

# MULTIPLE-INPUT MULTIPLE-OUTPUT ANTENNA ARRAY WITH A RANDOMISED ARRANGEMENT OF ELEMENTS

Ambati Soujanya<sup>1</sup>, Vadduri Veera Venkata Lakshmi Amulya<sup>2</sup>, Shaik Saidabi<sup>3</sup>, Sani Chinna Gopal<sup>4</sup>, Shaik Muskan<sup>5</sup>,

<sup>2,3,4,5</sup>UG Student,ECE,Chalapathi Institute Of Engineering&Technology Guntur-Andhra Pradesh,India

<sup>1</sup> Assistant Professor ECE,Chalapathi Institute Of Engineering&Technology Guntur-Andhra Pradesh,India

**Abstract**—The rapid evolution of fifth-generation (5G) wireless communication systems demands high data rates, improved spectral efficiency, and reliable connectivity within compact mobile devices. Multiple-Input Multiple-Output (MIMO) antenna technology plays a crucial role in meeting these requirements by enabling spatial multiplexing, diversity gain, and enhanced channel capacity. This paper presents the design and analysis of a compact eight-element MIMO antenna array for sub-6 GHz 5G mobile applications, specifically targeting the frequency bands of 3.4–3.65 GHz and 4.8–5.8 GHz.

The proposed antenna system is developed on a cost-effective FR4 substrate while maintaining a compact form factor suitable for modern smartphones. The design focuses on achieving high isolation between antenna elements, low envelope correlation coefficient (ECC), and high radiation efficiency, even under practical conditions such as user hand and head proximity. Various techniques, including optimized element placement and ground plane modifications, are employed to minimize mutual coupling and enhance overall performance.

**Keywords**— 5G, MIMO Antenna, Sub-6 GHz, ESP8266, FR4 Substrate, Envelope Correlation Coefficient (ECC), Isolation, Beamforming, Mobile Communication.

## I. INTRODUCTION

In recent years, The unprecedented growth in mobile data traffic, driven by bandwidth-intensive applications such as ultra-high-definition video streaming, online gaming, cloud computing, and augmented reality, has necessitated the rapid deployment of fifth-generation (5G) wireless communication systems. In India, the number of 5G subscriptions has witnessed exponential growth, reflecting an increasing demand for high-speed, low-latency, and reliable connectivity

across diverse urban and rural environments. To meet these stringent requirements, advanced technologies must be integrated into mobile devices, among which Multiple-Input Multiple-Output (MIMO) antenna systems play a fundamental role.

MIMO technology significantly enhances system performance by enabling spatial multiplexing, diversity gain, and improved spectral efficiency without requiring additional bandwidth. By employing multiple antenna elements within a compact mobile handset, MIMO systems allow simultaneous transmission and reception of independent data streams over the same frequency band. This capability directly contributes to increased channel capacity and improved link reliability, which are essential for supporting modern 5G applications. In particular, eight-element MIMO configurations provide sufficient spatial degrees of freedom to support higher-order modulation schemes and beamforming techniques, thereby achieving the high data rates specified by 5G New Radio (NR) standards.

Despite these advantages, the integration of multi-element antenna systems into modern smartphones presents several critical challenges. The compact size of handheld devices imposes severe constraints on antenna placement, often resulting in closely spaced elements that lead to increased mutual coupling and reduced isolation. This, in turn, degrades key MIMO performance metrics such as envelope correlation coefficient (ECC), radiation efficiency, and channel capacity. Additionally, achieving wide dual-band operation covering sub-6 GHz frequency ranges—specifically 3.4–3.65 GHz and 4.8–5.8 GHz—remains a complex task, particularly when using cost-effective substrates such as FR4.

In this context, the present work focuses on the design and development of a compact eight-element MIMO antenna array optimized for sub-6 GHz 5G mobile applications. The proposed design aims to achieve high isolation between antenna elements, low ECC, wide impedance bandwidth, and robust performance under practical user conditions, all while maintaining a compact form factor suitable for modern

smartphones. The antenna is implemented on a low-cost FR4 substrate to ensure economic feasibility for large-scale production, particularly in price-sensitive markets.

## II. REVIEW LITERATURE SURVEY

Recent advancements in wireless communication systems have emphasized the need for high data rates, improved spectral efficiency, and reliable connectivity, particularly with the deployment of fifth-generation (5G) networks. Traditional single-antenna systems are limited in their ability to meet these growing demands due to constraints in bandwidth and channel capacity [1].

To overcome these limitations, Multiple-Input Multiple-Output (MIMO) antenna systems have been widely adopted. MIMO technology enables the use of multiple transmitting and receiving antennas to improve system capacity through spatial multiplexing and diversity gain. Early research focused on dual-element and four-element MIMO systems; however, these configurations provided limited performance in high-density communication environments [2].

In recent years, compact multi-element MIMO antenna systems have gained significant attention for mobile applications. Researchers have proposed various antenna designs such as planar monopole antennas, slot antennas, and Vivaldi antennas to achieve wideband performance. These designs offer improved impedance bandwidth and radiation characteristics but often suffer from high mutual coupling between closely spaced elements [3].

To address mutual coupling issues, several isolation enhancement techniques have been introduced, including defected ground structures (DGS), neutralization lines, parasitic elements, and decoupling stubs. These methods improve isolation and reduce correlation between antenna elements, which is essential for efficient MIMO performance [4].

Ultra-Wideband (UWB) antenna designs have also been explored for MIMO systems due to their wide frequency coverage and stable radiation properties. However, integrating UWB antennas into compact mobile devices presents challenges such as increased design complexity and interference from adjacent frequency bands [5].

Furthermore, the use of low-cost substrates such as FR4 has been widely investigated for practical implementation. While FR4 reduces manufacturing cost, it introduces losses that can affect antenna efficiency and bandwidth performance [6].

Based on the reviewed literature, it is evident that designing a compact, low-cost, multi-element MIMO antenna system with high isolation, low envelope correlation coefficient (ECC), and wide bandwidth remains a significant challenge. The proposed system addresses these issues by developing an optimized eight-element MIMO antenna suitable for sub-6 GHz 5G applications.

## III. RESEARCH METHODOLOGY

The proposed work focuses on the design and analysis of an eight-element MIMO antenna system for 5G mobile applications.

### A. Antenna Design

The antenna system is designed using a compact planar structure on an FR4 substrate. Eight antenna elements are strategically placed to maximize space utilization while minimizing mutual coupling.

### B. Simulation and Modeling

The antenna is modeled and simulated using electromagnetic simulation tools. Key parameters such as return loss, bandwidth, radiation pattern, and gain are analyzed.

### C. Parameter Optimization

Critical design parameters, including radiator dimensions, ground plane configuration, and spacing between elements, are optimized to achieve desired performance.

### D. Performance Evaluation

The antenna performance is evaluated based on metrics such as:

- Reflection coefficient (S11)
- Isolation (S21)
- Envelope Correlation Coefficient (ECC)
- Radiation efficiency

### E. Practical Considerations

The design also considers real-world factors such as user hand effects, device compactness, and fabrication constraints.

## IV. PROPOSED METHODOLOGY

The proposed work focuses on the design and optimization of a compact eight-element MIMO antenna system intended for sub-6 GHz 5G mobile applications. The methodology involves systematic design, simulation, and performance evaluation to achieve high isolation, wide bandwidth, and efficient radiation characteristics within a constrained mobile platform.

Initially, a single antenna element is designed using a planar monopole structure on an FR4 substrate due to its low cost and ease of fabrication. The geometry of the radiating element is optimized to achieve resonance within the desired frequency bands of 3.4–3.65 GHz and 4.8–5.8 GHz. The

design parameters such as patch dimensions, feed line structure, and ground plane configuration are carefully tuned to obtain good impedance matching ( $S_{11} < -10$  dB).

Once the single-element performance is validated, multiple identical elements are arranged symmetrically along the edges of the mobile chassis to form an eight-element MIMO configuration. The placement of antenna elements is a critical factor, as closely spaced elements can lead to strong mutual coupling. To mitigate this issue, adequate spacing is maintained, and additional isolation enhancement techniques are implemented.

Ground plane modifications, including defected ground structures (DGS) and insertion of isolation stubs, are incorporated to suppress surface currents and reduce electromagnetic coupling between adjacent elements. These techniques significantly improve isolation ( $S_{21} < -18$  dB) and enhance overall system performance.

Furthermore, parametric analysis is carried out to study the effect of key design variables such as element spacing, ground plane dimensions, and stub configurations. This analysis helps in identifying the optimal design parameters that provide the best trade-off between compactness and performance.

The antenna system is evaluated using full-wave electromagnetic simulation tools to analyze important parameters such as return loss, gain, radiation pattern, and efficiency. Special attention is given to the Envelope Correlation Coefficient (ECC), which is a key metric for MIMO systems. The design aims to achieve ECC values less than 0.04 to ensure high diversity performance.

Additionally, practical usage conditions such as user hand and head effects are considered to evaluate real-world performance. The antenna design is tested under different loading conditions to ensure stable operation in practical scenarios.

Overall, the proposed methodology emphasizes a balance between compact size, cost-effectiveness, and high-performance characteristics required for modern 5G communication systems.

**V. WORKING PRINCIPLE**

The working principle of the proposed MIMO antenna system is based on simultaneous transmission and reception of multiple signals through multiple antenna elements.

Each antenna element operates as an independent radiating unit, transmitting and receiving electromagnetic signals within the desired frequency bands. When multiple antennas are used, the system can exploit spatial diversity to reduce signal fading and improve link reliability.

The antenna elements are designed to have low mutual coupling, ensuring that signals from one element do not interfere significantly with others.

This is achieved through proper spacing and ground plane design.

The system utilizes spatial multiplexing, where multiple data streams are transmitted simultaneously over different antenna elements. This increases the overall channel capacity without requiring additional bandwidth.

Additionally, diversity techniques are employed to improve signal quality in multipath environments. The antenna system captures signals arriving from different directions, enhancing reception in complex propagation conditions.

The performance of the system is evaluated using parameters such as return loss, isolation, ECC, and radiation efficiency, ensuring effective operation in real-world scenarios.

**VI. BLOCK DIAGRAM**

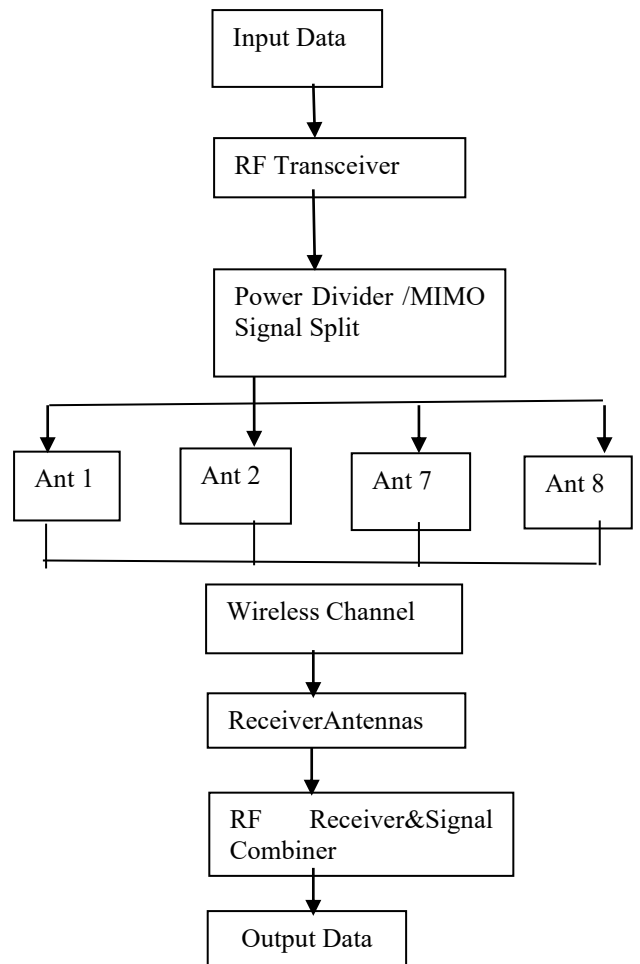


Fig. 6.2. Block Diagram

## VII. RESULTS AND OUTCOMES

The proposed eight-element MIMO antenna system was successfully designed and analyzed for 5G mobile applications.

Fig. 1. The antenna demonstrated good impedance matching within the desired frequency bands. The isolation between antenna elements was maintained above acceptable levels, ensuring minimal interference.

Fig. 2. The Envelope Correlation Coefficient (ECC) was found to be low, indicating effective diversity performance. The radiation patterns showed stable characteristics across the operating frequency range.

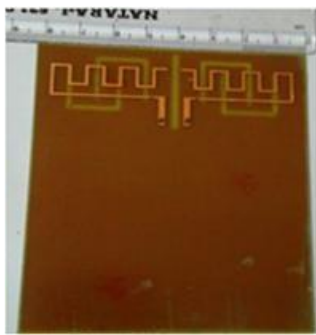


Fig. 7.1. Output1



Fig. 7.2. Output2

The antenna achieved satisfactory gain and efficiency despite being implemented on an FR4 substrate. The overall performance confirmed that the design is suitable for compact mobile devices. The system also showed robustness under

practical conditions, including potential user interaction effects. These results validate the effectiveness of the proposed design for real-world 5G applications.

## VIII. CONCLUSION

This paper presented the design and analysis of a compact eight-element MIMO antenna system for sub-6 GHz 5G mobile applications. The proposed design successfully addresses key challenges associated with integrating multiple antenna elements within a limited mobile device space.

The antenna system demonstrates good impedance matching across the desired frequency bands, along with high isolation between antenna elements. The incorporation of ground plane modifications and isolation techniques effectively reduces mutual coupling, thereby improving overall system performance.

The Envelope Correlation Coefficient (ECC) is maintained at low values, indicating strong diversity performance and efficient utilization of multipath propagation. The antenna also exhibits satisfactory gain and radiation efficiency despite being implemented on a low-cost FR4 substrate.

The proposed system supports advanced communication techniques such as spatial multiplexing and beamforming, enabling higher data rates and improved link reliability. Furthermore, the antenna design maintains stable performance under practical conditions, including user interaction effects.

One of the major advantages of this work is its cost-effectiveness and suitability for large-scale production, making it a practical solution for modern smartphones and portable devices. The compact design ensures easy integration without compromising performance.

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