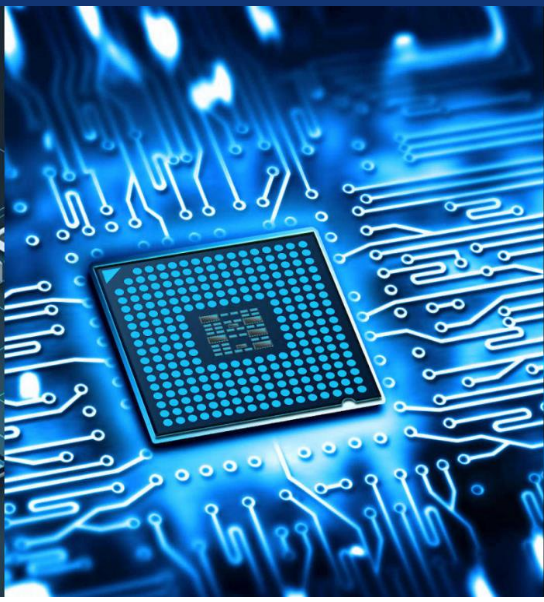
IJIRCCE

ISSN(O): 2320-9801

ISSN(P): 2320-9798



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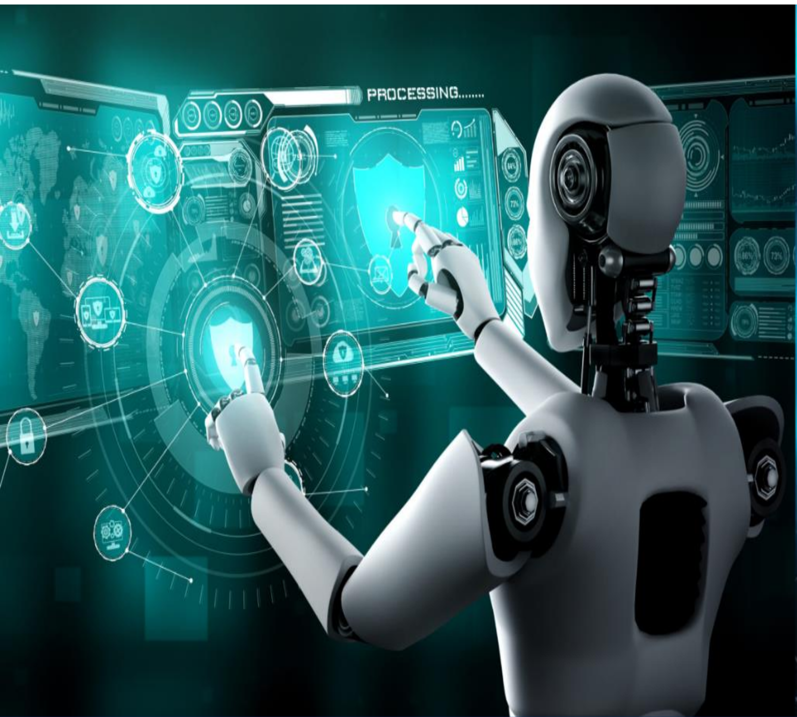

Impact Factor: 8.771

Volume 13, Issue 3, March 2025

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© 2025 IJIRCCE | Volume 13, Issue 3, March 2025| DOI: 10.15680/IJIRCCE.2025.1303101

www.ijircce.com | e-ISSN: 2320-9801, p-ISSN: 2320-9798| Impact Factor: 8.771| ESTD Year: 2013|

International Journal of Innovative Research in Computer and Communication Engineering (IJIRCCE)

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)

High-Isolation MIMO Antenna with a hybrid Decoupling Structure

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ABSTRACT: The demand for improved communication quality has rapidly increased. With the advantages of high channel capacity and transmission rates, MIMO antennas have attracted significant attention in wireless communications. This research presents a High-Isolation Dual-Band MIMO Antenna using a hybrid decoupling structure and a ground stub to mitigate mutual coupling and enhance antenna performance characteristics. The proposed dual-band MIMO antenna with high isolation is designed using a hybrid decoupling method that incorporates grounded stubs and defected ground structures. The final dimension of the antenna is 58 mm × 34 mm × 1.6 mm. It covers two operating frequency bands: 2.37-3.71 GHz and 4.07-5.73 GHz, with relative bandwidths of 44.08% and 33.88%, respectively. By expanding the ground with a rectangular stub and etching a slot cut in the middle part of the metal, the antenna achieves isolation levels of over 27 dB and 42 dB in the two operating bands, respectively, and the envelope correlation coefficient (ECC) is less than 0.0025. The antenna features a simple structure, excellent omnidirectional radiation characteristics, and high isolation. It covers the 3.4–3.6 GHz and 4.8–5 GHz bands specified in the 5G spectrum standards for non-millimeter-wave antennas.

KEYWORDS: High Isolation; MIMO Antenna; Decoupling Structures; Mutual Coupling

I. INTRODUCTION

The rapid advancement of mobile communication technology has increased the demand for wireless communication devices to achieve faster data transmission and reception, while also reducing bit error rates. Antennas, being a crucial component of wireless communication systems, must provide reliable wireless connections while maintaining cost-effective and low-profile [1]. Due to the growing demand for better data transmission, MIMO (Multiple Input, Multiple Output) technology has become essential for next-generation wireless communication systems. It utilizes multiple antennas at both the transmitter and receiver to enhance the channel capacity and reliability of signals, enabling faster data rates and more efficient bandwidth utilization for improved connectivity across various applications.

5G communication uses two main frequency ranges: sub-6 GHz (below 6 GHz) and millimeter wave (above 24 GHz) [2]. Many developed countries using the Sub-6 GHz spectrum, from 3.4 GHz to 3.8 GHz, have attracted significant interest from academia and industry [3]. Integrating multiple antennas in mobile devices with limited space can result in significant mutual coupling. This coupling reduces radiation efficiency and negatively impacts several important antenna parameters, including port isolation, impedance matching, gain, radiation patterns, and the correlation between antennas. [4].

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This research paper presents a dual-band MIMO antenna that achieves high isolation and reduces mutual coupling through a hybrid decoupling method using inverted T grounded stubs and defected ground structures. The antenna provides a dual-frequency bandwidth ranging from 2.37 to 3.71 GHz and 4.07 to 5.73 GHz, achieving 27 dB and 42 dB of port isolation in the two bands, respectively, and maintaining a very low Envelope Correlation Coefficient (ECC) of less than 0.001. This antenna supports Sub-6 GHz bands (n77-n79), making it suitable for IoT devices and 5G mobile applications.

II.RELATED WORK

In recent years, researchers have worked to reduce mutual coupling, enhancing the isolation and performance of MIMO antenna systems. Study [5] presents an efficient decoupling structure that achieves better isolation by utilizing both E-plane and H-plane coupling. This innovative approach has proven successful, yielding isolation values below 20 dB within the 2.3 to 2.9 GHz frequency range. To improve isolation in [6], adjust the ground plane structure beneath each resonator to create out-of-phase mutual coupling with free space. This can enhance isolation by over 10 dB between diagonal and adjacent elements, but it also increases antenna thickness, limiting its use in low-profile arrays. Reference [7], the authors presented a novel design using metal-graphene components to reduce interference, achieving a 10 dB improvement in isolation and enhancing signal separation for antennas operating between 2.5 and 2.65 GHz. The study in [8] introduces an eight-port antenna array designed for 5G MIMO systems in mobile devices, implementing a neutralized line to address coupling challenges. However, increasing the number of antennas may result in isolation issues. To ensure optimal performance in MIMO antenna systems, it is crucial to achieve low envelope correlation coefficients (ECCs) and high isolation while maintaining compact sizes [9] – [14]. Most MIMO antenna designs in literature effectively leverage diverse decoupling structures to ensure excellent isolation between elements. However, these designs frequently pose fabrication challenges.

III. PROPOSED ANTENNA DESIGN

A. *Antenna Design:*

Figure 1 shows the detailed structure of the high-isolation dual-band MIMO antenna designed in this paper. The antenna consists of a dielectric substrate, radiating elements, microstrip lines, a rectangular defected metal ground, and a slotted grounding branch. The dielectric substrate is made of FR4 material with a thickness of 1.6 mm, a relative permittivity of $\varepsilon r = 4.4$, and a loss tangent of $\tan\delta = 0.02$, with width w and length l.

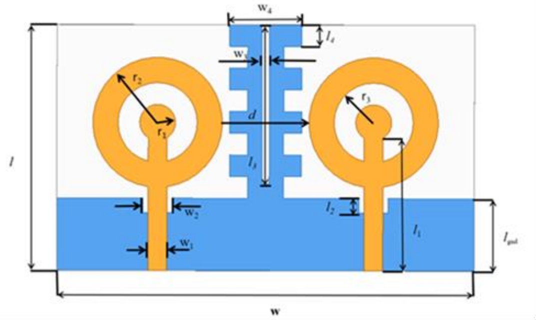


Fig 1 Proposed MIMO Antenna

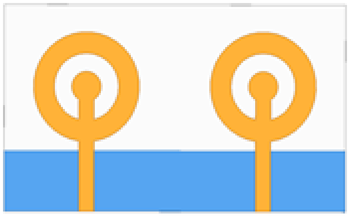
On its upper surface, two symmetrically placed antenna elements are printed. Each antenna element comprises a circular patch with an etched C-shaped slot and a rectangular microstrip line. The lower surface is covered with a rectangular metal ground. The isolation between the antenna ports is improved by introducing a T-shaped grounding stub and etching a rectangular slot structure. The antenna is fed using a 50 Ω microstrip line. The simulation and design were conducted using Ansoft HFSS software. After optimization, the overall dimensions of the antenna are 58mm × 34mm × 1.6mm, with detailed structural parameters listed in Table 1.

Table 3-1: Detailed Structural Parameters of the Dual-Band MIMO Antenna

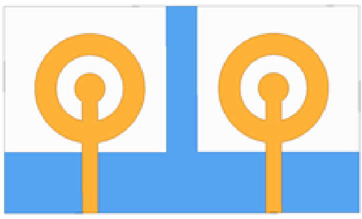
Parameters	Value (mm)	Parameters	Value (mm)
l	58	w	34
r_1	2.5	w_1	2.6
r_2	9	w_2	4
r_3	5.5	w_3	1.5
l_1	16.9	w_4	8
l_2	2	l_{gnd}	10
l_3	22	d	12
l_4	2	h	1.6

B. *Decoupling Structure Design*

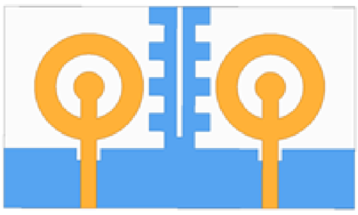
Figure 2 illustrates the design process of the high-isolation dual-band MIMO antenna. Initially, two identical dual-band monopole antennas are symmetrically placed on an FR4 substrate without a decoupling structure, leading to strong coupling due to a small edge spacing of 0.14 λL at 3.5 GHz. To reduce coupling, a rectangular parasitic inverted T grounding branch is added at the center of the ground plane, introducing a new coupling path and improving isolation. Further enhancement is achieved by etching a central rectangular slot and symmetric slots on the ground plane, optimizing coupling strength and impedance matching.



(a)



(b)



(c)

Fig. 2 Design process of the antenna structure: (a) Antenna1; (b) Antenna2; (c) Antenna3

IV. SIMULATION RESULTS

The following is the simulation results of a Dual-Band MIMO antenna with a hybrid rectangular Defected Ground Structure. The antenna's key performance parameters, such as Reflection Coefficient (S11), Transmission Coefficient

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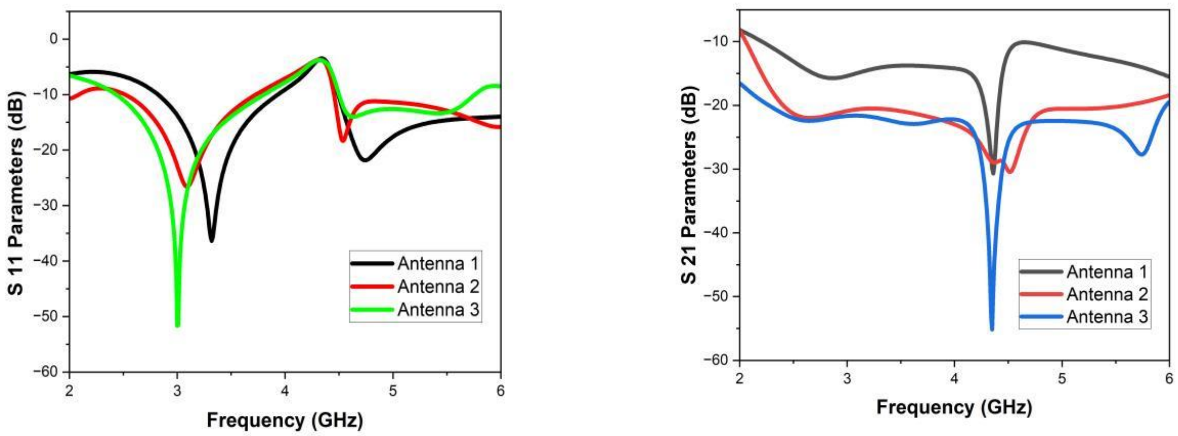
(S21), Radiation Pattern (E & H plane), Gain, ECC, and Diversity Gain, are studied throughout the simulation. All the simulation results are done using Ansys HFSS 2021 software.

C. Reflection & Transmission Coefficients (S11 & S21)

The reflection coefficient (S11) measures how efficiently an antenna radiates, with values below -10 dB indicating good impedance matching. The transmission coefficient (S21) shows power transfer between antenna ports, with values below -20 dB, ensuring minimal signal loss in MIMO systems. Two dual-band antenna elements are symmetrically placed on an FR4 dielectric substrate, forming Antenna 1, as shown in Figure 2(a). Due to physical space constraints, the antennas are closely spaced, with an edge distance of only 0.14 λL (where λL is the free-space wavelength at the low-frequency resonance of 3.5 GHz), leading to strong mutual coupling. Figure 3(a) presents the simulated S-11 parameters of the dual-band MIMO antenna. In Antenna 1, strong mutual coupling causes poor impedance matching at low frequencies. Antenna 2 introduces a rectangular grounding branch, improving low-frequency performance. Antenna 3 further enhances impedance matching by adding four rectangular slots and a ground plane slot. The resulting operating bands are 2.37-3.71 GHz (44.1%) and 4.07-5.73 GHz (33.9%), demonstrating good dual-band characteristics.



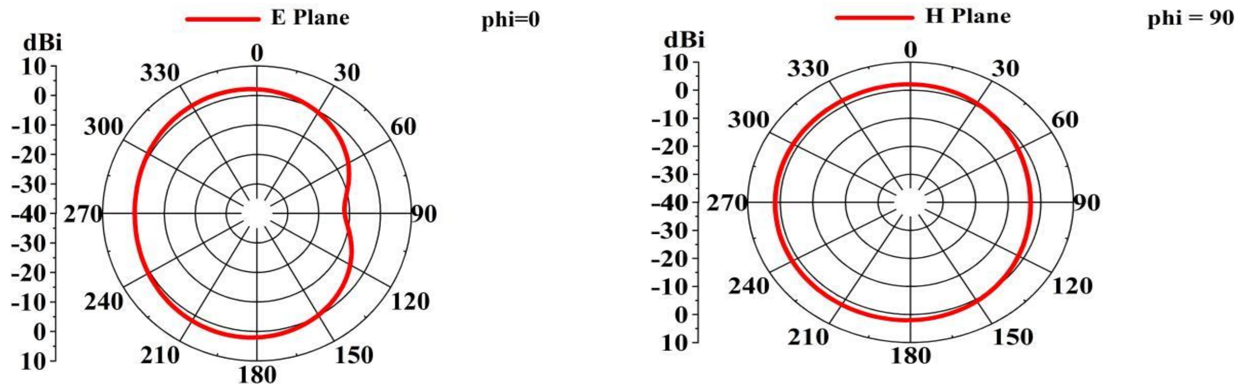
(a) (b)

Fig. 3 S-parameters of the Antenna: (a) Reflection Coefficients (S-11); (b) Transmission Coefficients (S-21)

Figure 3(b) shows the simulated transmission coefficient (|S21|) curves of the dual-band MIMO antenna. Antenna 1 has poor isolation (~15 dB) in both bands due to strong coupling. Antenna 2 improves isolation by adding a rectangular grounding branch, increasing isolation at 3.5 GHz (14 dB to 23 dB) and 4.8 GHz (10 dB to 32 dB). Antenna 3 further enhances isolation by etching rectangular slots, achieving >27 dB and >42 dB isolation in the two bands, with up to 42 dB at 4.8 GHz - a 32 dB improvement over Antenna 1. These results confirm that the decoupling structure effectively suppresses mutual coupling.

D. Radiation Pattern

Figure 4 shows the 2D radiation patterns of the antenna at 3.5 GHz and 4.8 GHz, with one port excited and the other terminated with a 50 Ω load. The decoupling structure slightly affects pattern symmetry but causes no significant distortion. The E-plane (xoz) and H-plane (yoz) patterns remain nearly circular, ensuring good omnidirectional radiation. The antenna achieves maximum gains of 3.1 dBi at 3.5 GHz and 4.5 dBi at 4.8 GHz.



(a)

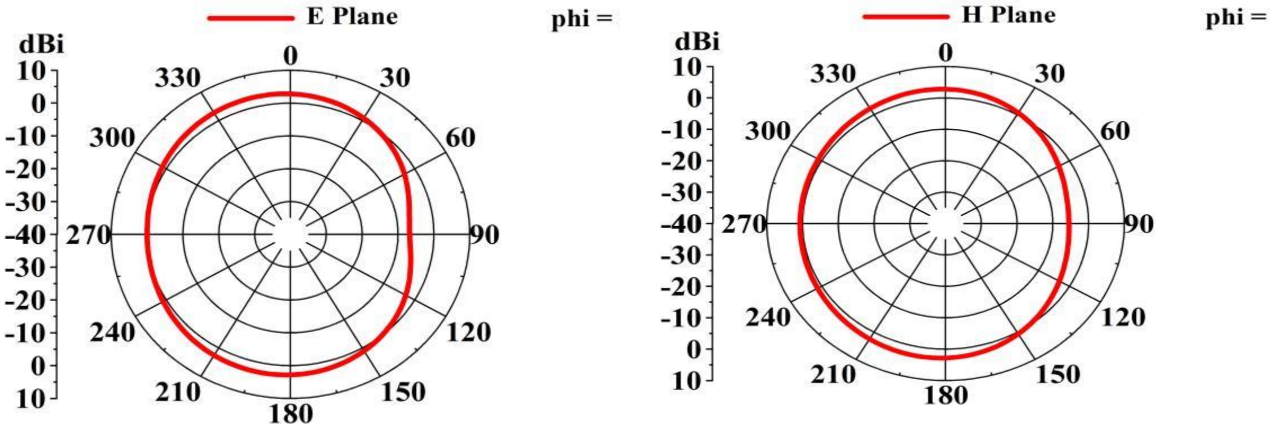


Fig. 4 Simulated antenna radiation patterns at 3.5 and 4.8 GHz: (a) 3.5 GHz; (b) 4.8 GHz.

E. ENVELOPE CORRELATION COEFFICIENTS (ECC)

The Envelope Correlation Coefficient (ECC) measures the degree of correlation between the signals received by multiple antennas in a MIMO system. A low ECC value (typically less than 0.5) is crucial for MIMO antenna designs as it ensures minimal mutual interference between antenna elements, leading to improved diversity, capacity, and overall system performance. Figure 5 shows the variation of the ECC for the dual-band MIMO antenna with frequency. The figure shows that the ECC of the antenna in both of its operating frequency bands is below 0.001, which meets the design requirement of ECC being less than 0.5 for MIMO antennas.

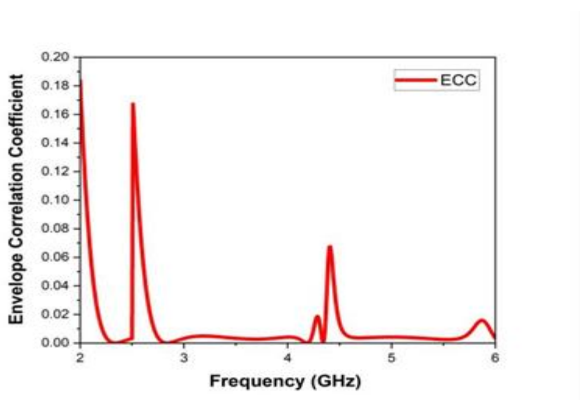


Fig. 5 The ECC Curve

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V. DISCUSSION

Table 2 compares the performance of the dual-band MIMO antenna designed in this paper with the MIMO antennas proposed in existing literature. As shown in the table, the dual-band MIMO antenna designed in this chapter is similar in size to the antenna designed in reference [15], but the antenna in this chapter offers higher isolation in the high-frequency band, along with a more favorable relative bandwidth and envelope correlation coefficient. The three-band MIMO antenna designed in reference [16] has a smaller and simpler decoupling structure, but its isolation in the low-frequency band is relatively low. The dual-band MIMO antennas proposed in references [17] and [18] offer good isolation at their resonant frequencies; however, they have larger overall sizes and complex decoupling structures, which hinder the miniaturization and integration of the antenna. Compared with reference [19], the dual-band MIMO antenna designed in this chapter has a smaller overall size, better isolation performance at both operating frequencies, a wider relative bandwidth, and a lower envelope correlation coefficient. In conclusion, the high-isolation dual-band MIMO antenna designed in this chapter has a simple structure and can achieve good isolation characteristics, wide relative bandwidth, and low envelope correlation coefficient in a compact size.

Table 2. Performance comparison with existing literature

Ref.	Operating Frequency (GHz)	Isolation (dB)	Relative Bandwidth (%)	Dimensions (mm)	ECC
[15]	2.45, 5.85	25, 27	4.1, 5.2	70 × 70 ×0.8	< 0.025
[16]	2.3, 3.5, 5.7	18.2, 32.4, 24.3	9.0, 19.2, 2.6	49 × 48 ×0.8	< 0.02
[17]	3.7, 4.1	34.2, 36.3	1.5, 2.0	60.6 × 48.5 × 20	< 0.01
[18]	2.6, 3.5	34, 28	7.7, 5.7	150 × 100 × 17.8	< 0.08
[19]	2.4, 5.5	21, 23	6.5, 20.7	77.5 × 52 × 1.6	< 0.2
This work	3.5, 4.8	27, 42	44.1, 33.9	58 × 34 ×1.6	< 0.001

VII. CONCLUSION AND FUTURE WORK

A high-isolation dual-band MIMO antenna is proposed, integrating grounded branches and a defected ground structure. A C-shaped slot on the circular monopole enables dual-band operation. T-shaped branches and rectangular slots enhance isolation, reaching 27 dB at 3.5 GHz and 42 dB at 4.8 GHz. The antenna (58mm × 34mm × 1.6mm) operates in 2.37-3.71 GHz and 4.07-5.73 GHz, with gains of 3.1 dBi and 4.5 dBi. ECC remains below 0.001, ensuring MIMO performance. Its compact, simple design and omnidirectional radiation make it ideal for 5G applications.

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