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Design and Development of a Dual-Band MIMO Antenna for Millimeter-Wave 5G and 2 GHz 4G Wireless Networks

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ABSTRACT

The rapid evolution of wireless communication technologies has created a growing demand for high-speed, reliable, and multi-band communication systems capable of supporting both existing 4G networks and emerging 5G applications. Traditional antenna systems are often limited in terms of bandwidth, efficiency, and simultaneous support for multiple frequency bands, making them unsuitable for next-generation communication requirements. The proposed Dual Functional MIMO Antenna System for mm Wave 5G and 2 GHz 4G Communication is designed to provide efficient operation in both sub-6 GHz and millimeter-wave frequency ranges using a compact and integrated antenna structure. The system supports Multiple Input Multiple Output (MIMO) technology to improve channel capacity, signal quality, and data transmission rates while reducing interference and multipath fading. The antenna structure is optimized to achieve high gain, improved isolation, low return loss, and enhanced radiation efficiency for modern wireless devices and communication infrastructures. The integration of dual-band functionality enables seamless compatibility between current 4G communication systems operating around 2 GHz and advanced 5G mm-wave communication standards. By combining advanced antenna design techniques with modern wireless communication principles, the proposed system enhances spectral efficiency, network performance, and communication reliability, making it suitable for applications such as smart devices, IoT systems, autonomous vehicles, and high-speed wireless networks.

Keywords: Dual Functional Antenna System, MIMO Antenna, 5G Communication, 4G LTE, Millimeter Wave Antenna, Wireless Communication, Antenna Design, High Gain Antenna, Multi-Band Communication, Radiation Efficiency, Beamforming, Smart Antenna System, Electromagnetic Waves, IoT Communication, Next Generation Networks.

I. INTRODUCTION

The rapid expansion of wireless communication has created a growing demand for antenna systems that can support higher data rates, wider bandwidth, reliable connectivity, and simultaneous operation across different frequency bands. Multiple-Input Multiple-Output (MIMO) technology has become an important solution for modern communication systems because it improves channel capacity and link reliability without requiring additional transmission power. Dual-band and multiband MIMO antennas are particularly useful for integrating existing mobile networks with emerging fifth-generation communication services [1], [2].

Millimeter-wave (mmWave) technology is considered one of the major enabling features of 5G communication due to the availability of wide spectrum resources at higher frequencies. Frequency bands around 28 GHz and 38 GHz have received significant attention for supporting high-speed data transmission and increased network capacity. Tadesse et al. [3] developed a compact four-port MIMO antenna for 28/38 GHz applications, showing the suitability of planar structures for mmWave communication. Similarly, Farahat and Hussein [4] presented **a** dual-band wideband MIMO antenna capable of operating at both 28 GHz and 38 GHz, demonstrating the potential of a single antenna platform to support multiple mmWave bands.

Although mmWave communication offers high data capacity, lower-frequency networks remain essential because of their wider coverage and better penetration characteristics. Therefore, integrating microwave or sub-6 GHz operation with mmWave functionality has become an important direction in antenna research. Ikram et al. [5] proposed a combined sub-6 GHz and mmWave MIMO array for 5G vehicle-to-everything communication, illustrating the practical value of multi-frequency antenna integration. Zahid et al. [6] also investigated a dual-band multi-element MIMO antenna for sub-6 GHz smartphone applications and emphasized the importance of compact size, diversity performance, and reduced interaction between antenna elements.

One of the major technical difficulties in designing integrated MIMO antennas is maintaining high isolation between closely positioned radiating elements. Poor isolation increases mutual coupling and can negatively affect antenna efficiency, radiation characteristics, and overall diversity performance. Jabeen and Khan [7] addressed this problem through an integrated MIMO configuration covering sub-6 GHz and millimeter-wave frequencies while maintaining high isolation. Such research indicates that careful radiator arrangement, ground-plane modification, and isolation enhancement techniques are necessary when multiple communication bands are incorporated into a compact antenna structure.

Recent developments have also focused on improving the gain, bandwidth, and diversity characteristics of mmWave MIMO antennas. The review presented by P. S. B. G. et al. [8] discussed the evolution of planar MIMO antenna technologies and identified compact integration, low mutual coupling, and efficient high-frequency performance as important research requirements. Jayanthi and Kalpana further demonstrated that multi-element MIMO configurations can enhance gain at 28 GHz and 38 GHz, making them suitable for high-capacity 5G wireless systems.

Despite these developments, many existing designs mainly concentrate either on lower-frequency communication or on dedicated mmWave bands. A practical requirement still exists for a compact dual-functional antenna system capable of supporting a conventional 2 GHz 4G band together with mmWave 5G communication. Such an arrangement can provide broader network compatibility by combining the coverage advantages of 4G with the high-speed capability of 5G. Therefore, this work focuses on the design and development of a dual-functional MIMO antenna system intended for 2 GHz 4G and mmWave 5G communication. The proposed approach aims to achieve suitable impedance matching, reduced mutual coupling, stable radiation behaviour, and effective MIMO performance across the targeted operating frequencies.

II. LITERATURE SURVEY

Omar and Ashraf (2021) Omar and Ashraf [1] presented a dual-band MIMO antenna based on a coplanar waveguide-fed slot configuration for 5G communication. The antenna was designed to operate at two frequency regions while maintaining a compact structure. The study focused on achieving suitable impedance bandwidth, low mutual coupling, and acceptable diversity performance. The proposed arrangement showed that a simple planar structure could effectively support dual-band wireless communication with reliable MIMO characteristics.

Tadesse, Acharya, and Sahu (2022) Tadesse et al. [3] developed a compact four-port planar MIMO antenna for 28 GHz and 38 GHz millimeter-wave 5G applications. The work concentrated on reducing the physical size of the antenna while supporting two important mmWave frequency bands. The four-port configuration provided improved diversity characteristics and supported high-data-rate wireless transmission. The study demonstrated the usefulness of compact planar MIMO structures for future 5G terminals.

Farahat and Hussein (2022) Farahat and Hussein [4] proposed a dual-band wideband

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MIMO antenna designed for 28/38 GHz 5G mobile applications. Their design achieved operation across two mmWave bands and addressed important parameters such as bandwidth, isolation, gain, and radiation behaviour. The authors showed that a properly arranged MIMO configuration could reduce mutual interaction among antenna elements while providing effective performance for high-frequency mobile communication.

Ikram, Sultan, Abbosh, and Nguyen-Trong (2022) Ikram et al. [5] introduced a MIMO antenna array that integrates sub-6 GHz and millimeter-wave frequency regions for 5G vehicle-to-everything communication. The proposed system combined the wider coverage capability of lower frequencies with the high-capacity benefits of mmWave transmission. This work is particularly relevant to dual-functional antenna research because it demonstrated the feasibility of supporting different communication frequency ranges within a common antenna platform.

Zahid et al. (2022) Zahid et al. [6] designed an H-shaped eight-element dual-band MIMO antenna for sub-6 GHz 5G smartphone applications. The research focused on compact integration, reduced mutual coupling, and reliable diversity performance among multiple antenna elements. The eight-element arrangement improved the capability of the antenna system to handle multiple communication channels. The study highlighted the importance of element placement and structural optimization in compact multi-antenna devices.

Jabeen and Khan (2022) Jabeen and Khan [7] proposed an integrated MIMO antenna system capable of supporting both sub-6 GHz and millimeter-wave applications. A major contribution of their work was the achievement of high isolation between antenna elements operating across different frequency regions. The study showed that lower-frequency and high-frequency radiators could be incorporated into an integrated structure without severely affecting each other’s performance. This work provides a strong foundation for developing a dual-functional MIMO antenna that combines 2 GHz 4G communication with mmWave 5G operation.

III. EXISTING SYSTEM

In the existing wireless communication systems, separate antenna structures are generally used for 4G and 5G communication applications. Conventional antenna systems are often designed to operate only within a single frequency band, limiting their capability to support modern multi-band wireless communication requirements. Existing 4G antenna systems operating around 2 GHz provide stable communication coverage and reliable connectivity but suffer from limited bandwidth and reduced data transmission speed compared to modern 5G systems.

Similarly, existing millimeter-wave antennas designed for 5G communication provide high-speed data transfer capabilities but experience challenges such as high propagation loss, poor penetration through obstacles, and reduced communication range. Most existing antenna systems also face problems related to mutual coupling, lower isolation between antenna elements, limited gain, and increased signal interference in compact wireless devices.

Another major limitation of current systems is the increased hardware complexity caused by using multiple antennas for different communication standards. This increases device size, power consumption, and implementation cost. In addition, many conventional antenna systems lack efficient integration techniques for supporting simultaneous dual-band operation and advanced MIMO communication features.

IV. PROPOSED SYSTEM

The proposed Dual Functional MIMO Antenna System is developed as an integrated wireless communication platform capable of supporting both 2 GHz 4G services and millimeter-wave 5G communication. Instead of using separate antenna modules for different generations of mobile networks, the proposed design combines low-frequency and high-frequency operation within a single compact antenna structure. This integration provides a practical solution for modern wireless devices that require continuous connectivity, wider frequency coverage, and improved communication capability. The 2 GHz operating band provides reliable long-range coverage and better signal penetration, whereas the mmWave frequency range supports high-speed transmission, larger channel bandwidth, and increased network capacity.

The antenna system employs multiple compact radiating elements arranged in a MIMO configuration. MIMO technology allows several independent data streams to be transmitted and received simultaneously, which can improve channel capacity, data throughput, and link reliability. The radiating elements are designed and optimized to provide efficient performance at the targeted 4G and 5G frequency bands. Careful selection of antenna dimensions, substrate properties, feeding mechanisms, element spacing, and ground-plane structure helps the system achieve suitable resonance at both lower and higher operating frequencies. Electromagnetic simulation and parameter optimization can be used to obtain the required antenna characteristics before physical fabrication.

A major challenge in a compact MIMO antenna is the electromagnetic interaction between closely placed radiating elements. Strong mutual coupling may reduce radiation efficiency, distort the radiation pattern, and affect the independent operation of individual antenna ports. To address this problem, the proposed system strategically positions the antenna elements to improve isolation between adjacent radiators. Suitable decoupling structures are introduced between the elements to restrict unwanted surface-current propagation and reduce signal leakage from one antenna port to another. Defected Ground Structure (DGS) techniques are also incorporated to modify the current distribution on the ground plane and further suppress mutual coupling.

The proposed antenna is designed to maintain good impedance matching over the required operating frequency ranges. A low reflection coefficient is targeted so that most of the supplied power is effectively radiated instead of being reflected toward the source. The design also aims to provide adequate bandwidth for practical 4G and 5G communication, along with improved gain and radiation efficiency. At the mmWave band, where propagation and penetration losses are comparatively high, the antenna configuration is optimized to produce sufficient directional gain. At the 2 GHz band, the design focuses on stable coverage and reliable communication performance.

In addition to basic dual-band operation, the proposed MIMO system supports diversity techniques to reduce the effect of fading and multipath propagation. Signals received through multiple antenna elements can improve communication reliability, particularly in indoor areas, urban environments, and locations containing several obstacles. Important MIMO performance parameters such as the Envelope Correlation Coefficient (ECC), Diversity Gain (DG), Total Active Reflection Coefficient (TARC), Channel Capacity Loss (CCL), and Mean Effective Gain (MEG) can be evaluated to determine the overall quality of the proposed system. Low correlation between antenna elements is expected to provide better diversity performance and more effective utilization of the available wireless channel.

The system can also support beamforming functionality at the mmWave frequency band. Since high-frequency signals experience significant path loss, directing the radiated energy toward the intended receiver can improve signal strength and communication range. By controlling the excitation of multiple antenna elements, the radiation beam can be directed toward a required region. This capability is useful in dense wireless networks where multiple users and devices communicate simultaneously. Beam steering and spatial diversity can therefore improve connection stability while reducing unwanted interference.

One of the main advantages of the proposed approach is the integration of 4G and 5G capabilities into a common antenna platform. Conventional devices may require separate antenna structures for low-frequency and mmWave communication, increasing hardware complexity and occupying additional space. The proposed dual-functional configuration reduces the need for independent antenna modules and supports more efficient use of the available device area. This approach can simplify system integration, reduce overall implementation cost, and support compact wireless product development.

The proposed system is suitable for a wide range of present and future wireless applications. In smartphones and portable communication devices, it can support compatibility with existing 4G networks while enabling access to high-speed 5G services. In wireless access points, the antenna can provide reliable lower-frequency connectivity and high-capacity short-range communication. The design can also be adapted for autonomous vehicles, intelligent transportation systems, IoT gateways, industrial wireless devices, military communication equipment, and advanced networking infrastructure.

Overall, the proposed Dual Functional MIMO Antenna System provides a unified solution for combining the coverage benefits of 2 GHz 4G communication with the high-data-rate advantages of mmWave 5G technology. Through compact multi-band radiators, improved element isolation, mutual coupling reduction, efficient impedance matching, diversity operation, and beamforming capability, the system aims to deliver reliable performance across different wireless environments. Its integrated and scalable structure makes it a promising solution for communication devices that must operate with current mobile networks while remaining compatible with future developments in wireless technology.

V. Block Diagram

The architecture of the Dual Functional MIMO Antenna System consists of multiple functional layers including the antenna layer, signal processing layer, communication control layer, and network interface layer. The antenna layer contains compact multi-band MIMO antenna elements designed using microstrip patch technology to support both 2 GHz 4G and mm-wave 5G frequency bands. These antenna elements are optimized for high isolation, low mutual coupling, and efficient radiation performance.

The signal processing layer manages frequency selection, impedance matching, beamforming operations, and signal enhancement functions. It processes incoming and outgoing electromagnetic signals to improve communication quality and reduce transmission losses. Advanced filtering techniques are implemented to suppress noise and maintain signal stability across multiple communication bands.

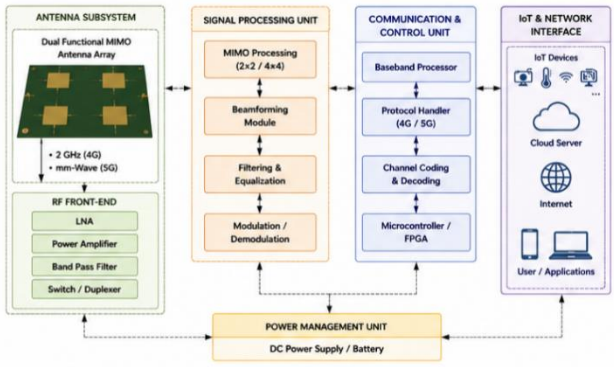

Fig 5.1: Dual Functional MIMO Antenna System Architecture

VI. IMPLEMENTATION

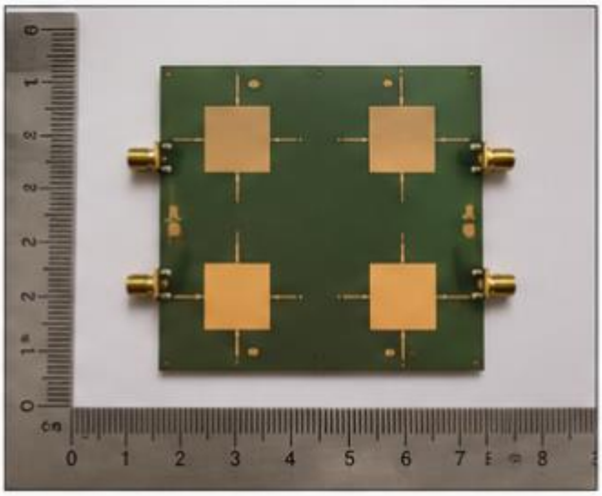

Fig 6.1: Antenna Element Design and Fabrication

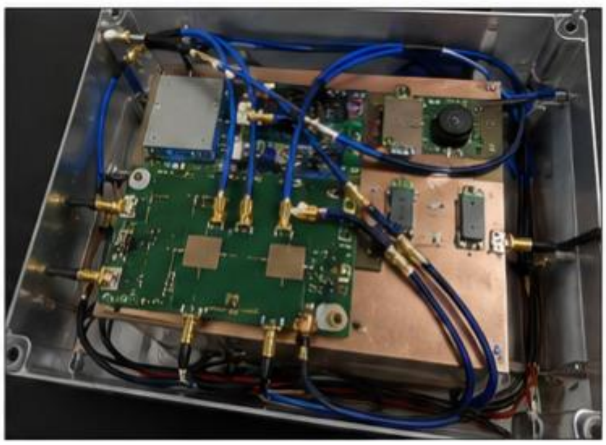

Fig 6.2: MIMO Signal Processing Integration

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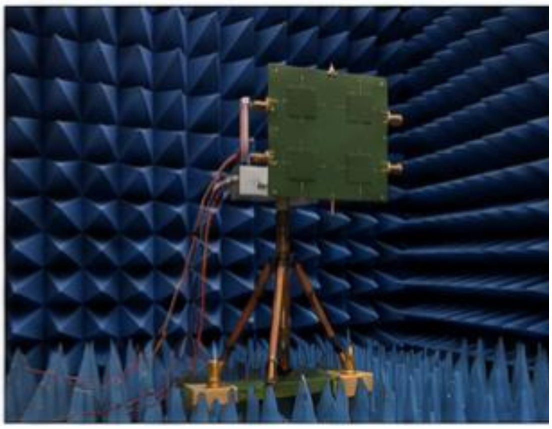

Fig 6.3: mm-Wave Frequency Performance Testing

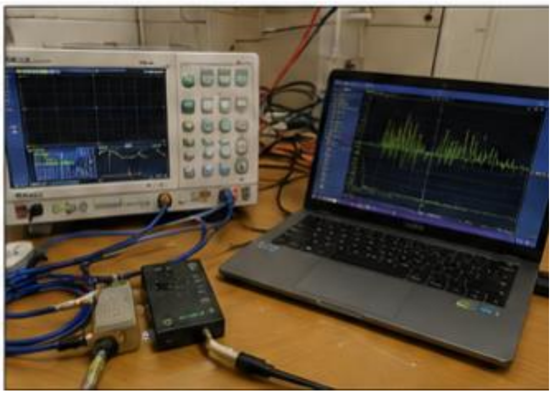

Fig 6.4: Dual-Band Communication Analysis and Validation

VII. CONCLUSION

The Dual Functional MIMO Antenna System for mm Wave 5G and 2 GHz 4G Communication provides an efficient and advanced solution for modern wireless communication applications. By integrating dual-band communication capabilities with MIMO technology, the proposed system achieves high-speed data transmission, improved signal quality, and enhanced communication reliability. The antenna system successfully supports both conventional 4G communication and next-generation 5G communication within a compact and optimized structure.

The proposed antenna design improves bandwidth performance, radiation efficiency, gain characteristics, and isolation between antenna elements while minimizing interference and propagation losses. The integration of beamforming and advanced electromagnetic optimization techniques further enhances overall communication performance in dense wireless environments. Thus, the proposed system serves as a reliable, scalable, and future-ready communication solution for advanced wireless networks, smart devices, and IoT communication infrastructures.

VIII. FUTURE SCOPE

The proposed Dual Functional MIMO Antenna System has significant potential for future enhancements and advanced communication applications. In the future, Artificial Intelligence and Machine Learning techniques can be integrated into the antenna control system to enable intelligent beam steering, adaptive frequency allocation, and real-time optimization of communication parameters. This will improve communication reliability and network efficiency in highly dynamic wireless environments.

The antenna system can also be extended to support 6G communication technologies, satellite communication systems, vehicular communication networks, and smart city infrastructures. Integration with Internet of Things (IoT) platforms and edge computing technologies can further improve device connectivity and low-latency communication performance. Advanced metamaterial structures and reconfigurable antenna technologies may be incorporated to achieve ultra-high gain, miniaturization, and enhanced frequency agility.

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