International Journal of Recent Development in Engineering and Technology
Website: www.ijrdet.com (ISSN 2347 - 6435 (Online) Volume 14, Issue 6, June 2025)

# Design and Performance of Microstrip Patch Antennas: A Review of Current Research and Developments

[1]Anamika Choudhary, [2]Dr. Rakesh Singh Rajput, [3]Rajdeep Shrivastava
*[1]M.Tech Scholar, Department of ECE, Lakshmi Narain College of Technology Excellence, Bhopal, India*
*[2]Associate Professor, Department of ECE, Lakshmi Narain College of Technology Excellence, Bhopal, India*
*[3]Assistant Professor, Department of ECE, Lakshmi Narain College of Technology Excellence, Bhopal, India*

***Abstract*****—** Microstrip Patch Antennas (MPAs) have gained significant attention in the field of wireless communication due to their low profile, lightweight, and ease of integration with electronic circuits. These antennas are widely used in applications such as mobile phones, satellite communications, radar systems, and wireless networking. The performance of MPAs is influenced by various factors, including substrate material, antenna shape, feeding techniques, and the design of the ground plane. This paper provides a comprehensive review of the latest advancements in MPA design, highlighting key parameters such as bandwidth, gain, and efficiency. The study also explores different feeding methods, including microstrip line, coaxial probe, and aperture coupling, and their impact on antenna performance. Challenges in terms of miniaturization, bandwidth enhancement, and cost-effective fabrication are also addressed. Finally, the paper outlines the future trends in MPA research, including the integration with 5G and IoT technologies.

*Keywords*—Antenna, 5G, Antenna Feed, Antenna Design, Bandwidth.

## 1. Introduction

Understanding the definition, function, parameters, and types of antennas is part of the "world of antennas" [1]. An antenna can be defined as an electromechanical devicethat can transmit or receive electromagnetic waves.

The rapid evolution of wireless communication technologies has ushered in the era of 5G (Fifth Generation) networks, which promise unprecedented data rates, ultra-low latency, enhanced connectivity, and massive scalability. These advancements are primarily driven by the need to support the exponential growth in demand for mobile broadband, the Internet of Things (IoT), and machine-to-machine (M2M) communication. In this context, microstrip patch antennas (MPAs) have emerged as a key technology for enabling 5G communications due to their unique combination of performance, cost-effectiveness, and ease of integration.

A microstrip patch antenna is a type of antenna consisting of a radiating patch on a dielectric substrate, typically with a ground plane on the opposite side. These antennas are recognized for their compact size, low profile, and lightweight design, making them ideal for integration into modern wireless communication devices, including smartphones, base stations, wearable devices, and automotive systems. Given their ability to operate at high frequencies, low power consumption, and versatility in beamforming, microstrip patch antennas are increasingly being tailored to meet the specific demands of 5G systems.

This paper explores the significance of microstrip patch antennas in the context of 5G applications and satellite communication, analyzing their design characteristics, performance metrics, and how they are optimized to support the key features of 5G networks, including massive MIMO**,** beamforming**,** small cell deployments**,** andhigh-frequency operation. Additionally, challenges related to the design of MPAs, such as bandwidth limitations and efficiency at higher frequencies, are discussed, alongside strategies for overcoming these challenges to ensure optimal performance in 5G environments.

## 2. Related Work

Number of papers on the design of microstrip patch antenna with slots isanalyzed. Summarized details of the research papers are outfit below including the description of necessary parameters.

The comparative analysis of Microstrip Patch Antenna (MPA) which has presented by Sumit K. Khandelwal et al., [1] in the ever-evolving landscape of wireless communication, the growing demand for compact, high-performance antennas capable of covering broad frequency ranges has highlighted the importance of microstrip patch antennas in modern wireless communication systems. This research provides a comprehensive comparative analysis of various microstrip patch antenna designs, specifically focusing on the 2.4-6 GHz frequency range. By examining the characteristics of E-shaped, U-shaped, Hexagonal, Circular, H-slot, Octagonal, and Rectangular microstrip patch antennas, the study offers valuable insights into key performance parameters such as bandwidth, gain, radiation pattern, return loss, impedance matching, and efficiency. These findings are essential for guiding engineers and researchers in selecting and designing antennas that meet the evolving demands of wireless technologies. Ultimately, this investigation contributes to a deeper understanding of antenna design principles, which will be crucial for the development of optimized communication systems in the future.

V. Preethi et al., [2] Finding a way to achieve great accuracy while maintaining a small size is an important aspect of communication equipment. In the course of this investigation, a collection of circular microstrip patch antennas (CMPAs) has been developed for the purpose of future applications involving 5G mobile data networks. This array is suited for use with mm wave antenna systems in conjunction with 5G technology. A Rogers RT5880 substrate with a $\epsilon r$ of 2.2, a loss tangent of 0.0013, and a height of 0.508 millimeters is used in the construction of the suggested antenna, which has a resonance frequency of 28 gigahertz. With a patch of 2.02 millimeters in diameter and a substrate measuring 8.08 millimeters by 8.08 millimeters, the micro antenna that exhibits little return loss and good gain is seen here.

J. Shah et al., [3] This rapid evaluation shows the review of use of structured metamaterial (MTM) in microstrip patch antenna design .Increasing demand of miniaturized ,highly functional widely used for such as mobile wireless systems, smart phones, GPS , wireless Internet devices, etc .The increasing demand makes designers work on wireless device and components and design must be compact and multifunctional, multifrequency band operation, conformal to the body oriented devices, reduced size, and capable of operating at multiple frequencies of wireless system. Negative property of Metamaterial which is not obtained naturally give -45 dbi at 40GHz and 15dbi at 25GHz .Performance of metamaterial an micro strip antenna reviewed in this research paper and shows improved efficiency ,return loss, better power dissipation .This antenna shows a metamaterial with Roger 5880 etched with copper patch which gives negative mu and epsilon simultaneously. The antenna patch made of a circular ring patch which gives high reflection coefficient at K band in the range 20-40 GHz.

M. M. Hasan Mahfuz et al., [4] drones have emerged as versatile tools for a wide range of applications, including hazardous area operations, environmental monitoring, agriculture, disaster management, and logistics. The ability to control a drone remotely through reliable communication systems is essential for their effective operation. Radio frequency (RF) transmission plays a key role in enabling two-way communication between the drone and its operator, ensuring real-time telemetry and sensor data exchange. For successful unmanned flight, a flexible and dependable communication system is crucial. Given the need for complete spatial coverage in drone communication, antennas that can radiate in an isotropic pattern are ideal. Microstrip patch antennas, with their compact size, low profile, and ease of integration, are therefore a promising and suitable choice for enhancing the performance and reliability of drone communication systems.

P. J, K. Ezhilarasan et al., [5] The rapid evolution of wireless communication technologies necessitates the continuous enhancement of antenna systems to meet the growing demands for compactness, flexibility, and multifunctionality. Among the myriad antenna technologies, microstrip patch antennas (MPAs) have emerged as a dominant and versatile solution for wireless applications. This literature survey reviews recent advancements in the design and analysis of microstrip patch antennas, focusing on their application in wireless communication. The survey explores various design techniques, analytical and numerical methods, emerging applications, and the challenges faced in the field. By synthesizing the latest research findings, this survey aims to provide a comprehensive overview of the state-of-the-art in microstrip patch antenna technology for wireless applications.

S. Sengar et al.,[6] the proposed antenna operates in three distinct bands at 15.2GHz, 23GHz, and 29.8GHz. The Roger RT/Duroid 5880 (tm) material has a permittivity (ε r = 2.2) and a thickness of 0.8mm, and the antenna was designed based on these attributes. This compact antenna utilizes a hexagon shape patch with three rectangular slots to enhance antenna performance. The obtained results indicate that the proposed antenna demonstrates a better return loss for all three frequencies are 15.2GHz, 23GHz, and 29.8GHz respectively. The antenna has a measured gains are 7.183dB at 15GHz, 5.79dB at 23GHz, and 6.72dB at 29.8GHz. The antenna directivity and radiation patterns are further investigated to determine the antenna's behavior. Simulation carried out using Ansys HFSS reveals an overall radiation efficiency of more than 95%. The proposed antenna is believed to have strong potential for 5G applications, mainly because of its small size, high gain, excellent radiation efficiency, and tri-band design.

V. Preethi et al.,[7] the significance of communication equipment is to attain high accuracy with miniature size. In this research, an array of circular microstrip patch antennas (CMPAs) is designed for future 5G mobile data networks applications and it is suitable for 5G technology with mm wave antenna systems. The resonance frequency of the proposed antenna is 28 GHz and it is constructed using a Rogers RT5880 substrate with a ϵr 2.2, a loss tangent of 0.0013, and a height of 0.508 mm. Patch with diameter 2.02 mm and substrate with size 8.08×8.08 mm-, Here it is shown the miniature antenna with minimal return loss and high gain. Using HFSS Software the simulated results are S11 = -16.2dB, gain is 7.5dB obtained for a single circular antenna, return loss = -18.5dB, gain is 8.8dB for a two-array antenna, return loss = -21.6dB, gain is 9.6dB for a four-array antenna.

Suhana M. et al.,[8]The use for the X and C bands is being studied. The suggested antenna measures 28 x 30 mm and is mounted on a dielectric substrate Rogers RO3003 with a thickness of 1.6 mm and a dielectric constant of 3. Rectangular patch antenna with full ground and a small slot. The antenna operates at frequencies ranging from 4 GHz to 12 GHz, which correspond to the C and X bands, respectively. For three resonant frequencies, the return loss is -31.1917dB, -13.44dB, and - 15.838dB. In all three frequencies, the VSWR1 <1.5. Gain > 4dB for all the resonating frequencies. CST simulator is used to develop, optimise, and analyse the proposed antenna.

S. Yadav et al.,[9] This particular design presents a patch antenna for the ultra wide application for C and X band. The model represents the multiple rectangular patches which are connected through a unit method. The antenna volume is 30 x 38 x 0.8 cubic mm and the ground length is stored corresponding to the dimensions of the bottom of the substrate. Bands produced through this layout are (5.024-5.402 Ghz), (6.865 - 6.998 Ghz), (8.428 − 8.503 Ghz), (8.814- 8.946 Ghz). The frequency bands will be generated on the C and X band. The advantage of ultra wide band microstrip patch antenna is that it shows a stable and easy design. The ultrawideband applications are space communication, public safety application, military purposes, keyless entry system and radar. This research is done to show that multiple rectangular patches produce multi-band properties in the antenna.As in our design there are no frequency bands from (1.00 - 3.00 Ghz) which can be referred to as the Notch filter. In this application wifi bands do not interfere in between.

R. K. Thakur et al.,[10] this paper presents a compact triple-band microstrip patch antenna utilizing the shorting post and gap-coupled methods, designed for C, X, and Ku band applications. By employing a coaxial probe feeding technique and using Rogers RT6010LM substrate with a high dielectric constant (10.7), the antenna achieves a compact form factor, making it suitable for various high-frequency applications. The shorting post method further optimizes the antenna's size and performance, while the gap coupling technique allows for resonant frequencies at three distinct bands: 6.3 GHz (wireless communication), 9.4 GHz (RADAR), and 14.3 GHz (satellite communications). The simulation, conducted using CST Studio Software, demonstrates the antenna's effective impedance matching, return loss, directivity, and gain characteristics. Overall, the proposed antenna design offers a versatile solution for medical, radar, and satellite communication applications.

S. Gore et al.,[11] Microwave antennas and radiofrequency (RF) devices are crucial elements in modern communication systems such as wireless communications, radar, and satellite communication. Designing, modeling, and optimizing these components can be challenging due to their complex geometries and electromagnetic properties. However, the use of machine learning (ML) has provided significant improvements in microwave engineering by enhancing the efficiency and performance of these components. This article presents a comprehensive review of recent developments in ML-enabled methods for the design, modeling, and optimization of microwave antennas and RF devices. The article discusses various ML techniques, including neural networks, support vector machines, and evolutionary algorithms, and their applications in antenna and device design. Furthermore, the article highlights the advantages and limitations of these methods and proposes future research directions in this field.

M. Sangwan et al.,[12], this survey highlights the crucial role of MIMO antennas in modern wireless communication systems, with a particular focus on the advancements made over the last decade. The review examines various MIMO antenna designs, including those with parasitic elements, which help mitigate issues such as mutual coupling and cross-polarization between patch arrays. Additionally, the paper emphasizes the importance of surface current analysis, ECC (Envelope Correlation Coefficient), and efficiency in evaluating MIMO antenna performance. The main challenges facing MIMO antennas, such as mutual coupling, low gain, narrow bandwidth, and high Voltage Standing Wave Ratio (VSWR),. This survey provides valuable insights into the ongoing research efforts and challenges in optimizing MIMO antennas for future wireless communication applications.

## 3. Challenges

Microstrip patch antennas (MPAs) have proven to be highly effective for various wireless communication applications, but they also face several challenges, particularly as the demand for higher data rates, smaller form factors, and advanced communication systems increases. Below are some of the key challenges in the design and implementation of MPAs for advanced communication:

### Bandwidth Limitation

- **Narrow Bandwidth**: Traditional microstrip patch antennas suffer from limited bandwidth due to their resonant nature. For advanced communication systems, such as those used in 5G and beyond, wideband or multi-band antennas are required to support high data rates and accommodate multiple frequency bands.
- **Solution**: To overcome this, techniques like aperture coupling, stacked patches, and the use of fractal geometries are applied to enhance the bandwidth of microstrip patch antennas.

### Frequency Selectivity and Noise

- **Interference and Noise**: In dense communication environments (such as urban areas for 5G networks), interference from other systems can affect antenna performance. Moreover, frequency selectivity may be required for operating across multiple bands or in dynamic spectrum environments.
- **Solution**: Frequency-selective surfaces (FSS), reconfigurable antennas, and adaptive filtering techniques can be used to reduce interference and improve the signal-to-noise ratio (SNR).

**Miniaturization**

- **Size Constraints**: As communication systems evolve, especially with the advent of miniaturized devices, there is a need for antennas that are both compact and efficient. For higher frequencies, the antenna needs to be smaller, which can affect its performance.

- **Solution**: Techniques like substrate miniaturization, the use of high dielectric constant materials, and innovative shapes (e.g., fractals, metasurfaces) are used to achieve compact designs while maintaining efficiency.

**Antenna Efficiency and Gain**

- **Low Efficiency and Gain at Higher Frequencies**: At higher frequencies (such as those used in 5G or satellite communication), microstrip patch antennas often experience increased losses due to factors like surface wave propagation and radiation resistance.

- **Solution**: Antenna efficiency and gain can be improved by optimizing the design to reduce surface wave losses beamforming, selecting low-loss materials for the substrate, and using advanced coating techniques.

## 4. Designing Approach

**Patch Dimensions and Feeding Technique:**

The patch dimensions are primarily determined by the operating frequency and the substrate material. A basic rectangular microstrip patch antenna can be designed by resonant frequency calculation, effective length, patch length, width of patch. On the other hand the feed method is crucial for impedance matching, bandwidth, and ease of fabrication. Common feed techniques include like Microstrip Line Feed, Coaxial Probe Feed and Aperture Coupled Feed.

**Selection of Substrate Material:**

For high-performance microstrip patch antennas, the optimal material selection involves using low-loss dielectric substrates such as Rogers RT/duroid or Teflon**,** which offer low dielectric constants ($\varepsilon r$ around 2.2 to 3.5) and low loss tangents ($\tan \delta < 0.005$), crucial for minimizing power dissipation and ensuring efficient radiation at high frequencies. These materials provide excellent performance in high-frequency and 5G applications and radar.

**Bandwidth Enhancement Techniques:**

Implement techniques such as stacking patches, using defected ground structures (DGS), or adding parasitic elements to increase bandwidth. This ensures operation across wide frequency ranges critical for 5G applications.

**Array Configuration and Beamforming**

Array configurations and beamforming significantly enhance the performance of microstrip patch antennas, enabling more controlled and efficient radiation patterns. By arranging multiple microstrip patches in an array, it is possible to achieve higher gain, better directivity, and the ability to steer the beam electronically. Beamforming techniques, including both conventional and adaptive methods, allow for dynamic control of the antenna's radiation pattern, minimizing interference and optimizing signal reception in desired directions.

**Simulation and Optimization**

Use advanced electromagnetic simulation tools (e.g., CST Microwave Studio, HFSS) for accurate modeling and optimization. Techniques like genetic algorithms, particle swarm optimization, and machine learning can be employed to refine design parameters.

## 5. Conclusion

Microstrip patch antennas offer a versatile and cost-effective solution for 5G communication systems. Their ability to operate at high frequencies, support wide bandwidths, and integrate with MIMO and beamforming technologies makes them highly suitable for 5G applications. Despite challenges related to miniaturization, fabrication complexity, and high gain at mmWave frequencies, several design innovations such as multiband operation, array configurations, and the use of metamaterials—have significantly enhanced their performance. As 5G technologies continue to evolve, microstrip patch antennas are expected to play a pivotal role in ensuring efficient, high-speed communication across various applications.

***References***

[1] S. K. Khandelwal, A. Verma, A. Yadav and A. Goyal, "Comparative Analysis of Various Slot in Patch Antennas: A Review," *2024 5th International Conference for Emerging Technology (INCET)*, Belgaum, India, 2024, pp. 1-5, doi: 10.1109/INCET61516.2024.10593030.

[2] V. Preethi, P. Swamalatha, V. Rajpoot, R. V. V. Krishna and S. Kumar, "Design and Implementation of Circular Microstrip Patch Array Antenna for 5G Communication Using Rogers RT5880," *2023 International Conference on Advanced & Global Engineering Challenges (AGEC)*, Surampalem, Kakinada, India, 2023, pp. 32-37, doi: 10.1109/AGEC57922.2023.00018.

[3] J. Shah and P. Vasisht, "A Novel Metamaterial Inspired Microstrip Patch Antennas for 5G Applications," *2022 International Conference on Smart and Sustainable Technologies in Energy and Power Sectors (SSTEPS)*, Mahendragarh, India, 2022, pp. 233-236, doi: 10.1109/SSTEPS57475.2022.00065.

[4] M. M. H. Mahfuz and C. -W. Park, "Review of Patch Antennas used in Drone Applications," in *IEEE Access*, vol. 11, pp. 58367-58388, 2023, doi: 10.1109/ACCESS.2023.3284040.

[5] P. J, K. Ezhilarasan and T. Y. Satheesha, "Literature Survey on Design and Analysis of Microstrip Patch Antenna for Wireless Application," *2024 Asia Pacific Conference on Innovation in Technology (APCIT)*, MYSORE, India, 2024, pp. 1-6, doi: 10.1109/APCIT62007.2024.10673506.

[6] S. Sengar and P. K. Malik, "A Compact Tri-band Microstrip Patch Antenna Design for 5G millimeter wave applications," *2023 14th International Conference on Computing Communication and Networking Technologies (ICCCNT)*, Delhi, India, 2023, pp. 1-6, doi: 10.1109/ICCCNT56998.2023.10308282.

[7] V. Preethi, P. Swamalatha, V. Rajpoot, R. V. V. Krishna and S. Kumar, "Design and Implementation of Circular Microstrip Patch Array Antenna for 5G Communication Using Rogers RT5880," *2023 International Conference on Advanced & Global Engineering Challenges (AGEC)*, Surampalem, Kakinada, India, 2023, pp. 32-37, doi: 10.1109/AGEC57922.2023.00018.

[8] S. M and S. J, "Design and Implementation of Miniaturize Patch Antenna for C band and X band Applications," *2023 Global Conference on Information Technologies and Communications (GCITC)*, Bangalore, India, 2023, pp. 1-5, doi: 10.1109/GCITC60406.2023.10426384.

[9] S. Yadav, P. K. Chakravarti, S. Sharma, A. Jain and S. k. Tripathi, "Ultra-Wide Band Patch Antenna For C and X Band Application," *2023 International Conference on IoT, Communication and Automation Technology (ICICAT)*, Gorakhpur, India, 2023, pp. 1-5, doi: 10.1109/ICICAT57735.2023.10263641.

[10] R. K. Thakur, A. Heddallikar, R. Pinto and A. Birwal, "Design and Analysis of Compact Triple band Microstrip Patch Antenna," *2022 2nd International Conference on Emerging Frontiers in Electrical and Electronic Technologies (ICEFEET)*, Patna, India, 2022, pp. 1-6, doi: 10.1109/ICEFEET51821.2022.9848240.

[11] S. Gore, "Machine Learning-enabled method for Design, Modelling and optimization of Microwave Antennas and RF Devices," *2023 1st International Conference on Cognitive Computing and Engineering Education (ICCCEE)*, Pune, India, 2023, pp. 1-6, doi: 10.1109/ICCCEE55951.2023.10424571.

[12] M. Sangwan, G. Panda and P. Yadav, "A Literature Survey on Different MIMO Patch Antenna," *2020*

International Journal of Recent Development in Engineering and Technology
Website: www.ijrdet.com (ISSN 2347 - 6435 (Online) Volume 14, Issue 6, June 2025)

*International Conference on Inventive Computation Technologies (ICICT)*, Coimbatore, India, 2020, pp. 912-918, doi: 10.1109/ICICT48043.2020.9112566.