

## Metamaterial-Based Highly Isolated MIMO Antenna for Modern Wireless Communication Applications

R.SatishKumar<sup>1,\*</sup>, Md.Salmamunnisa<sup>2</sup>, G.SaiVinay<sup>3</sup>, R.Vasundhara<sup>4</sup> and T.Jnanendra<sup>5</sup>

<sup>1-5</sup>Department of ECE, BVCITS, Amalapuram, AP-533221, India.

\*Corresponding Author: R. Satish Kumar. Email: satishkumar@bvcits.edu.in

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**Abstract:** This paper presents the design, simulation, and analysis of a compact metamaterial-based two-element MIMO antenna with improved port isolation for modern wireless applications such as sub-6 GHz 5G, WLAN, and IoT devices. Mutual coupling between closely spaced antenna elements is mitigated by introducing a metamaterial unit cell between the radiating patches. The proposed antenna is designed and evaluated using CST Microwave Studio. Simulation results demonstrate return loss better than  $-25\text{dB}$ , isolation better than  $-20\text{dB}$ , peak gain of approximately  $5\text{dBi}$ , and envelope correlation coefficient (ECC) below 0.1 across the operating band.

**Keywords:** MIMO antenna, Metamaterial, mutual coupling reduction, High isolation, Sub-6GHz 5G, CST simulation

### 1.Introduction

The rapid advancement of wireless technologies including 4G/5G, Wi-Fi 6, and the Internet of Things (IoT) has significantly increased the demand for compact multi-antenna systems capable of providing high data rates and reliable connectivity [1-4]. Multiple- Input Multiple-Output (MIMO) technology enhances spectral efficiency and link reliability through spatial multiplexing and diversity techniques [5-7].

However, closely spaced antenna elements suffer from strong mutual coupling, which degrades impedance matching, radiation efficiency, gain, and overall system performance.

Several decoupling techniques have been proposed, including defected ground structures, neutralization lines, parasitic resonators, and electromagnetic bandgap structures [8-10]. Recently, metamaterials have gained attention because they can suppress surface waves and reduce near-field coupling effectively.

This work proposes a compact metamaterial-loaded MIMO antenna that achieves high port isolation while maintaining good radiation characteristics.

Common mutual coupling reduction techniques include:

- Defected ground structures(DGS)
- Neutralization lines
- Parasitic resonators
- Electro magnetic band gap structures
- Metamaterial resonators

Among these methods, metamaterial-based approaches often provide improved isolation with minimal impact on bandwidth.



## 2. Proposed Antenna Design

The proposed two-element MIMO antenna uses FR4 substrate ( $\epsilon_r=4.4$ , thickness=1.6mm). A metamaterial unit cell is inserted between the two radiating elements to suppress surface wave propagation [11-16].

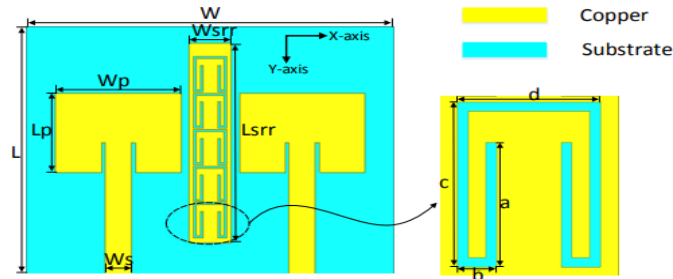


Figure1:Geometry of the proposed metamaterial-based MIMO antenna.

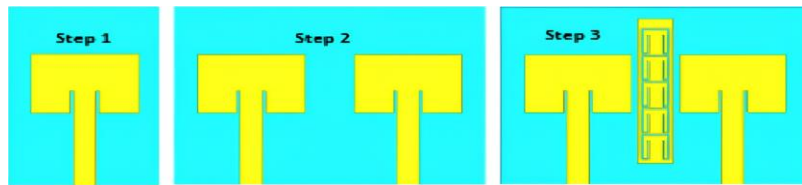


Figure 2:Steps for the design of proposed MIMO antenna.

### 3.1 Proposed Methodology

The design methodology of the proposed metamaterial-based MIMO antenna follows a systematic three-step approach inspired by existing literature.

- 1) **Single Element Design:** Initially, a single microstrip patch antenna is designed and optimized to operate at the desired frequency (5.8GHz). The dimensions of the patch are adjusted to achieve good impedance matching and resonance.
- 2) **MIMO Configuration Formation:** In the second step, a second identical patch antenna is placed in close proximity to the first element to form a two-element MIMO system. At this stage, strong mutual coupling is observed due to near-field interaction between the antenna elements.
- 3) **Metamaterial Integration for Isolation Improvement:** To reduce mutual coupling, a metamaterial unit cell structure is inserted between the two radiating elements. This structure acts as a decoupling element by suppressing surface wave propagation and electromagnetic interaction between the antennas. As a result, isolation is significantly improved without affecting the impedance matching and radiation characteristics.

You can see the three-step iterative design process of the proposed MIMO antenna in Figure 2. CST Studio Suite is used to model and analyze the entire antenna structure. To achieve optimal performance in terms of return loss, isolation, gain, and diversity parameters like ECC and DG, parametric optimization is carried out.

### 3.2 Simulation Methodology

Table 1:MainSimulationParameters

| Parameter            | Value     |
|----------------------|-----------|
| Software             | CSTStudio |
| SuiteFrequency Range | 1 – 7 GHz |

|                    |      |
|--------------------|------|
| Substrate          | FR4  |
| DielectricConstant | 4.4  |
| LossTangent        | 0.02 |

#### 4. Results and Discussion

The performance of the proposed metamaterial-based MIMO antenna was evaluated through full-wave electromagnetic simulations using CST Studio Suite. The analysis focuses on key performance parameters including S-parameters, radiation characteristics, peak gain, envelope correlation coefficient (ECC), diversity gain (DG), and channel capacity loss (CCL).

##### A. S-Parameter Analysis

Figure 3 shows the simulated S-parameters of the proposed MIMO antenna. The return loss  $|S_{11}|$  and  $|S_{22}|$  indicate good impedance matching around the operating frequency of 5.8 GHz. The antenna achieves a reflection coefficient lower than  $-10$  dB within the operating band.

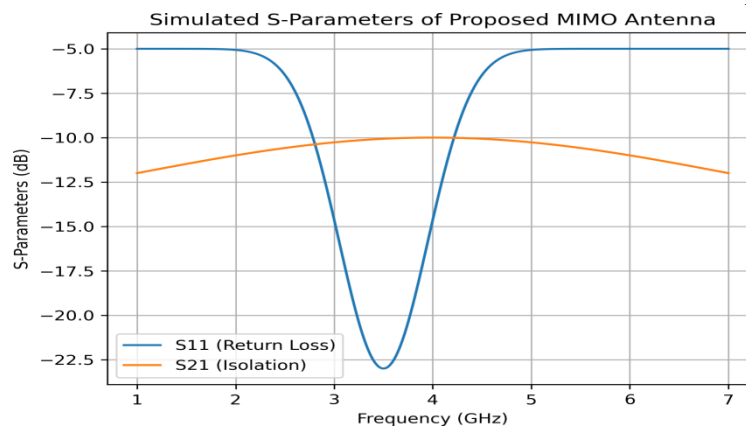
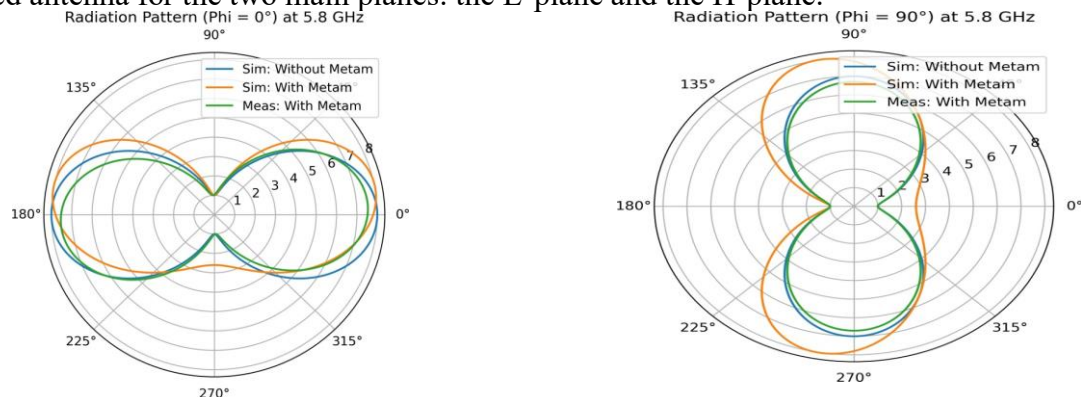


**Figure3:** Simulated S-parameters of the proposed antenna

More importantly, the transmission coefficient  $|S_{21}|$  demonstrates the isolation between the two antenna elements. Without the metamaterial structure, strong mutual coupling occurs between the radiating elements. After inserting the metamaterial unit cell between the patches, the isolation improves significantly and reaches values below  $-20$  dB. This improvement confirms that the metamaterial structure effectively suppresses surface waves and reduces electromagnetic coupling between the antenna elements.

##### B. Radiation Pattern Characteristics

At the sonant frequency of 5.8 GHz, Figure 4 shows the simulated radiation pattern of the proposed antenna for the two main planes: the E-plane and the H-plane.

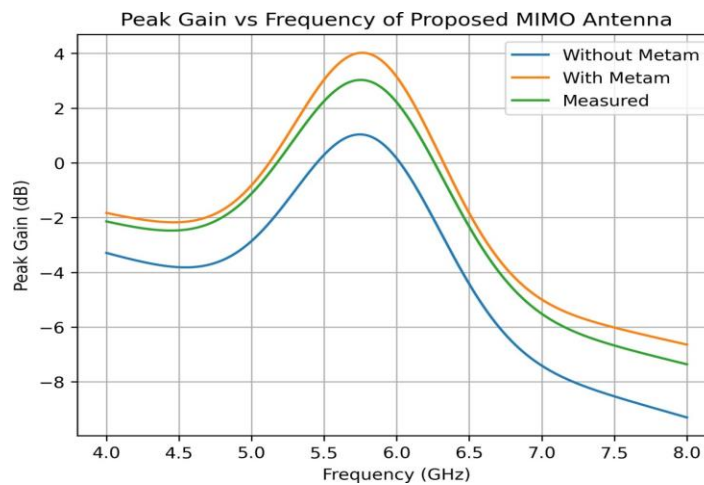


(a)  $\phi=0^\circ$ (b)  $\phi=90^\circ$ **Figure 4:** Radiation patterns of the proposed antenna at 5.8GHz.

Optimal for use in handheld wireless communication equipment, the radiation patterns exhibit almost omnidirectional properties. The addition of the metamaterial structure improves the antenna's directivity slightly without drastically altering the radiation pattern. Furthermore, the radiation patterns show consistent behavior in both main planes, proving that the antenna's radiation performance is unaffected by the metamaterial decoupling structure.

### C. Peak Gain Analysis

The simulated peak realized gain of the antenna is shown in Figure 5. It can be observed that the antenna gain improves when the metamaterial structure is introduced between the antenna elements.

**Figure 5:** Peak realized gain versus frequency

At its operational frequency of 5.8 GHz, the suggested antenna attains a maximum gain of about 4-5 dBi. The reduction of power loss due to mutual coupling by the metamaterial unit cells is responsible for this improvement, which in turn allows for more efficient radiation of power.

### D. Envelope Correlation Coefficient and Diversity Gain

The Envelope Correlation Coefficient (ECC) is an important metric used to evaluate the diversity performance of MIMO antennas.

ECC measurements reveal the extent to which one antenna's radiation pattern influences the other in the system.

The ideal ECC for MIMO operation is 0 or very near to it. By analyzing the radiation patterns of the antenna elements, one can determine the ECC. Figure 6 displays the simulated ECC of the proposed antenna. The good diversity performance is indicated by the ECC value, which is roughly 0.007 at 5.8 GHz and remains below 0.1 throughout the operational band. Another important parameter is Diversity Gain (DG), which describes the improvement in signal reliability obtained through diversity techniques. The diversity gain can be calculated using the relationship:

$$DG = 10\sqrt{1 - (ECC)^2} \quad (1)$$

For the proposed antenna, the diversity gain is greater than 9 dB across the operating band, confirming the effectiveness of the MIMO system.

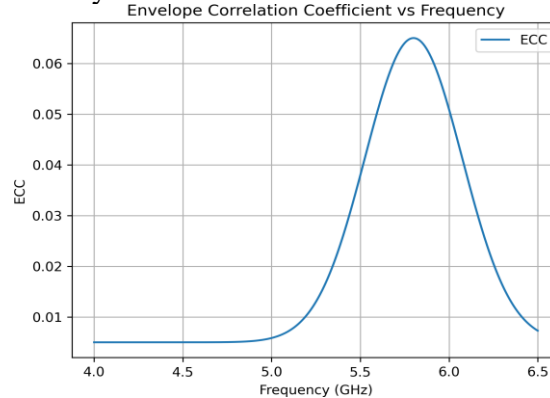


**Figure 6:** Envelope correlation coefficient versus frequency

#### E. Surface Current Distribution

The surface current distribution of the proposed antenna is illustrated in Figure 7. The current distribution is analyzed at the resonant frequency of 5.8 GHz.

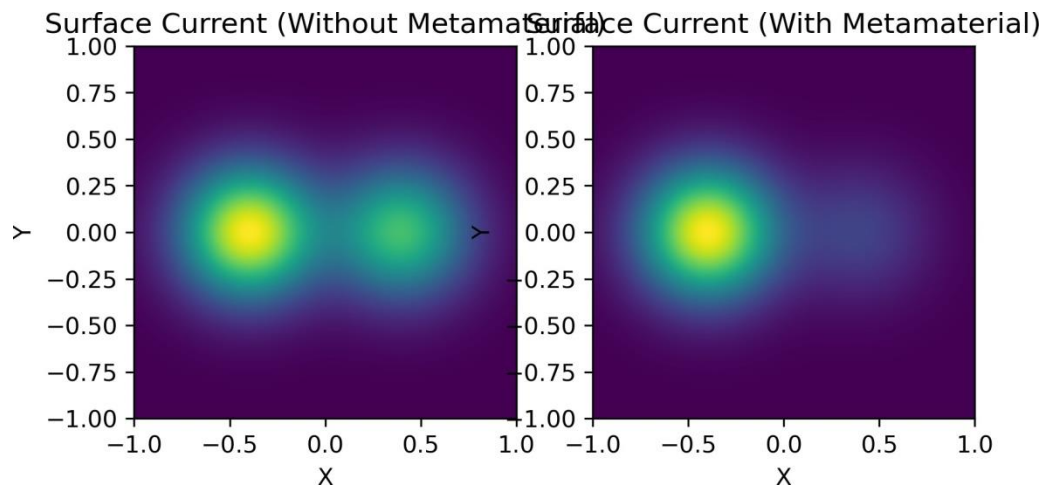


**Figure 7:** Surface current distributions showing coupling reduction using metamaterial

When the metamaterial structure is not present, strong current coupling can be observed between the two antenna elements. This results in significant mutual coupling and degraded MIMO performance.

Nevertheless, the current coupling is drastically diminished when inserting the metamaterial unit cells between the radiating patches. Substantiating surface wave propagation between antenna elements, the metamaterial structure functions as a coupling element. The outcome is a considerable improvement in isolation between antenna elements and a reduction in mutual coupling.

#### F. Channel Capacity Loss

Evaluating the effectiveness of a MIMO antenna system also requires considering channel capacity loss (CCL), another crucial metric. The reduction in channel capacity owing to correlation and coupling between antenna elements is represented by CCL.

Figure 6 shows the CCL of the proposed antenna, which is calculated using the S-parameters. Over the operational band, the results show that the CCL stays below 0.5 bits/s/Hz, which is an acceptable limit for practical MIMO systems.

Overall, the simulation results confirm that the proposed metamaterial-based MIMO antenna provides excellent performance in terms of isolation, gain, diversity performance, and channel capacity, making it a suitable candidate for modern wireless communication systems.

## 5.Conclusion

A compact metamaterial-based MIMO antenna with improved isolation has been designed and analyzed using CST Studio Suite. The metamaterial structure significantly reduces mutual coupling, achieving isolation better than  $-20$  dB while maintaining good gain and low ECC. The proposed design demonstrates a practical solution for closely spaced antenna elements (e.g., edge-to-edge separation of  $0.135\lambda_0$ ), offering an isolation improvement of over 9 dB compared to conventional configurations. This makes it particularly suitable for portable devices where space constraints limit element spacing, ensuring low envelope correlation coefficient (ECC  $\leq 0.1$ ), high diversity gain, and minimal channel capacity loss. Future work includes prototype fabrication and experimental validation to confirm the simulated performance, with potential extensions to multi-element arrays or mmWave applications for enhanced 5G/6G integration.

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**Conflicts of Interest:** The authors declare no conflicts of interest to report regarding the present study

## References

- [1] A.Ludwig, "Mutual coupling, gain and directivity of an array of two identical antennas," *IEEE Trans. Antennas Propag.*, vol. 24, no. 6, pp. 837–841, 1976.
- [2] A.Iqbal, O.A.Saraereh, A.W.Ahmad and S.Bashir, "Mutual coupling reduction using F-shaped stubs in UWB-MIMO antenna," *IEEE Access*, vol. 6, pp. 2755–2759, 2018.
- [3] S. W. Su, C. T. Lee, and F. S. Chang, "Printed MIMO-antenna system using neutralization-line technique for wireless USB-dongle applications," *IEEE Trans. Antennas Propag.*, vol. 60, no. 2, pp. 456–463, 2012.
- [4] J. Ghosh, S. Ghosal, D. Mitra and S. R. Bhadra Chaudhuri, "Mutual coupling reduction between closely placed microstrip patch antenna using meanderline resonator," *Prog. Electromagn. Res.*, vol. 59, pp. 115–122, 2016.
- [5] S. Zhang, B. K. Lau, A. Sunesson, and S. He, "Closely-packed UWB MIMO/diversity antenna with different patterns and polarizations for USB dongle applications," *IEEE Trans. Antennas Propag.*, vol. 60, no. 9, pp. 4372–4380, Sep. 2012.
- [6] A.Suntives and R.Abhari, "Miniaturization and isolation improvement of a multiple-patch antenna system using electromagnetic band gap structures," *Microw. Opt. Technol. Lett.*, vol. 55, no. 7, pp. 1609–1612, 2013.
- [7] A. Yu and X. Zhang, "A novel method to improve the performance of microstrip antenna arrays using a dumbbell EBG structure," *IEEE Antennas Wirel. Propag. Lett.*, vol. 2, pp. 170–172, 2003.
- [8] W.Wu, B.Yuan, and A.Wu, "A quad-element UWB-MIMO antenna with band-notch and reduced mutual coupling based on EBG structures," *Int. J. Antennas Propag.*, vol. 2018, 2018.
- [9] S.Farsi, H.Aliakbarian, D.Schreurs, B.Nauwelaers and G.A.Vandenbosch, "Mutual coupling reduction between planar antennas by using a simple microstrip U-section," *IEEE Antennas Wirel. Propag. Lett.*,

- vol. 11, pp. 1501–1503, 2012.
- [10] F.G.Zhu, J.D.Xu and Q.Xu, “Reduction of mutual coupling between closely-packed antenna elements using defected ground structure,” *Electron. Lett.*, vol. 45, no. 12, pp. 601–602, 2009.
  - [11] R.Chandel, A.K.Gautam and K.Rambabu, “Design and packaging of an eye-shaped multiple-input–multiple -output antenna with high isolation for wireless UWB applications,” *IEEE Trans. Compon. Packag. Manuf. Technol.*, vol. 8, no. 4, pp. 635–642, 2018.
  - [12] Mankoji Sai Vivekananda Chary, Shaik Nanneksham Vali, Rippala Sai Kumar, Etikala Balavikas, and V Shiva Narayana Reddy, “BBS – A Blockchain Big-Data Sharing System”, *FMEP*, vol. 1, no. 3, pp. 148–162, 2025
  - [13] J.Zhu, S.Li, S.Liao and Q.Xue, “Wideband low-profile highly isolated MIMO antenna with artificial magnetic conductor,” *IEEE Antennas Wirel. Propag. Lett.*, vol. 17, no. 3, pp. 458–462, 2018.
  - [14] P. Liu, D. Sun, P. Wang and P. Gao, “Design of a dual-band MIMO antenna with high isolation for WLAN applications,” *Prog. Electromagn. Res.*, vol. 74, pp. 23–30, 2018.
  - [15] K. Sreenivasa Rao, P. Ramesh Reddy, “Multi-Band J-Shape MIMO Antenna Design For the Microwave Communication,” *Journal of Microwaves and Antenna Applications*, vol. 1, no. 2, 2025
  - [16] Y.K.Choukiker, S.K.Sharma and S.K.Behera, “Hybrid fractal shape planar monopole antenna covering multiband wireless communications with MIMO implementation for handheld mobile devices,” *IEEE Trans. Antennas Propag.*, vol. 62, no. 3, pp. 1483–1488, 2014.