and harsh environments where antennas may be exposed to moisture, rain, chemicals, and contaminants. Selecting substrate materials with high moisture resistance and chemical stability is essential to ensure the long-term reliability and performance integrity of the antenna. Commonly used substrate materials such as FR-4 (Flame Retardant 4) epoxy resin offer moderate moisture resistance but may degrade in humid or wet environments over time, leading to changes in dielectric properties and performance degradation. Alternatively, specialized substrate materials such as polytetrafluoroethylene (PTFE) and polyimide offer superior moisture resistance and chemical stability, making them suitable for outdoor and industrial applications where environmental exposure is a concern. Moreover, techniques of protective coating and encapsulation can be used to increase the resistance of the antenna with regard to moisture and chemical exposure, therefore improving durability and performance in harsh environmental conditions. These protection measures, when integrated into the antenna, go a long way in greatly expanding the reliability and lifetime of the antenna, hence having the ability or capability to operate in a wide range of extreme conditions. It means taking into account moisture and chemical resistance to certain types of substances during the design phase, keeping the antenna suitable for a wide range of demanding applications (Sowe et al., 2022).

2.4 Performance Analysis

Analyzing the performance of microstrip patch antennas involves assessing various parameters such as radiation characteristics, impedance matching, bandwidth, efficiency, and gain. One crucial aspect is the radiation pattern, which describes how electromagnetic energy is distributed in space. The radiation pattern determines the antenna's directionality and coverage area, influencing its suitability for specific applications. Microstrip patch antennas typically exhibit a broadside radiation pattern, with maximum radiation perpendicular to the antenna's surface. However, variations in patch geometry, substrate properties, and feeding techniques can alter the radiation pattern, leading to directional, omnidirectional, or even electronically steerable patterns. There is another very critical performance measure that should not be overlooked when designing any wireless communication system, which ensures efficient power transfer from the antenna to the transmission line, known as impedance matching. Impedance mismatch would produce reflections and a considerable amount of loss in power propagation that results in performance degradation. A few techniques are used to attain an appropriate impedance matching, such as tuning the patch dimensions, changing the feed point location, or incorporation of an impedance matching network at a given frequency band. Bandwidth is yet another crucial factor as it provides the range of frequencies where the antenna works properly.

Microwave antennas are designed to handle signals over several frequency bands, and these bands are chosen based on modern communication systems. To be more specific, efficiency is defined as the ability of an antenna to convert input power into radiated energy, and gain is the measure of how directional the antenna can be considered. High-efficiency antennas minimize power losses and improve signal transmission, while high-gain antennas focus electromagnetic energy in specific directions, enhancing communication range and coverage. Performance analysis of microstrip patch antennas typically involves numerical simulations using electromagnetic simulation software or experimental measurements in an anechoic chamber. Simulation tools such as CST Microwave Studio, HFSS, and FEKO facilitate the analysis of antenna characteristics and optimization of design parameters. Experimental validation is essential to verify simulation results and ensure real-world performance compliance. Overall, a comprehensive performance analysis of microstrip patch antennas considers radiation pattern, impedance matching, bandwidth, efficiency, and gain, utilizing simulation tools and experimental techniques to optimize antenna design for various communication applications (Sumathi et al., 2021).

2.5 Technological Advancements

Microstrip patch antennas have undergone significant technological advancements over the years, enabling their widespread adoption in various wireless communication applications. This piece of work describes how microstrip patch antennas have changed and become more powerful to cater to the current needs of modern wireless communication systems. In the course of the article, we will examine some prominent technological advances that have occurred over recent years related to microstrip patch antennas:

2.5.1 Miniaturization and Compact Design

One of the most notable advancements in microstrip patch antennas is the achievement of miniaturization and compact design. Early microstrip patch antennas were relatively large and bulky, limiting their integration into portable devices and constrained-space environments. However, advancements in electromagnetic simulation tools, material science, and fabrication techniques have enabled researchers to design microstrip patch antennas with reduced size and footprint while maintaining or even enhancing their performance characteristics. Techniques such as fractal geometries, metamaterials, and high dielectric constant substrates have been explored to achieve miniaturization without sacrificing antenna performance (Suresh & Aruna, 2021).

2.5.2 Multiband and Wideband Operation

Another significant advancement in microstrip patch antennas is the ability to operate across multiple frequency bands or achieve wideband coverage. Traditional microstrip patch antennas were limited to narrowband operation due to their inherent structure and resonance properties. t is also worth mentioning that several methods have been proposed to improve the bandwidth of microstrip patch antennas, like parasitic elements, impedance matching networks, and meandering structures. Besides, integration of multiple radiating elements along with frequency-selective surfaces has made possible the development of multiband and wideband microstrip patch antennas, which can cover a large range of frequencies catering to different communication standards within one antenna design (Thaher & Hassan, 2019).

2.5.3 Enhanced Radiation Characteristics

Advancements in microstrip patch antenna technology have led to improvements in radiation characteristics such as gain, efficiency, and radiation pattern control. Techniques such as aperture coupling, substrate integrated waveguide (SIW) feeding, and metamaterial-inspired designs have been employed to enhance the radiation efficiency and gain of microstrip patch antennas. Furthermore, the integration of advanced feeding networks, such as corporate feed structures and hybrid couplers, has enabled precise control over the radiation pattern and polarization of microstrip patch antennas, making them suitable for applications requiring directional coverage and polarization diversity (Tiwari & Sharma, 2020).

2.5.4 Adaptive and Reconfigurable Antennas

Adaptive and reconfigurable antennas have emerged as a new technology in antenna design and are essential for modern wireless communication systems. Such antennas can vary their radiation patterns, polarizations, and frequency response adaptively according to environmental conditions and system needs. This helps establish quality signals that benefit adaptation, reduce interference, and improve communication reliability.

The core of the technology of these antennas involves variable reactive components and intelligent materials that can be reconfigured in no time. Control systems, mainly based on algorithms, sense the operating conditions and alter the characteristics of the antenna accordingly. Especially interesting will be when many users are present, and therefore, many signals exist within these radio frequency spectrums, like in urban landscapes, and for use when the device travels a diversified landscape of receiving scenarios—in mobile phones and satellite communications, for example.

How adaptive and reconfigurable antennas take part in implementing new technologies, such as 5G and IoT, proves to be quite significant for effective and robust wireless communication. These facilitate better network performance without investment in additional physical infrastructure and work toward cost-effective solutions in the dynamic telecommunication landscape.

With the advent of software-defined radio (SDR) and cognitive radio technologies, there is a growing demand for adaptive and reconfigurable antennas that can dynamically adjust their operating parameters to optimize performance based on changing environmental conditions and communication requirements. Microstrip patch antennas have been the focus of research in this area, with advancements in reconfigurable feeding networks, tunable materials, and MEMS (Micro-Electro-Mechanical Systems) actuators enabling the realization of adaptive beamforming, frequency tuning, and polarization reconfiguration capabilities in microstrip patch antennas.

2.5.5 Integration with RF Front-End Components

Another significant trend in microstrip patch antenna technology is the integration of antenna elements with RF front-end components such as filters, amplifiers, and transceivers. This integration aims to reduce system complexity, footprint, and cost by consolidating multiple functions into a single module or chip. Advances in packaging technology, system-on-chip (SoC) design, and heterogeneous integration techniques have enabled seamless integration of microstrip patch antennas with RF front-end components, resulting in compact, highly integrated wireless communication solutions for applications such as IoT, wearable devices, and smart sensors (Tiwari & Yogi, 2018).

2.5.6 Metamaterials and Meta-Surfaces

The exploration of metamaterials and meta-surfaces has opened up new possibilities for enhancing the performance of microstrip patch antennas. Metamaterial-inspired designs leverage engineered electromagnetic properties to achieve functionalities not attainable with conventional materials. Meta-surfaces, in particular, offer precise control over electromagnetic wave manipulation, enabling novel antenna functionalities such as polarization conversion, beam steering, and cloaking. By incorporating metamaterial-inspired structures and meta-surfaces into microstrip patch antennas, researchers have demonstrated improvements in bandwidth, efficiency, and radiation pattern control, paving the way for next-generation antenna designs with unprecedented performance capabilities (Toma & Shohagh, 2019).

2.5.7 Flexible and Wearable Antennas

The emergence of flexible and wearable electronics has spurred interest in flexible and conformal antenna designs that can seamlessly integrate with curved surfaces and conform to irregular shapes. Microstrip patch antennas have been adapted to flexible substrates such as polymers, paper, and textiles, enabling the development of flexible and wearable antennas for applications such as smart clothing, body-worn sensors, and biomedical implants. Advanced fabrication techniques such as inkjet printing, screen printing, and embroidery have been employed to realize flexible microstrip patch antennas with customizable form factors and mechanical properties, opening up new opportunities for wireless communication in emerging wearable technology platforms.

2.5.8 Energy Harvesting and Wireless Power Transfer

By incorporating energy harvesting elements such as rectifiers, antennas can convert ambient electromagnetic energy into electrical power to supplement or replace battery power in low-power devices. Similarly, wireless power transfer techniques such as magnetic resonance coupling and RF energy harvesting enable the transmission of power wirelessly to recharge or power electronic devices. Microstrip patch antennas have been integrated with energy harvesting and wireless power transfer circuits to create self-powered sensor networks, RFID tags, and IoT devices, extending their functionality and utility in remote and energy-constrained environments.

2.5.9 Millimeter-Wave and Terahertz Antennas

With the increasing demand for high-speed data transmission and ultra-wideband communication, there is growing interest in millimeter-wave (mmWave) and terahertz (THz) communication technologies. Microstrip patch antennas have been adapted to operate at these higher frequencies, leveraging advances in semiconductor technology, packaging, and antenna design. MmWave and THz microstrip patch antennas offer increased data rates, wider bandwidths, and reduced latency compared to traditional microwave antennas. Advances in materials, fabrication techniques, and beamforming technologies have further enhanced the performance and scalability of mmWave and THz microstrip patch antennas, paving the way for future generations of high-frequency wireless communication systems (Ton, 2018).

2.5.10 Advanced Fabrication Techniques

In addition to advancements in antenna design and materials, there have been significant improvements in fabrication techniques for microstrip patch antennas. Traditional fabrication methods such as photolithography and chemical etching have been augmented with emerging technologies such as additive manufacturing (3D printing), laser ablation, and nanoimprint lithography, enabling rapid prototyping and customization of antenna designs with high precision and repeatability. These advanced fabrication techniques offer greater flexibility and scalability in antenna production, facilitating the development of cost-effective, high-performance. In summary, microstrip patch antennas have undergone remarkable technological advancements in recent years, driven by innovations in design, materials, fabrication techniques, and integration with emerging wireless communication technologies. From miniaturization and multiband operation to adaptive beamforming and flexible form factors, microstrip patch antennas continue to evolve to meet the growing demands of modern wireless (Tripathi, 2023).

2.6 Recent Advances

Recent advances in microstrip patch antenna design have led to significant improvements in performance, efficiency, and versatility across various applications. One notable advancement is the integration of metamaterials and metamaterial-inspired structures to enhance antenna characteristics such as gain, bandwidth, and radiation efficiency. Metamaterial-based designs leverage artificially engineered electromagnetic properties to achieve unprecedented control over the antenna's electromagnetic response, enabling novel functionalities such as polarization diversity, beam steering, and frequency agility. Another significant trend is the development of multi-band and wideband microstrip patch antennas to support the increasing demand for multi-frequency communication systems. Innovative design approaches, including stacked and parasitic elements, coupled with advanced feeding techniques, enable broad frequency coverage while maintaining compact antenna dimensions. Moreover, the exploration of reconfigurable and tunable microstrip patch antennas has gained momentum, allowing dynamic adjustment of antenna parameters to adapt to changing communication requirements and environmental conditions. These advancements pave the way for the deployment of microstrip patch antennas in emerging technologies such as 5G communication, IoT devices, satellite communication systems, and unmanned aerial vehicles, where compactness, efficiency, and adaptability are paramount. Continued research efforts in material science, fabrication techniques, and electromagnetic modeling are expected to drive further advancements in microstrip patch antenna technology, unlocking new possibilities for wireless communication and sensing applications in the years to come (Verma & Srivastava, 2019).

2.7 Gaps identification, Challenges, and Future Directions

Through literature review it is assimilated that lot of challenges and future directions of microstrip patch antennas encompass a spectrum of issues and opportunities that shape the trajectory of research and development in this field.

One significant challenge lies in achieving multi-band and wideband operation while maintaining a compact antenna footprint

Overcoming bandwidth limitations and optimizing frequency coverage remain focal points for future research efforts, necessitating innovative design approaches and advanced materials.

Additionally, enhancing antenna efficiency and radiation characteristics poses another challenge, particularly in dynamic and complex electromagnetic environments. To overcome such obstacles, new ideas on feeding techniques, substrate materials, and antenna arrays should be found in order to make the gain, radiation pattern, and polarization diversity work at optimal performance levels. What's more, microstrip patch antennas are incorporated into these developing technologies like 5G, Internet of Things (IoT), and autonomous systems because they pose both challenges and prospects. From the system level to that of the integrated circuit, it is necessary for such an antenna to achieve high data rate operation with low latency, as well as reliable connectivity under strict requirements in these applications through interdisciplinary collaboration across different departments and optimization at the system level holistically.

Furthermore, the proliferation of wireless communication systems and the miniaturization trend in electronics underscore the importance of developing compact, low-profile antennas with enhanced capabilities and versatility. Future research directions may also encompass exploring unconventional materials, such as graphene and metamaterials, for realizing novel antenna functionalities and overcoming traditional design constraints. Moreover, advancing fabrication techniques, including additive manufacturing and flexible electronics, can enable the realization of conformal, lightweight, and cost-effective antenna solutions for diverse applications. In conclusion, while microstrip patch antennas have made significant strides in wireless communication systems, addressing ongoing challenges and embracing future opportunities will drive continued innovation and evolution in this vital area of antenna technology.

It is learned from Literature review that very less work has been carried out in the domain of Microstrip Patch Antennas, or MPAs as they are small antennas that can help handheld devices these days and much faster data speeds are needed for modern wireless transfer and reception standards. Multiple-Input Multiple-Output (MIMO) transmitters have problems with the skin effect, even though they are more reliable and can send data faster in the high-frequency range. Multiple-Input Multiple-Output (MIMO) microstrip antenna devices have ports that are next to each other, which can cause unwanted mutual coupling to happen.

The proposed objective of this research work is to find ways, means and techniques to lower coupling and to stop them from interacting with each other, study about both the real and predicted frequency responses of the 5G MIMO, the return loss. It is proposed to carry out research work through High Frequency Structure Simulator (HFSS) software and research about conductors, dielectrics, and radiation, substrate thickness , shapes.

CHAPTER – 3

AN INTROSPECTION INTO THE EVOLUTION OF MICROSTRIP PATCH ANTENNA DESIGN TECHNIQUES FOR ENHANCED WIRELESS APPLICATIONS

An Antenna plays a very crucial role in a wireless application system. A microstrip patch antenna generally finds use in high-grade wireless communication features that have both high gain and narrow bandwidth. Due to the advancements in the wireless communication and Integrated Circuit technology, Patch Antennas are being widely implemented as printed antenna for wireless communication, satellite communication, microwave communication and cell phones. It has gained a lot of attention over the past years due to its compact structure, low weight, low profile, low cost and a capability to reconfigure on different frequency bands. Furthermore, a hybrid combination of a slot and patch antenna can enhance the overall performance parameters. This paper presents an introspection into the evolution of various designing, simulation and fabrication techniques adopted for designing of microstrip patch antenna. The research investigates elements of the microstrip patch antenna design, for example: the selection of substrate material, geometrical configuration, feed methods, and methods of bandwidth enhancement. Indeed, very little work has been done in looking into the existence of the few antenna designs that demonstrate a comparison related to enhanced performance parameters such as the dimensions of the bandwidth for the patch, return loss, directivity, and efficiency associated with the patch antenna designs.

3.1 Introduction

In the recent years, there has been a phenomenal progress in the Wireless communication systems. This has created a thrust for design enhancements in the conventional antenna structures. In line with this a Microstrip Patch Antenna (MPA) offers the required features of Miniaturized size, wider bandwidth, enhanced radiation, improvised fabrication and integration capabilities.

A Microstrip antenna is a small-sized antenna made up of two metallic planes that are spaced apart by a dielectric Substrate. The bottom level consists of the ground plane, whereas the top one is a radiating patch. These two planes are insulated with a low-loss dielectric media known as substrate. As the process of designing a Printed Circuit board and microstrip antenna are the same, a microstrip antenna is also known as a "printed antenna" (Verma &

Srivastava, 2021). The conducting slot radiates because of the fringing fields developed at the corners of the patch and the reference plane. An inherent advantage of using a Microstrip Patch Antenna (MPA) is its simple feeding mechanism and the ease of interfacing with other ICs. Additionally, MPA can be used in arrays and with other microstrip circuit devices. Although the shapes most commonly employed are circles and rectangles, the patch that can be designed with this kind of antenna may be rectangular, square, circular, dipole, triangular, elliptical, disc sector, circular ring, or ring sector. Furthermore, the Dielectric Resonator Antennas loaded with these features are being upgraded continuously to meet these diverse requirements are under investigation from past two decades (Waterhouse, 2018).

In the realm of wireless communications, microstrip patch antennas have emerged as fundamental components due to their versatility, compact size, and cost-effectiveness. The chapter "An Introspection into the Evolution of Microstrip Patch Antenna Design Techniques for Enhanced Wireless Applications" delves into the intricate journey of microstrip patch antenna design from its inception to the present day, unraveling the technical enhancements that have significantly bolstered its applicability in various wireless applications. The evolution of microstrip patch antennas is a testament to the relentless pursuit of optimizing performance metrics such as gain, bandwidth, efficiency, and size reduction. Initially conceived for military applications, the adoption of microstrip patch antennas has since permeated through numerous sectors including telecommunications, satellite communication, and even medical devices, underscoring their indispensable role in modern wireless systems (Devarapalli & Moyra, 2023).

This chapter begins by tracing the historical roots of microstrip patch antenna technology, highlighting pivotal developments that set the stage for subsequent innovations. The early design iterations, primarily focused on simplistic rectangular and circular patches, laid the groundwork for more sophisticated designs. Over the years, with the changing landscape of wireless communication, the requirements on antenna performance have been drivers for antenna researchers and engineers to look for solutions far beyond traditional design paradigms. A significant part of this chapter is thus devoted to the elaborate discussion of the various design techniques developed over time. Techniques such as the use of different substrate materials, the introduction of novel patch shapes, and the implementation of multiple feed points have all contributed to enhancing the performance of microstrip patch antennas. Additionally, the integration of advanced technologies like metamaterials and the application of optimization algorithms have further refined antenna design, enabling customtailored solutions for specific wireless applications (Singh & Kumawat, 2020).

The chapter also explores the impact of these design advancements on the functionality and efficiency of microstrip patch antennas in real-world applications. From enhancing data transmission rates in mobile networks to improving the accuracy of satellite-based navigation systems, the enhancements in antenna design have had far-reaching implications. This introspective journey through the evolution of microstrip patch antenna design techniques not only chronicles the technical milestones achieved but also sets the stage for future innovations. As wireless communication continues to evolve at a breakneck pace, the quest for more efficient, versatile, and high-performing antennas remains a central focus of the field. The movement of this chapter will outline the past, present, and future of the microstrip patch antenna design to orient researchers, practitioners, and enthusiasts in the field of burgeoning wireless communications.

Size and shape are two parameters that mainly influence the performance of the antenna; in this manner, size and shape pertain to what relates to the length, width, and thickness of a substrate and, the location of the feed line, whether it is beneath or above these lengths, widths, or thicknesses, and material of the substrate, for instance. A major limitation of an antenna is narrow bandwidth and gain adjustment. From the application perspective bandwidth is a and needs to be enhanced for wideband performance. Figure 1 represents a variety of shapes assumed by a rectangular 1(a) the square 1(b) the rectangle, 1(c) the circle,1(d)the triangle, 1(e) the donut, and 1(f) the dipole.

3.2 Related Work

This section provides the chronological development of patch antenna as proposed by various designers. Authors (Ullah, S., Ruan, et.al. 2019) proposed a MPA operating at a design frequency of 2.45 GHz. In this work, performance in antenna design has been analyzed for two different materials, FR4 & Roggers RT Duroid. After comparative parametric analysis of the antenna materials, it is revealed that the performance of the Antenna employing Roggers RT droid material rendered a better result in terms of superior gain of 2.59 dB, return loss of -12.54 dB, directivity gain of 8.58 dBi, VSWR of 1.61, and efficiency close to 94% approximately, compared to its counterpart FR4. Apart from this it exhibits excellent radiation and capable to work over a wide frequency band.

Authors (Taybi, et. al. 2019) has proposed a compact rectangular patch with enhanced bandwidth and efficiency, employing a hybrid technique, thereby increasing its suitability for

UWB applications. This designed antenna employs a Defected ground structure as the initial stage. The proposed design takes into account various crucial antenna design parameters such as frequency of oscillation, width and length of the patch, effective dielectric constant, dimensions of the ground plane. The proposed design yields an improved efficiency of 95.77 % and a bandwidth of 19.7 GHz. This design has rendered a bandwidth and efficiency enhancement of nearly 17 GHz and 3.5 % respectively with respect to a basic antenna with DGS. This design becomes a better candidate for Wireless applications.

Authors (Bhat & Mehra 2022) has suggested a dual-band patch antenna utilizing a LI slot as a suitable candidate for 5G communications .This design employs various permutations & combinations of multiple LI slots. The objective was to operate the antennas at dual resonant frequencies of 26 GHz and 28 GHz respectively. Four sets of designs have been suggested and compared with each other. It is observed that the four designs render a performance which is far more superior to the identical designs proposed by other designers. It was investigated that the slotted antenna designs employing various configurations were well suited for 5G communication handsets in which case simple design and small size are the primary constraints for evaluation.

In this work, Authors (Khatun et. al., 2021) performance in antenna design has been analyzed for two different materials, FR4 & Roggers RT Duroid. After comparative parametric analysis of the antenna materials, it is revealed that the performance of the Antenna employing Roggers RT droid material rendered a better result in terms of superior gain of 2.59 dB, return loss of -12.54 dB, directivity gain of 8.58 dBi, VSWR of 1.61, and efficiency close to 94% approximately, compared to its counterpart FR4.

Authors (Sivasangari et. al., 2023) has proposed and investigated an antenna using a wideband Dielectric resonator having a high gain and low cross polarization. The emphasis is laid on the improvement of bandwidth and gain. A return loss of -10dB with an efficiency of 25.6%.Thiss further yields an average gain of 7.54 dBi. Due to the simplicity of the antenna design, it can be utilized to form an antenna array.

Authors (Tadesse & Acharya, 2016) proposed MPA using several Microstrip elements to form an array. The main objective is to enhance the overall gain and bandwidth. The antenna is designed at a frequency of 2.48 GHz using FR4 at a dielectric constant of 4.3. In this design, two rectangular patches of the same size are used and combined to improve the return loss and reflection coefficient besides improvement in bandwidth and gain as iterated earlier.

Authors (Khatun et al. 2021) have designed a Directional pattern Microstrip patch-slot antenna with frequencies. The antenna proposed in the work can be reconfigured to six frequencies of 1.7 GHz to 3.5 GHz. The current study also uses a reflector, which will improve the antenna's directivity. Frequency agility of the antenna is provided by using switches inside the antenna slot.

Mishra et al. (2018) reported a reconfigurable wideband antenna with circular polarization and an E-shaped patch. The fabricated antenna is on a plane sheet of RT-duroid 5880 with a dielectric substrate with a permittivity of 2.2. A narrow slit is etched on the E-shaped pattern. This final design shows a 7% improvement in bandwidth with a gain of 7.5 dBi. The antenna structure fabricated covers the band of frequencies in the WLAN IEEE 802.11 b/g to be used with stationary terminal wireless applications.

Authors (Rana et. al., 2012) suggested a High gain patch antenna to form a wired Yagi-Uda array operating in the frequency band of 5.45 to 5.75 GHz. In this design the Yagi-uda element is replaced by wired patch antennas.

Authors (Kartha et. al., 2011) presents a Microstrip antenna using fractal terminology that renders a wide band of operation. It has been established in the prototype can operate over a frequency band of 10-50 GHz and a 40 GHz bandwidth.

3.3 Design Methodology

This chapter explains the basic design steps carried out in shaping the Rectangular Microstrip Patch Antenna (RMPA) and details the feeding techniques orientated toward enhancement of the major performance parameters: bandwidth, gain, return loss, directive gain, and other scattering parameters. In RMPA, the material adopted as a substrate for the desired resonating frequency was optimized, and the optimized dimension was for building up the patch structure determined according to the systematic plan design. Feeding techniques are also noticed to play an essential and imperative role in deciding the performance of the RMPAs. The method chosen will also determine in huge part the impedance matching, resonant frequency, return loss, and bandwidth of the antenna—be it the microstrip line, coaxial probe, aperture coupling, or proximity coupling. The idea is to feed correctly into the antenna the power from the transmission line and obtain maximum radiation efficiency with minimum reflection.

Enhancing the bandwidth of RMPAs is a primary focus in this design process. Adjustments in the substrate's thickness and the patch's dimensions, alongside the employment of various feeding techniques, are scrutinized to widen the operational bandwidth. The goal is to create an antenna that can operate effectively over a broader range of frequencies, catering to the demands of modern wireless communication systems. Similarly, efforts to improve the antenna's gain and directive gain are essential for achieving higher directivity and efficiency. These improvements are critical for applications requiring focused radiation patterns and long-range communication capabilities. Additionally, optimizing scattering parameters further refines the antenna's performance, ensuring it meets the stringent requirements of advanced wireless communication systems. Through a meticulous design process, the RMPA's capabilities are fine-tuned, aiming for an optimal balance of all these critical parameters to achieve superior performance in wireless applications.

3.3.1 Rectangular MPA Design Using HFSS

Figure 3.1 represents a basic topology of a MPA .This design utilizes two basic materials FR4 and glass as dielectric materials. The bandwidth of the antenna can be modified by varying the 3 dimensions & shape. This technique is known as Dimensional optimization. The bandwidth primarily depends upon the thickness of the dielectric medium used and width of designed patch. Table 3.1 gives the parametric details of the incorporated dielectric material, feeding method used and the type of simulation software employed in design. This method involves meticulously adjusting these parameters to enhance the antenna's performance characteristics. Table 3.1 provides an in-depth look at the parametric details involved in this optimization process, including the specific dielectric materials used, the feeding methods employed, and the simulation software utilized in the design process.

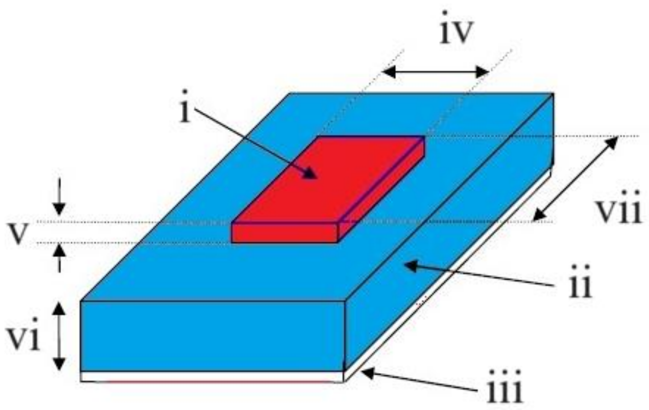

Figure 3.1: A Layout of Rectangular Microstrip patch Antenna. with (i) Patch (ii) Dielectric

substrate (iii)Ground plane (iv)Length(L) of the patch (v)Thickness(t) of the patch (vi)Height of dielectric medium(h) (vii)Width(W) of the patch

Table 3.1: Parametric details of the RMPA design using various dielectric materials

Dielectric material Parameters	Glass	FR-4
Width(mm)	20.8	22.6
Length(mm)	14.77	16.6
Resonant frequency	4.1 GHz	4.06 GHz
Return loss	-6.4 dB	-10.4dB
Gain	6.6dB	6.92 dB
Dielectric constant(Ɛ)	5.5	4.4
Reflection coefficient(S_{11})	-10	-10.4

The parametric calculations make use of the following equations

Equation 1 gives the width (W) of the patch in MPA

$$W = \frac{C\sqrt{2}}{2fr\sqrt{1+\varepsilon}} \tag{1}$$

Equation 2 gives the length (L) of the patch in MPA

$$L = \frac{C\sqrt{2}}{2fr\sqrt{\varepsilon r}} - 2\Delta L \tag{2}$$

The simulated image of the patch antenna in the High Frequency Simulation Software (HFSS) tool is shown in Figure 3. Initially, the MPA was designed with a rectangular patch; the dielectric substrate was glass, having a dielectric constant of 5.5 at a design frequency of 4 GHz, thereby giving results of a return loss of around -10 dB. Later, it was tested on FR4 as a dielectric medium with a dielectric constant of 4.4. The reflection coefficient is -10.4, as shown in Table 3.1 above.

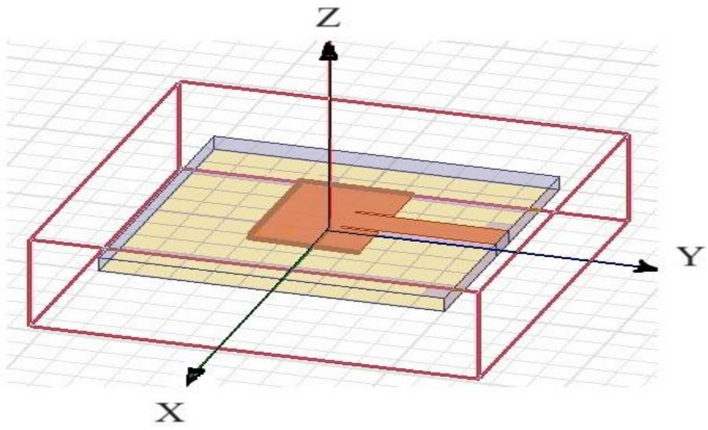

Figure 3.2: Simulated structure of Rectangular Microstrip patch Antenna. (RMPA) using HFSS

3.4 Results and Discussions

Table 3.1 presents the results obtained while designing a Microstrip patch antenna using various dielectric materials with variable dimensions. The parametric details of the incorporated dielectric material, the feeding technique used, and the type of simulation software employed in design-1. For example, the FR-4 substrate of a base structure, having 4.06 GHz of resonant frequency, has a return loss of -6.4 dB, while similar glass epoxy, having a resonant frequency of 4.1 GHz, results in a return loss of -10.4 dB. The bandwidth for the said antenna is enhanced from some specific design to shoot up high by about 300 MHz, which is phenomenal. Table 3.1 last but not least, highlights the results of the design of a Microstrip patch antenna – the effect of the various dielectric materials and dimensions on the functioning of the antenna. Table 3.1 carefully lists each of the dielectric materials, the particular feeding techniques, and the software used to simulate the first set of designs. More so, using an FR-4 substrate, the antenna resonates at a frequency of 4.06 GHz with a return loss value of -6.4 dB. Using glass epoxy for the substrate material, the slightly sizeable rising edge increases the frequency somewhat to 4.1 GHz, but it has a much better return loss of -10.4 dB.

The data encapsulated in Table 3.1 is crucial for understanding how different materials and design choices influence the functionality and efficiency of Microstrip patch antennas. The comparison between FR-4 and glass epoxy substrates is particularly illuminating, demonstrating how material selection can significantly affect key performance indicators like resonant frequency and return loss. Moreover, a standout observation from the table is the notable enhancement in bandwidth, which sees an impressive increase of approximately 300 MHz. This enhancement is not only significant in magnitude but also indicates the potential for substantial improvements in wireless communication performance through thoughtful design and material selection. In essence, Table 3.1 serves as a vital reference point for antenna designers and researchers, offering concrete data on how specific changes in the design process can lead to tangible improvements in antenna performance. Such insights are invaluable for pushing the boundaries of what is achievable with Microstrip patch antennas, driving advancements in wireless communication technology.

3.5 Conclusion

The research presented delves into the advancements in microstrip patch antenna (MPA) design, underscoring the critical influence of dielectric material selection and patch dimensions on antenna performance. This study not only charts the progress in MPA design but also elucidates the intricate relationship between various design facets, including substrate material choice, geometric configurations, feeding methods, and bandwidth optimization techniques, and their collective impact on key antenna parameters such as gain, return loss, directivity, and reflection coefficient. The findings unequivocally establish that the choice of dielectric material and the specific dimensions of the patch are pivotal determinants of an MPA's efficiency and effectiveness. These elements are shown to significantly affect the antenna's operational characteristics, including its ability to resonate at desired frequencies, maintain low return loss levels, and achieve optimal directivity and gain.

The research accentuates that meticulous selection and fine-tuning of these parameters can substantially enhance the antenna's performance, making it more suited for advanced wireless applications. Moreover, the study highlights improvements in the antenna's scattering parameters, indicating a superior ability to manage and minimize undesirable signal reflections, which is crucial for maximizing energy transmission and reception efficiency. This enhancement in scattering parameters points to a broader implication of the research: by optimizing material and design choices, one can significantly boost the antenna's overall performance, thereby contributing to the development of more reliable and efficient wireless communication systems. In conclusion, this work provides valuable insights into the interplay of various design elements in MPA development, offering a comprehensive understanding of how strategic choices in material and design can lead to substantial improvements in antenna performance, paving the way for future innovations in the field of wireless communications.

CHAPTER – 4

DESIGN AND DEVELOPMENT OF A HIGH-PERFORMANCE HYBRID PATCH ANTENNA WITH ENHANCED BANDWIDTH FOR WIRELESS COMMUNICATION

Modern antennas rely increasingly on patch antennas, since the main advantages of patch antennas are that they have a compact size, a low profile, and a suitability in a wide range of applications. Therefore, they are imperative for modern wireless technologies. New design approaches have to be investigated to satisfy higher data rate, increased bandwidth demands, and improved radiation characteristics. This chapter presents, in detail, the design and development of the High-Performance Hybrid Patch Antenna with Enhanced Bandwidth for Wireless Communications. New design enhancements that offer significantly enhanced performance and flexibility are discussed within this chapter. In summary, the development of this advanced hybrid patch antenna optimized for superior bandwidth and high gain is presented as an interesting alternative for high performance compared to the designs presented before. The outcome derived from this work will be of great value to the researchers and the engineers working in this area of antenna technology and can act as a driving force for further research and advancement in the development of more efficient hybrid antennas.

4.1 Introduction

A Microstrip patch antenna came into existence in the middle of the twentieth century. This antenna became so famous within a period of two decades due to certain inherent advantages that were immensely appreciated by the researchers themselves. The advancement in these wireless communications technologies is forcing, on the other hand, the development of more sophisticated and efficient antigens. Among these, the most relevant antennas are microstrip patch antennas because of their low profile, lightweight, and compatibility with integrated circuitry. However, conventional microstrip patch antennas often face limitations regarding bandwidth, efficiency, and gain. To address these challenges, this research focuses on the design and development of a high-performance hybrid patch antenna, which incorporates innovative design techniques and materials to achieve enhanced bandwidth and superior performance metrics, aligning with the burgeoning demands of modern wireless communication systems (Mahmud & Roy, 2022).

The genesis of this research is rooted in the critical examination of existing antenna designs, where the quest for increased bandwidth and performance in a compact form factor remains paramount. Traditional microstrip patch antennas, while advantageous for their simplicity and ease of fabrication, often exhibit narrow bandwidth and limited gain, restricting their applicability in broad-spectrum wireless systems. The hybrid patch antenna concept introduced in this study aims to transcend these limitations by amalgamating different materials and design strategies to forge an antenna that not only broadens the operational bandwidth but also enhances other vital performance parameters such as gain, directivity, and efficiency. Central to this endeavor is the exploration of innovative materials and novel engineering techniques. The use of advanced dielectric substrates, integration of multiple resonant structures, and employment of cutting-edge fabrication methods are pivotal to the antenna's design, facilitating a substantial improvement in its electromagnetic properties. The hybrid approach allows for a synergistic combination of materials and geometries that can be fine-tuned to achieve specific performance objectives, offering a versatile platform for addressing diverse communication needs (Okoro & Oborkhale, 2021).

Moreover, the development process of this hybrid patch antenna meticulously considers the integration of various feeding techniques and impedance matching mechanisms to optimize the power transfer and radiation efficiency of the antenna. By leveraging sophisticated simulation tools and empirical testing, the design is refined iteratively, ensuring that the final product not only meets but exceeds the performance benchmarks set forth at the outset of this research. This innovative endeavor not only aims to enhance the technical capabilities of patch antennas but also strives to address the practical considerations of modern wireless communication systems, such as size constraints, cost-effectiveness, and ease of integration with existing technologies. The anticipated outcome is an antenna that not only offers a superior performance profile but also aligns with the pragmatic needs of industry and end-users, facilitating smoother adoption and integration into various wireless systems. The hybrid patch antenna's potential to support a wide array of wireless applications, from mobile communications to satellite broadcasting, underscores its significance in the broader context of communication technology advancement. Through this research, the hybrid patch antenna is poised to set a new benchmark in antenna design, offering a tangible solution to the pressing demands for better, more efficient wireless communication capabilities in an increasingly connected world (Vidhya et al., 2019).

The design and development of this high-performance hybrid patch antenna represent a significant stride forward in antenna technology, with the potential to catalyze advancements in wireless communication. By pushing the boundaries of traditional microstrip antenna design and embracing a holistic approach that incorporates a fusion of materials, design concepts, and technological innovations, this research aims to contribute a robust and versatile antenna solution, poised to meet the evolving challenges and opportunities in the field of wireless communications. Furthermore, printed circuit technology was effectively employed in the Microstrip patch antenna that paved ways for integration of antenna within existing wireless systems. This resulted in the fabrication of standalone systems comprising of an array of such elements arranged in a particular pattern (Saraereh et al., 2022; Musa et al., 2023).

Recent years have shown a tremendous utilization of Wireless data transmission networks resulting in expansion of Wi-Fi distribution. In order to address the increasing demand of consumers, antennas with higher bandwidth and smaller dimensions are best suited (Lodro et al., 2019). The general structure of the patch antenna is shown in Figure 4.1. It is shown that the major component of the patch antenna is a Rectangular patch, as well as the feed line. In enabling the support between the fabrication design of the antenna analysis, this patch is commonly designed into a rectangular, circular, triangular, elliptical, or some other regular shape. For a rectangular patch, the length of this is usually taken to be 0.33 to 0.5 λ.

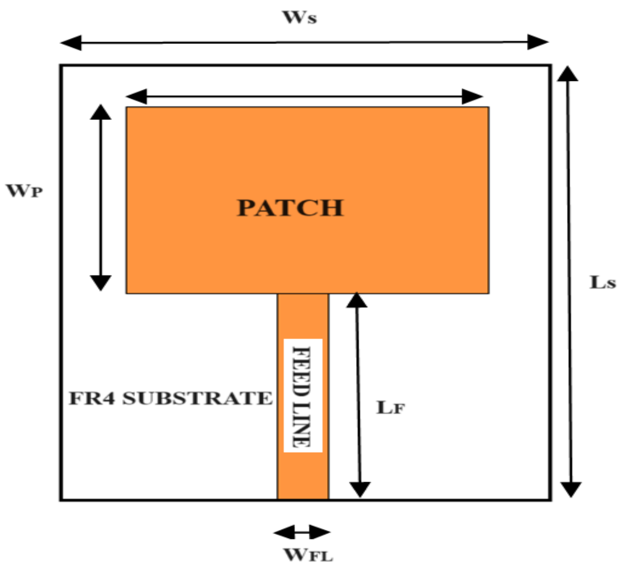

Figure 4.1: A front view of the proposed Rectangular Microstrip patch Antenna. with dimensional details.

Table 4.1 represents the dimensional details and the design parameters applicable to a conventional patch antenna. This article proposes a hybrid patch antenna design using a combination of T-Shaped and F-shaped patches. The proposed antenna has been fabricated and achieves a bandwidth and gain enhancement by a marginal factor.

Table 4.1: Typical design parameters of a Rectangular patch antenna employing FR4

Parameter (symbol)	Details	Typical value
W_S	Width of the substrate	20mm
W_P	Width of the patch	18mm
L_P	Length of the patch	14mm
L_S	Length of the substrate	30mm
f_o	Operating frequency	7GHz
ε_r	Permittivity of the material	4.5

4.2 Design Procedure

This section meticulously outlines the design specifics of the proposed hybrid rectangular patch antenna, which employs FR-4 as the substrate material and is optimized to operate at specific design frequencies. The choice of FR-4, a commonly used substrate in the realm of printed circuit board (PCB) manufacturing, is pivotal due to its well-balanced electrical properties, cost-effectiveness, and accessibility. This material offers a reasonable dielectric constant and loss tangent, making it a suitable candidate for achieving a robust antenna design.

The hybrid design approach adopted in this antenna integrates multiple resonant elements and advanced engineering techniques to enhance its performance across the designated frequencies. By leveraging the hybrid nature, the antenna aims to combine the advantageous aspects of different design methodologies to improve parameters such as bandwidth, gain, and efficiency. The rectangular shape of the patch is strategically chosen to facilitate ease of analysis and fabrication while allowing for effective radiation pattern control and impedance matching.

It involves simulation in the antenna design process; therefore, it is a very meticulous step for variation of different dimensions of the rectangular patch, say length, width, and placement of the feed point. These are the most vital dimensions which intentionally influence the resonant frequency, radiation pattern, and impedance matching of the antenna. The feeding technique, a crucial component of the design, is selected to optimize power transfer and bandwidth. This hybrid rectangular patch antenna represents a significant step forward in antenna technology, promising enhanced performance for diverse wireless communication applications.
Table 4.2 represents the design specifications employed in the proposed structure tested for two sets of fabricated antenna configurations.

Table 4.2: Results of antenna performance with two different operating frequencies and dimensions

	Dimensions in mm				**Frequency band**
	L	**W**	**L_T**	**Wt**	
Antenna 1	28	33	25	5	15GHZ
Antenna 2	28.5	33	25.1	5.8	75GHz

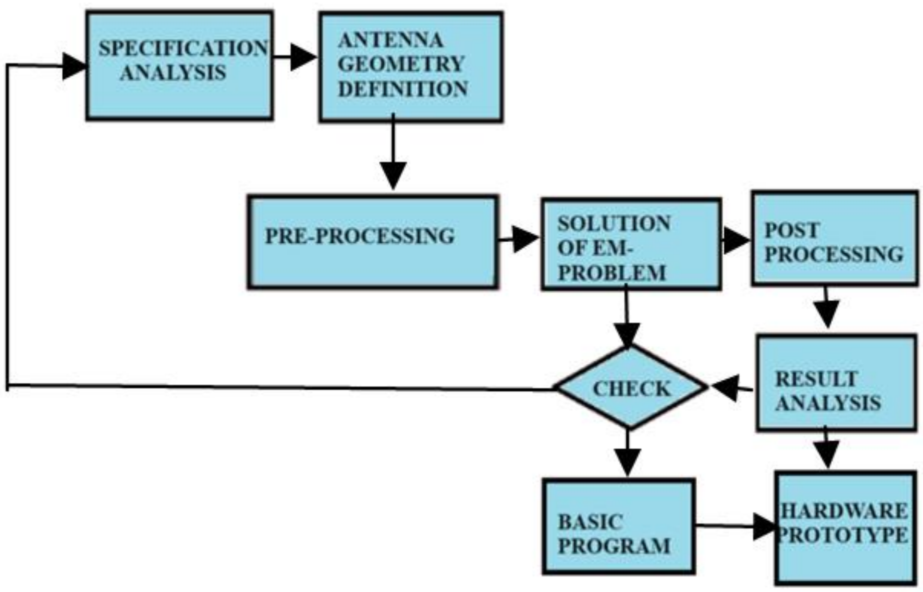

Figure 4.2: Design steps followed in modern Hybrid patch antenna design

4.3 Adopted Procedure

Figure 4.2 shows the steps initiated for designing a patch antenna using software simulation techniques. In this paper antennas have been designed at a frequency of 70 GHz. All the four elements have been designed by modifying the patches using a combination of T-shaped and F-shaped elements as shown below. The design makes use of FR4 as a substrate with a permittivity of 3.3. It comprises of two rectangular patches of T and F shape that are fabricated on the sides of the patch. The length of the patch is designated as L. In order to estimate the performance comparison of the antennas have been constructed with two different thicknesses. One antenna with a thickness of 0.65mm and 1.35mm for a frequency band of 15 GHz and with thickness of 0.15mm and 0.30 mm for a frequency band of 75 GHz. The design specifications employed in the proposed design are represented in Table 4.2.

4.4 Design Specifications

The proposed patch antenna topology is represented in the Figure 4.3 below. It comprises of F-shaped and T-shaped slots organized in a symmetrical structure. In Figure 4.3, the proposed design specifications are represented as L-Length of the patch, width of the patch, WT is the thickness of the Microstrip transmission line.

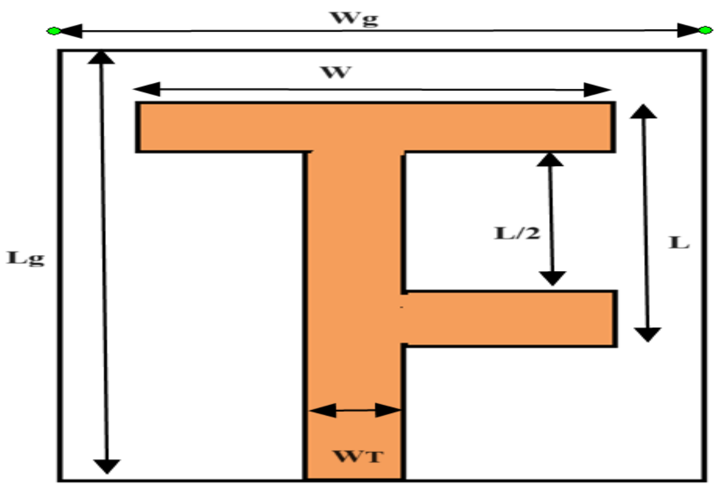

Figure 4.3: A hybrid patch antenna with T and F shaped rectangular patches for bandwidth enhancement

4.5 Modelling Techniques and Tools

Prior to hardware implementation, circuits and components to be used in filter design are simulated in a three dimensional environment known as Field Solvers. These electromagnetic field solvers provide reliable simulation results that finally match with the experimentation results on actual hardware. This aids in reducing the EM design costs and provide valuable analytical data through which a designer can visualize how microwave components actually behave. This speeds up the design convergence and leads to design convergence and optimized design selection by validating number of design options in a lesser time. Commercial EM tools currently available amounts to tremendous compactness in component size and hence the resultant structure. Trimming techniques are carried out to remove excessive roughage in multilayered devices before actual simulation is carried out. Simulation Field solver techniques can be virtually applied to all microwave components but they render efficient results for filters. The following field solver techniques have been used for Design optimization and enhancement in the EBG geometries for producing efficient devices and components:

4.5.1 IE3D

IE3D software is the high modeling accurate for high-frequency circuit design and signal integrity engineers across multiple design domains. The high design capacity requirements posed by current technological advancements are addressed by IE3D both at circuit and component level. This simulation is powered with multi-threaded and distributed simulation architecture providing cost effective solutions coupled with compact designs and parametric enhancements. It delivers the desired design accuracy. IE3D has been extensively used for antenna design

This is effectively carried out by designing a high capacity unit array cell and the cell is replicated to create a large antenna array structure. It also satisfies the boundary conditions and offers space optimization desired for a large array antenna. It is also used for RFID design that combines antenna and embedded passive design. Using accelerated design closure capabilities of this software, the performance of the resulting RF-ID tag can be improvised. Furthermore, it can be implemented for complete designing and validation of multi-chip system architectures exploring full 3D capabilities.

4.5.2 HFSS

HFSS (High-Frequency Structure Simulator) is design and simulation software at high frequencies for antennas, filters, IC packages, and printed circuit boards. This is high-frequency 3D EM software most helpful in high-frequency circuits that are fit for fabrication in radars, satellites, and the Internet of Things. This software is integrated with versatile solvers and a brilliant Graphic user interface(GUI) for introspection in 3D EM problems. It is loaded with tools such as thermal, structural and fluid dynamics that are suitable for multi-physics analysis. HFSS is categorized in the gold standard accuracy range due to its adaptive meshing and sophisticated solving techniques. This is superior as it enhances the quality of design, improves product reliability , compactness and performance.

4.5.3 CST Studio

CST(Computer Simulation Technology) studio is capable of simulating and solving problems in all segments of Electromagnetic spectrum ranging from low frequency applications to high frequency, microwave and optical frequencies. It comprises of seven different studios namely- Microwave Studio, EM Studio, Design Studio, Particle Studio,

MPHYSISCS Studio, Cable Studio and PCB Studio. Each studio is utilized for designing of a specific area of application. It provides accurate, efficient computational solution for EM designs. This software can be coupled to perform hybrid simulations and the whole system can be visualized and analyzed in terms of components. It facilitates shorter development cycles and reduced costs. The current areas of interest in which this software is used potentially are-Performance improvement in filters and Antenna circuits, Electromagnetic Interference (EMI), Exposure to fields, Thermal effects in high power devices.

4.6 Results

Table 4.2 depicts the results obtained regarding bandwidth enhancement. The parametric details of the incorporated dielectric material, the feeding method used, and the type of simulation software employed in design-1. In this case, the FR-4 substrate with a resonant frequency of 4.06 GHz produces a return loss of -6.4 dB, whereas glass epoxy operating at a resonant frequency of 4.1 GHz produces a return loss of -10.4 dB. It is found that the bandwidth of the antenna in the design is enhanced drastically by around 300 MHZ, which is quite phenomenal. In the proposed methodology, the simulated versus measured values of the return display a good closeness, which is a figure of merit. The set of fabricated antennas is shown below in Figure 4.3.

4.7 Conclusion

The presented work has highlighted the use of a hybrid combination of elements to fabricate a Patch antenna. The research presented delves into the innovative fabrication of a patch antenna utilizing a hybrid combination of elements, marking a significant stride in antenna design and development. This study meticulously explores the performance of the fabricated antennas across various operating frequencies and dimensional configurations, providing a comprehensive understanding of their operational characteristics. A key finding from this investigation is the identification of a fundamental trade-off between bandwidth and gain, two critical parameters in antenna performance. The study reveals that enhancing the antenna's gain, which is crucial for increasing the strength of the received or transmitted signal, often results in a reduction of bandwidth. Conversely, expanding the bandwidth, which is essential for supporting a broader range of frequencies and thereby accommodating diverse communication needs, tends to diminish the antenna's gain.

This trade-off underscores a pivotal challenge in antenna design: balancing gain and bandwidth to meet specific application requirements. The research demonstrates that while it is possible to optimize one parameter, it often comes at the expense of the other, necessitating a careful and strategic design approach to achieve the desired performance balance. The implications of such work are far-reaching and, in fact, very relevant to designers and engineers working in the wireless communication domain. Understanding and moving through the trade-off in this sense enables practitioners to smoothly tailor antenna designs for the intricate demands of different wireless applications concerning best performance and efficiency in real-life communication systems. This study not only contributes to the academic discourse on antenna design but also provides practical guidelines for the development of more versatile and effective communication devices.

CHAPTER – 5

5G MIMO ANTENNA DESIGN WITH MICROSTRIP PATCH ANTENNA

The central concept discussed in the paper is a rapid, low-cost antenna development so that numerous devices can connect, being able to transmit and receive waves. Due to their increasing importance in professional and daily life, mobile phones have been adopted in a growing number of people. This increase paved the way for the colossal use of wireless devices, which further caused immense changes within the device, like an increase in frequency, quick data transference, and more reliable connections. Later in the paper, it is shown that the topic of array gain, spatial multiplexing gain, and spatial diversity gain is further explored—finally, a quick survey through the MIMO Antenna literature. The simulation counts a wireless communication system with more inbound and outbound antennas, which analyze return loss and the envelope correlation coefficient in dB per GHz. The detailed s-parameters include parameters like S11, S22, S21, and S12. The paper models the frequency of the Microstrip Patch Antenna in GHz and its input impedance parameters and the parameter S11 in dB.

5.1 INTRODUCTION

Modern wireless devices like cell phones, tablets, and PDAs are all used for personal contact. WiFi and Long-Term Evolution (LTE) are two examples of changes that have been made. Several antennas are used in Multiple Input Multiple Output (MIMO) technology to allow a lot of senders and listeners. This method makes the best use of the radio, which increases capacity and makes things more reliable (Megahed et al., 2023).

In MIMO systems, the channel factors control whether the channel capacity (shown in bits per second) goes up or down. As more listeners are added, the channel's power goes up in a straight line. Because of this, more listeners would mean more multipath channels in a perfect world. The speed boost would not work if the antennas' radiation patterns lined up or conflicted. Because of this, the antenna engineering team has a tough time making MIMO systems where elements do not communicate much (Cao et al., 2023).

One can easily find low-cost, flexible printed antenna technology that makes it easy to build and add printed antennas that use the device's system ground plane to small gadgets. Printed

MIMO antennas are made separately, even in small devices with closed antenna parts. In turn, this means that old antennas do not always meet the needs of modern wireless devices. Many people think Microstrip Patch Antennas (MPAs) are the best for wireless connection. Microstrip Patch Antennas have some excellent points, but they are limited by their low gain, narrow bandwidth, and inability to handle enough power.

Fixing crosstalk and getting the most out of frequency economy is very important. Spectrum may soon run out because more people want services that use much data, like file sharing, mobile video, and portable internet. The signal is more likely to be messed up by other services when more data is being used. Ultra-wideband is an excellent example of how movements can interact with each other (Ghadeer et al., 2023).

It is a goal of the information sector to make better use of the radio spectrum. The future of communications looks bright thanks to intelligent antennas, which could change the game as these technologies improve. Communication technologies have only recently made it possible for changes to be made that go beyond code, data, and time. At the range, there are strict rules and laws. If someone does not want to use a regular antenna, they should use an intelligent antenna or some other type of spatial domain antenna. Two sensors at each end of the channel are needed for multiple data streams in space and time. The data streams are sent to and received by two different terminals. Many more people can use the airwaves with the help of MIMO devices, which can process data much faster. This is the worst kind of radio channel, called multipath fading (Ismam & Hossain, 2023).

It uses “multipath” to discuss how electromagnetic waves send messages at different times, angles, and frequencies as they move through space. Wireless communication systems are challenging to build because they can handle infinite frequencies. Radio transmission architecture has changed a lot since MIMO technology came out. MIMO systems are different from single-antenna systems because they can use both time and frequency. It is better to use the MIMO approach because it helps with arraying, spatial diversity, spatial multiplexing, and reducing interference.

A new type of wireless cell network will appear as wireless communication technology improves. Many believe that MIMO technology is critical for 5G radio networks to work well. Innovative antenna technology and wireless broadcast antenna diversity technology are the technologies that came before MIMO technology (Abdel-Fattah et al., 2023). It has the best SIMO and MISO systems features because data comes from a single source and is sent to many places. MIMO means that both ends of the transmission use more than one antenna. It can significantly improve the quality and speed of wireless links without needing more power or bandwidth.

For MIMO technology to work, the multiantenna device must function well. Multiple antenna systems can be affected by more than just their structure and design. The multipath properties of the wireless channel can also play a role. In MIMO multiantenna design, people investigate things like mutual coupling analysis, multiple antenna patterns, and the shape of antenna elements. Most MIMO multiantenna system research is focused on finding low-cost, high-performance antenna and design choices right now (Alassawi & Ali et al., 2023).

To get the needed electromagnetic efficiency, antennas are often attached to the outside of the carrier. The bent antenna was made because of this. One can use a conformal antenna design outside the page to save space and prevent mechanical support from getting damaged. There is no one part of the outside of the box where this happens. Conformal antennas come in many types, such as microstrip, stripline, and crack antennas. One of the many great things about the microstrip antenna is its small, light, and low profile.

For this reason, bent antennas work better. Lately, many people have been talking about 5G technology and the unique qualities of the millimetre-wave band, like its short wavelength, wide frequency range, and ability to pass through dust, fog, and snow. Because of this, much time has been spent studying millimetre wave microstrip antennas. Figure 1 displays a 5G MIMO antenna design overview.

The antenna parts that send and receive signals are in the front of a MIMO curved antenna. As the radiation parts in this layout, Microstrip Patch Antennas are used. When designing rectangular microstrip antennas, two main steps must be taken. After doing much study on the method, academics used simulation and optimization to test their ideas. The first step in the process is choosing an insulating material. In the millimeter-wave frequency band, the microstrip circuit loses much power. There are three ways that energy can be lost: dielectric loss, circuit loss, and radiation loss. One can reduce dielectric loss by using a base with a low-loss tangent dielectric (Ibrahim et al., 2023).

There is no change in the total loss of a microstrip when the characteristic impedance is changed. Their low dielectric constant is the reason for this matter. In a medium with a high dielectric constant, on the other hand, both the microstrip loss and the characteristic impedance will change quickly. As the base gets thicker, there will be more radiation losses and the chance of a surface wave.

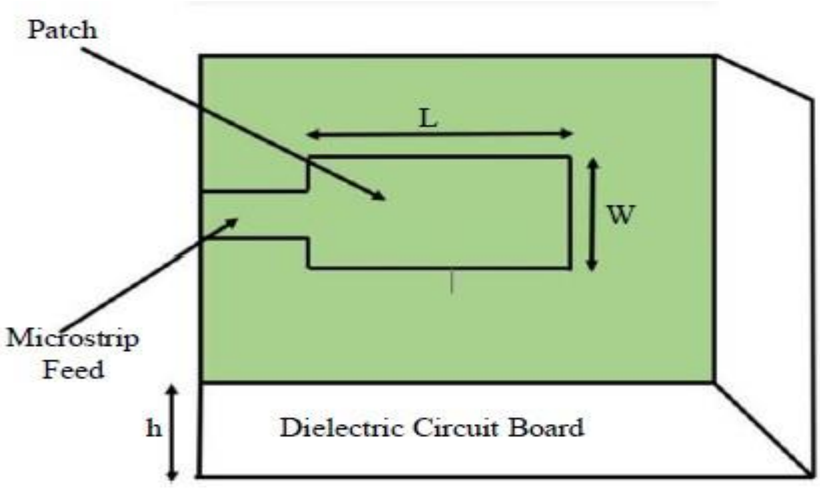

Figure 5.1 5G MIMO antenna design overview

A shorter height is better to stop the higher setting and reduce radiation leaks. Many countries have spent much money on research and development to prepare for the switch to Fifth-Generation (5G) wireless internet, which will happen anyway. It is because people want better internet and more space on their phones. Many of these countries and places have made their own 5G wireless protocols because people wish wireless data transfer speeds 100 times faster than 4G LTE. Governments, companies, and researchers are increasingly using Millimetre Wave (mm-Wave) frequencies because it is getting harder to assign frequencies.

For 5G technology to work, antennas must have features that have never been seen in a user experience. Putting the signal’s emission pattern right where the listener is can help networked devices talk to each other wirelessly better, and this method is called beamforming. More bandwidth and faster data processing rates are needed because there are so many new mobile apps. It can be hard to find a good balance between the technical problems of making millimetre wave antennas and business goals like low cost, small size, high radiation efficiency, high directivity, broadband performance, and so on. Microstrip Patch Antennas (MPAs) with the coplanar layout of the radiation parts and the feed network are a good choice for 5G users who need a functional part that is hard to make but works well. The electrical and physical properties of the dielectric base have a significant effect on two performance factors of millimetre wave (high frequency) antennas: their directionality and bandwidth (Hu, & Li, 2023).

5.2 LITERATURE REVIEW

In the (Ibrahim et al., 2023; Hu, & Li, 2023; Mak et al., 2014) were some of the authors who wrote about cable pair interference in multi-channel digital broadcast systems, and these files are always being watched by MIMO. MIMO is a pretty standard mathematical model, even though there are not many real-world examples of sending multiple data streams in more than one way.

The mid-1980s saw more work by Jack Salz at Bell Laboratories on the effectiveness of multi-user systems made up of "mutually interconnected linear and additive noise networks." Many people choose the MPA for wireless connection because it can be used in many situations and is simple to put together. Because it can put them on circuit boards, they are instrumental. The MPA is often used even though it has a few minor problems because it has so many benefits. Here are some of the perks of the MPA: -

- Portable Structure
- Unobtrusive
- Processing a dual-frequency and tri-frequency operating range.

5.2.1 Expand an Antenna's Bandwidth

By dropping the dielectric constant and making the antenna stronger, the device's bandwidth can be made better.

5.2.2 Boost an Antenna's Gain

Changing the shape of the patch could make it work better or worse. Rectangular patches are used in this study because they have a higher gain and a smaller patch size (by 65–70%).

Mak et al. (2014) describe how the circularly polarized patch antenna that was used in this study could be used in modern cell phones. The main goals will be to increase the patch antenna's beamwidth and make it smaller. Since 4G is still being used and improved, all eyes are now on 5G, which is the next generation of wireless networking. For broadcasting on land, most studies use antennas with linear polarization. However, 5G phones may be able to send and receive info through space. Land-based cell phones now offer stable, high-quality service in areas with lots of people. Sound, text, and data transfers make it possible to send and receive visual media like photos and live-streamed videos. However, the current land network might not be able to reach some very faraway parts of the earth.

Patil et al. (2015) describe that at the age of 4G, researchers have made several antennas that can handle multiple services at the same time. Wireless communication has grown at a fantastic rate over the last few decades. The number of wireless subscribers has grown faster than the number of fixed-line consumers since the year 2000. Since the end of 2010, four times as many people have signed up for cell phones as for landlines.

However, both the sellers and the service providers know how important it is to have a well-designed network. Examples of how CNNs and transfer learning techniques can be combined to process medical pictures are given in the literature. Transfer learning is the process of applying knowledge from one domain-natural photography, for instance-to another-medical pictures, for instance. Studies like the one carried out have shown how crucial transfer learning is to improving deep learning models' capacity to detect lung nodules in chest CT images. This method allows models to benefit from insights from more extensive and varied datasets, which is particularly helpful when labelled medical imaging datasets.

Saini et al. (2016) and their colleagues describe that some of the plots that will be shown and talked about to show the shape of the antenna are gain plots, return loss plots, Voltage Standing Wave Ratio (VSWR) plots, and radiation pattern plots. The simulation results are shown next to the measured numbers, which match up well. To keep up with the smaller size of cell phones, antennas have had to get smaller, too. For mobile communication, many antenna designs are used instead of a single antenna. MPA has quickly become a popular extra for handheld devices because it is small and can work with several frequency bands. Microstrip Patch Antennas are better than other types of antennas because they are cheap, easy to build, and movable.

A Microstrip Patch Antenna has some good points, but one of the biggest problems is that it has a minor frequency. Even in the context of deep learning, conventional machine learning methods are still helpful for medical image interpretation. The usage of this simple yet efficient technique is made possible by the K-Nearest Neighbors' (KNN) capacity to recognize patterns in feature space. A 2023 research by Ibrahim et al. found that KNN performed competitively in lung nodule categorization. This result highlights the need to consider both traditional machine- learning methods and their deep-learning counterparts. Wang et al. (2023) describe the huge number of people who use cell phones these days; please explain why cell phone touch is so important. People who use smart devices are always expecting more. For instance, when it comes to online dating, they want all the related apps to have a streamlined user experience, better communication rates, and shorter wait times in traffic. With 5G technology, service providers will be able to meet the wants of their mobile customers better. 5G technology lets it use more than one frequency band, cover a more extensive area, provide better services with less delay, and send data much more quickly.

Verma et al. (2016) describe that in the future, these devices will help smartphones and dongles. It is easy to see the ground planes and the eight MIMO antennas on top of the base. When it comes to performance and gain, the best gadget has its electromagnetic bandgap on the ground plane. There is no chance of nuclear leaks because everything is wired into the central hub. There are only so many channels that can be used, so as more people use the frequency band, it finally fills up. A certain number of devices can use the same radio frequency at the same time. When more people use a channel, co-channel noise starts to get worse as well. As the use of HD and QHD video grows, it becomes harder for mobile devices to send and receive large video files over 3G and 4G frequency bands. Sending and receiving high-quality video across displays quickly requires more bandwidth and faster transfer rates.

Abirami et al. (2017) describe a fresh multiband patch antenna design for millimetre waves that can be used for 5G wired networking. The 5G millimetre-wave multiband antenna's microstrip-based design is the lightest, most cheap, smallest, most highly gainable, and most valuable. One example is that 5G networks make it easier to add new software and hardware. Fast data rates are needed to send and receive large amounts of traffic and high-definition video. The frequency range of microwaves below 6 GHz does not have enough high absolute bandwidth to meet demand. A 5G wireless network is better because it can send info quickly. Radio waves called Millimetre Waves (mm- Wave) are needed for 5G WiFi and multigigabit connections.

Shoaib et al. (2018) describe that connection has always been an essential part of how people grow and progress. It has had a significant effect on the past and will have a massive effect on the future. Wireless communications have grown over thousands of years as people have tried to be faster and better. It seems like every new generation of communications starts a time of technological progress that is decades faster than the last. In the short time since they came out, 4G networks have spread faster than any other type. Also, there is more and more pressure to meet the needs of the telecom infrastructure for 5G networks. So they can join the Better World Network, the gadgets need to be updated right away. Any changes to the transmission equipment will not work with the new network. However, since things change so quickly, the antennas would have to change too. This shows how important it is to know what needs to be done to make an antenna that works in the 5G transmission area. A common choice for this use is the Microstrip Patch Antenna. There are many microstrip antennas used in transmission because they are small and easy to make, which makes them perfect for low-profile uses. Most changes that are made to smartphones are good because they make the hardware smaller.

Murugan et al. (2021) describe that MIMO antennas are a powerful way to make cellular networks better at separating data from noise. To increase the channel's carrying ability, the signal-to-noise ratio needs to be raised. Also, make sure the parts have enough space to breathe. In the future, mobile phones will need to have more storage room and faster internet speeds so that more people can connect. In a multipath setting, signals weaken quickly, making it hard to improve the Signal-to-Noise Ratio (SNR).

The signal-to-noise ratio would be better with a more robust receiver. If only one antenna, it can get the most gain by making the beam of that antenna bigger. If there are several lines, this problem can be fixed with a MIMO antenna, which increases both the gain and signal-to-noise ratio. Having more than one MIMO antenna, especially one placed at different network nodes, can improve coverage. There was a method used for this called "space diversity." For MIMO to work, the cameras need to be far apart. High throughput, high bandwidth, and almost no delay in sending and getting data are what make 5G transmission unique.

Rashmitha et al. (2020) describe that the first idea in this study is a circle Microstrip Patch Antenna with a single element that works at 28 GHz. It has an elliptical slot and a ground design that does not work well. 5G technology has grown in popularity over the past few years thanks to its low latency and fast transfer speeds. Million-wave front ends have been the subject of much study because bandwidth and data rates go in the opposite direction. Moving from 3G to 4G is now complete. Even though technology has changed quickly in the past few years, the need for faster data transfer rates and processing times has not been met. Mobile data flow is expected to grow faster than 4G networks can handle.

This is because of apps like video streaming, social networking, and cloud computing. To meet this need, scientists are putting in much work to make Fifth Generation (5G) networks the norm around the world. This is a challenging job because of the higher volume and faster transmission speeds. This can only be fixed by putting in place MIMO technology and making wide-area data transfer better. While the multipath feature does not add extra data transmission power, it can improve channel capacity and range effectiveness. The MIMO design needs to be rearranged to split the broadband further from the parts. This is very important for the operation to go well.

Lodro et al. (2019) describe that there are always new and better ways to talk to each other, as shown by the growth of the internet. Scientists and engineers are interested in the new 5G wireless transfer. However, better antenna design is needed for wireless communication to work as it should. The main goal of the suggested study is to make a tall antenna so that 5G wireless communication can work better. This piece suggests using a circle of Microstrip Patch Antennas (MPAs) to make 5G wireless networks reach farther. The multi-input, multi-output feeding method is used to improve the antenna design that was planned. Cell phones, WiFi, Bluetooth, WiMAX, ISM, and other devices already use the lower spectrum. Also, the best frequency range for 5G technology has not yet been found.

Alassawi et al. (2023) describe that in mesoelectric piezoelectric arrays, a metal patch is kept away from the ground by a shielding layer. The base and the ground together are more extensive than a square. Microstrip Patch Antennas are a new idea. They can send and receive wireless messages through many inputs and outputs. MIMO wireless technology lets more data be sent to both the sender and the receiver at the same time. This speeds up communication and lowers the number of errors. The number of antennas on access points and wireless routers is one of the most essential parts of wireless network technology. Microstrip antenna design is a popular area of study right now for radio communication. They are essential for wireless communication, especially for internet and ultra-wideband needs, because they are so small. The feeder part, the base, the ground plane, and the patch are the four main parts of a single-layer MPA.

5.3 WIRELESS COMMUNICATION SYSTEM WITH MIMO

A complicated grid may be needed for Multiple-Input Multiple-Output (MIMO) devices to work. In all these cases, the Shannon extended capacity method is used to figure out the highest speed that can be sent over the MIMO channel. The amount of association seen depends on how many antenna elements are used, how far apart they are, and how many simulations are run for models where both the transmitter and the receiver use a lot of them. Most of the time, two patch antennas are used.

Each one is attached to a base and has its own on/off switch. Because of how they are set up, the two transmitters cannot face each other. With the switch from traditional to digital communication, wireless and mobile devices can be used in a lot of new ways. Interoperability, support for multiple frequency bands, meeting SAR standards, and being able to work with hearing aids are just some of the problems that new antenna designs must solve. There are also problems caused by not having enough space. For digital communication to work, issues like changing data transfer rates, too much capacity, and the inability to rearrange bandwidth on mobile devices and base stations must be fixed.

5.3.1 The Capacity Formula of Shannon

The Shannon capability formula is used to find the possible maximum channel transmission (without considering fading and interference). To use a white Gaussian noise track, this formula figures out the possible channel bandwidth, signal strength, and single-side noise spectrum.

5.3.2 Formula for Extended Capacity

Both the sender and the listener can use different antennas. That is why this kind of antenna is called MIMO, which stands for “Multiple Input and Multiple Output.” Everyone can figure out how much power this receiver can handle by using Shannon’s method.

5.4 KEY FEATURES OF 5G MIMO MICROSTRIP PATCH ANTENNA

“Key enablers” are the essential technologies and parts that 5G networks need to work the way they are supposed to. Those that make 5G possible provide the services and skills that are needed for it to work and benefit from its unique features.

5.4.1 Millimetre-Wave (mm Wave)

Millimetre-Wave (mm Wave) technology is an essential part of Fifth-Generation (5G) cell phone networks. There are more empty rooms, less delay, and faster data flow rates with this broader frequency range. A problem with millimetre wave technology is that shorter wavelengths at higher frequencies lead to more signal loss from artificial buildings and objects, as well as more signal interference from plants. To get around this issue, Millimetre Wave 5G networks usually put more base stations, which are also called access points, closer together. Millimetre Wave communications are also more likely to be harmed by other wireless signals and things in the environment, like fog and rain.

A lot of different types of advanced signal processing let millimetre-wave 5G networks send signals to specific areas where they can be heard more clearly and with less interference. Even with these problems, millimetre wave technology has many benefits for 5G networks, such as more space, less delay, and faster data transfer rates. There are many ways that these characteristics could be used. Some examples are High-Definition (HD) video streaming, Virtual Reality (VR), and Augmented Reality (AR).

5.4.2 MIMO/m-MIMO

Also, m-MIMO technology is an integral part of 5G radio communication. When many antennas that can send and receive data at the same time are added to a network, its range and speed are both improved. In standard wireless communication systems, signals have also been sent and received using SISO, SIMO, and MISO.

Huge MIMO does not work because both the sender and the listener need many antennas. The network can send and receive more data at once, which increases its range and capacity. Massive MIMO technology uses complex signal processing techniques to separate the many messages sent and received by the many antennas. The government and phone companies will be able to use the radio more effectively because there will be less background noise. Massive MIMO technology improves the reliability of wireless data and grows the reach of wireless networks.

5.4.3 Small Cells

Small cells can now be set up because networks have gotten better, and more people need to send and receive data. For wireless networks, these minor, low-power access points can only work in the approved spectrum and must follow the rules set by the carrier. This makes cellular range and capacity better. They can help fill coverage holes, keep service quality stable, and make better use of capacity. This situation can be solved by tiny cells, which offer better coverage and capacity in places where giant cell towers are not needed. Micro, metro, femto, and macro are the four sizes of microscopic cells.

Micro and metro small rooms can be hundreds of meters long in cities. One can often find pico cells in public places like subways, airports, and shopping malls. They can be with one another for just a few tens of meters, whether it is inside or outside. Because of this, femtocells are primarily used in homes because their range is only a few tens of meters. A lot of Access Points (APs) are used by these microcells, which are set up in cities by connecting to power lines, lights, and other things that are already there. With the help of small cells, 5G wireless networks can provide more power and coverage in crowded urban areas, which is essential for Internet of Things (IoT) devices, self-driving cars, and smart cities. When femtocells and microcells are used, problems can happen with the allocation of spectrum, handovers, and scheduling at the cell border.

5.4.4 Network Slicing

Network slicing is another feature of a 5G wireless network. This feature lets telecom companies offer personalized services to their customers by building multiple virtual networks inside a single physical network. Most cellular networks put limits on which users can get to which resources. This means that networks cannot handle a lot of different services that need different amounts of bandwidth, delay, and dependability. Network slices are more minor, separate parts of a more extensive network. The QoS of each “slice” is looked at during segmentation to see how well it was made. Network slicing is the idea of breaking networks up into smaller, easier-to-handle pieces so that they can be used more efficiently and in different ways. Network slicing, in its most basic form, lets the network’s features be changed to better meet the needs of specific users or apps. Network slicing lets operators make virtual networks with different sets of tools and functions.

After that, these systems can be used to offer many different programs and services. Networks can be “sliced” to do many different things. Two good examples are low delay for self-driving cars and high bandwidth for streaming videos. Network slicing is vital for many uses of 5G, such as smart towns, healthcare, and automated factories. Even though each service has different needs for bandwidth, delay, and stability, the network may be able to handle them all. Customers and use cases may also be able to get goods and features that are better fit for them by service providers.

5.4.5 Cloud Computing

Cloud computing is used by both 5G and B5G, which is suitable for digital contact. It talks about how to connect the gadget to a faraway computer online so that it can use servers, data storage, apps, and other computer services. In a 5G network, people and their devices can use cloud computing to get the services and apps like AI, Internet of Things, and edge computing. Cloud-based services and apps help 5G wireless networks handle the vast amounts of data they need to send and receive and the strict performance standards they must meet.

AI and Machine Learning techniques can be used on massive datasets in a cheap and scalable way with cloud computing. One great thing about machine learning is that it can look through massive datasets and find patterns. Machine learning methods get better over time with little help from people because they can learn and change on their own. In situations where things change quickly and dramatically, like in 5G/6G, these methods work amazingly well when dealing with complicated, multidimensional data. Also, machine learning programs can learn new things better, especially when they are given complex problems to solve. For many 5G uses, like self-driving cars and automatic factories, this is very important because data needs to be processed in real- time.

5.4.6 Virtualization

For ease of use and control, physical assets are turned into digital copies in this case. Networks, computer servers, and data centres are all types of building tools. In 5G networks, virtualization is used to make VNEs and VNFs, which stand for virtual network elements and functions. This could help companies get more people by giving them services and apps that can change as their needs do. Virtualization can save money and make it easier to add more resources by running network tasks on regular hardware instead of expensive specialized gear. The option to make “network slices” is one of the best things about virtualization in a 5G network. Virtualization makes it easier for operators to move resources around quickly to meet the needs of users for different services and apps. As a result, the network works better and costs less because it can adapt more quickly to changes in traffic.

5.4.7. Edge Computing

Communications based on edge computing have shown promise in getting ready for new technologies like 5G and 6G. Because smart gadgets and data flow are becoming more popular, operators are looking into new ways to build base stations, such as cloud computing and virtualization. Virtualization lets customers access a shared pool of scalable computer resources whenever they need to with Cloud-RAN (C-RAN), a cutting-edge RAN system. Data is processed on the gadget itself instead of being sent to a central server. Edge computing is the use of moving computers and storage capabilities closer to the user, like near a Radio Access Network (RAN) or base station. Information does not have to be sent to a central place; it can be processed and analyzed right away at the edge of the network. The edge cloud works as a go-between, only sending data to the leading network when it is really needed. This level of speed is needed for a lot of 5G uses, like self-driving cars and automated factories.

5.4.8 Carrier Aggregation (CA) and Beamforming

It is possible to send more data more quickly when several frequency bands are combined into one bigger band. What this is called is "carrier aggregation." To better help their customers and make better use of the spectrum they have access to, service providers can do it. When user devices and a base station send and receive signals in the same way, they can talk to each other. This is what we call "beamforming." Signals are focused on narrow beams that can be pointed at specific places or things to stop them from spreading. When service providers do this, they can make better use of their spectrum, connect more people, and send info more quickly. Beamforming is an essential method for sending vast amounts of data very quickly over Millimetre Wave (mm-Wave) bands and is used by some 5G networks. Millimetre waves lose much energy as they travel through the world and are easily absorbed by things like buildings and trees. Because it only sends the signal to the people or tools that need it, beamforming helps operators get around these signal loss problems.

5.5 MICROSTRIP ANTENNA TECHNOLOGY

The hardest thing for Radio Frequency (RF) experts is figuring out how to send and receive messages in very complicated systems. It is not enough to only look at parts of a communication link. The efficiency of the antenna is significant for the MIMO system to work. Different kinds of MIMO devices use the channel's multipath features. Choosing antennas based on the propagation route leads to the best antenna design for the medium of propagation. The relationship between channel coefficients changes depending on the antenna settings. Self-coupling effects can happen when transmitters are placed next to each other in a MIMO system.

As it plans the MIMO antenna array, think about how each might change it. Putting many sensors on small, movable devices is one of the biggest problems with MIMO systems. It is essential to build antennas that work because MIMO technology depends on them. Microstrip geometry was first used in high-performance missiles, spaceships, and aeroplanes in the 1950s because it was small, cheap, very practical, easy to install, and shaped to be aerodynamic. Figure 5.2 describes the Microstrip Patch Antenna overview.

The metal patch comprises feed and parasite patches, as was said in the beginning. Businesses and the government already have rules about how to use cell phones and wireless messages.

In 1952, around the same time that microstrip transmission lines came out, Grieg and Englemann made heaters that could be used with them. A broadcast line that looks like a microstrip and an antenna that looks like it was used for the first time to talk. Figure 5.3 shows the Microstrip Patch Antenna circuit theory. Many things influence these antennas:

• Their low profile makes them less visible and helps them blend in with different surfaces.

• Made from printed circuit boards, they are cheap and straightforward to make.

• Putting them on a stable surface makes them structurally strong.

• The modelling model and the shape of the patch both have significant effects on the

patterns and polarization that are made.

• Maybe other radios can be made in microstrip and hooked up to a microstrip antenna, so

there is no need to add more steps to the making process.

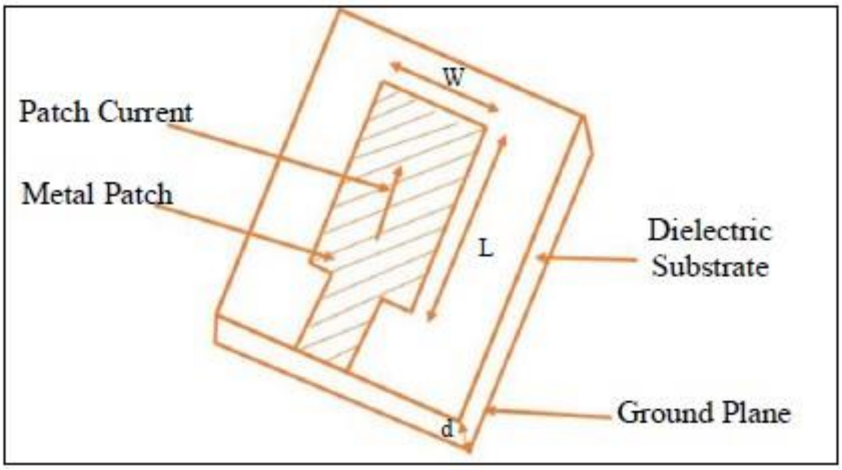

Figure 5.2 Microstrip Patch Antenna

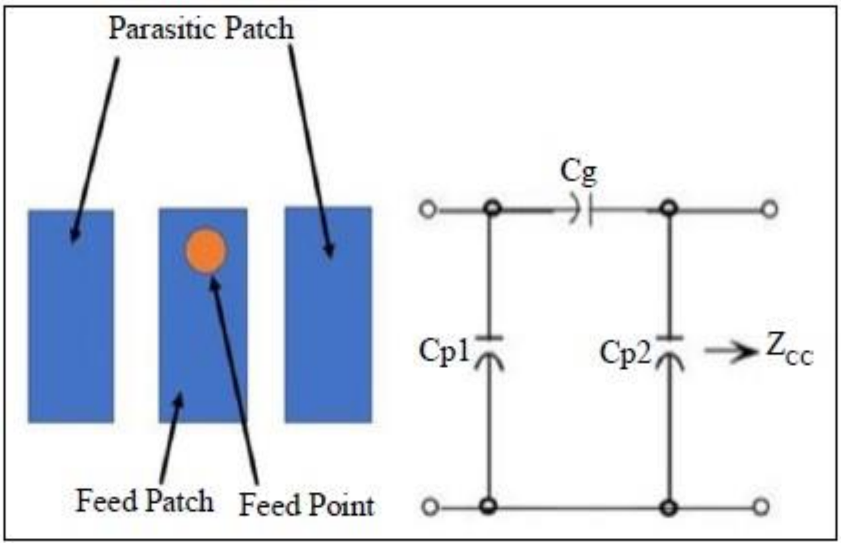

Figure 5.3 Circuit theory of Microstrip Patch Antenna

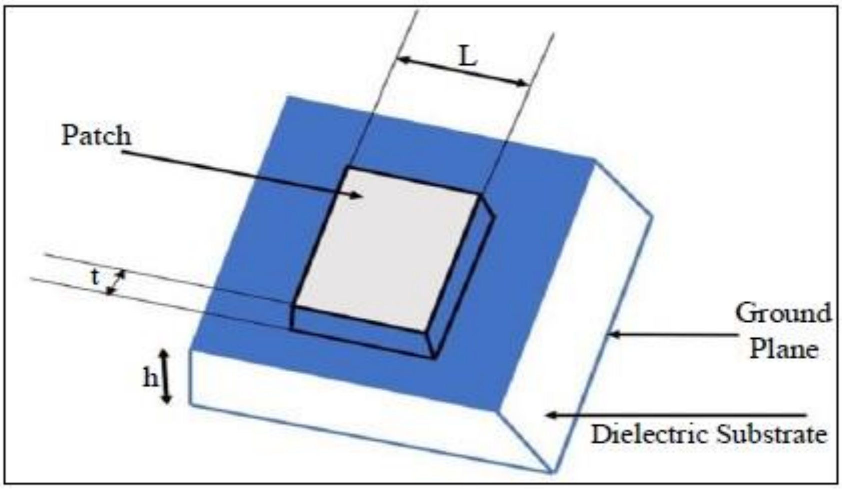

Figure 5.4 Design of Microstrip Patch Antenna

The first version of microstrip antennas had a bandwidth of only a few megahertz. This meant they could only handle moderate power levels, and their polarization was unstable. Much work has likely gone into meeting these needs since most studies have been about fixing problems that system standards cause. Some of these changes are new designs for microstrip antennas and a fresh look at the issues they will surely face. Figure 5.4 shows the Microstrip Patch Antenna design.

5.6 RESULT AND DISCUSSION

These are the “antenna techniques” that are used to make sure antennas meet the standards. This part talks about all the antenna’s S-parameters, such as ECC and return loss. In Figure

5.5, Figure 5.6, Figure 5.7, and Figure 5.8, one can see both the real and predicted frequency responses of the 5G MIMO.

The value of the return loss is shown in Figure 5.9 and Figure 5.10 of the ECC. The generated prototype's isolation and loss of return with the S-Parameter. This is the prototype's resonance frequency, and it is here because less return loss means more efficiency. HFSS will be used for all simulations after this one. Figure 5.11 shows this y-parameter for the rectangular Microstrip Patch Antenna. Radiation elements are added as the first step in building a MIMO conformal antenna. Microstrip Patch Antennas are used as radiation elements as part of the design. A rectangular microstrip antenna is usually put together in two steps. In microstrip circuits, there is much loss in the millimetre range. There are three ways that losses can happen: through conductors, dielectrics, and radiation.

When using a substrate with a low dielectric constant, the characteristic impedance and overall loss of the microstrip remain largely unaffected. However, with a high dielectric constant substrate, both the characteristic impedance and the loss associated with the microstrip exhibit significant variations. An increase in substrate thickness also raises the likelihood of encountering radiation losses and damage from surface waves. Conversely, a substrate with a lower height helps in suppressing higher modes and reducing radiation losses, which is particularly advantageous. This characteristic makes thinner and more flexible substrates preferable for conformal antennas, which need to adapt to curved surfaces without compromising performance.

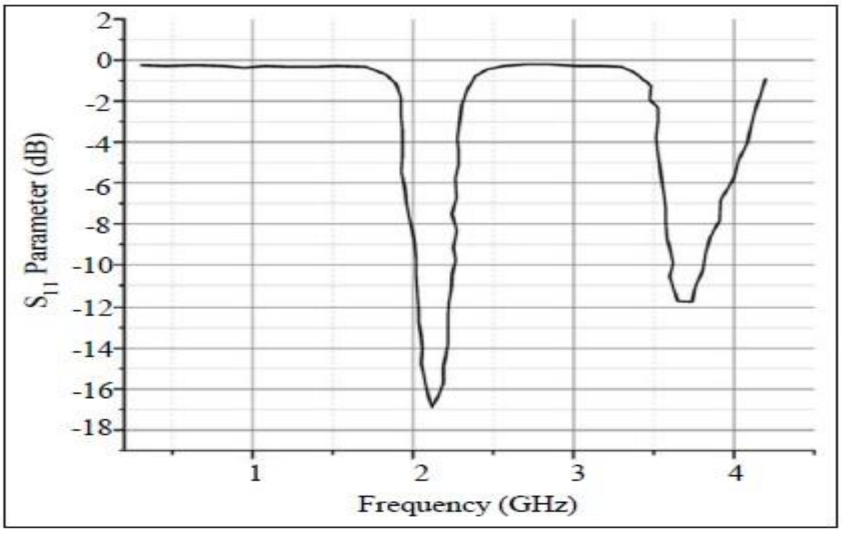

Figure 5.5 S_{11} parameter of MIMO antenna

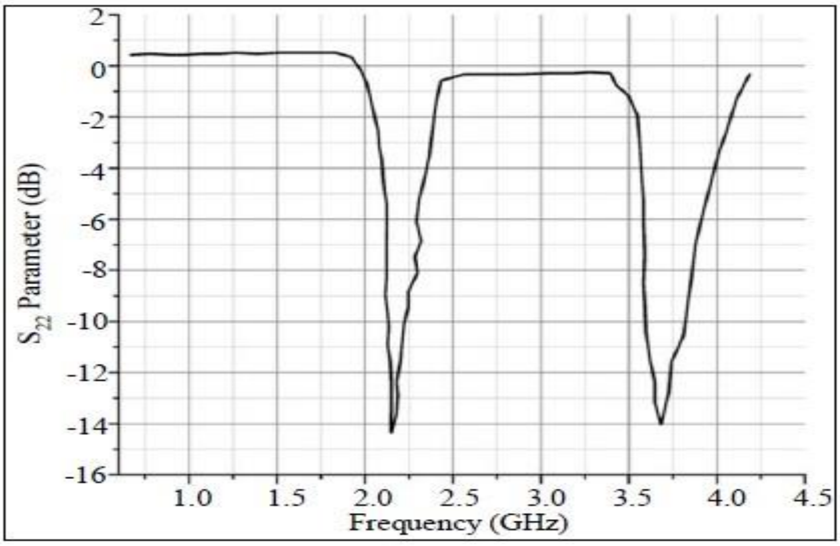

Figure 5.6 S_{22} parameter of MIMO antenna

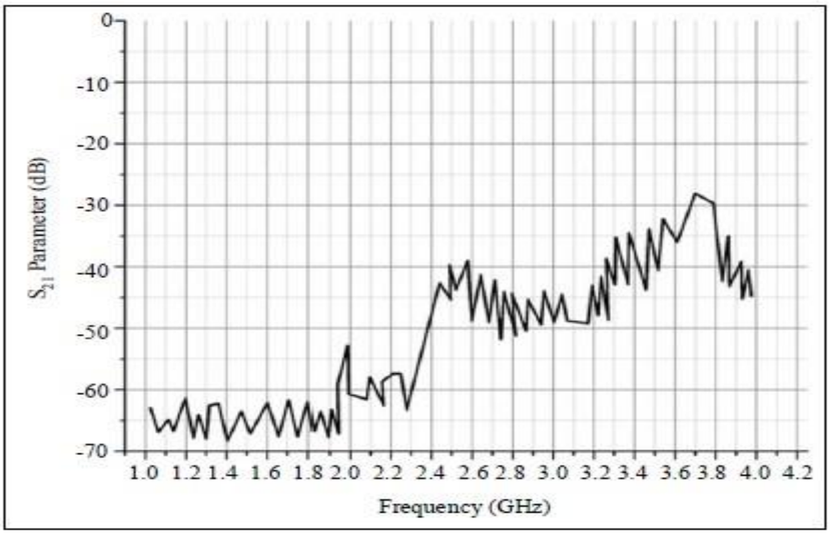

Figure 5.7 S_{21} parameter of MIMO antenna

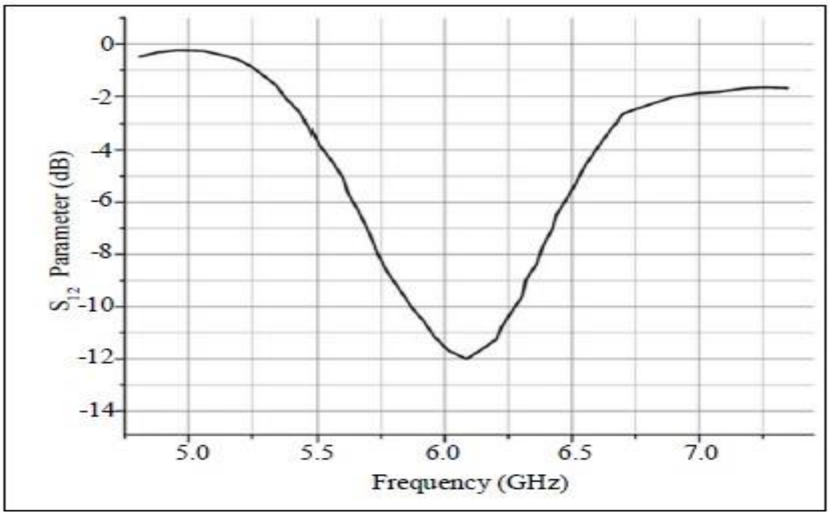

Figure 5.8 S_{12} parameter of MIMO antenna

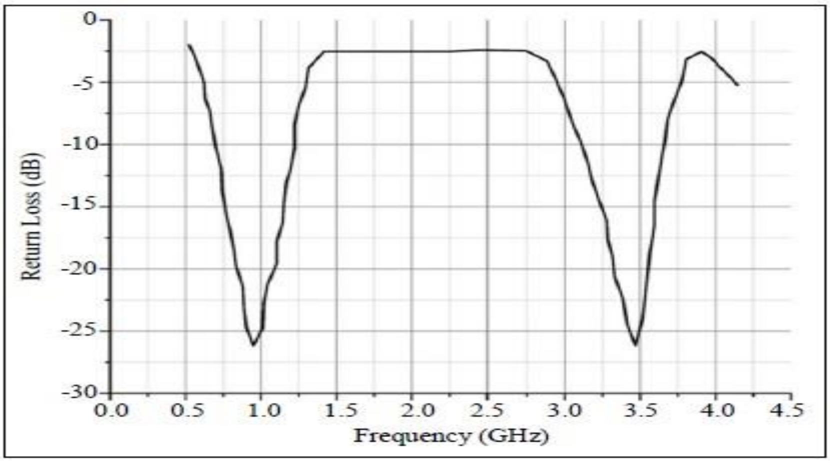

Figure 5.9 Return loss parameter of MIMO antenna

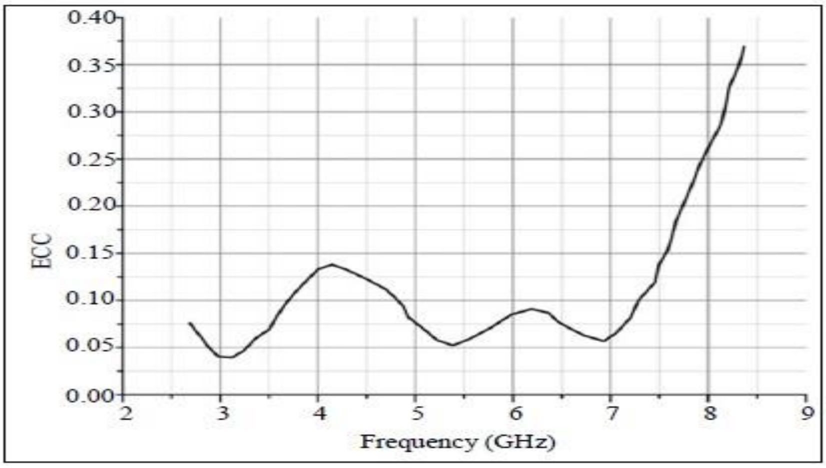

Figure 5.10 Envelope Correlation Coefficient parameter of the MIMO antenna

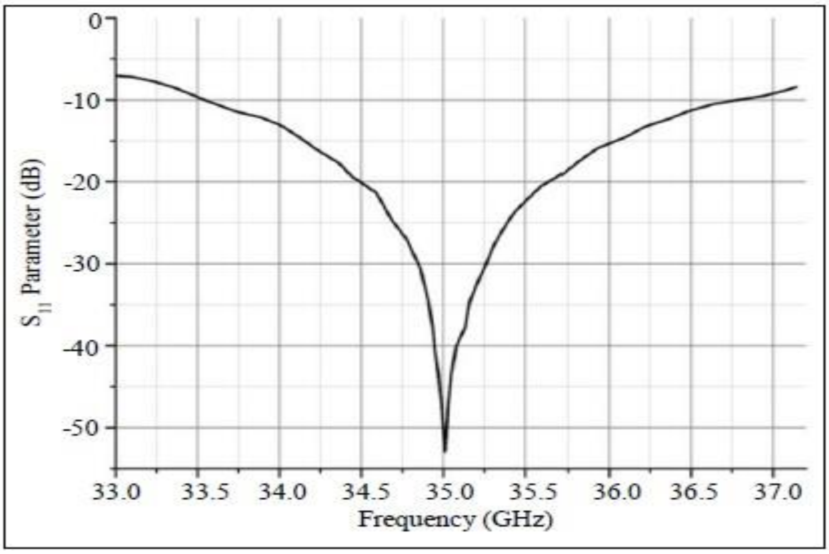

Figure 5.11 S_{11} parameter of Microstrip Patch Antenna

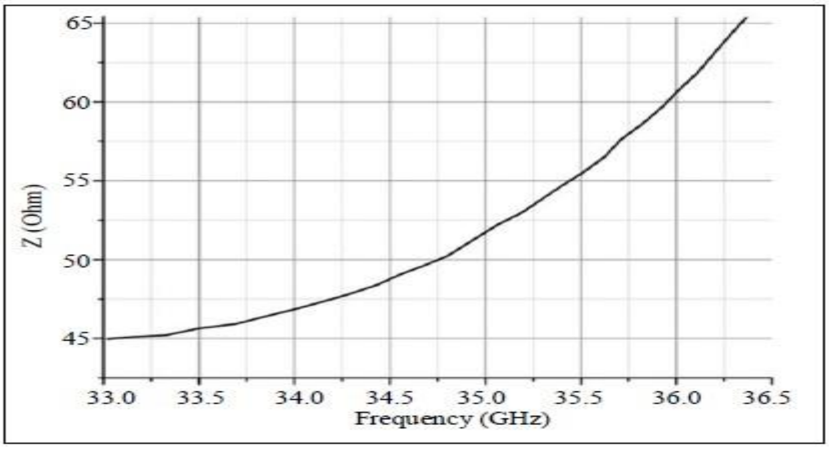

Figure 5.12 Input impedance of rectangular Microstrip Patch Antenna

The input impedance for a rectangular Microstrip Patch Antenna, as detailed in Figure 5.12, illustrates these principles in action. This depiction highlights how the physical properties of the substrate can critically influence the functionality and efficiency of microstrip antennas. As the dielectric constant of a substrate increases, there are pronounced changes in both the characteristic impedance and the microstrip's total loss. In contrast, a low dielectric constant results in negligible alterations in these properties.

5.7 CONCLUSION

Microstrip Patch Antennas, or MPAs, are small antennas that can help handheld devices these days. Much faster data speeds are needed for modern wireless transfer and reception standards. It is very fast to send and receive data with a Microstrip Patch Antenna that has Multiple Inputs and Multiple Outputs (MIMO). Fifth-Generation (5G) wireless networks are meant to send data much more quickly than present wireless networks. Multiple-Input Multiple-Output (MIMO) transmitters have problems with the skin effect, even though they are more reliable and can send data faster in the high-frequency range. Multiple-Input Multiple-Output (MIMO) microstrip antenna devices have ports that are next to each other, which can cause unwanted mutual coupling to happen. Neutralization lines, electromagnetic band gap structures, faulty ground structures, and improving port isolation are just some of the many ways to lower coupling. To stop them from interacting with each other, the space between antenna ports needs to be widened. This makes antennas get smaller. The simulated “antenna techniques” are used to make sure antennas meet the standards and discussabout all the antenna’s S-parameters, such as ECC and return loss and one can see both the real and predicted frequency responses of the 5G MIMO.

The value of the return loss has been graphed. The generated prototype’s isolation and loss of return with the S-Parameter is the prototype’s resonance frequency, and it is here because less return loss means more efficiency. HFSS has been used for all simulations after this as shown for this y-parameter for the rectangular Microstrip Patch Antenna. Radiation elements are added as the first step in building a MIMO conformal antenna and Microstrip Patch Antennas are used as radiation elements as part of the design. In microstrip circuits, there is much loss in the millimetre range and there are three ways that losses can happen: through conductors, dielectrics, and radiation. It is concluded that when using a substrate with a low dielectric constant, the characteristic impedance and overall loss of the microstrip remain largely unaffected. However, with a high dielectric constant substrate, both the characteristic impedance and the loss associated with the microstrip exhibit significant variations. An increase in substrate thickness also raises the likelihood of encountering radiation losses and damage from surface waves. Conversely, a substrate with a lower height helps in suppressing higher modes and reducing radiation losses, which is particularly advantageous. This characteristic makes thinner and more flexible substrates preferable for conformal antennas, which need to adapt to curved surfaces without compromising performance. This research also highlights how the physical properties of the substrate can critically influence the functionality and efficiency of microstrip antennas. As the dielectric constant of a substrate increases, there are pronounced changes in both the characteristic impedance and the microstrip's total loss. In contrast, a low dielectric constant results in negligible alterations in these properties.

CHAPTER – 6

CONCLUSIONS AND FUTURE SCOPE

6.1 Conclusions

AI will be telling you the whole story of the microstrip patch antenna, from its roots and history through methods of designing and construction, which resulted in creating an innovative and effective antenna. All of these are finally presented in the final part of this doctoral thesis. A synthesis is also provided in the conclusion of the valuable results and views collected, brought up by this study, as well as the extensive implications within wireless communications. In Chapter 1, we have laid a strong base to introduce microstrip patch antennas because they are very important when it comes to the wireless communication field.

The First Chapter served as an introduction to microstrip patch antennas, presenting the basic concepts, principles, and benefits of these antennas, which will be expanded upon in later sections. The Second Chapter went into further depth with a detailed literature review, providing an extensive overview of the research conducted thus far, as well as advancements made within microstrip patch antenna technology. This thorough analysis revealed various design strategies and material options that researchers have explored over the years, while also pointing out gaps and trends observed in the existing knowledge base. Such contextualization laid down grounds for the subsequent parts of this dissertation to present new experimental results, highlighting the dynamic and changing nature of antenna technology.

In the Third Chapter, the historical development of microstrip patch antenna design methods were studied. This section looks back and highlights the constant change that has taken place within this field as wireless technology continues to advance. This reflective process provided a deep insight into how design paradigms have changed in line with technological advancements to enhance antenna performance, which could be used as an input for future research directions. The thesis's core contribution, the novel design and development of a high-performance hybrid patch antenna with improved bandwidth, was presented in Chapter Four. This unprecedented design, which combined sophisticated materials and new structural modifications, was seen as a major stride towards attaining greater antenna proficiency. The hybrid antenna was tested and validated to measure the improved performance level, suggesting that the introduction of a hybrid design concept could enhance the effectiveness of microstrip patch antenna technology in advanced applications.

Through the process of research, a three-pronged and multifaceted methodology that covered theoretical analysis, simulation, as well as empirical testing was employed to guarantee the strength and reliability of the results. By combining these multiple techniques, it is possible to thoroughly explore microstrip patch antennas in all their aspects, thus enriching the thesis with a good volume of analytical information and ideas. Regarding the contribution of this research, it is not only academic but also practical, as it produces design principles and workable solutions for implementation in real wireless communication systems. This study, which aims to deepen and broaden the knowledge and skills related to microstrip patch antennas, has great potential to benefit many wireless technologies, such as mobile communications and satellite broadcasting. In summary, this PhD study, while complementing the field of microstrip patch antennas, paves the way for future development and innovation.

The brand new architecture outlined in this work provides numerous opportunities for further studies, with the main focus being the integration of emerging materials and technologies in the search for an antenna system that will be even more effective. It is clear that the growth and development of international communications networks rely on advancements in the field of wireless communication systems, where undoubtedly, my results and conclusions will serve as building blocks for the next generation of antennas, which are highly sophisticated to aid global communication networks.

The value of the return loss has been graphed. The generated prototype’s isolation and loss of return with the S-Parameter is the prototype’s resonance frequency, and it is here because less return loss means more efficiency. HFSS has been used for all simulations after this as shown for this y-parameter for the rectangular Microstrip Patch Antenna. Radiation elements are added as the first step in building a MIMO conformal antenna and Microstrip Patch Antennas are used as radiation elements as part of the design. In microstrip circuits, there is much loss in the millimetre range and there are three ways that losses can happen: through conductors, dielectrics, and radiation. It is concluded that when using a substrate with a low dielectric constant, the characteristic impedance and overall loss of the microstrip remain largely unaffected. However, with a high dielectric constant substrate, both the characteristic impedance and the loss associated with the microstrip exhibit significant variations. An increase in substrate thickness also raises the likelihood of encountering radiation losses and damage from surface waves. Conversely, a substrate with a lower height helps in suppressing higher modes and reducing radiation losses, which is particularly advantageous. This characteristic makes thinner and more flexible substrates preferable for conformal antennas, which need to adapt to curved surfaces without compromising performance. This research also highlights how the physical properties of the substrate can critically influence the functionality and efficiency of microstrip antennas. As the dielectric constant of a substrate increases, there are pronounced changes in both the characteristic impedance and the microstrip's total loss. In contrast, a low dielectric constant results in negligible alterations in these properties.

6.2 Future Scope of the Work

The future scope of research and development in the field of microstrip patch antennas (MPAs) for wireless communication is expansive and promising, driven by the relentless advancement in wireless technologies and the increasing demand for efficient, compact, and cost-effective communication systems. As the world continues to move towards more interconnected and wireless-driven technologies, the role of MPAs becomes increasingly significant. Here are some prospective areas where research can further enhance the performance and utility of MPAs:

1. **Material Innovation**: Future studies could focus on exploring new materials or composites that can enhance the performance characteristics of MPAs, such as bandwidth, gain, and efficiency. Materials like graphene, metamaterials, and ferroelectric substrates hold potential for improving the operational capabilities of MPAs while also reducing their size and weight.

2. **Integration of Advanced Technologies**: Incorporating technologies such as the Internet of Things (IoT), 5G, and beyond will be crucial. Research can be directed towards the development of MPAs that support higher frequency bands and massive MIMO (Multiple Input Multiple Output) systems. This will facilitate faster data rates and more reliable connections, essential for the burgeoning number of IoT devices and next-generation mobile networks.

3. **Enhanced Design Techniques**: The design and optimization of MPAs using AI and machine learning algorithms could revolutionize their performance by predicting optimal antenna designs and configurations that maximize performance for specific

applications. AI-driven design tools can also automate and speed up the design process, reducing development costs and time-to-market.

4. **Environmentally Adaptive Antennas**: Research could focus on developing smart MPAs that can dynamically adjust their parameters in response to environmental changes or signal requirements. This adaptability can significantly improve the efficiency and functionality of wireless systems in complex environments, such as urban areas or disaster-struck regions.

5. **Energy Efficiency and Sustainability**: With the increasing emphasis on sustainability, future research could explore ways to make MPAs more energy-efficient and environmentally friendly. This could involve developing low-power MPAs for sustainable IoT applications or utilizing recyclable materials in antenna construction.

6. **Multi-functional Systems**: The integration of MPAs with other functionalities such as sensors or energy harvesting devices could open new avenues for multifunctional wireless platforms. These systems can simultaneously communicate, sense environmental parameters, and even harvest energy from ambient sources, leading to more integrated and autonomous wireless networks.

7. **Space and Aeronautical Applications**: As space exploration and satellite communications continue to expand, specialized MPAs that can operate in extreme conditions and provide reliable communication in space environments will be in high demand. Research could also explore the development of MPAs for unmanned aerial vehicles (UAVs) and other aeronautical applications where compact and efficient communication systems are crucial.

By addressing these areas, the future research on microstrip patch antennas will not only enhance their performance but also expand their applications across various cutting-edge wireless platforms, driving forward the innovations in global communication infrastructures.

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Curriculum-Vitae

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B.E.(Electronics Engg), M.Tech (Electronics & Communication Engineering)

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Name of Degree : **M.Tech (Electronics & Communication Engineering.)**

Name of Institution : **Delhi College of Engineering, Delhi University**

Division & %, year : **First, 70%, 2009**

(B) Graduation

Name of Degree : **B.E.(Electronics Engineering)**

Name of Institution : **Shivaji University, Kolhapur**

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Professional Experience

18+ Experience is in Teaching of B.Tech. Courses as well as Administrative Work of Institute of Varied Nature.

Name of Employer : **Bharati Vidyapeeth's College of Engineering, New Delhi**

Period of Employment : **Associate Professor (August 1, 2009 – till date),**

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Duties : **Teaching & Various College Activities**

Summer School/Winter School/Workshops/Conferences Attended

FDPs / STTPs Attended:

- FDP ON "ADVANCES IN INDUSTRIAL AND SYSTEMS ENGINEERING" AT DR B R AMBEDKAR NATIONAL INSTITUTE OF TECHNOLOGY JALANDHAR – **13-17 DEC 21**
- ICT/LMS TOOLS FOR TEACHING LEARNING KC COLLEGE OF ENGG & MNGT, THANE **- 16-19 JUNE 2020**
- WEBINAR ON ONLINE TEACHING , LEARNING AND EVALUATION DURING COVID-19 GOVT. COLLEGE, NARNUL **-19 JUNE 2020**
- ONE DAY WEBINAR SESSION IN THE DOMAIN OF "DATA SCIENCE, MACHINE LEARNING & ARTIFICIAL INTELLIGENCE"" AT DTU **- 10-SEP 2020**
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Computer Proficiency

Well versed with various computer systems such as Window-98, Win-NT,Window XP, DOS etc., can handle various commercial & technical software.

Area of Specialization Embedded systems & Microprocessor

Theory Courses Taught (Under-Graduate Level)

Embedded System, Microprocessor, Analog Electronics, EDC and their related Laboratories

Projects Guided Numerous projects to B. Tech Students in the field of ECE for last 15 Years.

Membership of Professional Bodies

Life member – Indian Society for Tech. Education (India)

Other Administrative Responsibilities

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- Member NBA Team

Research Publications

- Aditya Aryan , Lakhan Singh, Anupriya , Kapil Kumar , Ashok Kumar , **Neera Agarwa**l, An Ultra-wideband Asymmetric Feed Micro-strip Patch Antenna for Sub-6 GHz Applications" Volume 4, International Journal of Emerging Trends in Research , ISSN No.: 2455-6130, , Issue 4, 2020, pp. 12-17

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Date :
Place: **(Neera Agarwal)**

LIST OF PUBLICATIONS

1. Neera Agarwal, Kalyan Acharjya, Ramendra Singh (2023). "Design and Development of a High Performance Hybrid Patch Antenna with Enhanced Bandwidth for Wireless Communication", International Journal on Recent and Innovation Trends in Computing and Communication, 11(9), 2065–2069. https://doi.org/10.17762/ijritcc.v11i9.9206

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Design and Development of a High Performance Hybrid Patch Antenna with Enhanced Bandwidth for Wireless Communication

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Abstract—In the current scenario of modern antenna design, patch antennas have emerged as a fundamental component in modern wireless technology due to their compact size, low profile, and versatility in diverse applications. However, to meet the ever-increasing demands for higher data rates, extended bandwidth, and improved radiation characteristics, innovative design approaches have become essential. In conclusion, this research paper showcases the current state of modern patch antenna design, emphasizing the significant improvements in performance and versatility. The research work introspects into the design of a hybrid patch antenna with a modified cutting-edge design employing an optimization techniques resulting in a high performance Patch antenna with better bandwidth and high gain in comparison to its counterparts. The results obtained insights provided in this study will be valuable for researchers, engineers, and designers in the field of antenna technology, paving the way for the development of more efficient designs in hybrid antenna technology.

Keywords-Bandwidth, defected ground structure efficiency,hybrid patch antenna and reconfigurable antennas

I. Introduction

A Microstrip patch antenna came into existence in the middle of twentieth century. Within a span of two decades, this antenna became so popular due to its inherent advantages that were quite appreciated by the researchers [1]. Furthermore, printed circuit technology was effectively employed in the Microstrip patch antenna that paved ways for integration of antenna within existing wireless systems. This resulted in the fabrication of standalone systems comprising of an array of such elements arranged in a particular pattern [2]. .Recent years have shown a tremendous utilization of Wireless data transmission networks resulting in expansion of Wi-Fi distribution. In order to address the increasing demand of consumers, antennas with higher bandwidth and smaller dimensions are best suited. Figure 1 represents the basic structure of a patch antenna .It primarily comprises of a Rectangular patch coupled with a feed line. In order to facilitate the analysis prediction of the fabricated antenna, the patch shape is generally selected as rectangular circular, triangular, elliptical or some other regular shape[3] Usually for a rectangular patch, the length of the patch ranges from 0.33λ to 0.5λ[4] .

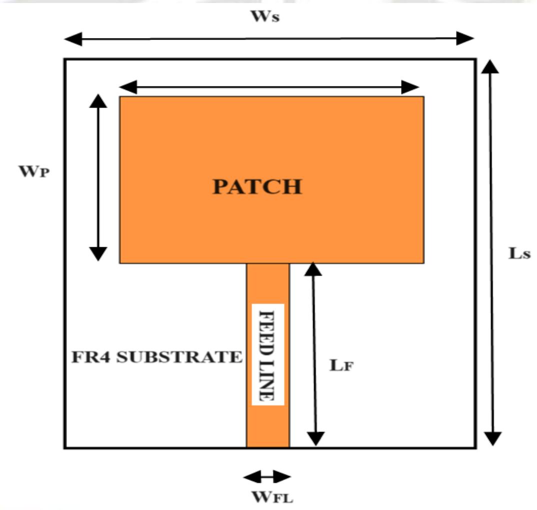

Figure 1. A front view of the proposed Rectangular Microstrip patch Antenna. with dimensional details provided in table 1

Table 1 represents the dimensional details and the design parameters applicable to a conventional patch antenna. This article proposes a hybrid patch antenna design using a combination of T-Shaped and F-shaped patches. The proposed antenna has been fabricated and achieves a bandwidth and gain enhancement by a marginal factor.

II. DESIGN PROCEDURE

This section provides the design description of the proposed Hybrid rectangular patch antenna using FR-4 operating at design frequencies

A. Adopted Procedure

Figure 2 shows the steps initiated for designing a patch antenna using software simulation techniques. In this paper antennas have been designed at a frequency of 70 GHz. All the four elements have been designed by modifying the patches using a combination of T-shaped and F-shaped elements as shown below. The design makes use of FR4 as a substrate with a permittivity of 3.3[5].It comprises of two rectangular patches of T and F shape that are fabricated on the sides of the patch. The length of the patch is designated as L. In order to estimate the performance comparison of the antennas have been constructed with two different thicknesses.One antenna with a thickness of 0.65mm and 1.35mm for a frequency band of 15 GHz and with thickness of 0.15mm and 0.30 mm for a frequency band of 75 GHz.

The design specifications employed in the proposed design are represented in Table 2.

B. Design Specifications

The proposed patch antenna topology is represented in the Figure 3 below. It comprises of F-shaped and T-shaped slots organized in a symmetrical structure.In Figure 3, the proposed design specifications are represented as L-Length of the patch,

Table 1. Typical design parameters of a Rectangular patch antenna employing FR4

Parameter (symbol)	Details	Typical value
W_S	Width of the substrate	20mm
W_P	Width of the patch	18mm
L_P	Length of the patch	14mm
L_S	Length of the substrate	30mm
f_o	Operating frequency	7GHz
εr	Permittivity of the material	4.5

width of the patch,W_T is the thickness of the Microstrip transmission line.

III. MODELLING TECHNIQUES AND TOOLS

Prior to hardware implementation, circuits and componentsto be used in filter design are simulated in a three dimensional environment known as Field Solvers.. Theseelectromagnetic field solvers provide reliable simulationresults that finally match with the experimentation resultson actual hardware. This aids in reducing the EM designcosts and provide valuable analytical data through whicha designer can visualize how microwave componentsactually behave. This speeds up the design convergenceand leads to design convergence and optimized designselection by validating number of design options in a lessertime. Commercial EM tools currently available amounts totremendous compactness in component size and hence theresultant structure. Trimming techniques are carried out toremove excessive roughage in multilayered devices beforeactual simulation is carried out.Simulation Field solver techniques can be virtually appliedto all microwave components but they render efficientresults for filters.The following field solver techniques have been used forDesign optimization and enhancement in the EBGgeometries for producing efficient devices and components:

A. IE3D

IE3D software is the first scalable Electromagnetic designand verification platform. It is attributed to high modelingaccuracy both for the high-frequency circuit design andsignal integrity engineers across multiple design domains.The high design capacity requirements posed by currenttechnological advancements are addressed by IE3D bothat circuit and component level..This simulation is poweredwith multi-threaded and distributed simulation architectureproviding cost effective solutions coupled with compactdesigns and parametric enhancements. It delivers thedesired design accuracy.IE3D has been extensively used forantenna design

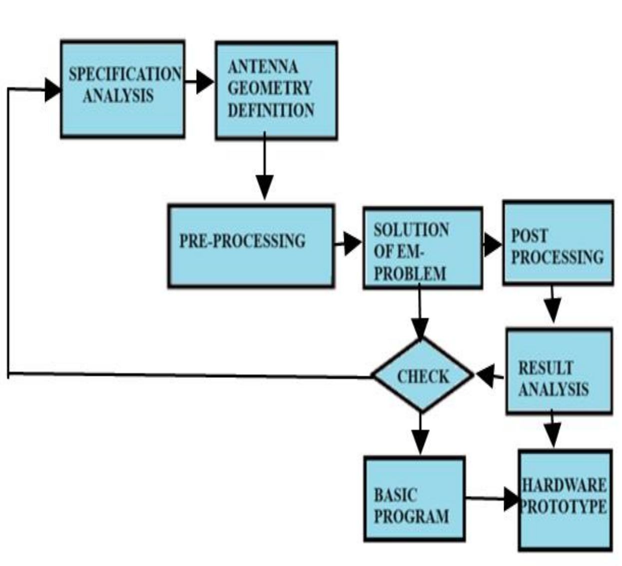

Figure 2. Design steps followed in modern Hybrid patch antenna design

Table -3 represents the design specifications employed in the proposed structure tested for two sets of fabricated antenna configurations.

This is effectively carried out by designinga high capacity unit array cell and the cell is replicated tocreate a large antenna array structure. It also satisfies theboundary conditions and

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offers space optimization desiredfor a large array antenna. It is also used for RFID designthat combines antenna and embedded passive design.Using accelerateddesign closure capabilities of this software, theperformance of the resulting RF-ID tag can be improvised.Furthermore,it can be implemented for complete designingand validation of multi-chip system architectures exploringfull 3D capabilities.

B. HFSS

HFSS(High frequency structure simulator) is a 3D simulation software for designing and simulation of high frequency devices such as antennas,filters,IC packagesPrinted circuit boards. This software is most suitable forhigh frequency circuits suitable for fabricating radars,satellites, Internet of Things(IOT).This software is integrated with versatile solvers and abrilliant Graphic user interface(GUI) for introspectionin 3D EM problems. It is loaded with tools such asthermal, structural and fluid dynamics that are suitablefor multi-physics analysis. HFSS is categorized in thegold standard accuracy range due to its adaptive meshingand sophisticated solving techniques. This is superior as itenhances the quality of design, improves product reliability, compactness and performance.

C. CST Studio

CST(Computer Simulation Technology) studio is capableof simulating and solving problems in all segments ofElectromagnetic spectrum ranging from low frequencyapplications to high frequency, microwave and opticalfrequencies.It comprises of seven different studios namely- MicrowaveStudio, EM Studio, Design Studio, Particle Studio,

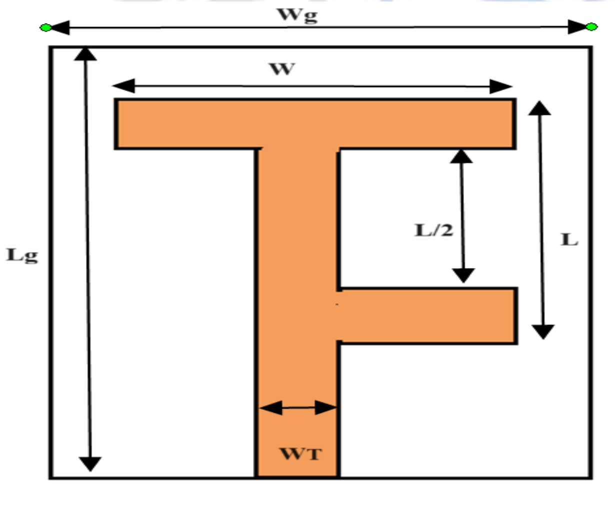

Figure 3. A hybrid patch antenna with T and F shaped rectangular patches for bandwidth enhancement

MPHYSISCS Studio,Cable Studio and PCB Studio.Each studio is utilized for designing of a specific area ofapplication. It provides accurate, efficient computational solution forEM designs. This software can be coupled to performhybrid simulations and the whole system can be visualizedand analyzed in terms of components. It facilitates shorter development cycles and reduced costs. The current areasof interest in which this software is used potentially are- Performance improvement in filters and Antenna circuits,Electromagnetic Interference (EMI), Exposure to fields,Thermal effects in high power devices.

IV. RESULTS

Table 2 presents the results obtained in terms of bandwidth enhancement The parametric details of the incorporated dielectric material, feeding method used and the type of simulation software employed in design-1.In this case the FR-4 substrate with a resonant frequency of 4.06 GHz produces a return loss of -6.4 dB whereas glass epoxy operating at a resonant frequency of 4.1 GHz produces a return loss of -10.4 dB. It is observed that the bandwidth of the antenna in the design is enhanced drastically by around 300 MHZ which is quite phenomenal. It is observed that in the proposed methodology, the simulated and measured values of the return loss display a close agreement which is a figure of merit.

Table 2 Results of antenna performance with two different operating frequencies and dimensions

	Dimensions in mm				**Frequency band**
	L	**W**	**L_T**	**Wt**	**fr**
Antenna 1	28	33	25	5	15GHZ
Antenna 2	28.5	33	25.1	5.8	75GHz

The set of fabricated antenna s is shown below in Figure 4

V. CONCLUSION

The presented work has highlighted the use of a hybrid combination of elements to fabricate a Patch antenna. The antennas were tested on a set of operating frequencies and different dimensions. It has been established that a trade off between the bandwidth and gain has to be worked out. With increasing gain, we have to compromise with bandwidth and vice-versa.

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CONFLICTS OF INTEREST

The authors state that there is no conflict of interest regarding the publication of this paper.

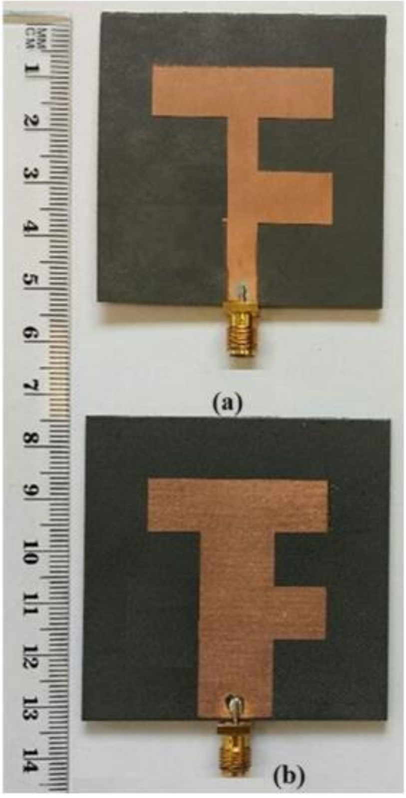

Figure 4. Fabricated antennas with a combination of T and F elements

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Original Article

An Introspection into the Evolution of Microstrip Patch Antenna Design Techniques for Enhanced Wireless Applications

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Abstract *- An antenna plays a pivotal role in a wireless application system. A Microstrip Patch Antenna is widely used in advanced wireless communication and is characterized by high gain and narrow bandwidth. As a result of the developments in wireless networks and integrated circuit technology, patch antennas are being widely implemented as printed antenna for wireless communication, satellite communication, microwave communication and cell phones. It has gained much attention over the past years due to its compact structure, low weight, low profile, low cost and capability to reconfigure on different frequency bands. Furthermore, a hybrid combination of a slot and patch antenna can enhance the overall performance parameters. This paper examines the evolution of various designing, simulation and fabrication techniques adopted for designing microstrip patch antenna. This research delves into various microstrip patch antenna design aspects, including substrate material selection, geometrical configuration, feed techniques, and bandwidth enhancement methods. A currently designed antenna has been investigated, rendering a comparative analysis of enhanced performance parameters such as bandwidth dimensions of the patch, return loss, directivity and efficiency for various patch antenna designs.*

Keywords *- Bandwidth, Efficiency, Microstrip Patch Antenna, Reconfigurable antennas, Defected ground structure.*

1. Introduction

In recent years, there has been phenomenal progress in Wireless communication systems. This has created a thrust for design enhancements in the conventional antenna structures. In line with this, a Microstrip Patch Antenna (MPA) offers Miniaturized size, wider bandwidth, enhanced radiation, improvised fabrication and integration capabilities.

A Microstrip Antenna (MSA) is a compact antenna comprising two metallic planes separated by a dielectric Substrate. The bottom layer constitutes the ground plane, whereas the top layer is a radiating patch. These two planes are isolated with a low loss dielectric medium known as substrate. As the technique of manufacturing a printed circuit board and Microstrip Antenna is identical, a Microstrip Antenna is also known as a “printed antenna” [1]. The conducting slot radiates due to the fringing fields developed at the corners of the upper metallic layer and the reference plane. An inherent advantage of using a Microstrip Patch Antenna (MPA) is its simple feeding mechanism and the ease of interfacing with other ICs. Additionally, MPA can be used in arrays and with other microstrip circuit devices. The patch fabricated in the antenna can be rectangular, square, circular, dipole, triangular, elliptical, disc sector, circular ring, ring sector, but the most popularly used shapes are circle and rectangle. Furthermore, the dielectric resonator antennas loaded with these features are being upgraded continuously to meet these diverse requirements and have been under investigation for the past two decades [2].

Two crucial parameters that affect the antenna’s performance are its size and shape. Furthermore, the dimensions of the substrate are essential [3] from the designing perspective. A significant limitation of an antenna is narrow bandwidth and gain adjustment. From the application perspective, bandwidth is a crucial parameter. and needs to be enhanced for wideband performance [4]. Figure 1 represents a variety of shapes assumed by a rectangular 1(a) the square 1(b) the rectangle, 1(c) the circle,1(d) the triangle, 1(e) the donut, and 1(f) the dipole.

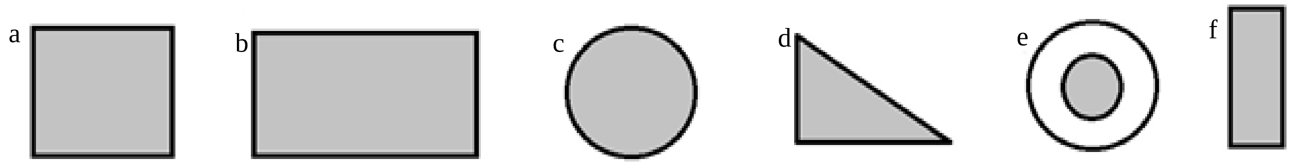

Fig. 1 Discrete shapes employed for designing of Microstrip Patch Antenna: 1(a) The square, 1(b) The rectangle, 1(c) The circle, 1(d) The triangle, 1(e) The donut, and 1(f) The dipole.

2. Literature Review

This section provides the chronological development of patch antenna as various designers propose.

Sohel Rana et al. 2023 proposed an MPA operating at a design frequency of 2.45 GHz. This work analyses the performance of two materials in antenna design, FR4 & Roggers RT duroid. After a comparative parametric analysis of the antenna materials, it is revealed that the performance of the antenna employing Roggers RT duroid rendered better results in terms of superior gain of 2.59 dB, return loss of -12.54 dB, directivity gain of 8.58 dBi, VSWR of 1.61 and efficiency close to 94 % approximately concerning its counterpart FR4. It exhibits excellent radiation and can work over a wide frequency band [2].

Firoz Ahmed et al. 2023 have proposed a compact rectangular patch with enhanced bandwidth and efficiency, employing a hybrid technique, thereby increasing its suitability for UWB applications. This designed antenna uses a defected ground structure as the initial stage. The proposed design considers various crucial antenna design parameters such as oscillation frequency, patch width and length, dielectric constant, and ground plane dimensions. The proposed method yields an improved efficiency of 95.77 % and a bandwidth of 19.7 GHz. This design has rendered a bandwidth and efficiency enhancement of nearly 17 GHz and 3.5 % concerning a basic antenna with DGS. This design becomes a better candidate for Wireless applications [3].

Mouaaz Nahas 2022 has suggested a dual-band patch antenna utilizing a LI slot as a suitable candidate for 5G communications. This design employs various permutations & combinations of multiple LI slots. The objective was to maintain the antennas at resonance values of 28 GHz and 26 GHz, respectively. Four sets of designs have been suggested and compared with each other. It is observed that the four designs render a performance far superior to the identical designs proposed by other designers. It was investigated that the slotted antenna designs employing various configurations were suitable for 5G communication equipment, in which case simple design and small size are the essential constraints for evaluation [4].

Mohammad Sarwar Hossain Mollah et al. 2021 have proposed a Patch antenna using graphene as the base material. The primary goal of the work is obtaining better performance. The designed antenna at 2.45 GHz renders a maximum return loss of -23.67 dB, directivity of 7.30 dBi and a gain of 6.80 dB. The paper presents a comparative performance analysis of the designs employing different materials. It is established that graphene drastically improves the scattering parameter compared to a primary antenna utilizing a DGS as a reference plane.

Feibiao Dong et al. 2017 proposed and investigated an antenna using a wideband Dielectric resonator with a high gain and low cross-polarization. The emphasis is laid on the improvement of bandwidth and gain. A return loss of -10 dB with an efficiency of 25.6%.This further yields an average increase of 7.54 dBi. Due to the simplicity of the antenna design, it can be utilized to form an antenna array [1].

Rahul Dev Mishra et al. 2016 proposed MPA using several microstrip elements to form an array. The primary objective is to improve the overall gain and bandwidth. The antenna is designed at a frequency of 2.48 GHz using FR4 at a dielectric constant of 4.3. In this design, two rectangular patches of identical size are combined to improve the return loss and reflection coefficient, besides improvement in bandwidth and gain as iterated earlier [7].

Huda A. Majid et al. 2014 suggested a frequency reconfigurable Microstrip Patch-slot Antenna having a directional radiation pattern. The proposed antenna can reconfigure up to six frequencies from 1.7 GHz to 3.5 GHz. A reflector has been incorporated into this design, enhancing the antenna's directivity. The frequency switching is achieved by employing switches in the antenna slot [18].

Ahmed Khidre et al. 2013 present a reconfigurable wideband antenna with circular polarization and E shaped patch. The antenna is fabricated on a plane sheet of RT-droid 5880 with a dielectric substrate with a permittivity of 2.2. A narrow slit is etched on the E-shaped pattern. The final design exhibits a bandwidth improvement of 7% with a gain of 7.5 dBi. The fabricated antenna structure covers the WLAN IEEE 802.11 b/g to be used in a band of frequencies in stationary terminals of wireless applications [13].

Hongjiang. Z et al. 2012 suggested a high gain patch antenna to form a wired Yagi-Uda array operating in the frequency band of 5.45 to 5.75 GHz. In this design, wired patch antennas replace the Yagi-uda element [15].

Abolfazl, A. et al. 2011 present a Microstrip Antenna using fractal terminology that renders a broad band of operation. It has been established that the prototype can operate over a frequency band of 10-50 GHz and a 40 GHz bandwidth.

3. Design Methodology

An insight into the basic design procedure adopted for designing a Rectangular Microstrip Patch Antenna (RMPA) and feeding techniques employed, emphasising improvement of bandwidth, gain, return loss, directive gain and other scattering parameters, is introduced.

3.1. Rectangular MPA Design Using HFSS

Figure 2 represents the basic topology of a MPA. This design utilizes two basic materials, FR4 and glass, as dielectric materials. The antenna's bandwidth can be modified by varying the dimensions & shape. This technique is known as dimensional optimization. The bandwidth primarily depends upon the dielectric medium's thickness and the designed patch's width [5]. Table 1 gives the parametric details of the incorporated dielectric material, the feeding method used, and the type of simulation software employed in the design.

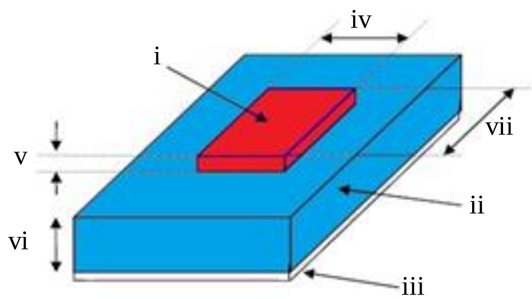

Fig. 2 A layout of Rectangular Microstrip Patch Antenna with (i) Patch, (ii) Dielectric substrate, (iii) Ground plane, (iv) Length (l) of the patch, (v) Thickness, (t) of the patch, (vi) Height of dielectric medium (h), (vii) Width, and (w) of the patch.

Table 1. Parametric details of the RMPA design using various dielectric materials

S. No.	Details	Table Header
Dielectric Material Used	Glass	FR-4
Width (Mm)	20.8	22.6
Length (Mm)	14.77	16.6
Resonant Frequency	4.1 GHz	4.06 GHz
Return Loss	-6.4 dB	-10.4dB
Gain	6.6dB	6.92 dB
Dielectric Constant (Ɛ)	5.5	4.4
Reflection Coefficient (S_{11})	-10	-10.4

The parametric calculations make use of the following equations. Equation 1 gives the Width (W) of the patch in MPA.

$$\mathrm{W} = \frac{C\sqrt{2}}{2\,fr\sqrt{1+\varepsilon}} \tag{1}$$

Equation 2 gives the Length (L) of the patch in MPA

$$\mathrm{L} = \frac{C\sqrt{2}}{2\,fr\sqrt{\varepsilon r}} - 2\Delta L \tag{2}$$

The simulated image of the patch antenna in the High-Frequency Simulation Software (HFSS) tool is shown in Figure 3. Initially, the MPA is designed with a rectangular patch [19]; the substrate is glass with a dielectric constant of 5.5 at a design frequency of 4 GHz, yielding a return loss of around -10db. Then, it is tested on a FR4 as a dielectric medium with a dielectric constant of 4.4. The reflection coefficient is found to be -10.4, as shown in the table above.

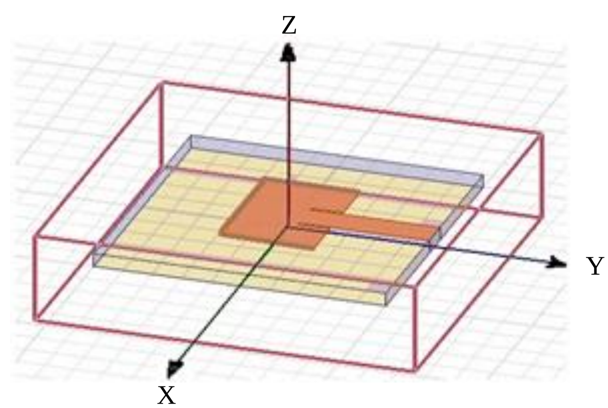

Fig. 3 Simulated structure of Rectangular Microstrip Patch Antenna (RMPA) using HFSS

4. Results and Discussions

Table 1 presents the results of designing a Microstrip Patch Antenna using various dielectric materials with variable dimensions. The parametric details of the incorporated dielectric material, the feeding method used and the type of simulation software employed in design-1.

In this case, the FR-4 substrate with a resonant frequency of 4.06 GHz produces a return loss of -6.4 dB, whereas glass epoxy operating at a resonant frequency of 4.1 GHz produces a return loss of -10.4 dB. It is observed that the antenna's bandwidth in the design is enhanced drastically by around 300 MHZ, which is phenomenal. In the proposed methodology, the simulated and measured return loss values display close agreement, a figure of merit.

5. Conclusion

The presented work has highlighted the progress in the MPA design. It further established that selecting the dielectric material and patch dimensions impacts the overall performance. This research further shows a link between various Microstrip Patch Antenna design aspects, including substrate material selection, geometrical configuration, feed techniques and bandwidth enhancement methods on the antenna's gain, return loss, directivity and reflection coefficient. Thus, it is established that the dielectric material selection and the patch's dimensions affect the patch antenna's performance. Apart from this, the scattering parameters of the designed antenna are enhanced to a higher degree.

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Original Article

5G MIMO Antenna Design with Microstrip Patch Antenna

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Abstract *- The paper's main idea is a fast and cheap antenna that connects multiple devices and sends and receives signals. As mobile phones become more valuable in work and everyday life, more and more people are buying them. Many people now have wireless devices, which has led to many critical technological improvements, such as more bandwidth, faster data transfer rates, and more reliable connections. Array gain, spatial multiplexing gain, and spatial diversity gain are some things discussed after that. Many people also worked on the Multiple Input Multiple Output Antenna literature study, a short survey. The simulation includes a wireless communication system with many in-and-out antennas, return loss, and an envelope correlation coefficient in decibels (dB) per GHz. It also contains several S-parameters, such as S11, S22, S21, and S12. The frequency (in GHz) of the Microstrip Patch Antenna, its input impedance parameter, and the S11 parameter are modelled in decibels. Finally, many study projects are now going on that use many different in- and out-bound antennas.*

Keywords *- Microstrip Patch Antennas (MPA), Multiple Input Multiple Output (MIMO), Long Term Evolution (LTE), Multiple-Input Single-Output (MISO), Single-Input Single-Output (SISO).*

1. Introduction

Modern wireless devices like cell phones, tablets, and PDAs are all used for personal contact. WiFi and Long-Term Evolution (LTE) are two examples of changes that have been made. Several antennas are used in Multiple Input Multiple Output (MIMO) technology to allow a lot of senders and listeners. This method makes the best use of the radio, which increases capacity and makes things more reliable [1].

In MIMO systems, the channel factors control whether the channel capacity (shown in bits per second) goes up or down. As more listeners are added, the channel's power goes up in a straight line. Because of this, more listeners would mean more multipath channels in a perfect world. The speed boost would not work if the antennas' radiation patterns lined up or conflicted. Because of this, the antenna engineering team has a tough time making MIMO systems where elements do not communicate much [2].

One can easily find low-cost, flexible printed antenna technology that makes it easy to build and add printed antennas that use the device's system ground plane to small gadgets. Printed MIMO antennas are made separately, even in small devices with closed antenna parts. In turn, this means that old antennas do not always meet the needs of modern wireless devices. Many people think Microstrip Patch Antennas (MPAs) are the best for wireless connection. Microstrip Patch Antennas have some excellent points, but they are limited by their low gain, narrow bandwidth, and inability to handle enough power.

Fixing crosstalk and getting the most out of frequency economy is very important. Spectrum may soon run out because more people want services that use much data, like file sharing, mobile video, and portable internet. The signal is more likely to be messed up by other services when more data is being used. Ultra-wideband is an excellent example of how movements can interact with each other.

It is a goal of the information sector to make better use of the radio spectrum. The future of communications looks bright thanks to intelligent antennas, which could change the game as these technologies improve. Communication technologies have only recently made it possible for changes to be made that go beyond code, data, and time [3]. At the range, there are strict rules and laws. If someone does not want to use a regular antenna, they should use an intelligent antenna or some other type of spatial domain antenna. Two sensors at each end of the channel are needed for multiple data streams in space and time. The data streams are sent to and received by two different terminals. Many more people can use the airwaves with the help of MIMO devices, which can process data much faster. This is the worst kind of radio channel, called multipath fading. It uses “multipath” to discuss how electromagnetic waves send messages at different times, angles, and frequencies as they move through space. Wireless communication systems are challenging to build because they can handle infinite frequencies. Radio transmission architecture has changed a lot since MIMO technology came out. MIMO systems are different from single-antenna systems because they can use both time and frequency. It is better to use the MIMO approach because it helps with arraying, spatial diversity, spatial multiplexing, and reducing interference [4].

A new type of wireless cell network will appear as wireless communication technology improves. Many believe that MIMO technology is critical for 5G radio networks to work well. Innovative antenna technology and wireless broadcast antenna diversity technology are the technologies that came before MIMO technology. It has the best SIMO and MISO systems features because data comes from a single source and is sent to many places. MIMO means that both ends of the transmission use more than one antenna. It can significantly improve the quality and speed of wireless links without needing more power or bandwidth.

For MIMO technology to work, the multiantenna device must function well. Multiple antenna systems can be affected by more than just their structure and design. The multipath properties of the wireless channel can also play a role. In MIMO multiantenna design, people investigate things like mutual coupling analysis, multiple antenna patterns, and the shape of antenna elements. Most MIMO multiantenna system research is focused on finding low-cost, high-performance antenna and design choices right now [5].

To get the needed electromagnetic efficiency, antennas are often attached to the outside of the carrier. The bent antenna was made because of this. One can use a conformal antenna design outside the page to save space and prevent mechanical support from getting damaged [6]. There is no one part of the outside of the box where this happens. Conformal antennas come in many types, such as microstrip, stripline, and crack antennas. One of the many great things about the microstrip antenna is its small, light, and low profile.

For this reason, bent antennas work better. Lately, many people have been talking about 5G technology and the unique qualities of the millimetre-wave band, like its short wavelength, wide frequency range, and ability to pass through dust, fog, and snow [7]. Because of this, much time has been spent studying millimetre wave microstrip antennas. Figure 1 displays a 5G MIMO antenna design overview.

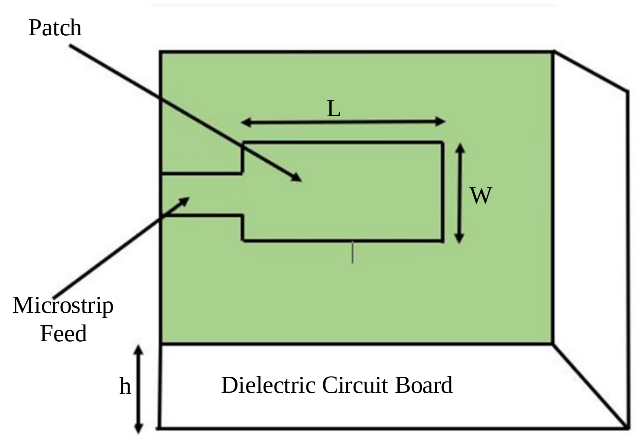

Fig. 1 5G MIMO antenna design overview [8]

The antenna parts that send and receive signals are in the front of a MIMO curved antenna. As the radiation parts in this layout, Microstrip Patch Antennas are used. When designing rectangular microstrip antennas, two main steps must be taken. After doing much study on the method, academics used simulation and optimization to test their ideas. The first step in the process is choosing an insulating material. In the millimeter-wave frequency band, the microstrip circuit loses much power. There are three ways that energy can be lost: dielectric loss, circuit loss, and radiation loss. One can reduce dielectric loss by using a base with a low-loss tangent dielectric [9].

There is no change in the total loss of a microstrip when the characteristic impedance is changed. Their low dielectric constant is the reason for this matter. In a medium with a high dielectric constant, on the other hand, both the microstrip loss and the characteristic impedance will change quickly. As the base gets thicker, there will be more radiation losses and the chance of a surface wave.

A shorter height is better to stop the higher setting and reduce radiation leaks. Many countries have spent much money on research and development to prepare for the switch to Fifth-Generation (5G) wireless internet, which will happen anyway. It is because people want better internet and more space on their phones. Many of these countries and places have made their own 5G wireless protocols because people wish wireless data transfer speeds 100 times faster than 4G LTE. Governments, companies, and researchers are increasingly using Millimetre Wave (mm-Wave) frequencies because it is getting harder to assign frequencies [10].

For 5G technology to work, antennas must have features that have never been seen in a user experience. Putting the signal’s emission pattern right where the listener is can help networked devices talk to each other wirelessly better, and this method is called beamforming. More bandwidth and faster data processing rates are needed because there are so many new mobile apps. It can be hard to find a good balance between the technical problems of making millimetre wave antennas and business goals like low cost, small size, high radiation efficiency, high directivity, broadband performance, and so on. Microstrip Patch Antennas (MPAs) with the coplanar layout of the radiation parts and the feed network are a good choice for 5G users who need a functional part that is hard to make but works well [11]. The electrical and physical properties of the dielectric base have a significant effect on two performance factors of millimetre wave (high frequency) antennas: their directionality and bandwidth.

2. Literature Review

In the 1970s, Brandenburg & Wyner (1974), W. van Etten (1975, 1976), and AR Kaye & DA George (1970) were some of the authors who wrote about cable pair interference in multi-channel digital broadcast systems, and these files are always being watched by MIMO [12]. MIMO is a pretty standard mathematical model, even though there are not many real-world examples of sending multiple data streams in more than one way.

The mid-1980s saw more work by Jack Salz at Bell Laboratories on the effectiveness of multi-user systems made up of “mutually interconnected linear and additive noise networks.” Many people choose the MPA for wireless connection because it can be used in many situations and is simple to put together. Because it can put them on circuit boards, they are instrumental. The MPA is often used even though it has a few minor problems because it has so many benefits. Here are some of the perks of the MPA: -

- Portable Structure
- Unobtrusive
- Processing a dual-frequency and tri-frequency operating range.

2.1. Expand an Antenna’s Bandwidth

By dropping the dielectric constant and making the antenna stronger, the device’s bandwidth can be made better.

2.2. Boost an Antenna’s Gain

Changing the shape of the patch could make it work better or worse. Rectangular patches are used in this study because they have a higher gain and a smaller patch size (by 65–70%).

Chan et al. (2014) describe how the circularly polarized patch antenna that was used in this study could be used in modern cell phones. The main goals will be to increase the patch antenna’s beamwidth and make it smaller. Since 4G is still being used and improved, all eyes are now on 5G, which is the next generation of wireless networking. For broadcasting on land, most studies use antennas with linear polarization. However, 5G phones may be able to send and receive info through space. Land-based cell phones now offer stable, high-quality service in areas with lots of people. Sound, text, and data transfers make it possible to send and receive visual media like photos and live-streamed videos. However, the current land network might not be able to reach some very faraway parts of the earth [13].

Rohokale et al. (2015) describe that at the age of 4G, researchers have made several antennas that can handle multiple services at the same time. Wireless communication has grown at a fantastic rate over the last few decades. The number of wireless subscribers has grown faster than the number of fixed-line consumers since the year 2000. Since the end of 2010, four times as many people have signed up for cell phones as for landlines.

However, both the sellers and the service providers know how important it is to have a well-designed network [14]. Examples of how CNNs and transfer learning techniques can be combined to process medical pictures are given in the literature. Transfer learning is the process of applying knowledge from one domain-natural photography, for instance-to another-medical pictures, for instance. Studies like the one carried out have shown how crucial transfer learning is to improving deep learning models’ capacity to detect lung nodules in chest CT images. This method allows models to benefit from insights from more extensive and varied datasets, which is particularly helpful when labelled medical imaging datasets [19–21].

Saini et al. (2016) and their colleagues describe that some of the plots that will be shown and talked about to show the shape of the antenna are gain plots, return loss plots, Voltage Standing Wave Ratio (VSWR) plots, and radiation pattern plots. The simulation results are shown next to the measured numbers, which match up well. To keep up with the smaller size of cell phones, antennas have had to get smaller, too. For mobile communication, many antenna designs are used instead of a single antenna. MPA has quickly become a popular extra for handheld devices because it is small and can work with several frequency bands. Microstrip Patch Antennas are better than other types of antennas because they are cheap, easy to build, and movable.

A Microstrip Patch Antenna has some good points, but one of the biggest problems is that it has a minor frequency [15]. Even in the context of deep learning, conventional machine learning methods are still helpful for medical image interpretation. The usage of this simple yet efficient technique is made possible by the K-Nearest Neighbors’ (KNN) capacity to recognize patterns in feature space. A 2021 research by Silva et al. found that KNN performed competitively in lung nodule categorization. This result highlights the need to consider both traditional machine-learning methods and their deep-learning counterparts.

Abirami et al. (2017) describe the huge number of people who use cell phones these days; please explain why cell phone touch is so important. People who use smart devices are always expecting more. For instance, when it comes to online dating, they want all the related apps to have a streamlined user experience, better communication rates, and shorter wait times in traffic. With 5G technology, service providers will be able to meet the wants of their mobile customers better. 5G technology lets it use more than one frequency band, cover a more extensive area, provide better services with less delay, and send data much more quickly [16].

Chen et al. (2018) describe that in the future, these devices will help smartphones and dongles. It is easy to see the ground planes and the eight MIMO antennas on top of the base. When it comes to performance and gain, the best gadget has its electromagnetic bandgap on the ground plane. There is no chance of nuclear leaks because everything is wired into the central hub. There are only so many channels that can be used, so as more people use the frequency band, it finally fills up. A certain number of devices can use the same radio frequency at the same time. When more people use a channel, co-channel noise starts to get worse as well. As the use of HD and QHD video grows, it becomes harder for mobile devices to send and receive large video files over 3G and 4G frequency bands. Sending and receiving high-quality video across displays quickly requires more bandwidth and faster transfer rates [17].

Tirmizi et al. (2019) describe a fresh multiband patch antenna design for millimetre waves that can be used for 5G wired networking. The 5G millimetre-wave multiband antenna's microstrip-based design is the lightest, most cheap, smallest, most highly gainable, and most valuable. One example is that 5G networks make it easier to add new software and hardware. Fast data rates are needed to send and receive large amounts of traffic and high-definition video. The frequency range of microwaves below 6 GHz does not have enough high absolute bandwidth to meet demand. A 5G wireless network is better because it can send info quickly. Radio waves called Millimetre Waves (mm-Wave) are needed for 5G WiFi and multigigabit connections [18].

Jugale et al. (2020) describe that connection has always been an essential part of how people grow and progress. It has had a significant effect on the past and will have a massive effect on the future. Wireless communications have grown over thousands of years as people have tried to be faster and better. It seems like every new generation of communications starts a time of technological progress that is decades faster than the last. In the short time since they came out, 4G networks have spread faster than any other type. Also, there is more and more pressure to meet the needs of the telecom infrastructure for 5G networks. So they can join the Better World Network, the gadgets need to be updated right away. Any changes to the transmission equipment will not work with the new network. However, since things change so quickly, the antennas would have to change too. This shows how important it is to know what needs to be done to make an antenna that works in the 5G transmission area. A common choice for this use is the Microstrip Patch Antenna. There are many microstrip antennas used in transmission because they are small and easy to make, which makes them perfect for low-profile uses. Most changes that are made to smartphones are good because they make the hardware smaller [19].

Murugan et al. (2021) describe that MIMO antennas are a powerful way to make cellular networks better at separating data from noise. To increase the channel's carrying ability, the signal-to-noise ratio needs to be raised. Also, make sure the parts have enough space to breathe. In the future, mobile phones will need to have more storage room and faster internet speeds so that more people can connect. In a multipath setting, signals weaken quickly, making it hard to improve the Signal-to-Noise Ratio (SNR).

The signal-to-noise ratio would be better with a more robust receiver. If only one antenna, it can get the most gain by making the beam of that antenna bigger. If there are several lines, this problem can be fixed with a MIMO antenna, which increases both the gain and signal-to-noise ratio. Having more than one MIMO antenna, especially one placed at different network nodes, can improve coverage. There was a method used for this called "space diversity." For MIMO to work, the cameras need to be far apart. High throughput, high bandwidth, and almost no delay in sending and getting data are what make 5G transmission unique [20].

Arora et al. (2022) describe that the first idea in this study is a circle Microstrip Patch Antenna with a single element that works at 28 GHz. It has an elliptical slot and a ground design that does not work well. 5G technology has grown in popularity over the past few years thanks to its low latency and fast transfer speeds. Million-wave front ends have been the subject of much study because bandwidth and data rates go in the opposite direction. Moving from 3G to 4G is now complete. Even though technology has changed quickly in the past few years, the need for faster data transfer rates and processing times has not been met. Mobile data flow is expected to grow faster than 4G networks can handle.

This is because of apps like video streaming, social networking, and cloud computing. To meet this need, scientists are putting in much work to make Fifth Generation (5G) networks the norm around the world. This is a challenging job because of the higher volume and faster transmission speeds. This can only be fixed by putting in place MIMO technology and making wide-area data transfer better. While the multipath feature does not add extra data transmission power, it can improve channel capacity and range effectiveness. The MIMO design needs to be rearranged to split the broadband further from the parts. This is very important for the operation to go well [21].

Paramesha et al. (2022) describe that there are always new and better ways to talk to each other, as shown by the growth of the internet. Scientists and engineers are interested in the new 5G wireless transfer. However, better antenna design is needed for wireless communication to work as it should. The main goal of the suggested study is to make a tall antenna so that 5G wireless communication can work better. This piece suggests using a circle of Microstrip Patch Antennas (MPAs) to make 5G wireless networks reach farther. The multi-input, multi-output feeding method is used to improve the antenna design that was planned. Cell phones, WiFi, Bluetooth, WiMAX, ISM, and other devices already use the lower spectrum. Also, the best frequency range for 5G technology has not yet been found [22].

Sneha et al. (2023) describe that in mesoelectric piezoelectric arrays, a metal patch is kept away from the ground by a shielding layer. The base and the ground together are more extensive than a square. Microstrip Patch Antennas are a new idea. They can send and receive wireless messages through many inputs and outputs. MIMO wireless technology lets more data be sent to both the sender and the receiver at the same time. This speeds up communication and lowers the number of errors. The number of antennas on access points and wireless routers is one of the most essential parts of wireless network technology. Microstrip antenna design is a popular area of study right now for radio communication. They are essential for wireless communication, especially for internet and ultra-wideband needs, because they are so small. The feeder part, the base, the ground plane, and the patch are the four main parts of a single-layer MPA [23].

3. Wireless Communication System with MIMO

A complicated grid may be needed for Multiple-Input Multiple-Output (MIMO) devices to work. In all these cases, the Shannon extended capacity method is used to figure out the highest speed that can be sent over the MIMO channel. The amount of association seen depends on how many antenna elements are used, how far apart they are, and how many simulations are run for models where both the transmitter and the receiver use a lot of them. Most of the time, two patch antennas are used.

Each one is attached to a base and has its own on/off switch. Because of how they are set up, the two transmitters cannot face each other [24]. With the switch from traditional to digital communication, wireless and mobile devices can be used in a lot of new ways. Interoperability, support for multiple frequency bands, meeting SAR standards, and being able to work with hearing aids are just some of the problems that new antenna designs must solve. There are also problems caused by not having enough space. For digital communication to work, issues like changing data transfer rates, too much capacity, and the inability to rearrange bandwidth on mobile devices and base stations must be fixed.

3.1. The Capacity Formula of Shannon

The Shannon capability formula is used to find the possible maximum channel transmission (without considering fading and interference). To use a white Gaussian noise track, this formula figures out the possible channel bandwidth, signal strength, and single-side noise spectrum.

3.2. Formula for Extended Capacity

Both the sender and the listener can use different antennas. That is why this kind of antenna is called MIMO, which stands for “Multiple Input and Multiple Output.” Everyone can figure out how much power this receiver can handle by using Shannon’s method.

4. Key Features of 5G MIMO Microstrip Patch Antenna

“Key enablers” are the essential technologies and parts that 5G networks need to work the way they are supposed to [25]. Those that make 5G possible provide the services and skills that are needed for it to work and benefit from its unique features.

4.1. Millimetre-Wave (mm Wave)

Millimetre-Wave (mm Wave) technology is an essential part of Fifth-Generation (5G) cell phone networks. There are more empty rooms, less delay, and faster data flow rates with this broader frequency range. A problem with millimetre wave technology is that shorter wavelengths at higher frequencies lead to more signal loss from artificial buildings and objects, as well as more signal interference from plants. To get around this issue, Millimetre Wave 5G networks usually put more base stations, which are also called access points, closer together. Millimetre Wave communications are also more likely to be harmed by other wireless signals and things in the environment, like fog and rain.

A lot of different types of advanced signal processing let millimetre-wave 5G networks send signals to specific areas where they can be heard more clearly and with less interference. Even with these problems, millimetre wave technology has many benefits for 5G networks, such as more space, less delay, and faster data transfer rates. There are many ways that these characteristics could be used. Some examples are High-Definition (HD) video streaming, Virtual Reality (VR), and Augmented Reality (AR).

4.2. MIMO/m-MIMO

Also, m-MIMO technology is an integral part of 5G radio communication. When many antennas that can send and receive data at the same time are added to a network, its range and speed are both improved. In standard wireless communication systems, signals have also been sent and received using SISO, SIMO, and MISO.

Huge MIMO does not work because both the sender and the listener need many antennas. The network can send and receive more data at once, which increases its range and capacity. Massive MIMO technology uses complex signal processing techniques to separate the many messages sent and received by the many antennas. The government and phone companies will be able to use the radio more effectively because there will be less background noise. Massive MIMO technology improves the reliability of wireless data and grows the reach of wireless networks.

4.3. Small Cells

Small cells can now be set up because networks have gotten better, and more people need to send and receive data. For wireless networks, these minor, low-power access points can only work in the approved spectrum and must follow the rules set by the carrier. This makes cellular range and capacity better. They can help fill coverage holes, keep service quality stable, and make better use of capacity. This situation can be solved by tiny cells, which offer better coverage and capacity in places where giant cell towers are not needed. Micro, metro, femto, and macro are the four sizes of microscopic cells.

Micro and metro small rooms can be hundreds of meters long in cities. One can often find pico cells in public places like subways, airports, and shopping malls. They can be with one another for just a few tens of meters, whether it is inside or outside. Because of this, femtocells are primarily used in homes because their range is only a few tens of meters. A lot of Access Points (APs) are used by these microcells, which are set up in cities by connecting to power lines, lights, and other things that are already there. With the help of small cells, 5G wireless networks can provide more power and coverage in crowded urban areas, which is essential for Internet of Things (IoT) devices, self-driving cars, and smart cities. When femtocells and microcells are used, problems can happen with the allocation of spectrum, handovers, and scheduling at the cell border.

4.4. Network Slicing

Network slicing is another feature of a 5G wireless network. This feature lets telecom companies offer personalized services to their customers by building multiple virtual networks inside a single physical network. Most cellular networks put limits on which users can get to which resources. This means that networks cannot handle a lot of different services that need different amounts of bandwidth, delay, and dependability. Network slices are more minor, separate parts of a more extensive network. The QoS of each “slice” is looked at during segmentation to see how well it was made. Network slicing is the idea of breaking networks up into smaller, easier-to-handle pieces so that they can be used more efficiently and in different ways. Network slicing, in its most basic form, lets the network’s features be changed to better meet the needs of specific users or apps. Network slicing lets operators make virtual networks with different sets of tools and functions.

After that, these systems can be used to offer many different programs and services. Networks can be “sliced” to do many different things. Two good examples are low delay for self-driving cars and high bandwidth for streaming videos. Network slicing is vital for many uses of 5G, such as smart towns, healthcare, and automated factories. Even though each service has different needs for bandwidth, delay, and stability, the network may be able to handle them all. Customers and use cases may also be able to get goods and features that are better fit for them by service providers.

4.5. Cloud Computing

Cloud computing is used by both 5G and B5G, which is suitable for digital contact. It talks about how to connect the gadget to a faraway computer online so that it can use servers, data storage, apps, and other computer services. In a 5G network, people and their devices can use cloud computing to get the services and apps like AI, Internet of Things, and edge computing. Cloud-based services and apps help 5G wireless networks handle the vast amounts of data they need to send and receive and the strict performance standards they must meet.

AI and Machine Learning techniques can be used on massive datasets in a cheap and scalable way with cloud computing. One great thing about machine learning is that it can look through massive datasets and find patterns. Machine learning methods get better over time with little help from people because they can learn and change on their own. In situations where things change quickly and dramatically, like in 5G/6G, these methods work amazingly well when dealing with complicated, multidimensional data. Also, machine learning programs can learn new things better, especially when they are given complex problems to solve. For many 5G uses, like self-driving cars and automatic factories, this is very important because data needs to be processed in real-time.

4.6. Virtualization

For ease of use and control, physical assets are turned into digital copies in this case. Networks, computer servers, and data centres are all types of building tools. In 5G networks, virtualization is used to make VNEs and VNFs, which stand for virtual network elements and functions. This could help companies get more people by giving them services and apps that can change as their needs do. Virtualization can save money and make it easier to add more resources by running network tasks on regular hardware instead of expensive specialized gear. The option to make "network slices" is one of the best things about virtualization in a 5G network. Virtualization makes it easier for operators to move resources around quickly to meet the needs of users for different services and apps. As a result, the network works better and costs less because it can adapt more quickly to changes in traffic.

4.7. Edge Computing

Communications based on edge computing have shown promise in getting ready for new technologies like 5G and 6G. Because smart gadgets and data flow are becoming more popular, operators are looking into new ways to build base stations, such as cloud computing and virtualization. Virtualization lets customers access a shared pool of scalable computer resources whenever they need to with Cloud-RAN (C-RAN), a cutting-edge RAN system. Data is processed on the gadget itself instead of being sent to a central server. Edge computing is the use of moving computers and storage capabilities closer to the user, like near a Radio Access Network (RAN) or base station. Information does not have to be sent to a central place; it can be processed and analyzed right away at the edge of the network. The edge cloud works as a go-between, only sending data to the leading network when it is really needed. This level of speed is needed for a lot of 5G uses, like self-driving cars and automated factories.

4.8. Carrier Aggregation (CA) and Beamforming

It is possible to send more data more quickly when several frequency bands are combined into one bigger band. What this is called is "carrier aggregation." To better help their customers and make better use of the spectrum they have access to, service providers can do it. When user devices and a base station send and receive signals in the same way, they can talk to each other. This is what we call "beamforming." Signals are focused on narrow beams that can be pointed at specific places or things to stop them from spreading. When service providers do this, they can make better use of their spectrum, connect more people, and send info more quickly. Beamforming is an essential method for sending vast amounts of data very quickly over Millimetre Wave (mm-Wave) bands and is used by some 5G networks. Millimetre waves lose much energy as they travel through the world and are easily absorbed by things like buildings and trees. Because it only sends the signal to the people or tools that need it, beamforming helps operators get around these signal loss problems.

5. Microstrip Antenna Technology

The hardest thing for Radio Frequency (RF) experts is figuring out how to send and receive messages in very complicated systems. It is not enough to only look at parts of a communication link. The efficiency of the antenna is significant for the MIMO system to work. Different kinds of MIMO devices use the channel's multipath features. Choosing antennas based on the propagation route leads to the best antenna design for the medium of propagation. The relationship between channel coefficients changes depending on the antenna settings [26]. Self-coupling effects can happen when transmitters are placed next to each other in a MIMO system.

As it plans the MIMO antenna array, think about how each might change it. Putting many sensors on small, movable devices is one of the biggest problems with MIMO systems. It is essential to build antennas that work because MIMO technology depends on them. Microstrip geometry was first used in high-performance missiles, spaceships, and aeroplanes in the 1950s because it was small, cheap, very practical, easy to install, and shaped to be aerodynamic. Figure 2 describes the Microstrip Patch Antenna overview.

The metal patch comprises feed and parasite patches, as was said in the beginning. Businesses and the government already have rules about how to use cell phones and wireless messages. In 1952, around the same time that microstrip transmission lines came out, Grieg and Englemann made heaters that could be used with them. A broadcast line that looks like a microstrip and an antenna that looks like it was used for the first time to talk. In 1955, Gutton and Baissinot got a patent for their idea for a microstrip antenna [28]. Figure 3 shows the Microstrip Patch Antenna circuit theory. Many things influence these antennas:

- Their low profile makes them less visible and helps them blend in with different surfaces.
- Made from printed circuit boards, they are cheap and straightforward to make.
- Putting them on a stable surface makes them structurally strong.
- The modelling model and the shape of the patch both have significant effects on the patterns and polarization that are made.
- Maybe other radios can be made in microstrip and hooked up to a microstrip antenna, so there is no need to add more steps to the making process.

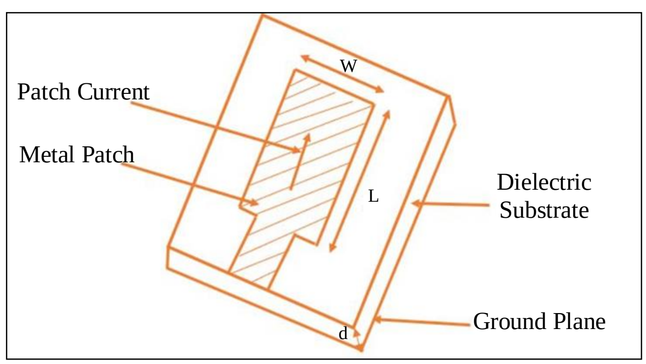

Fig. 2 Microstrip Patch Antenna overview [27]

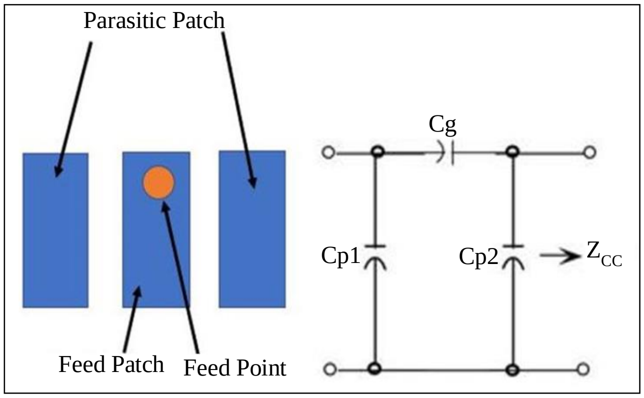

Fig. 3 Circuit theory of Microstrip Patch Antenna [29]

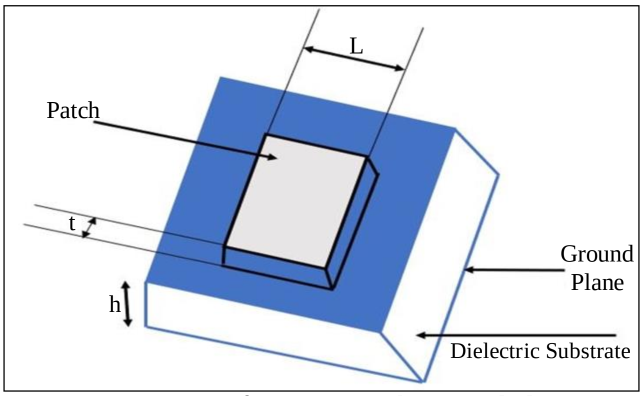

Fig. 4 Design of Microstrip Patch Antenna [30]

The first version of microstrip antennas had a bandwidth of only a few megahertz. This meant they could only handle moderate power levels, and their polarization was unstable. Much work has likely gone into meeting these needs since most studies have been about fixing problems that system standards cause. Some of these changes are new designs for microstrip antennas and a fresh look at the issues they will surely face. Figure 4 shows the Microstrip Patch Antenna design.

6. Results and Discussion

These are the "antenna techniques" that are used to make sure antennas meet the standards. This part talks about all the antenna's S-parameters, such as ECC and return loss. In Figure 5, Figure 6, Figure 7, and Figure 8, one can see both the real and predicted frequency responses of the 5G MIMO.

The value of the return loss is shown in Figure 9 and Figure 10 of the ECC. The generated prototype's isolation and loss of return with the S-Parameter. This is the prototype's resonance frequency, and it is here because less return loss means more efficiency. HFSS will be used for all simulations after this one. Figure 11 shows this y-parameter for the rectangular Microstrip Patch Antenna. Radiation elements are added as the first step in building a MIMO conformal antenna. Microstrip Patch Antennas are used as radiation elements as part of the design. A rectangular microstrip antenna is usually put together in two steps. In microstrip circuits, there is much loss in the millimetre range. There are three ways that losses can happen: through conductors, dielectrics, and radiation.

When the dielectric constant is low, neither the characteristic impedance nor the total loss of the microstrip changes. There are significant changes in the characteristic impedance and microstrip loss when the dielectric constant of the substrate is high. As the substrate gets thicker, the chance of radiation losses and surface wave damage goes up. At lower heights, it is easier to block the higher mode and lose less radiation. For conformal antennas, a substrate that is thinner and more flexible works best. The input impedance of the rectangular Microstrip Patch Antenna is shown in Figure 12.

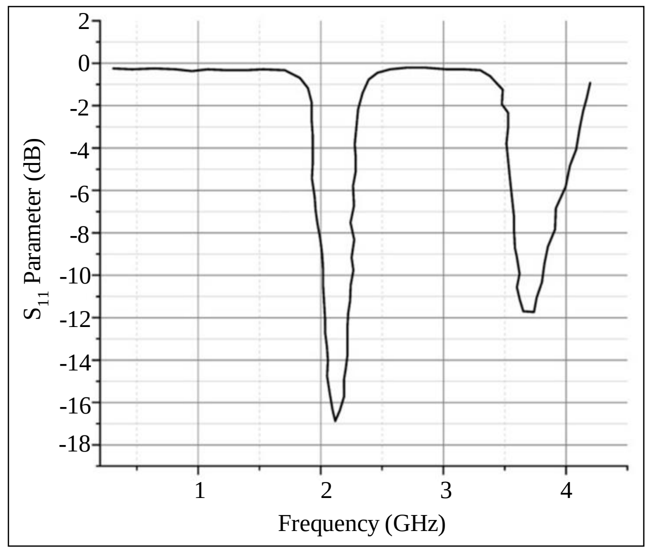

Fig. 5 S_{11} parameter of MIMO antenna

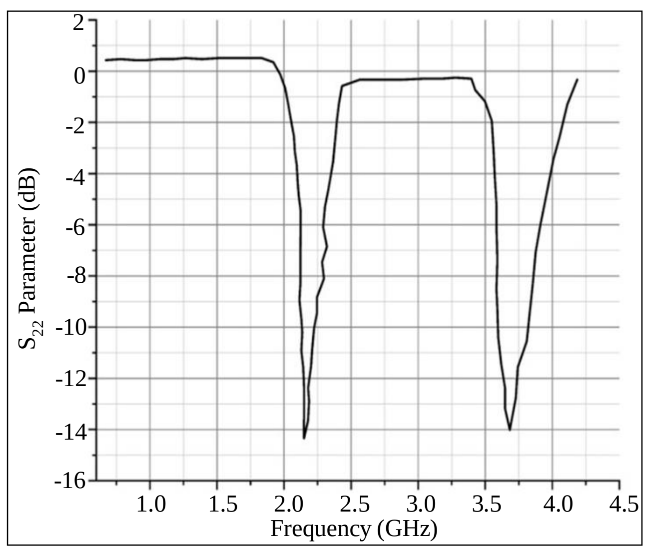

Fig. 6 S_{22} parameter of MIMO antenna

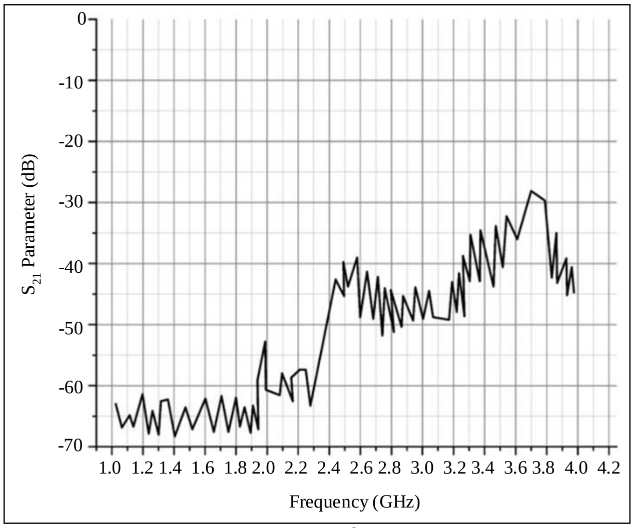

Fig. 7 S_{21} parameter of MIMO antenna

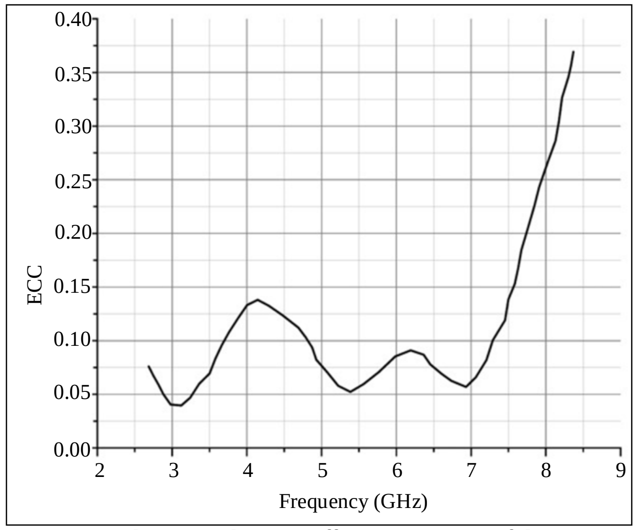

Fig. 10 Envelope Correlation Coefficient parameter of the MIMO antenna

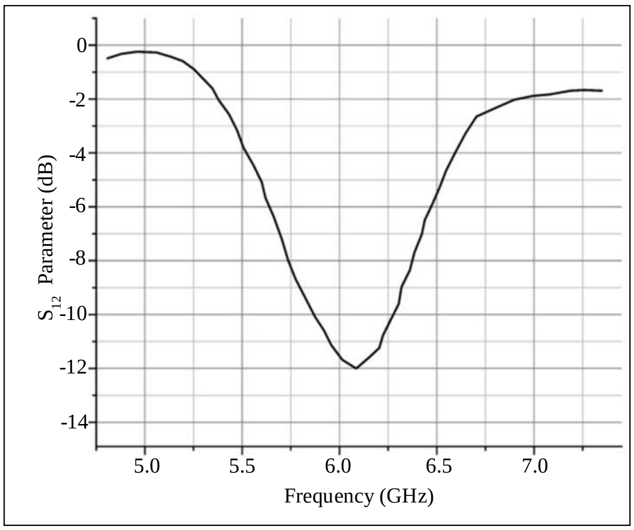

Fig. 8 S_{12} parameter of MIMO antenna

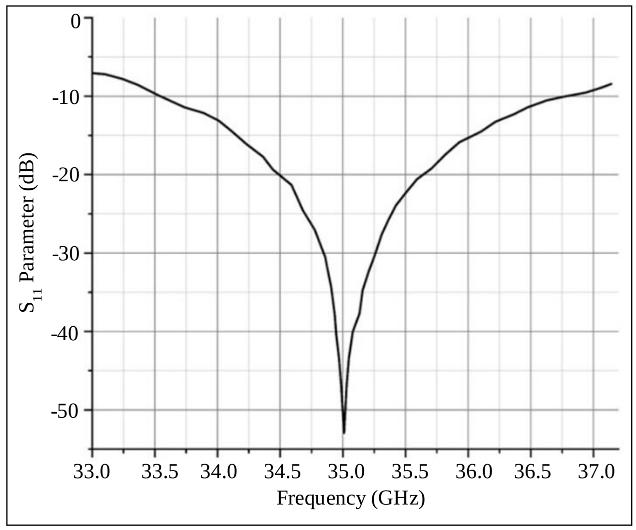

Fig. 11 S_{11} parameter of Microstrip Patch Antenna

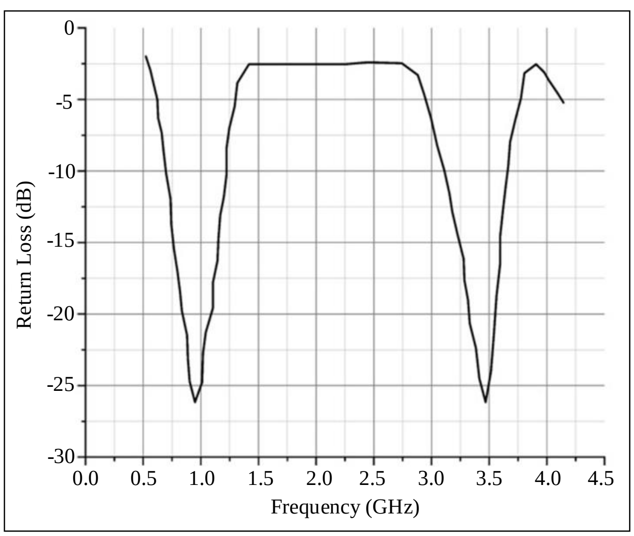

Fig. 9 Return loss parameter of MIMO antenna

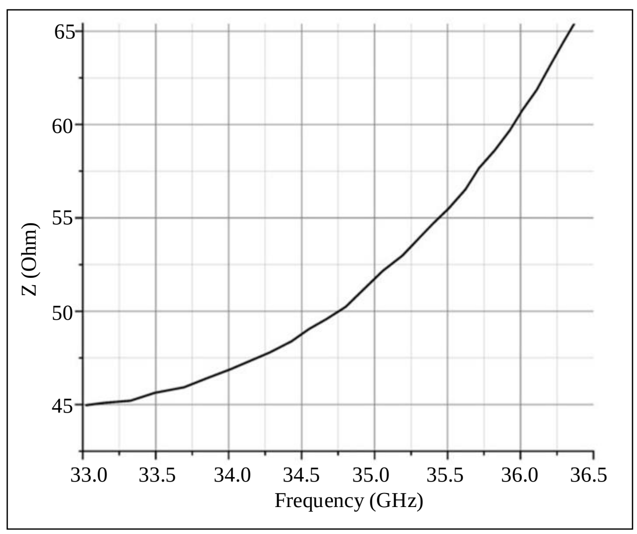

Fig. 12 Input impedance of rectangular Microstrip Patch Antenna

7. Conclusion

Microstrip Patch Antennas, or MPAs, are small antennas that can help handheld devices these days. Much faster data speeds are needed for modern wireless transfer and reception standards. It is very fast to send and receive data with a Microstrip Patch Antenna that has Multiple Inputs and Multiple Outputs (MIMO). Fifth-Generation (5G) wireless networks are meant to send data much more quickly than present wireless networks. Multiple-Input Multiple-Output (MIMO) transmitters have problems with the skin effect, even though they are more reliable and can send data faster in the high-frequency range. Multiple-Input Multiple-Output (MIMO) microstrip antenna devices have ports that are next to each other, which can cause unwanted mutual coupling to happen.

Neutralization lines, electromagnetic band gap structures, faulty ground structures, and improving port isolation are just some of the many ways to lower coupling. To stop them from interacting with each other, the space between antenna ports needs to be widened. This makes antennas get smaller.

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