Industrial Engineering Journal
ISSN: 0970-2555
Volume : 53, Issue 8, No.3, August : 2024

DESIGN OF HEXAGONAL SHAPED PLUS SLOT EMBEDDED TWO PORT MIMO ANTENNA FOR WIRELESS APPLICATIONS

Ramamohan. B, Associate Professor, Lendi Institute of Engineering & Technology.
Banu Prakash B, UG Student, Lendi Institute of Engineering & Technology.
Ch. Chandrahaas, UG Student, Lendi Institute of Engineering & Technology.
Indumathi B, UG Student, Lendi Institute of Engineering & Technology.
Sravanthi. P, Assistant Professor, Lendi Institute of Engineering & Technology

Abstract

A compact dual band 2 X 2 multiple-input-multiple-output (MIMO) antenna design with the dimension20 X 25 X 1.6 mm^3 is designed for the 5^{th} generation region. The designed MIMO antenna structure consists of Plus- shaped slot in the hexagonal patch. Defective ground structure (DGS) is used in ground plane to improve the isolation between the two radiating elements. The measured lower and upper frequency bandwidths are respectively (3.5–3.75 GHz) and (7.93–10.26GHz). The antenna covers the potential 5G band ranging from 3.3 to 3.8 GHz having circular polarization characteristics. The low envelope correlation coefficient and the isolation between the antenna elements greater than 15 dB justify the acceptance of the proposed design as a MIMO antenna. The proposed design exhibits good agreement between the simulated and the measured results.

Keywords:
MIMO, plus-shaped, Defective ground structure (DGS), isolation.

Introduction

Linearly polarized antennas in lineof-sight communication often receive unequal signal powers, which leads to the receiving antenna with the lowest power placing a higher limit on the diversity gain and, consequently, on the Signal-to-Noise Ratio (SNR). Additionally, due to polarization mismatch, highly isolated antennas experience inadequate signal gains in both indoor and outdoor environments. In recent years, extensive research and significant industrial advancements have highlighted the overwhelming relevance of circularly polarized (CP) antennas in wireless communications. Circular Polarization antennas have the ability to equally divide signal power among receiving antennas, thereby addressing the problem of polarization mismatch. CP-MIMO antennas are known to enhance the data rate, capacity, and diversity gain. With the continuous evolution of communication modes and the increasing need for highly reliable communication techniques, research, industry, and market dynamics have significantly shifted towards Multiple Input Multiple Output (MIMO) technology. This shift is primarily attributed to MIMO's exceptional performance in meeting both indoor and outdoor wireless communication needs. There has been extensive research and investigation into MIMO antenna systems, particularly for Wireless Local Area Networks (WLAN) operating in the frequency bands of 2.4–2.484 GHz, 5.15–5.35 GHz, and 5.725–5.825 GHz. Additionally, MIMO technology has been thoroughly explored for Worldwide Interoperability for Microwave Access (WiMAX) within the frequency bands of 2.5–2.69 GHz, 3.3–3.8 GHz, and 5.25–5.85 GHz, as well as for Global System for Mobile Communications (GSM) in the frequency ranges of 850.2–893.8 MHz, 880.0–960.0 MHz, 1710.2– 1879.8 MHz, and 1850.2–1989.8 MHz The presence of MIMO has become an essential requirement in the advancement of antenna technology, ensuring enhanced performance and reliability across a variety of communication systems.

The design of a 2 × 2 CP-MIMO antenna intended to resonate within the 3.5 to 3.75 GHz WLAN band. CP antennas are known to solve multipath propagation problems in all environmental conditions, irrespective of the type of fading and diversity techniques. They provide flexibility in phase variations and render the antennas orientation independent, allowing CP antenna radiations to penetrate in all directions. In this document, the approach followed to design the CP antenna involve the use of plus slots to generate the CP mode. A compact dual-band 2 × 2 MIMO antenna design, with dimensions of 20 × 25 × 1.6 mm^3, has been developed for the 5th generation region. The designed MIMO antenna structure consists of a plus-shaped slot in the hexagonal patch. To improve isolation between the two radiating elements, a defective ground structure (DGS) is employed in the ground plane. The measured lower and upper frequency bandwidths are 3.5–3.75 GHz and 7.93–10.26 GHz, respectively. The two closely coupled antenna radiators can be de-correlated using space variation. This space variation is key to achieving low mutual coupling, although large variations can lead to a significant increase in the overall MIMO dimensions. The sources of mutual coupling in closely packed radiators include coupling and common conductor (ground) emission. The behavior of the correlation coefficient reveals the nature of the designed MIMO. Mutual coupling is studied in terms of ground and patches, separation, and orientation of radiators. In order to reduce mutual coupling between two radiating elements, an effective diversity technique called space diversity is utilized in this design. Mutual coupling also depends on the type and shape of the MIMO antenna radiators. The antenna covers the potential 5G band, which ranges from 3.3 to 3.8 GHz, and exhibits circular polarization characteristics. The low envelope correlation coefficient and isolation between the antenna elements greater than 15 dB justify the acceptance of the proposed design as a MIMO antenna. The proposed design exhibits good agreement between the simulated and the measured results. A two-port LHCP and RHCP MIMO antenna with 50.0 Ω ports is designed to uniformly distribute signal power between radiators. An FR-4 dielectric substrate (with a thickness of 1.6 mm, permittivity of 4.4, and a loss tangent of 0.025), measuring 20 × 25 mm, is used for the fabrication. A microstrip feed is preferred to avoid the emission of secondary fields. CP in the presented 2 × 2 MIMO antenna is generated by using plus slots at the center of a hexagonal patch. Two orthogonal modes are generated with a 90° phase difference and equal amplitudes and are excited by the slots, resulting in the division of total power between the radiators.

Antenna Design:

The MIMO antenna have crafted boasts a distinctive design, featuring hexagonal patches inter-connected with rectangular strips. This innovative configuration not only optimizes the radiating elements but also facilitates efficient signal transmission and reception. Fig 1. Shows the single hexagonal patch antenna with plus slot. Incorporating plus slots on the hexagonal elements enhances circular polarization, ensuring robust connectivity in diverse environments. Moreover, the integration of defective ground technique elevates performance, minimizing unwanted coupling and enhancing antenna isolation. Each element of the design has been meticulously engineered to achieve superior functionality and reliability in MIMO systems. The hexagonal patches serve as the primary radiators, efficiently capturing and emitting electromagnetic waves. The interconnected rectangular strips play a pivotal role in shaping radiation patterns and improving impedance matching across frequency bands. Together, these elements form a cohesive structure that embodies the synergy of precision engineering and innovative design principles. This MIMO antenna represents a culmination of research and development, promising exceptional performance and versatility in modern communication networks. Additionally, the hexagonal patches offer geometric advantages, promoting compactness and scalability in antenna arrays. The incorporation of plus slots enhances axial ratio performance, crucial for maintaining signal integrity in dynamic propagation environments. Through meticulous design and careful implementation, this antenna embodies a harmonious balance of form and function, poised to meet the demands of next generation wireless communication systems.

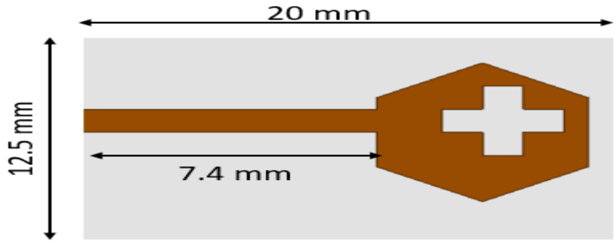


Fig 1. Plus slotted hexagonal patch

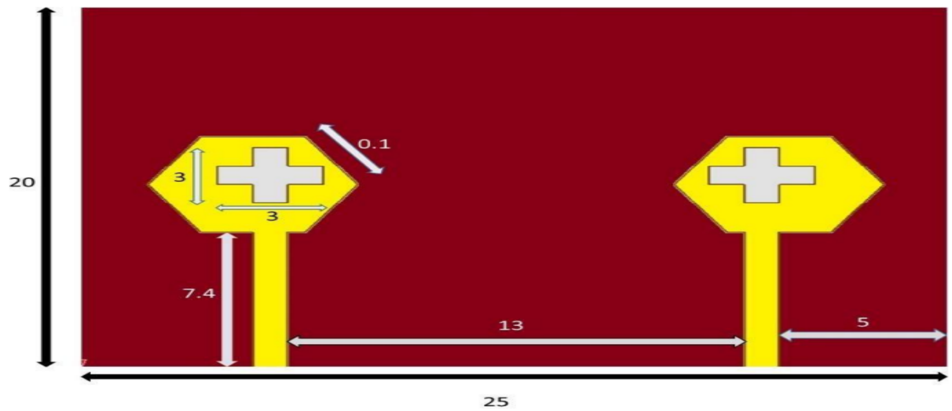


Fig 2. 2x2 MIMO friend view without DGS.

Hexagonal patches enable a more efficient use of space compared to square or circular patches, making them ideal for compact antenna arrays and systems with limited real estate. The symmetry of the hexagonal shape promotes more uniform radiation patterns in multiple directions, enhancing coverage and reducing signal distortion. Hexagonal patches exhibit six-fold rotational symmetry, ensuring uniformity in radiation characteristics and simplifying design optimization. Fig 2. Shows the MIMO antenna without Defective Ground Structure(DGS).Hexagonal patches can be engineered to support both linear and circular polarization, offering versatility in adapting to different communication standards and network configurations. By leveraging these advantageous properties, hexagonal patches enable the development of highly efficient and versatile antennas for a wide range of wireless communication applications. The geometry of hexagonal patches allows for easy adjustment of resonant frequencies by varying the dimensions, facilitating multi-band or wideband operation without compromising performance. Plus slots introduce additional degrees of freedom in controlling the distribution of electromagnetic fields on the antenna surface. These slots create asymmetry in the current distribution, resulting in the generation of orthogonal components of electric field polarization. By adjusting the dimensions and orientation of the plus slots, designers can manipulate the phase and amplitude of the circularly polarized wave components, effectively tailoring the antenna's polarization characteristics. As a result, the antenna radiates circularly polarized waves with improved purity and efficiency, making it well-suited for applications requiring robust polarization diversity and enhanced performance in challenging propagation environments. Overall, the integration of plus slots on hexagonal patches represents a sophisticated yet practical approach to achieving circular polarization in antennas, offering a compelling solution for modern wireless communication systems. By promoting circular polarization, the antenna becomes less sensitive to changes in the polarization of incoming signals. This characteristic enhances spatial diversity and reduces interference between multiple antennas in close proximity, thereby improving system reliability and data throughput in MIMO configurations. Plus slots can be implemented without significantly increasing the physical footprint of the antenna. This compactness is particularly advantageous in applications where space is limited, such as in small-form-factor devices or densely populated antenna arrays.

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 53, Issue 8, No.3, August : 2024

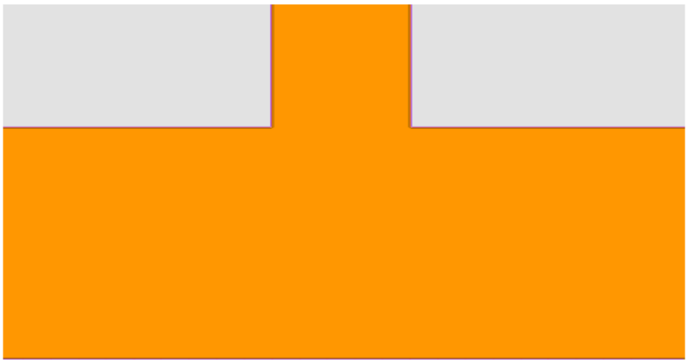


Fig 3. 2x2 MIMO back view without DGS

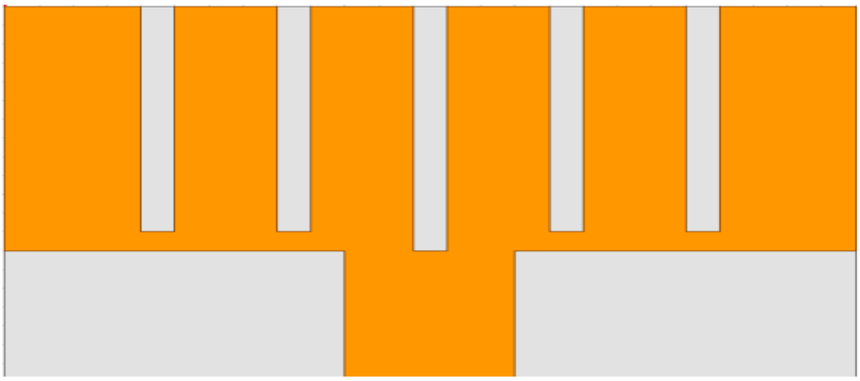
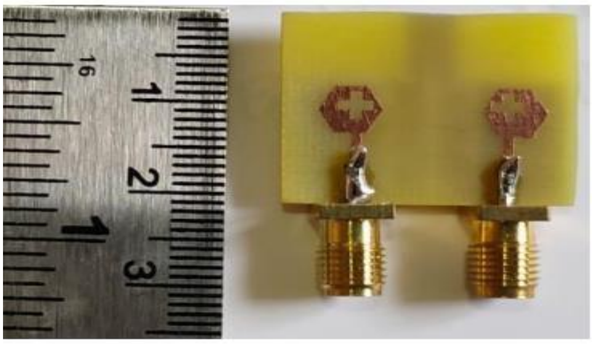


Fig 4. Antenna back view with Defective Ground Structure (DGS)

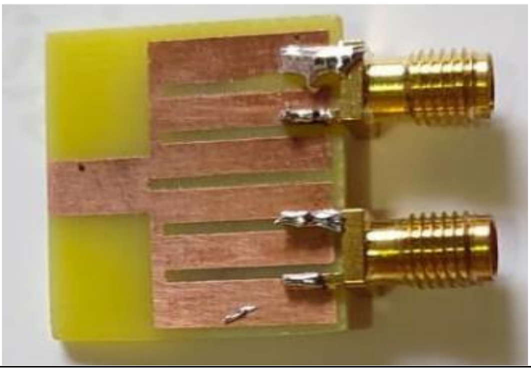
Defective Ground Structure (DGS) is a technique employed in antenna design to enhance performance, particularly in MIMO systems, by strategically introducing discontinuities or defects in the ground plane. DGS disrupts the propagation of surface waves along the ground plane, thereby reducing unwanted coupling between antenna elements. This suppression minimizes mutual coupling and enhances isolation between antennas, crucial for maintaining the independence of MIMO channels. By introducing controlled defects in the ground plane, DGS can mitigate losses associated with surface wave propagation and reflections. This improvement in antenna efficiency translates to enhanced signal transmission and reception capabilities, resulting in better overall system performance's disrupts the propagation of surface waves along the ground plane, thereby reducing unwanted coupling between antenna elements.fig 3 ,fig 4. Shows the front and back view of DGS. This suppression minimizes mutual coupling and enhances isolation between antennas, crucial for maintaining the independence of MIMO channels. By introducing controlled defects in the ground plane, DGS can mitigate losses associated with surface wave propagation and reflections. This improvement in antenna efficiency translates to enhanced signal transmission and reception capabilities, resulting in better overall system performance. DGS can be tailored to exhibit frequency-dependent behavior, allowing designers to achieve band-notched characteristics or frequency-selective filtering. This capability enables the suppression of interference from specific frequency bands, enhancing the signal-to-noise ratio and overall system reliability in congested RF environments. DGS can be implemented using simple geometrical structures, such as slots, meander lines, or fractal patterns, without significantly increasing the antenna's physical footprint. This compactness is advantageous for applications where space is limited, such as in small-form-factor MIMO devices or phased array antennas.

DGS can be strategically positioned around antenna elements to shape radiation patterns, improve impedance matching, and suppress undesired side lobes. By modifying the electromagnetic environment surrounding the antenna, DGS facilitates better control over radiation properties, resulting in improved coverage and link reliability in MIMO systems. By suppressing surface waves and reducing mutual coupling between antennas, DGS enhances isolation, allowing for more independent communication channels in MIMO configurations. This isolation translates to improved spatial multiplexing gain and higher data rates. DGS can mitigate interference from external sources or neighboring antennas operating in close proximity. By selectively attenuating specific frequency components or spatial modes, DGS helps maintain signal purity and reliability in the presence of interfering signals. Overall, the integration of hexagonal patches with plus slots and defective ground structures represents a sophisticated yet practical approach to antenna design, offering enhanced performance, versatility, and reliability for a wide range of wireless communication applications.

The below proposed antenna is printed on a FR4_epoxy substrate with permittivity (εr = 4.4). The size of the antenna is 20×25×1.6 mm^3 . The antenna design began with a hexagonal patch shape to optimize space utilization and radiation pattern uniformity. Plus slots were strategically introduced onto the hexagonal patch for controlling polarization characteristics. Dimensions and orientation of the plus slots were carefully determined to achieve the desired polarization characteristics. Length=3, width=3 of the plus slots were adjusted to manipulate the phase and amplitude of circularly polarized wave components. A coaxial feed network suitable for MIMO operation was designed, incorporating multiple feeding points corresponding to each antenna element. Impedance matching and isolation between feeding points were ensured to minimize interference and maximize antenna performance. Suitable substrate material with desirable dielectric properties was chosen to support the antenna's operating frequency range. Materials with low loss tangent were selected to minimize signal losses and improve antenna efficiency. Electromagnetic simulation software was utilized to model and optimize the antenna design. Parametric studies were conducted to fine-tune dimensions of the hexagonal patch and plus slots for optimal performance. Antenna's radiation characteristics, impedance matching, and polarization properties were verified through simulations. The antenna is fed by a 50-Ω coaxial cable. The inner and outer conductor of the coaxial cable is connected to the two arms of the rectangular patches. Fig 5. Shows the front and back view of fabricated MIMO antenna.



a



b

Fig 5. Fabricated antenna a) Front view   b) Back view

RESULTS AND DISCUSSION

S Parameters are used to detail how energy can propagate through an electrical network. Fig 6 shows the S-Parameters of MIMO antenna without plus slot, without Defective Ground Structure (DGS), with DGS. Defective Ground Structure (DGS) is a technique employed in antenna design to enhance performance, particularly in MIMO systems, by strategically introducing discontinuities or defects in the ground plane. The defects on the ground plane disturb the current distribution of the ground plane; this disturbance changes the characteristics of a transmission line by including some parameters (slot resistance, slot capacitance and slot inductance) to the line parameters (line resistance, line capacitance). Effective Capacitance and effective inductance of the model are changed by embedding the slots on the ground plane, resulting in shifting of resonance frequency to its lower side. A Gain plot, also known as a gain-frequency plot or magnitude plot, is a graphical representation of the gain of a system as a function of frequency. Fig 6 shows gain of a MIMO antenna. The term Antenna Gain describes how much power is transmitted in the direction of peak radiation to that of an isotropic source. A Gain plot in antenna engineering typically shows how the antennas gain varies with frequency or direction.it helps to understand the antennas performance characteristics.

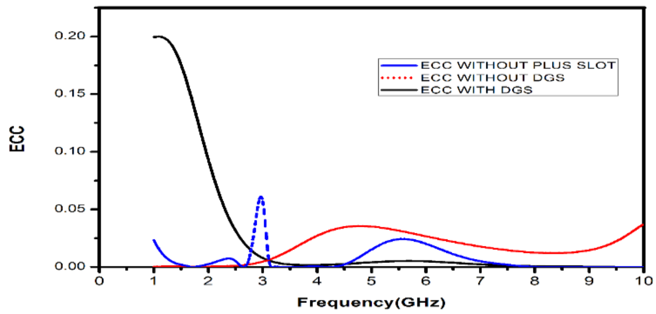
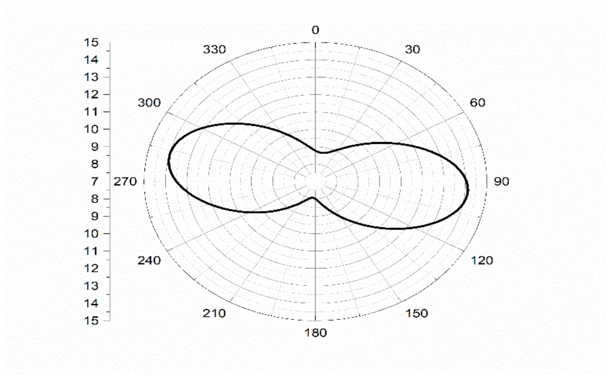
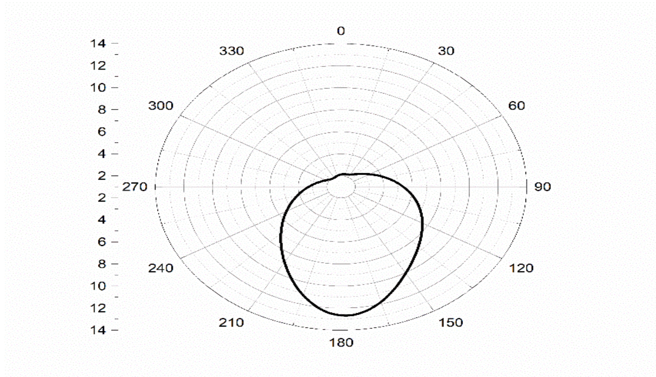


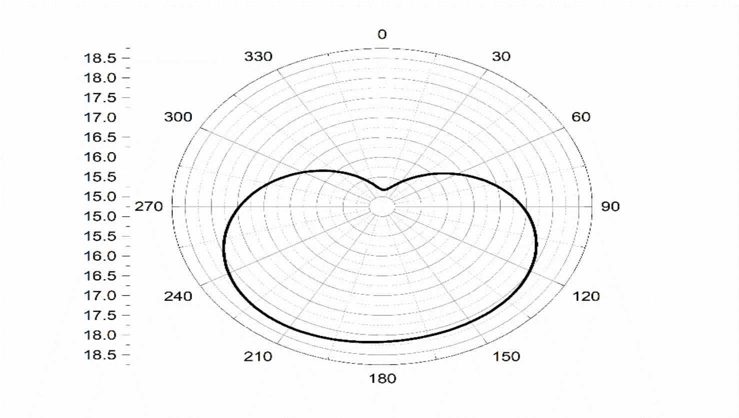
Fig 6. S-Parameters of a MIMO antenna



a)



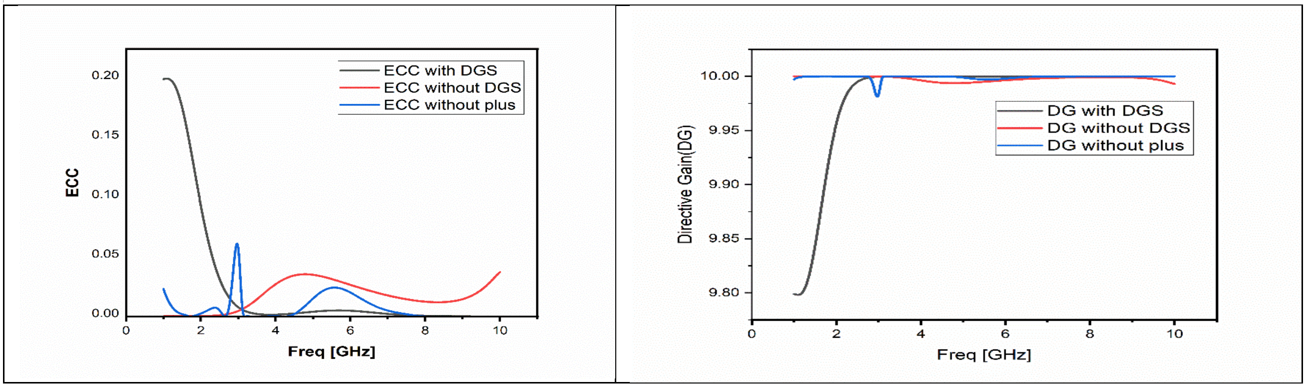
b)



c)

Fig 6. Gain of MIMO antenna a) without plus slot b) without DGS c) with DGS

Envelop Correlation Coefficient (ECC) and Diversity Gain (DG) are the two important permeates for the analysis of MIMO antenna. These two simulated graphs are shown in fig 8 antenna without plus slot, without DG, withDG.ECC less than 0.1 and DG equal to 9.9 obtained for the prosed antenna.



a b

Fig 8. MIMO characteristics a) frequency vs ECC b) Diversity Gain (DG) vs frequency

CONCLUSION

The design of compact broadband MIMO antennas with reduced mutual coupling and improved diversity gain is a critical area of research, given the exponential growth in wireless communication demands. This paper addresses several key challenges and opportunities within this domain. The emergence of Multiple Input Multiple Output (MIMO) technology has significantly enhanced data rates, spectral efficiency, and signal reliability in wireless communication systems. However, the compactness required for modern wireless devices often leads to challenges such as mutual coupling and ground disturbance. These phenomena degrade antenna performance by causing integration-related distortion effects. Through this project, we have explored various strategies to mitigate these challenges. We have investigated different types of separation techniques, including spatial separation and polarization, to control the effects of interconnection. By optimizing the design parameters and configurations of MIMO antennas, we aimed to achieve reduced mutual coupling less than 0.1 and enhanced diversity gain equal to 9.9. Furthermore, aimed to ensure that the designed antennas can operate across multiple frequencies, with support for various input-output configurations (e.g.1x1, 2x2and 4x4). This versatility is crucial for meeting the diverse communication standards and services prevalent in today's wireless ecosystem. In conclusion, the design of compact broadband MIMO antennas represents a significant advancement in wireless communication technology. By addressing challenges related to mutual coupling, diversity gain, and frequency bandwidth, our project contributes to the development of efficient and versatile antenna solutions. These antennas have the potential to enhance connectivity and support a wide range of applications in today's interconnected world.

REFERENCES

1. Tiwari, R. N., Singh, P., & Kanaujia, B. K. (2019). A compact UWB MIMO Antenna with neutralization line for WLAN/ ISM/mobile applications. International Journal of RF and Microwave Computer Aided Engineering, 29(11), e21907.
2. Khan, M. S., M. F. Shafique, A. D. Capobianco, E. Autizi, I. Shoaib, and I. Ali, "Compact UWB-MIMO antenna array with a floating digitated decoupling structure," IET Microwaves, Antennas & Propagation, Vol. 8, No. 10, 747–753, Mar. 2014.
3. Outer Elo, D. A., Alejos, A. V., Sanchez, M. G., & Isasa, M. V. (2015). Microstrip antenna for 5G broadband communications: Overview of design issues. In IEEE international symposium on antennas and propagation, Vancouver, Canada.
4. P.M. Ndao, Y. Erhel, D. Lemur and L. Le Masson: "Design of a highfrequency (3-30 MHz) multiple-input multiple-output system resorting to polarisation diversity" lET Microw. Antennas Propag. -- 19 August 2011 -- Volume 5, Issue 11, p.1310-1318.

5. Y. F. Lu and Y. C. Lin, "Electromagnetic band-gap based corrugated structures for reducing mutual coupling of compact 60 GHz cavity-backed antenna arrays in low temperature co-fired ceramics," IET Microwaves, Antennas & Propagation, vol. 7, no. 9, pp. 754-759, June 18 2013.
6. Pasumarthi S. Rao1, *, Kamili J. Babu2, and Avala M. Prasad1, "Compact Multi-Band MIMO Antenna with Improved Isolation", Progress in Electromagnetics Research M, Vol. 62, 199–210, 2017.
7. Saber Soltani, Parisa Lotfi, and Ross D. Murch, "A Port and Frequency Reconfigurable MIMO Slot Antenna for WLAN Applications", IEEE Transactions on Antennas and Propagation.
8. Ming Yang | Jinzhi Zhou," A compact pattern diversity MIMO antenna with enhance bandwidth and high-isolation characteristics for WLAN/5G/ Wi-Fi applications", Microwave Optical Technology Lett. 2020;1–12.
9. Manish Sharma1, "Design and Analysis of MIMO Antenna with High Isolation and Dual Notched Band Characteristics for Wireless Applications", Wireless Personal Communications.
10. Naoki Honma, Hiroshi Sato, Koichi Ogawa, and Yoshitaka Tsunekawa, "Accuracy of MIMO Channel Capacity Equation Based only on S-parameters of MIMO Antenna", IEEE ANTENNAS AND WIRELESS PROPAGATION LETTERS, VOL. XX, 20XX.
11. I. Adam1, m. N. M. Yasin2, n. Ramli3, m. Jusoh1, h. A. Rahim1, t. A. Latef4, t. F. T. M. N. Izam4 and t. Sabapathy1, "Mutual Coupling Reduction of a Wideband Circularly Polarized Microstrip MIMO Antenna", IEEE ACCESS.
12. Zhengyi Li, Zhengwei Du, Masaharu Takahashi, Senior Member, IEEE, Kazuyuki Saito, Member, IEEE, and Koichi Ito, Fellow, IEEE, "Reducing Mutual Coupling of MIMO Antennas with Parasitic Elements for Mobile Terminals", IEEE transactions on antennas and propagation, vol. 60, no. 2, February 2012.
13. Zhengyi Li, Zhengwei Du, Masaharu Takahashi, Senior Member, IEEE, Kazuyuki Saito, Member, IEEE, and Koichi Ito, Fellow, IEEE, "Reducing Mutual Coupling of MIMO Antennas with Parasitic Elements for Mobile Terminals", IEEE transactions on antennas and propagation, vol. 60, no. 2, February 2012.
14. Xiaochao Jiang, Hengxu Wang, and Tao Jiang, "A Low Mutual Coupling MIMO Antenna Using EBG Structures", 2017 Progress in Electromagnetics Research Symposium — Spring (PIERS).
15. Hao-Tao Hu, Fu-Chang Chen, and Qing-Xin Chu, "A Compact Directional Slot Antenna and Its Application in MIMO Array", IEEE Transactions on Antennas and Propagation.
16. M. A. B. Abbasi, S. S. Nikolaou, M. A. Antoniades, M. Nikolic Ste- ´ vanovic, and P. Vryonides, "Compact ebg-backed planar monopole for ban ´ wearable applications," IEEE Transactions on Antennas and Propagation, vol. 65, no. 2, pp. 453–463, Feb 2017.
17. Desai, A.; Bui, C.D.; Patel, J.; Upadhyaya, T.; Byun, G.; Nguyen, T.K. Compact Wideband Four Element Optically Transparent MIMO Antenna for mm-Wave 5G Applications. IEEE Access 2020, 8, 194206–194217.
18. M. Alibakhshikenari, M. Khalily, B.S. Virdee, C.H. See, R.A. Abd-Alhameed, E. Limiti, Mutual coupling suppression between two closely placed microstrip patches using EM bandgap metamaterial fractal loading, IEEE Access 7 (2019) 23606–23614.
19. Z. H. Jiang, Z. Cui, T. Yue, Y. Zhu, and D. H. Werner, ‘‘Compact, highly efficient, and fully flexible circularly polarized antenna enabled by silver nanowires for wireless body-area networks,’’ IEEE Trans. Biomed. Circuits Syst., vol. 11, no. 4, pp. 920–932, Aug. 2017.
20. Dwivedi, A. K., Sharma, A., Singh, A. K., & Singh, V. (2020). Circularly polarized two port MIMO cylindrical DRA for 5G applications. In 2020 international conference on UK-China emerging technologies (UCET) (pp. 1– 4). Glasgow: IEEE.
21. D. Piazza, P. Mookiah, M. D'Amico, and K. Dandekar, "Computational electromagnetic analysis of a reconfigurable multiport circular patch antenna for MIMO communications," to appear in Proceedings of the International Symposium on Electromagnetic Theory, EMTS, 2007.