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Compact Triple-Band Orthogonal MIMO Antenna

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Abstract

The study proposes a compact triple-band orthogonal multiple-input multiple-output (MIMO) antenna design intended for operation in three distinct frequency bands: C band downlink (3.7-4.6 GHz), Wi-Fi 6E (6.1-7.2 GHz), and X band (8.4-10.1 GHz). The proposed antenna configuration incorporates four radiating elements with partially ground planes strategically arranged to achieve isolation between the bands and maintain desirable radiation characteristics across all three bands. The antenna is designed on a flame-retardant FR-4 substrate with a compact size of 30 mm x 30 mm, making it suitable for integration into various multi-band wireless devices. The proposed antenna can be used in applications such as wireless communication, satellite communication, and radar systems.

Keywords: MIMO, Multiband Antenna, U-shaped slot, Triple-band.

1. Introduction

Microstrip antennas are a popular choice for wireless communication systems due to their low profile, ease of fabrication on printed circuit boards (PCBs), and compatibility with planar circuits. However, achieving multi-band functionality (operating at multiple distinct frequencies) in a compact design with minimal interaction (orthogonality) between the resonant bands presents a significant design challenge. This study explores recent

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advancements in compact triple-band microstrip antenna designs targeting the wideband range of 3.1-10.6 GHz, encompassing various critical applications such as Wi-Fi (WLAN), WiMAX, and satellite communication.

One prevalent approach for achieving triple-band resonances involves introducing modifications to the radiating patch itself. In [1], two configurations for microstrip antennas employ parasitic patches on the radiating element to create triple-band resonances while maintaining a compact form factor. For applications with size constraints, adjusting the ground plane offers new alternatives. Similarly, [2] introduces a compact triple-band antenna with an optimized rectangular notch etched in the ground plane. This disrupts the surface currents, introducing additional resonant frequencies that fall within the desired bands without significantly affecting the antenna size. Recent advancements have explored incorporating metamaterials to manipulate antenna characteristics. In [3], a compact slotted rectangular microstrip antenna with coaxial feed has been proposed. The simulated results depicted that the antenna is suitable for triple band applications such as wireless local area networks. In another study [4], a triple-notch band antenna was reported as suitable for the C/X/Ku/K bands. The suggested antenna is compact and useful for high-frequency bands, such as satellite applications. Antenna designers have used different shaped slots to achieve a multiband response, such as V-shaped slots [5], U-shaped slots [6], C-shaped slots [7], L-shaped slots [8], and binary tree slots [9]. The UWB-MIMO antennas proposed in [10]-[18] fail to incorporate notch structures to address the problem of electromagnetic interference resulting from the coexistence of C-band satellite communication (3.7–4.2 GHz). Recent research [19] investigates numerous notching structures to eliminate unwanted frequency band interference in the excited UWB spectrum.

This study proposes a compact triple-band orthogonal multiple-input multiple-output (MIMO) antenna design intended for operation in three distinct frequency bands: C band downlink (3.7-4.6 GHz), Wi-Fi 6E (6.1-7.2 GHz), and X band (8.4-10.1 GHz). The proposed antenna configuration incorporates four radiating elements with L-shaped partially grounded planes strategically arranged to achieve isolation between the bands and maintain desirable radiation characteristics across all three bands. The antenna is designed on a flame-retardant FR-4 substrate with a compact size of 30 mm x 30 mm, making it suitable for integration in various multi-band wireless devices. The proposed antenna can be used in wireless communication, satellite communication, and radar systems.

2. Antenna Design

This design features a MIMO antenna made up of four orthogonal identical radiating elements placed on the top layer of the substrate as shown in Figure 1. The substrate is made of a material called FR4 and is 1.6 mm thick. The size of the antenna is 30 mm x 30 mm. The L-shaped ground structure is located on the bottom layer of the substrate. All the design parameters are tabulated in Table 1.

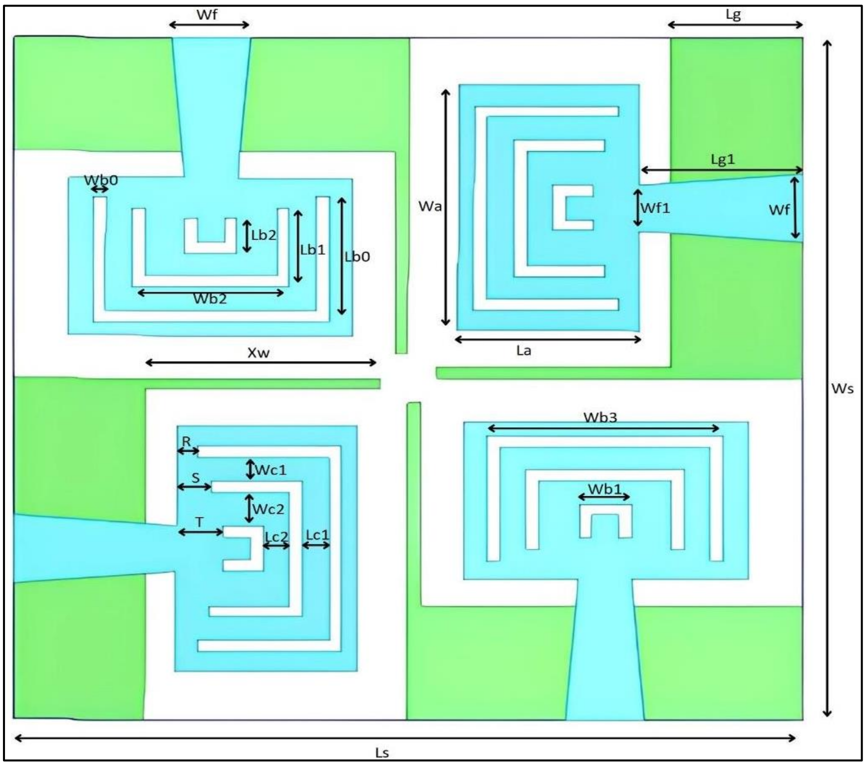


Figure 1. Layout of Proposed MIMO Antenna.

Table 1. Optimized Design Parameters.

Parameters	**Wf**	**Ws**	**Ls**	**Wb0**	**La**	**Wb1**	**Wb2**	**Wb3**	**Wa**
Units (mm)	3	30	30	0.5	6.9	2	6	9	10.8
Parameters	Lb0	Lb1	Lb2	Lg	Lg1	Wf1	Wc2	Lc1	Lc2

Units (mm)	5.5	3.5	1.5	5	6.2	2	1.5	1	1
Parameters	Wc1	Xw	Lz	R	S	T			
Units (mm)	1	8.9	0.5	1.3	1.8				

Each radiating element has a feeding mechanism equipped with a 50-ohm microstrip feed. This feed helps to send and receive signals effectively. To design and optimize the antenna, the proposed study uses a software called Ansys HFSS (15.0) 3-D electromagnetic simulator. This software allows to simulate and fine-tune various parameters of the antenna to ensure it works efficiently. In simpler terms, this MIMO antenna is made of four parts arranged on a small platform. The material used and the design of the ground structure have been adjusted to make it work better. Each part of the antenna has a special feeding mechanism to handle signals.

2.1 Evolution Steps of Antenna

The initial design consists of a 30 x 30 MIMO antenna with an orthogonal radiating patch and a rectangular microstrip feedline of 50 ohms, as shown in Figure 2(a). This design exhibited resonance at 3.7 to 4.0 GHz, 5.5 to 7.7 GHz, and 9.1 to 11.1 GHz. However, despite its broad resonance range, challenges were encountered due to poor isolation between bands, which negatively affected the overall performance. To address this issue, the antenna's design was refined by making strategic changes. One significant modification involved switching the rectangular microstrip feedline to a trapezoid microstrip feed, as shown in Figure 2(b). This alteration was instrumental in improving isolation between bands while also slightly adjusting the resonance frequencies. As a result, the antenna now resonates at 6.1 to 7.2 GHz and 8.4 to 10.7 GHz, showcasing enhanced performance characteristics. The aim of the proposed study is to develop a triple-band antenna capable of covering specific frequency ranges essential for modern communication systems. To achieve this goal, additional enhancements were incorporated into the antenna design.

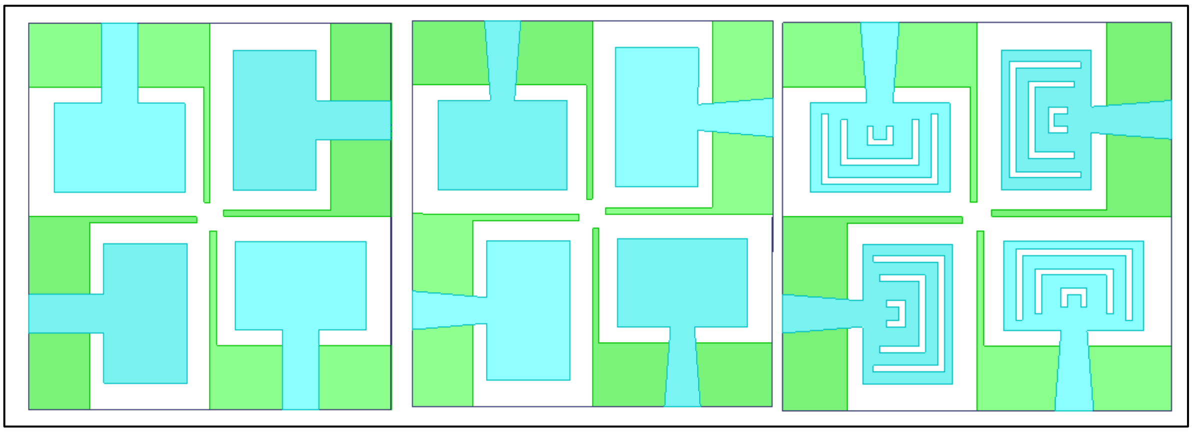


Figure 2. Antenna with (a) Rectangular Microstrip Feed (b) Trapezoid Microstrip feed (c) Triple U-Slot.

The key innovation involved adding three inverted U slots on all radiating patches, as shown in Figure 2(c). This strategic modification equipped the antenna with triple-band characteristics, enabling resonance in the C band (3.7 GHz to 4.6 GHz), Wi-Fi 6E band (6.1 GHz to 7.2 GHz), and X band (8.4 GHz to 10.1 GHz). The incorporation of these inverted U slots was a pivotal step in achieving the research objectives. These slots acted as impedance transformers, facilitating efficient coupling between the feedline and radiating elements. By strategically positioning these slots, the resonance frequencies of the antennas were fine-tuned to ensure optimal performance across the desired frequency range. Figure 3 and Figure 4 show the simulated results of the comparison of S_{11} and isolation parameters at different steps in antenna design.

It is observed from Figure 3 and Figure 4 that the results for S-parameters are improved as we moved from Rectangular microstrip feed to Trapezoid microstrip feed and finally to triple U-shaped slot.

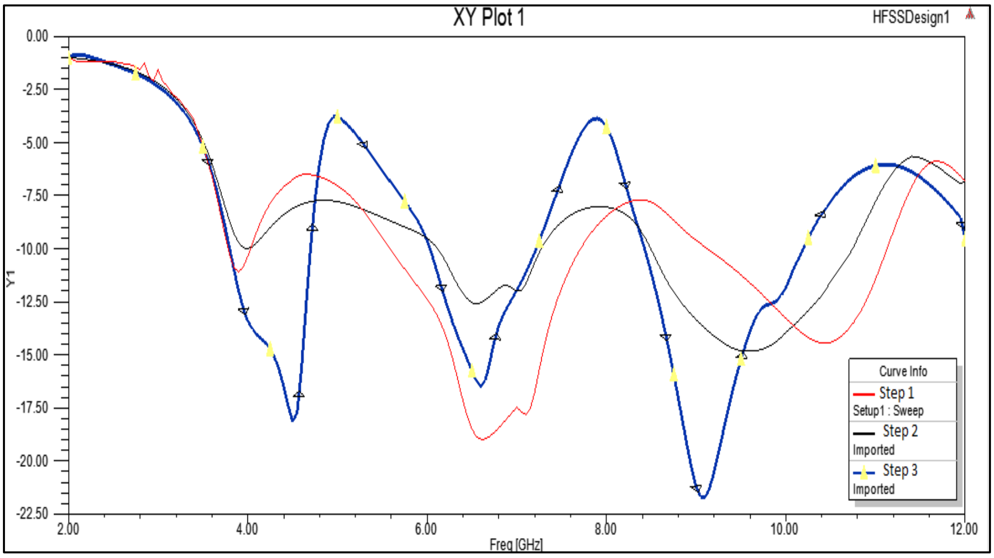


Figure 3. Comparison of S_{11} for Different Steps in Antenna Design.

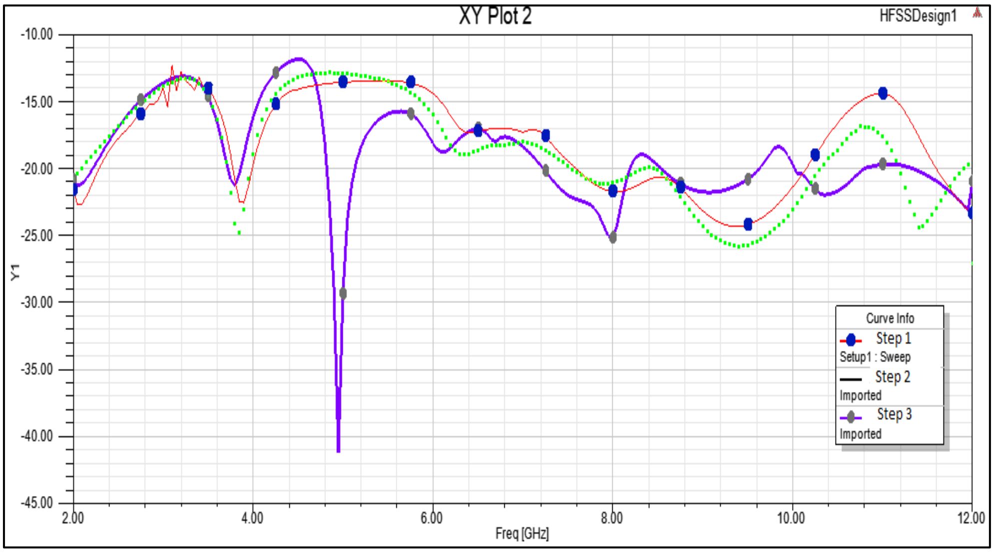
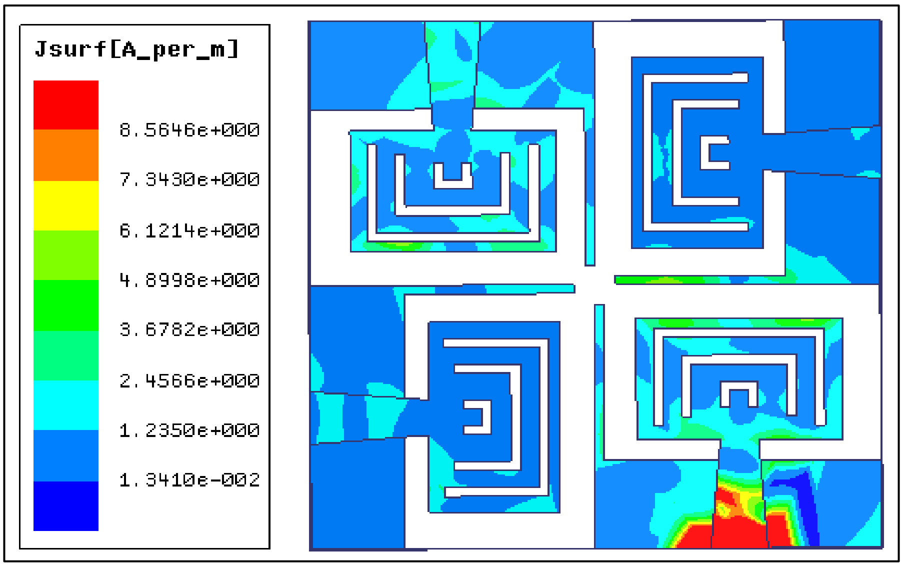


Figure 4. Isolation Parameter at Different Steps in Antenna Design.

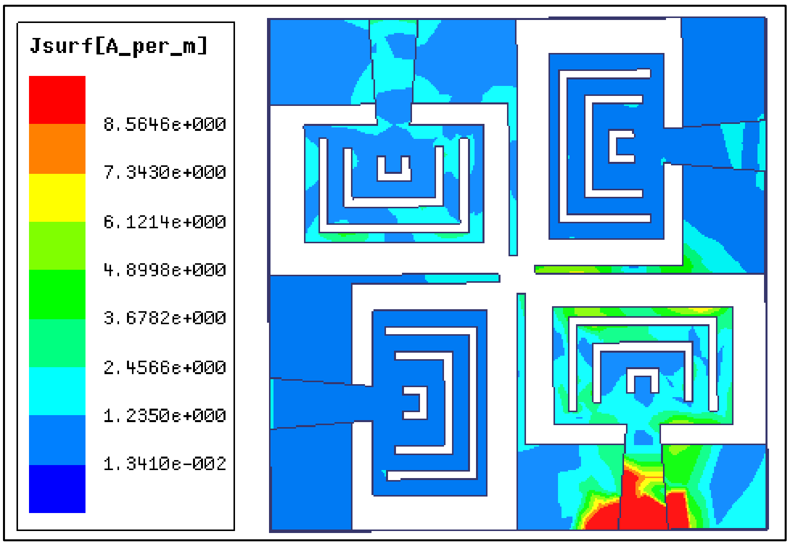
2.2 Current Distribution

Figure 5 illustrates how the distribution of surface currents in an antenna system varies at different frequencies, specifically at 4.6 GHz, 7.6 GHz, and 9.1 GHz. The antenna system features an L-shaped ground plane, which plays a significant role in shaping the current distribution across the antenna's surface. At 4.6 GHz, the surface currents are influenced by the L-shaped ground plane, affecting the antenna's ability to transmit and receive signals at this frequency.

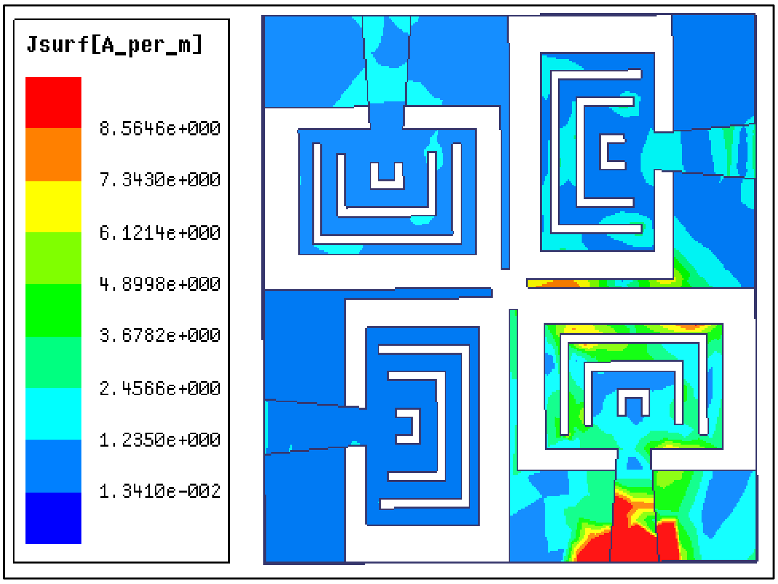


(a)

The unique shape of the ground plane helps in controlling the flow of electrical currents, reducing interference, and improving signal clarity. At 7.6 GHz, the distribution of surface currents changes, demonstrating the antenna system's adaptability to different frequencies. The L-shaped ground plane continues to guide the currents effectively, ensuring that the antenna maintains good performance and efficiency at this higher frequency. At 9.1 GHz, the highest frequency in this analysis, the surface currents are again distributed in a pattern that benefits from the L-shaped ground plane. This design minimizes interference between different parts of the antenna, leading to stronger signal transmission and reception.



(b)



(c)

Figure 5. Simulated Surface Current Distribution at (a) 4.6 GHz (b)7.6 GHz and (c) 9 GHz.

3. Result and Discussion

The reflection coefficient in antenna design is a measure of how well an antenna can transmit and receive signals. It tells us how much of the signal that is sent to the antenna is actually reflected back instead of being transmitted or received. A low reflection coefficient means that most of the signal is being used effectively, while a high reflection coefficient means that a significant portion of the signal is being lost or reflected away. Antenna designers aim to minimize the reflection coefficient to maximize the antenna's efficiency and performance in sending and receiving signals.

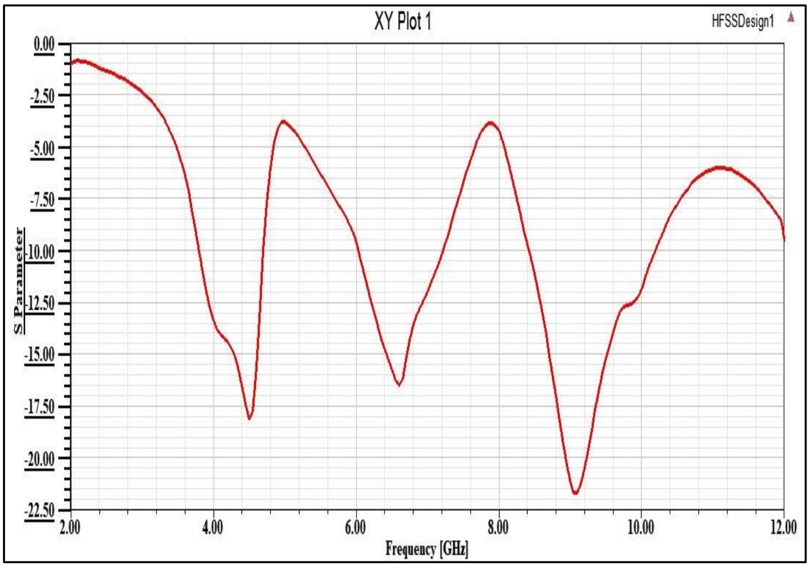


Figure 6. Simulated Reflection Coefficient

The graph shown in Figure 6 displays a triple-band characteristic, with each segment playing a pivotal role in different technological domains. The first band, spanning from 3.7 to 4.6 GHz, known as the C-band, is fundamental for satellite communication, enabling services like direct-to-home television, satellite internet, and telecommunication applications. It forms the backbone of global communication networks, facilitating connectivity across vast distances. Moving to the 6.1 to 7.2 GHz range, the study encounters Wi-Fi 6E, representing the forefront of wireless technology. Wi-Fi 6E enhances previous standards with faster data rates, reduced latency, and increased capacity, catering to bandwidth-intensive activities like streaming, gaming, and real-time communication. As demand for high-speed internet access rises, Wi-Fi 6E provides a solution meeting the needs of today's data-hungry applications. Lastly, the 8.4 to 10.1 GHz band is essential for advanced radar systems and satellite communication. It enables radar systems to achieve high-resolution imaging crucial for weather monitoring, air traffic control, and defence surveillance. Moreover, it supports automotive radar systems, which are integral to modern vehicle safety features such as collision avoidance. Additionally, this band serves as a backbone for microwave backhaul links, facilitating high-capacity data transfer in telecommunications networks, essential for connecting remote areas and ensuring reliable communication services. Isolation in antenna systems refers to the degree of separation between different antenna elements. It measures how much one antenna element affects another nearby element. Ideally, isolation should be high, meaning that there is minimal interaction between elements, to prevent interference and ensure efficient signal transmission and reception. A high isolation value, typically measured in decibels (dB), indicates that signals transmitted or received by one antenna element do not significantly impact the performance of neighbouring elements. This helps maintain signal clarity and fidelity in wireless communication systems.

Figure 7, depicts the isolation parameter for three frequency bands: 3.7 to 4.6 GHz, 6.1 to 7.2 GHz, and 8.4 to 10.1 GHz. The performance of these bands is measured in terms of isolation, which indicates how well the antennas can avoid interference from each other. For the first band (3.7 to 4.6 GHz), the isolation is less than 10 dB. This means there is some interference, but it is relatively low. For the other two bands (6.1 to 7.2 GHz and 8.4 to 10.1 GHz), the isolation is less than 15 dB, which indicates even better performance with less interference between the antennas.

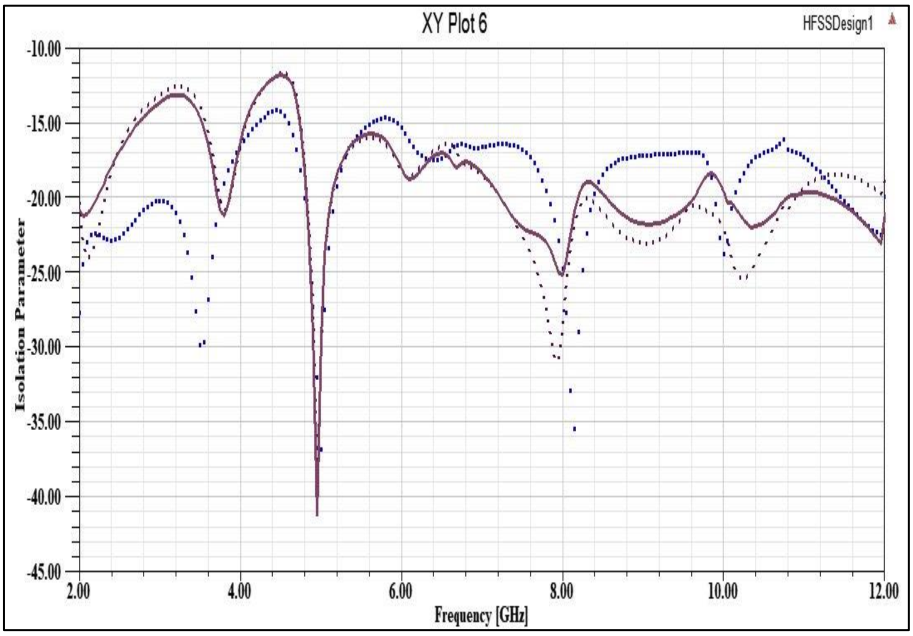
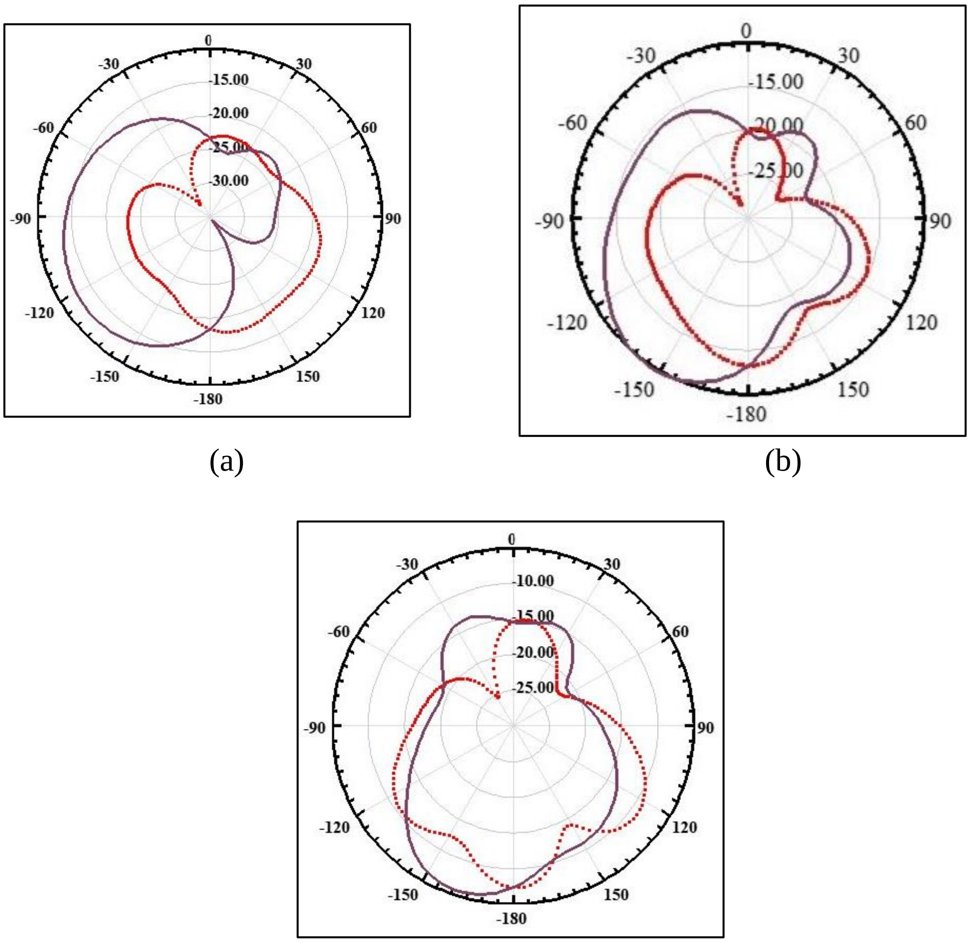


Figure 7. Simulated Isolation Parameter

3.1 Radiation Pattern

Figure 8 shows the simulated radiation patterns of the proposed antenna design at 4 GHz, 6.6 GHz, and 9.1 GHz. A radiation pattern, also known as an antenna pattern, is a graphical representation of the distribution of radiated power from an antenna as a function of direction in space. It provides crucial information about how an antenna radiates or receives energy. Typically depicted in azimuthal (horizontal) and elevation (vertical) planes, the radiation pattern shows radiation characteristics in respective planes, usually plotted in polar coordinates where the distance from the origin represents radiation intensity or power level at a given angle. Key parameters include the main lobe, which is the direction where the antenna radiates the most energy, side lobes, which are secondary peaks of radiation at other angles; the back lobe, which is radiation in the opposite direction of the main lobe; and beamwidth, which is the angular width of the main lobe measured at the points where the power drops to half its maximum value (3 dB points).



(c)

Figure 8. Simulated Radiation Patterns at (a) 4 GHz (b) 6.6 GHz and (c) 9.1 GHz

Understanding radiation patterns is essential for designing antennas that focus energy in desired directions and minimize interference, fundamental in applications such as wireless communication, radar, and broadcasting.

4. Conclusion

The development of a compact orthogonal MIMO antenna with three notches spanning the frequency bands of 3.7 to 4.6 GHz, 6.1 to 7.2 GHz, and 8.4 to 10.1 GHz marks a significant advancement in wireless communication technology. This antenna offers improved performance and efficiency by effectively mitigating interference and optimizing signal transmission within specific frequency ranges. By incorporating three notches, the antenna can selectively block out unwanted signals or interference from neighbouring frequency bands, ensuring clearer and more reliable communication. This capability is especially crucial in crowded frequency environments where multiple wireless devices operate simultaneously.

Furthermore, the compact design of the antenna makes it suitable for integration into various communication systems and devices, enhancing their connectivity and performance. Its versatility allows its usage in diverse fields such as telecommunications, radar systems, satellite communication, and more. The antenna design is capable of handling all three bands simultaneously. This means it can support various wireless technologies without needing separate antennas for each. Whether using a phone to browse the internet, a radar system to track objects, or a satellite to send data, this antenna provides comprehensive coverage.

Overall, the compact orthogonal MIMO antenna with three notches demonstrates the continuous innovation and evolution of wireless communication technology, offering improved signal quality, reliability, and efficiency across multiple frequency bands. As advancements continue in this field, such antennas will play a vital role in meeting the growing demands for seamless connectivity in an increasingly interconnected world.

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References

[1] Alkanhal, Majeed. "Composite compact triple-band microstrip antennas." Progress In Electromagnetics Research 93 (2009): 221-236.

[2] Verma, R.K., Srivastava, D.K. Design and Analysis of Triple-Band Rectangular Microstrip Antenna Loaded with Notches and Slots for Wireless Applications. Wireless Pers Commun 114, 1847–1864 (2020).

[3] Singh, V. & Ali, Zakir. (2010). Design of Compact Triple Band Microstrip Antenna for Wireless Communication. International Journal of Electronics and Communication Engineering. 3. 323-330.

[4] Kumar, Akhilesh, Prabina Pattanayak, and Abhishek Dhar. "Compact triple band microstrip patch antenna for satellite and C/X/K/Ku bands applications." Wireless Personal Communications 129, no. 1 (2023): 57-70.

[5] Ahmadi, B., and R. Faraji-Dana. "A miniaturised monopole antenna for ultra-wide band applications with band-notch filter." IET microwaves, antennas & propagation 3, no. 8 (2009): 1224-1231.

[6] Seo, Yeon Seok, J. W. Jung, Hae June Lee, and Y. S. Lim. "Design of trapezoid monopole antenna with band-notched performance for UWB." Electronics letters 48, no. 12 (2012): 673-674.

[7] Gao, Peng, Ling Xiong, Jianbo Dai, Shuang He, and Yi Zheng. "Compact printed wide-slot UWB antenna with 3.5/5.5-GHz dual band-notched characteristics." IEEE Antennas and Wireless Propagation Letters 12 (2013): 983-986.

[8] Nguyen, Dang Trang, Dong Hyun Lee, and Hyun Chang Park. "Very compact printed triple band-notched UWB antenna with quarter-wavelength slots." IEEE Antennas and wireless propagation letters 11 (2012): 411-414.

[9] Jahromi, M. Naghshvarian, Abolfazl Falahati, and R. M. Edwards. "Application of fractal binary tree slot to design and construct a dual band-notch CPW-ground-fed

ultra-wide band antenna." IET microwaves, antennas & propagation 5, no. 12 (2011): 1424-1430.

[10] Raheja, Dinesh Kumar, Sachin Kumar, and Binod Kumar Kanaujia. "Compact quasi-elliptical-self-complementary four-port super-wideband MIMO antenna with dual band elimination characteristics." AEU-International Journal of Electronics and Communications 114 (2020): 153001.

[11] Lin, Guo-Sheng, Che-Hui Sung, Jing-Lun Chen, Lih-Shan Chen, and Mau-Phon Houng. "Isolation improvement in UWB MIMO antenna system using carbon black film." IEEE Antennas and Wireless Propagation Letters 16 (2016): 222-225.

[12] Addepalli, Tathababu, and V. R. Anitha. "A very compact and closely spaced circular shaped UWB MIMO antenna with improved isolation." AEU-International Journal of Electronics and Communications 114 (2020): 153016.

[13] Tiwari, Rakesh N., Prabhakar Singh, Binod Kumar Kanaujia, and Kunal Srivastava. "Neutralization technique based two and four port high isolation MIMO antennas for UWB communication." AEU-International Journal of Electronics and Communications 110 (2019): 152828.

[14] Kumar, Niraj, and K. Usha Kiran. "Meander-line electromagnetic bandgap structure for UWB MIMO antenna mutual coupling reduction in E-plane." AEU-International Journal of Electronics and Communications 127 (2020): 153423.

[15] Khan, Muhammad Saeed, Antonio-Daniele Capobianco, Muhammad Farhan Shafique, Bilal Ijaz, Aftab Naqvi, and Benjamin D. Braaten. "Isolation enhancement of a wideband MIMO antenna using floating parasitic elements." Microwave and Optical Technology Letters 57, no. 7 (2015): 1677-1682.

[16] Kaur, Amanpreet, and Sheifali Gupta. "A complementary Sierpinski gasket fractal antenna array for wireless MIMO portable devices." Microwave and Optical Technology Letters 61, no. 2 (2019): 436-442.

[17] Tang, Xiaocong, Zhao Yao, Yang Li, Weihua Zong, Guoxia Liu, and Fukai Shan. "A high performance UWB MIMO antenna with defected ground structure and U-shape

branches." International Journal of RF and Microwave Computer-Aided Engineering 31, no. 2 (2021): e22270.

[18] Sohi, Arashpreet K., and Amanpreet Kaur. "A complementary Sierpinski gasket fractal antenna array integrated with a complementary Archimedean defected ground structure for portable 4G/5G UWB MIMO communication devices." Microwave and Optical Technology Letters 62, no. 7 (2020): 2595-2605.

[19] Kumar, Gurpreet, and Rajeev Kumar. "A survey on planar ultra-wideband antennas with band notch characteristics: Principle, design, and applications." AEU-International Journal of Electronics and Communications 109 (2019): 76-98.