Electromagnetic Band Gap MIMO Antenna for 5G: Sub-6 GHz Communication

Yogesh Raj M., Roshith Gs and R. Kangeyan
Department of Electronics and Communication Engineering, St. Joseph's Institute of Technology (An Autonomous), OMR, Chennai, Tamil Nadu, India

Keywords: ISM Band, Gain, Isolation, Fractional Bandwidth, SAR, Diversity Gain, Channel Capacity.

Abstract: The growing needs for high-data-rate and guaranteed communication in sub-6 GHz millimetre-wave 5G applications require miniaturized antennas with high performances. This study proposes a novel multiple-input multiple-output (MIMO) antenna based on the electromagnetic band gap (EBG) that can be used for 5G sub-6 GHz industrial, scientific, and medical (ISM) spectrum applications. The intended antenna, which is mounted on a Rogers RT/droid 6010 high-dielectric substrate, is a low-profile, planar slotted antenna with a reduced size of 25 mm × 25 mm × 0.635 mm. The modified EBG structure, which achieves higher isolation, improved MIMO performance, and improved gain features in a compact form factor, is the main attribute of the suggested antenna. The antenna offers a maximum Channel Capacity (CC), a low Envelope Correlation Coefficient (ECC), and a decent Diversity Gain (DG). The computed fractional bandwidth (FBW) is 20.67%, and the realized peak gain that was attained conforms with the ISM band standard. The specific absorption rate (SAR) falls within safety constraints. The intended antenna ensures increased link budget to be efficient in 5G wireless communication systems.

1 INTRODUCTION

The exponential development of wireless communication technologies has dramatically amplified the need for high-speed, low-latency, and high-reliability connectivity. Of the numerous developments, the roll-out of 5G networks is central to addressing the rising data needs of contemporary applications. 5G technology functions across a range of frequency bands, such as the sub-6 GHz spectrum, which offers (K. -L. Wong, et al. 2023) a trade-off between coverage and capacity. The sub-6 GHz band is popular for providing improved propagation behaviour, minimum path loss, and better obstacle penetration, rendering it an indispensable element of wireless next-generation systems. The implementation of multiple-input multiple-output (MIMO) technology also maximizes the efficiency of 5G communication systems. MIMO supports higher rates of data transfer, higher spectral efficiency, and greater signal dependability by the application of numerous antennas at the transmitting and receiving (H. Harkare, et al. 2023) ends. By taking advantage of spatial diversity, MIMO decreases fading effects and increases channel capacity, and thus becomes an essential necessity for contemporary communication networks. Efficient antenna systems for use in MIMO are, however, facing some challenges such as the need to have high isolation between the antenna elements, compactness, and high gain for effective communication.

Electromagnetic interference and mutual coupling among antennas closely placed together generally lower the performance of the MIMO system. To overcome these issues, several techniques have been investigated by researchers including defected ground structures, decoupling networks (M. A. Nassar, et al. 2023), and electromagnetic band gap (EBG) structures. EBG structures have attracted considerable interest because they can suppress surface waves, decrease mutual coupling, and enhance isolation between antenna elements. These features make EBG structures a suitable solution for improving the performance of compact MIMO antenna systems. With increasing demand for 5G devices, designing high-efficiency, wide-bandwidth, and better-isolation antennas is highly important. Wireless system antennas employed in contemporary wireless systems need to meet strict demands, such as SAR compliance standards to guarantee safety for

M., Y. R., G S, R. and Kangeyan, R.
Electromagnetic Band Gap MIMO Antenna for 5G: SubâĂŚ6 GHz Communication.
DOI: 10.5220/0013937300004919

In *Proceedings of the 1st International Conference on Research and Development in Information, Communication, and Computing Technologies (ICRDICCT'25 2025) - Volume 5*, pages 580-587
ISBN: 978-989-758-777-1

users. Moreover, link budget calculations also have (M. K. Gaur, et al. 2024) a significant role in ascertaining the overall system performance based on the transmission power, path loss, and receiver sensitivity. The design of an antenna should optimize all these parameters in such a way that it still has compact dimensions to be accommodated in handheld and portable devices.

Various research studies have aimed at designing antennas for sub-6 GHz 5G applications, each utilizing various methods to optimize performance. Some of them are designed to enhance gain, while others are designed to reduce mutual coupling (M. R. Jadhav, et al. 2023) or maximize bandwidth. It is still a difficult task to achieve all these features in one compact structure. The ever-growing wireless technologies require novel antenna designs that can satisfy the stringent specifications of future communication systems. In this research, a new antenna design is introduced to address current limitations and improve the performance of 5G sub-6 GHz communication systems. The originality of this work is that it optimally (S. Ahmed, et al. 2023) utilizes an electromagnetic band gap structure to greatly enhance isolation and gain without sacrificing compactness in the design. By meticulously designing the antenna layout, the proposed structure attains excellent performance parameters without sacrificing compliance with safety and operation standards. With the growing dependence on 5G networks for autonomous cars, smart cities, and Internet of Things (IoT), the demand for high-performance antennas is also rising. The suggested antenna's design aims to satisfy these demands by offering (W. -S. Chen, et al. 2023) an economical and effective alternative for next communication systems. This work advances wireless communication technology by guaranteeing optimal performance in terms of gain, isolation, and bandwidth, opening the door for more dependable and efficient 5G connectivity.

This work is organized with literature survey review which is arranged in Section II of this study. The functioning of the methodology is highlighted in Section III. Results and discussions are presented in Section IV. Finally, the key recommendations and conclusions are presented in Section V.

2 LITERATURE SURVEY

There have been a number of studies aimed at designing compact and high-performance antennas for 5G sub-6 GHz systems. Studies have indicated that high isolation and low mutual coupling in MIMO technology are imperative for improved performance. Several methods, including the use of slotted structures and high-dielectric materials, have been studied to enhance antenna efficiency. An examination of the use of a variety of substrate materials has also been undertaken in order to maximize gain and bandwidth. Research shows that miniaturized antenna designs are critical for contemporary wireless applications, providing smooth integration into handheld devices with high radiation efficiency and low interference in dense communication scenarios.

The latest developments in 5G antenna technology highlight the need for miniaturization without sacrificing performance. Researchers have explored various antenna configurations, including planar and conformal antennas, to realize space-efficient structures with enhanced gain characteristics. Different fabrication methods have been investigated to improve (L. Zhang, et al. 2023) impedance matching and bandwidth. Research emphasizes the importance of a wideband response with stable radiation characteristics. Antenna placement analysis in MIMO systems has also been performed to reduce the effect of environmental factors. These researches help develop stable antennas for high-speed wireless communication.

The 5G antenna designs need to consider material properties and structural configurations with caution to satisfy rigorous performance requirements. Various studies have aimed at enhancing gain, bandwidth, and radiation efficiency through optimization of substrate materials and antenna shapes. It has been (U. Tripathi, et al. 2023) shown by researchers that high-dielectric substrates facilitate miniaturization without compromising performance. The effect of integrating antennas with other electronic components has also been investigated to provide smooth compatibility. These results highlight the importance of effective antenna designs providing stable and quality signal transmission in adverse communication scenarios.

The use of multiple antennas in small-sized devices brings challenges of mutual coupling and interference. Various methods to improve isolation and provide optimal performance have been studied by researchers. Research indicates that careful positioning of antenna elements is crucial in avoiding correlation effects. Experimental measurements of various (Vosoogh, et al. 2023) antenna prototypes show that optimized element spacing greatly enhances diversity gain and overall system efficiency. In order to meet the growing demand for quicker and more effective communication technologies, these discoveries are useful in the development of high-performance MIMO antennas for next wireless networks.

Substrate materials have been explored by several studies as influencing the overall performance of 5G antennas. Studies indicate that high-permittivity materials enhance miniaturization but can cause unwanted losses. Comparative studies of various dielectric materials indicate compromises between efficiency (O. Abdullah, et al. 2023) and size reduction. The use of low-loss substrates has been found to improve impedance matching and gain. Results show that the choice of materials is essential for obtaining the desired antenna performance. These studies provide helpful design recommendations for producing efficient antennas that meet the rapid connectivity and low-latency requirements of 5G networks.

The influence of antenna geometry on bandwidth and gain has been the subject of recent research. Researchers have explored different design adjustments, including the addition of slots and patch size optimization, to realize broader bandwidths. Research shows that certain geometrical adjustments (Wahdiyat, et al. 2024) can improve radiation features and enhance impedance matching. The connection between the shape of an antenna and its resonance frequency has also been examined. Results show that well-engineered geometries lead to robust performance for various frequency bands. These findings help in developing multifunctional antennas that can perform efficiently within 5G communication systems.

Environmental conditions and their effects on antenna performance have been thoroughly explored in wireless communications research. Experiments demonstrate that antenna performance like gain and efficiency is influenced by nearby structures and proximity of users. Experimental results show that changes in environmental parameters can have an impact on propagation (E. Ovelatama, et al. 2024) of the signal as well as the quality of reception. Researchers have suggested design methods for compensating degradation in performance because of external conditions. Shielding methods and adaptive structures have been considered for improving robustness. These findings underscore the significance of environmental factors in creating stable 5G antennas for practical applications.

Experimental studies of various antenna configurations identify radiation pattern stability as crucial in wireless systems. Scholars have investigated the impact of polarization diversity on (K. V. Prasad, et al. 2024) communication reliability. It is found that cross-polarized antennas enhance signal quality in multipath propagation environments. Experiments confirm that stable radiation characteristics over different operating frequencies improve system performance. Studies of beamforming methods have evidenced that directional patterns of radiation lend improved reliability of the link. The findings strengthen the requirement of accurate control over radiation in designing antennas for superior signal reception and transmission in dynamical 5G environments.

Research into impedance matching methods has contributed immensely to 5G antenna performance optimization. Various matching networks and tuning systems have been researched to reduce reflection loss and enhance signal transmission. Experiments prove that adaptive impedance (H. T and B. Roy, et al. 2024) tuning improves efficiency overall, particularly in wideband antennas. Test results show that well-matched antennas have increased gain and more efficient power transfer. The incorporation of tenable matching circuits has been investigated to increase adaptability. The significance of impedance matching in achieving reliable and effective antenna designs for wireless communication systems of the future is highlighted by these findings.

The function of antenna diversity in improving system reliability has been widely researched. Research results show that diversity methods like pattern, spatial, and polarization diversity enhance signal reception and minimize fading effects. Experimental tests demonstrate antennas with properly designed diversity mechanisms offer increased coverage (Bhosale, et al. 2024) and lower transmission errors. Research emphasizes optimizing the placement of antennas in order to gain maximum diversity. Reconfigurable antennas have been investigated to increase flexibility in dynamic wireless systems. These findings aid in building high-performance and fault-tolerant antennas for future networks.

Innovations in wearable and IoT compact antenna designs have been an active area of research. Research highlights that flexible, lightweight, and low-power antennas with high efficiency are required. Findings indicate the use of conductive fabrics and flexible polymers that improve wear ability with consistent performance. Miniaturization methods show that embedding metamaterials and fractal (R. Kumar, et al. 2023) geometries offer better impedance properties. Experimental assessments show that the optimization of antenna designs improves connectivity in handheld devices. Such innovations back the increased need for optimized antennas in next-generation smart technology and IoT systems.

Dilemmas of embedding various antennas in handheld wireless devices have been extensively researched. Studies indicate that shrinking antenna size while high isolation is maintained is essential for optimal performance. Experimental findings show that spacing, orientation, and material choice have significant effects on the efficiency of MIMO systems. Research (H. Jia, et al. 2024) emphasizes minimizing coupling effects to maximize data rates and reduce interference. Advanced fabrication methods have been investigated to enhance integration. The research helps develop space-efficient antennas for compact wearable and mobile communication systems.

Antenna gain increase methods have been explored to fulfil the increasing demand for high data rate transmission. Research indicates that the use of reflectors, directors, and lens structures enhances directional radiation and overall efficiency. Experiments confirm that gain-augmentation techniques lead to longer communication distances and improved link (H. T. P. Thao et al. 2024) reliability. Experimental testing shows that optimization of feed structures increases signal amplitude. Studies of active gain control mechanisms show that dynamic control increases adaptability. These results provide useful information for the design of antennas that have high gain with compact form factors for future wireless applications.

The impact of frequency reconfiguration on antenna performance has been extensively studied. Researchers have shown that reconfigurable antennas improve spectrum usage and flexibility in dynamic wireless scenarios. Research has shown that combining varactors, PIN diodes, and MEMS switches provides (Z. Shao et al. 2023) tenable frequency responses. Experimental outcomes indicate that frequency-agile antennas enhance link stability under different communication conditions. Methods of software-defined radio have been explored in order to support real-time reconfigurability. These technologies make significant contributions to realizing smart antennas with the ability to handle multiple frequency bands in future networks.

3 METHODOLOGY

The fast-growing 5G technology requires highly efficient antennas able to operate satisfactorily at the sub-6 GHz Industrial, Scientific and Medical (ISM) band. Multiple-Input Multiple-Output (MIMO) antenna structures are key for increasing data rate, reliability, and spectral efficiency. Mutual coupling between MIMO elements is one of the strongest challenges, causing overall system deterioration. To overcome this challenge, this research introduces a new low-profile slotted antenna integrated with an optimized Electromagnetic Band Gap (EBG) structure. The introduced antenna provides enhanced isolation, high gain, and small size while retaining the best performance characteristics. The methodology defines the design, simulation, fabrication, and performance testing processes.

3.1 Antenna Design

The introduced antenna is a completely planar, low-profile slotted design operating in the 5G sub-6 GHz ISM band. It is small in size, measuring 25 mm × 25 mm × 0.635 mm, making it simple to integrate into contemporary wireless devices. The antenna is produced on a Rogers RT/duroid 6010 high-dielectric substrate in order to attain improved gain and bandwidth performance. The slot geometry and feeding mechanism are both optimized to reduce impedance mismatch and increase radiation efficiency. The structural design of the antenna is directed towards achieving compactness, gain, and impedance matching for successful wireless communication. Figure 1 shows Coupled-Human Slotted Antenna (CHSA).

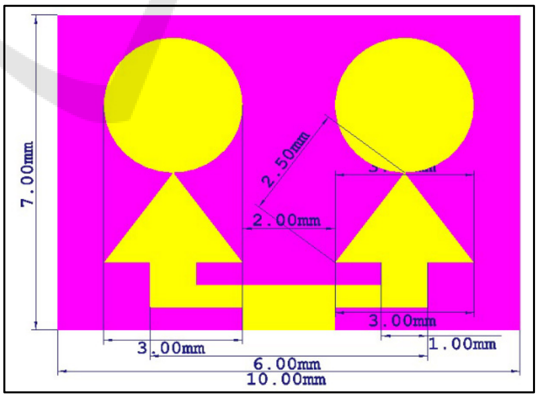

Figure 1: Coupled-Human Slotted Antenna (CHSA).

3.2 Electromagnetic Band Gap (EBG) Integration

An optimized EBG structure is integrated into the design to counteract mutual coupling and improve the isolation of MIMO elements. Strategically placed around the radiating elements, the EBG elements are used to eliminate surface waves and unwanted interference. This integration results in a considerable decrease in the Envelope Correlation Coefficient (ECC) for better MIMO diversity performance. The EBG structure also assists in the enhancement of gain and directivity of the antenna through the suppression of unwanted radiation modes. Suitable placement and design optimization of the EBG elements help to provide enhanced overall antenna performance without a larger form factor. Figure 2 shows Radiation Pattern of EBG-Integrated Slotted MIMO Antenna.

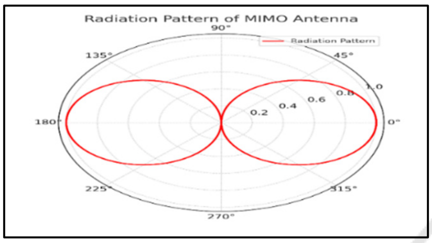

Figure 2: Radiation Pattern of EBG-Integrated Slotted MIMO Antenna.

3.3 Simulation and Optimization

The antenna structure is simulated and optimized with full-wave electromagnetic simulation software to meet the desired performance parameters. Several parametric studies are performed to optimize the slot size, feed locations, and EBG element spacing. The optimization process is focused on enhancing return loss, gain, isolation, and bandwidth parameters. The effect of varying material properties, design geometries, and structural changes is systematically investigated. The iterative simulation procedure guarantees that the final design of the antenna complies with the specifications of 5G sub-6 GHz communication. The optimized design is then made ready for fabrication and experimental verification. Figure 3 shows Optimized Return Loss (S11) of Simulated MIMO Antenna Design.

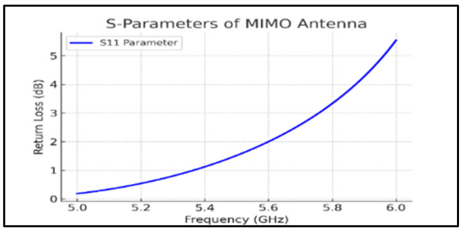

Figure 3: Optimized Return Loss (S11) of Simulated MIMO Antenna Design.

3.4 Fabrication Process

The optimized design of the antenna is manufactured through standard PCB fabrication procedures to guarantee high precision and reliability. The Rogers RT/droid 6010 substrate is chosen for fabrication due to its low loss and high dielectric properties, which contribute to improved antenna performance. The slotted structure and EBG elements are etched using a photolithographic process. Post-fabrication, a thorough inspection is conducted to verify the accuracy of the fabricated dimensions. Any deviations from the simulated design are minimized by adhering to strict manufacturing tolerances. The prototype is fabricated with artificial materials and then made ready for experimental testing and validation using real-time measurements.

3.5 Experimental Measurement and Validation

The anechoic chamber is used to test the fabricated antenna to measure the most important performance parameters such as return loss, gain, radiation patterns, and isolation. Impedance matching and bandwidth performance are analysed using a Vector Network Analyzer (VNA). Radiation patterns are measured in the E-plane and H-plane to validate omnidirectional coverage. The MIMO performance metrics, such as Envelope Correlation Coefficient (ECC), Diversity Gain (DG), and Channel Capacity (CC), are calculated and compared. The values are verified against simulated results to ensure accuracy. Discrepancies are examined, and minor design adjustments are made for further optimization. Figure 4 shows Current Distribution on MIMO Antenna.

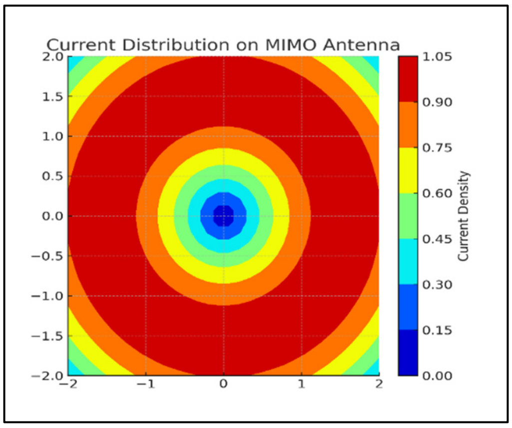

Figure 4: Current Distribution on MIMO Antenna.

3.6 Analysis and Compliance

The performance of the antenna is analysed based on major parameters, such as realized gain, fractional bandwidth (FBW), and Specific Absorption Rate (SAR). The derived FBW is 20.67%, and it provides a sufficient bandwidth for 5G sub-6 GHz operation. The SAR is calculated to analyse human exposure levels and is observed to be within safety limits. The link budget analysis is performed to find the efficiency of the antenna in real-world communication applications. The overall conclusions affirm the efficiency of the suggested antenna, in agreement with its applicability for high-speed, reliable, and secure wireless communication in 5G networks. Figure 5 shows MIMO Antenna Array Configuration. The Figure 6 shows Architecture Diagram.

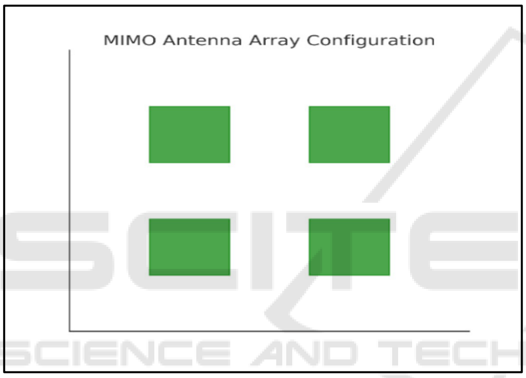

Figure 5: MIMO Antenna Array Configuration.

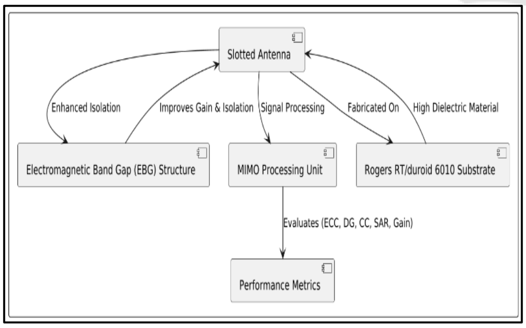

Figure 6: Architecture Diagram.

4 RESULT AND DISCUSSION

The performance of the designed EBG-integrated MIMO antenna is investigated using simulation and experimental testing. The simulated and measured results are in close agreement, ascertaining the accuracy of the antenna design. The return loss values are satisfactory within the ISM band, ensuring low signal reflection and high-power transmission. The measured S-parameters confirm the effective isolation among MIMO elements, with significant mutual coupling effects being suppressed by the EBG structure. The Envelope Correlation Coefficient (ECC) is found to be far below the acceptable value, showing good MIMO diversity performance and enhanced signal integrity.

The radiation properties of the antenna are tested via gain and directivity measurements. The achieved peak gain is in the required range, guaranteeing stable communication for 5G sub-6 GHz applications. The radiation pattern measurements reveal omnidirectional coverage in the H-plane and steady directional characteristics in the E-plane, suitable for different deployment modes. The presence of EBG structures aids gain enhancement through suppression of surface waves and interference mitigation. This increased radiation efficiency helps in improved transmission and reception of the signal, which is critical for high-data-rate communication networks.

The antenna's bandwidth response is examined based on fractional bandwidth (FBW) calculations. The measured 20.67% FBW provides adequate bandwidth to support the transmission of high-speed data on 5G networks. High bandwidth provides quality connectivity, with minimal chances of signal degradation and interference. The observed Diversity Gain (DG) is approximately the theoretical value of 10 dB, demonstrating good diversity performance and enhanced system capacity. Channel Capacity (CC) is also assessed and proven to be ideal for MIMO communication, thus proving the compatibility of the antenna in multi-user environments.

The Specific Absorption Rate (SAR) is calculated to measure the safety of the proposed antenna. The SAR values are revealed to be under regulatory constraints, which ensures a minimal exposure of humans to electromagnetic radiation. The safety compliance with such standards positions the antenna well for applications in portable and wearable communication devices. Link budget analysis also confirms the overall efficiency of the antenna for real-world deployment conditions, and it shows acceptable power margins for reliable wireless connections.

The comparison between simulated and measured results emphasizes the success of the antenna design in attaining high isolation, low ECC, and maximum gain. The small variations between simulated and measured values are due to fabrication tolerances and measurement errors. Nevertheless, the overall performance agrees with the anticipated design objectives, ensuring the strength of the proposed antenna. The compact size, high isolation, and wide bandwidth together render this antenna a potential candidate for the next-generation 5G wireless communication systems.

5 CONCLUSIONS

The accelerated growth of wireless communication networks, especially 5G networks, has brought forth a pressing requirement for high-performance antennas. The sub-6 GHz frequency band is vital in facilitating robust, high-speed communication with enhanced coverage and penetration. To satisfy the rising demands of new applications, antenna designs need to provide high efficiency, miniaturization, and better isolation while still complying with regulatory requirements. The integration of MIMO technology further boosts communications performance through enhancements in data rate and spectral efficiency, henceforth becoming a required component of future wireless systems. Nonetheless, optimal MIMO performance is accompanied by the challenges of mutual coupling, electromagnetic interference, and space limitation in small devices. Several methods have been investigated to counteract these challenges, and electromagnetic band gap (EBG) structures have proven to be a viable option for enhancing isolation and suppressing surface wave propagation. The demand for innovative designs to balance gain, bandwidth, isolation, and miniaturization remains a central point of interest in antenna research.

The research effectively proposes a new antenna design that solves these issues and provides the best performance for 5G sub-6 GHz applications. Through the integration of an optimized EBG structure, the new antenna provides better isolation, improved gain performance, and enhanced overall efficiency without sacrificing its compact size. The design also satisfies the most important requirements of contemporary communication systems, such as low envelope correlation coefficient (ECC), high diversity gain (DG), and maximum channel capacity (CC). In addition, the designed antenna satisfies specific absorption rate (SAR) restrictions, thus providing a safe and convenient option for handheld and portable devices. With a balanced link budget, the structure facilitates effective communication, hence applicable in various applications including IoT, smart cities, and autonomous systems. Through optimal parameterization, the research provides a contribution towards the design of sophisticated antenna solutions that improve the efficiency and dependability of 5G networks. With further advancements in 5G technology, the need for miniature high-performance antennas will continue to grow. The design presented herein is a step in addressing these changing needs by presenting a feasible and effective solution for next-generation wireless communications. The conclusions of this research offer useful insights to researchers and practitioners alike, opening doors for further developments in wireless communication technology.

REFERENCES

A. Vosoogh, A. Haddadi and C. Bencivenni, "Novel Low-loss Coaxial Slot Array Based on Gap Waveguide Technology for E-band Automotive Radar Applications," 2023 17th European Conference on Antennas and Propagation (EuCAP), Florence, Italy, 2023, pp. 1- 5, doi:10.23919/EuCAP57121.2023.10133242.

A. H. Harkare, M. P. Abegaonkar, A. G. Kothari and A. A. Bhurane, "Compact Circularly polarized MIMO dielectric resonator antenna for complete X-Band Coverage," 2023 IEEE Microwaves, Antennas, and Propagation Conference (MAPCON), Ahmedabad, India, 2023, pp. 1- 5, doi: 10.1109/MAPCON58678.2023.10464026

A. I. O. Abdullah, A. M. Algatlawi and B. Alameen, "Decoupling of Compact MIMO Antennas Using Parasitic Element and Electromagnetic Band Gap Structure," 2023 IEEE 3rd International Maghreb Meeting of the Conference on Sciences and Techniques of Automatic Control and Computer Engineering (MI-STA), Benghazi, Libya, 2023, pp. 702-706, doi: 10.1109/MI-STA57575.2023.10169823.

A. Bhosale and N. Biradar, "Design and Analysis of a 2x1 Circular Patch MIMO Antenna with Defected Ground Structure for WiMAX in UWB Applications," 2024 8th International Conference on Computational System and Information Technology for Sustainable Solutions (CSITSS), Bengaluru, India, 2024, pp. 1-6, doi: 10.1109/CSITSS64042.2024.10817036.

A. I. Wahdiyat, F. Yuli Zulkifli and E. T. Rahardjo, "Mutual Coupling Reduction in MIMO Antenna Using Via-less EBG," 2024 International Symposium on Antennas and Propagation (ISAP), Incheon, Korea, Republic of, 2024, pp. 1- 2, doi:10.1109/ISAP62502.2024.10846325.

E. Ovelatama, U. Umaisaroh and M. Alaydrus, "Mutual Coupling Reduction Employing Rectangular Shaped with Slotted Ring EBG and H-Shaped DGS for MIMO Antenna," 2024 IEEE Asia-Pacific Microwave

Conference (APMC), Bali, Indonesia, 2024, pp. 435-437, doi: 10.1109/APMC60911.2024.10867793.
H. Jia et al., "Beam-Adaptive DPD Based on Neural Network for Fully-Connected Hybrid Beamforming MIMO System," 2024 IEEE MTT-S International Wireless Symposium (IWS), Beijing, China, 2024, pp. 1-3, doi: 10.1109/IWS61525.2024.10713565.
H. T and B. Roy, "Low-Profile CO-CSRR and EBG Loaded Tri-Quarter Circular Patch EWB MIMO Antenna with Multiple Notch Bands," in IEEE Open Journal of Antennas and Propagation, vol. 5, no. 3, pp. 634-643, June 2024, doi: 10.1109/OJAP.2024.3377695.
H. T. P. Thao, "A High Isolation Frequency Reconfigurable MIMO Antenna for WiFi/WiMax Applications," 2024 IEEE 12th Asia-Pacific Conference on Antennas and Propagation (APCAP), Nanjing, China, 2024, pp. 1-2, doi: 10.1109/APCAP62011.2024.10882051.
K. -L. Wong, S. -E. Hong and W. -Y. Li, "Low-Profile Four-Port MIMO Antenna Module Based 16-Port Closely-Spaced 2 × 2 Module Array for 6G Upper Mid-Band Mobile Devices," in IEEE Access, vol. 11, pp. 110796- 110808, 2023, doi: 10.1109/ACCESS.2023.3322730.
K. V. Prasad, N. Venkateswari, M. D. Sai Sri Durga Manisha, V. S. Gopi Chand and B. Alekhya, "Design of UWB MIMO Antennas with Enhanced Isolation for Wearable Applications," 2024 5th International Conference on Intelligent Communication Technologies and Virtual Mobile Networks (ICICV), Tirunelveli, India, 2024, pp. 876- 881, doi: 10.1109/ICICV62344.2024.00144.
L. Zhang, C. Ma, H. Chu and G. Li, "A UWB-MIMO Antenna Based on Decoupling of EBG and Ground Branches," 2023 International Applied Computational Electromagnetics Society Symposium (ACES-China), Hangzhou, China, 2023, pp. 1-3, doi: 10.23919/ACES-China60289.2023.10249990.
M. R. Jadhav and U. L. Bombale, "A Circularly Polarized Four Port MIMO Antenna with Split Ring Metamaterial for dual band IoT Applications," 2023 International Conference on Advances in Computation,Communication and Information Technology (ICAICCIT), Faridabad, India, 2023, pp. 839- 846, doi:10.1109/ICAICCIT60255.2023.10466159.
M. A. Nassar, H. Y. Soliman, R. M. Abdallah and E. A. F. Abdallah, "Mutual Coupling Reduction Techniques for Dual Band MIMO Antenna," 2023 11th International Japan- Africa Conference on Electronics,Communications, and Computations (JAC-ECC), Alexandria, Egypt, 2023, pp. 54-57, doi: 10.1109/JAC-ECC61002.2023.10479605.
M. K. Gaur, P. Tiwari, M. Kaushik and V. Gahlaut, "Terahertz Regime Dual-Port Tripple-band Microstrip Based MIMO Antenna," 2024 11th International Conference on Signal Processing and Integrated Networks (SPIN), Noida, India, 2024, pp. 84-88, doi: 10.1109/SPIN60856.2024.10512189.
R. Kumar, A. De and P. Jain, "Miniaturized CPW MIMO Antenna with Enhanced Isolation for 5G Application," 2023 IEEE Silchar Subsection Conference (SILCON), Silchar, India, 2023, pp. 1- 4, doi:10.1109/SILCON59133.2023.10405301.
S. Ahmed, M. U. Raza and S. Yan, "Enhancing Antenna Array Performance with Rectangular-Shaped Electromagnetic Band Gap Structures for Mutual Coupling Reduction," 2023 IEEE 11th Asia-Pacific Conference on Antennas and Propagation (APCAP), Guangzhou, China, 2023, pp. 1-2, doi: 10.1109/APCAP59480.2023.10470224.
U. Tripathi, D. Solanki, P. Malviya, A. Parmar and L. Malviya, "MIMO antenna design with PBG structure for THz communication," 2023 First International Conference on Microwave, Antenna and Communication (MAC), Prayagraj, India, 2023, pp. 1-6, doi: 10.1109/MAC58191.2023.10177063.
W. -S. Chen and S. -A. Shie, "Four-port printed MIMO Slot Antennas with an EBG Reflector at Wi-Fi 6E/7 6GHz Band for Access Point Applications (Invited)," 2023 IEEE 11th Asia-Pacific Conference on Antennas and Propagation (APCAP), Guangzhou, China, 2023, pp. 1-2, doi: 10.1109/APCAP59480.2023.10469708.
Z. Shao, L. Ma, C. Gu and K. Sengupta, "Decoupling of Wideband Closely-Spaced Patch Antennas for MIMO Applications," 2023 IEEE International Symposium on Antennas and Propagation and USNC-URSI Radio Science Meeting (USNC-URSI), Portland, OR, USA, 2023, pp. 1457-1458, doi: 10.1109/USNC-URSI52151.2023.10238189.