(IJCSNT) International Journal of Communication Systems and Network Technologies
ISSN Number: 2053-6283
Volume 14, Issue No. 2, 118–130

https://journals.mirlabs.in/index.php/ijcsnt
DOI-10.18486/ijcsnt/14.2.011
IJCSNT

# Design of an Ultra-Wideband Two-Element MIMO Antenna with Improved Performance

**Krishna Rao Pedada[1], T. Reshma[2], Chaitanya Kumar Marpu[3], K. Tejasree[4], S. Akhila[5], S. Mythili[6]**


## Abstract

In this paper an efficient two element ultra wideband MIMO antenna is designed. First single UWB is designed. Then two element MIMO antenna is designed and its characteristics are observed. Then using double couplet defected ground structure the antenna performance is improved interms of isolation, ECC, DG. The designed 2 element MIMO antenna with DGS operates over (2.09-12.01)GHz. Due to DGS the mutual copuling has reduced by 13.61dB and return loss improved by 10.1dB at X-band frequency. ECC close to zero and diversity gain nearly 10 are achieved for the MIMO antenna with DGS. The simulations are carried using HFSS software and simulation results are compared with measured results.



## Keywords

Defected Ground Structure (DGS), Ultra-wideband (UWB), Envelope Correlation Coefficient (ECC), Diversity Gain (DG) and MIMO Antenna

**Received:** 10 May 2025; **Revised:** 11 July 2025; **Accepted:** 04 August 2025;
**Published:** 31 August 2025;


[1, 2, 3, 4, 5, 6]Department of Electronics and Communication Engineering, Aditya Institute of Technology and Management, Srikakulam, Andhra Pradesh, India.

**Corresponding author:**
Email: pkr.ece@adityatekkali.edu.in

## Introduction

Ultra-wideband (UWB) communication technology has attracted significant attention due to its ability to support high data rates, low power consumption, precise ranging, and immunity to multipath fading. Since the allocation of the UWB spectrum from 3.1 to 10.6 GHz by the Federal Communications Commission (FCC), UWB systems have found widespread applications in short-range wireless communications, radar imaging, biomedical sensing, and Internet of Things (IoT) devices [1–3]. One of the critical components in such systems is the antenna, which must exhibit wide impedance bandwidth, stable radiation characteristics, compact size, and ease of integration with planar circuits.

To further enhance channel capacity and link reliability in UWB systems, multiple-input multiple-output (MIMO) technology has been extensively explored [4,5]. By employing multiple antennas at the transmitter and receiver, MIMO systems can exploit spatial diversity and multipath propagation to improve spectral efficiency and reduce fading effects. However, the implementation of UWB MIMO antennas poses several challenges, particularly due to the strong mutual coupling between closely spaced antenna elements, which degrades impedance matching, radiation efficiency, envelope correlation coefficient (ECC), and overall diversity performance [6].

Various techniques have been reported in the literature to mitigate mutual coupling and improve isolation in UWB MIMO antenna designs. These include orthogonal antenna placement [7], neutralization lines [8], parasitic elements [9], electromagnetic bandgap (EBG) structures [10], and defected ground structures (DGS) [11–13]. Among these approaches, DGS has emerged as an effective and compact solution due to its ability to suppress surface currents, enhance isolation, and improve impedance bandwidth without significantly increasing antenna size or complexity.

Defected ground structures introduce intentional perturbations in the ground plane, thereby modifying the current distribution and equivalent inductance–capacitance characteristics of the antenna system [14]. Several DGS geometries, such as slots, dumbbell shapes, fractal patterns, and coupled resonant structures, have been investigated for UWB and MIMO applications [15–17]. In particular, coupled or multi-resonant DGS configurations have shown superior performance in terms of isolation enhancement and correlation reduction across wide frequency bands.

Motivated by these observations, this paper presents the design and analysis of an efficient two-element UWB MIMO antenna employing a double-couplet defected ground structure to enhance antenna performance. The design process begins with the development of a single UWB antenna element, which is then extended to a two-element MIMO configuration. Subsequently, a double-couplet DGS is introduced in the ground plane to suppress mutual coupling and improve key MIMO performance metrics such as isolation, envelope correlation coefficient (ECC), and diversity gain (DG).

The proposed UWB MIMO antenna with DGS operates over a wide frequency range of 2.09–12.01 GHz, covering the entire UWB band and extending beyond it. The introduction of the DGS results in a significant reduction in mutual coupling by 13.61 dB and an improvement in return loss by 10.1 dB at the X-band frequency. Furthermore, the antenna exhibits ECC values close to zero and a diversity gain approaching the ideal value of 10 , confirming its excellent diversity performance. The antenna is designed and simulated using HFSS, and the simulated results are validated through experimental measurements, demonstrating good agreement.

The remainder of this paper is organized as follows: Section II describes the antenna geometry and design methodology. Section III presents the simulated and measured results, including S-parameters, radiation characteristics, and MIMO performance metrics. Section IV provides a comparison with existing works, and Section V concludes the paper.

## The Antenna Geometry and Design Methodology

First, single square patch antenna dimensions are calculated for resonant frequency of $f_0$ = 4.56GHz, on FR4 substrate with dielectric constant $\varepsilon_r$ = 4.4. The height of the substrate is h = 1.6mm. The length and width and length are calculated using the following equation[18,19].

$$L = W = \frac{c}{2f_0\sqrt{\frac{\varepsilon_r + 1}{2}}} \tag{1}$$

Then the edges of the patch are cut in a stair case manner as shown in figure-1 and tapered edge feeding is given for the antenna. Then partial ground is maintained as shown in figure-1. The partial ground plane dimension of 15mm is obtained by optimization for ultra-wideband bandwidth.

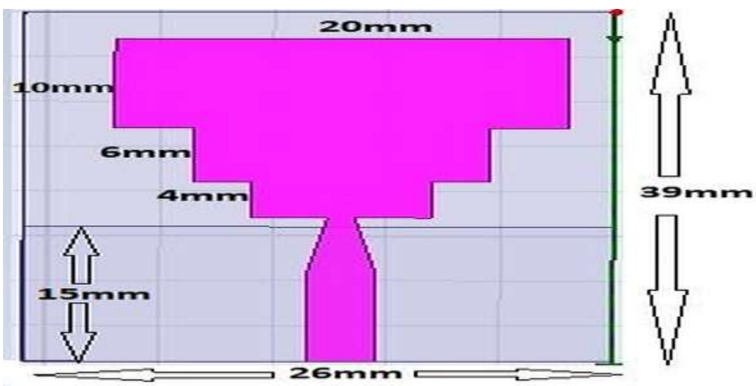


**Figure 1.** single UWB antenna.

Then in step2, two element MIMO antenna is designed using single element discussed above with a spacing of 0.4$\lambda$ as shown in figure 2.

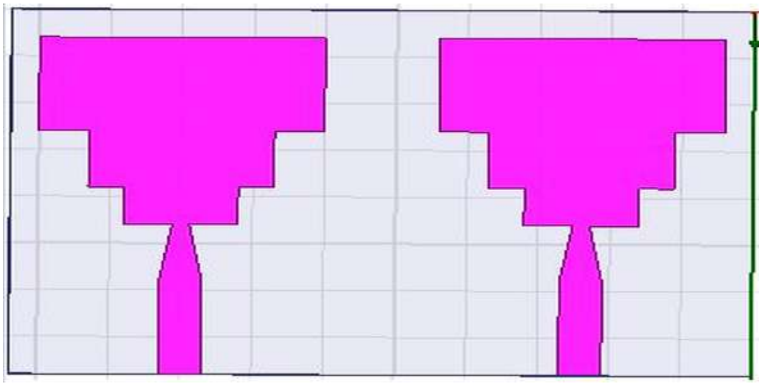

**Figure 2.** Two element MIMO antenna.

Then in step3, a 2x3 matted structure with double couplet structure as unit cell is realized in the ground plane as defected ground structure(DGS) for the two element MIMO antenna. Figure 3 shows the two element MIMO antenna with DGS. The dimensions of the double couplet unit cell, antenna dimensions are shown in the table-1 below.

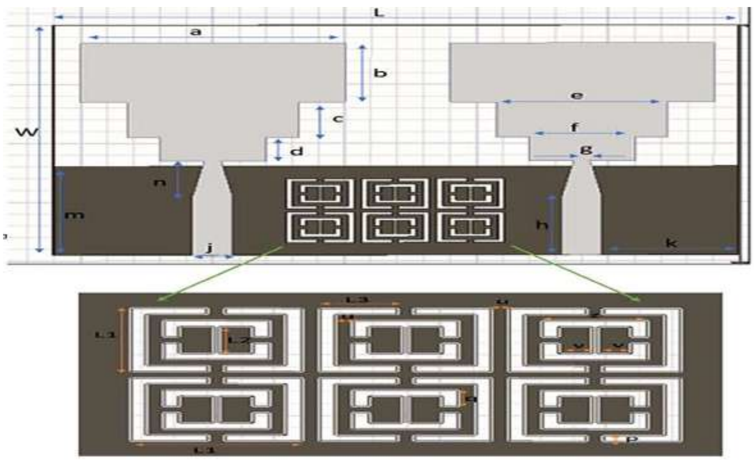


**Figure 3.** Two element MIMO antenna with DGS

**Table 1.** Dimensions of the 2 element MIMO antenna with DGS

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| a | b | c | d | e | f | g | h | k | j |
| 20 | 10 | 6 | 4 | 13 | 8 | 1.2 | 10 | 10.5 | 3 |
| m | n | L | W | L1 | L2 | L3 | u | v | z |
| 15 | 6 | 52 | 39 | 5.2 | 2.2 | 2.35 | 0.5 | 1 | 3.2 |
| q | p | | | | | | | | |
| 1.35 | 0.5 | | | | | | | | |

By placing single double couplet DGS cell between the antennas, the mutual coupling will reduce within the x-band. To further reduce mutual coupling, the cell is repeated as 2x3 patterns. Based on the size of unit cell the frequency band of isolation can be varied. Surface waves are one of the main reasons for mutual coupling between the antennas. By placing the double couplet matted DGS structure in the ground plane, it disturbs the uniform current distribution and also increases the effective inductance and capacitance due narrow gaps in the cell. As a whole this DGS will exhibit stop-band behaviour at high frequencies. This results in reducing the mutual coupling between the antennas.

## Simulated and Measured Results

Figure 4 shows the return loss plot for the single UWB antenna designed. This antenna has bandwidth of 9.44GHz from 2.16GHz to 11.6GHz.

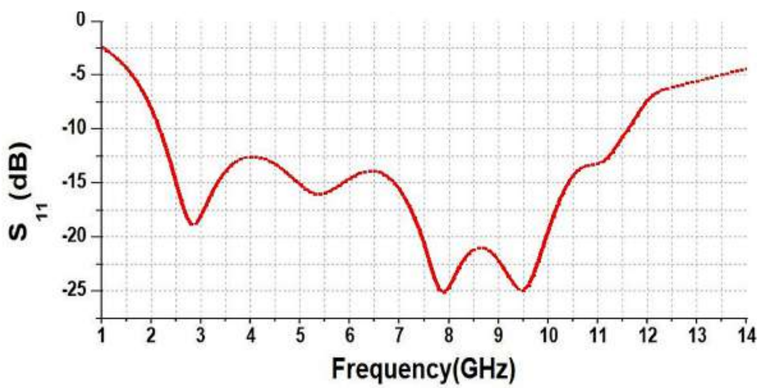


**Figure 4.** Return loss plot for single UWB antenna

Figure 5 shows the return loss comparison plot for the 2 element MIMO antenna in two cases. Without DGS the MIMO antenna has 8.9GHz impedance bandwidth, whereas with DGS the MIMO antenna gives 9.92GHz bandwidth. There is an improvement of bandwidth by 1.02GHz due to DGS.

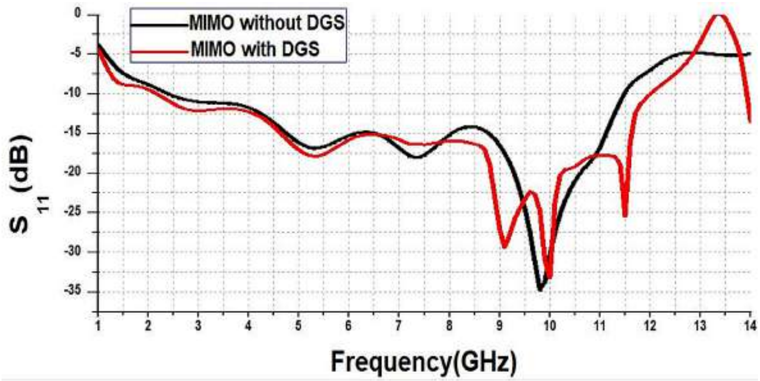


**Figure 5.** Return loss comparison plot for 2 element MIMO antenna

Figure 6 shows the comparison plot for mutual coupling with respect to frequency in case of MIMO antenna in both cases. At 10.1GHz, mutual coupling of -20.4dB is observed without DGS. Whereas, after placing DGS mutual coupling of -34dB is observed at 10.1GHz. An improvement of 13.6dB in isolation is observed. Not only at 10.1GHz but over a band of frequencies in X-band, this is observed.

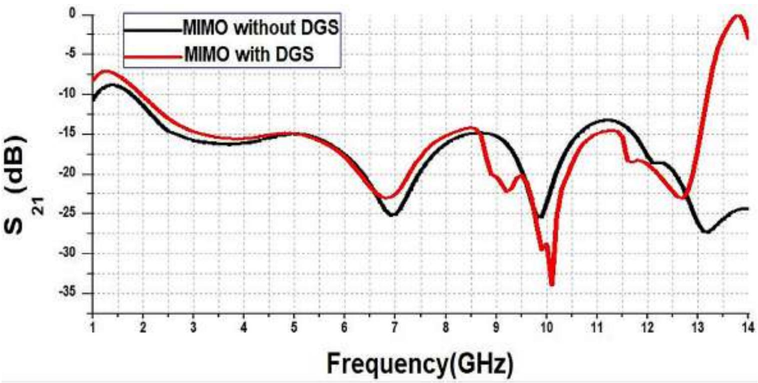


**Figure 6.** Mutual coupling comparison plot for 2 element MIMO antenna

Figure 7 shows the comparison plot of envelope correlation coefficient (ECC) in two cases for the MIMO antenna. ECC values close to zero are obtained in both cases.

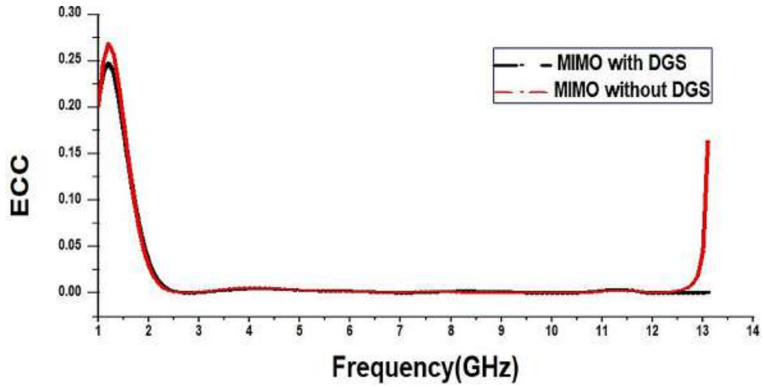


**Figure 7.** ECC comparison plot for 2 element MIMO antenna

Figure 8 shows the comparison plot of diversity gain (DG) in two cases for the MIMO antenna. DG values close to 10 are obtained in both cases.

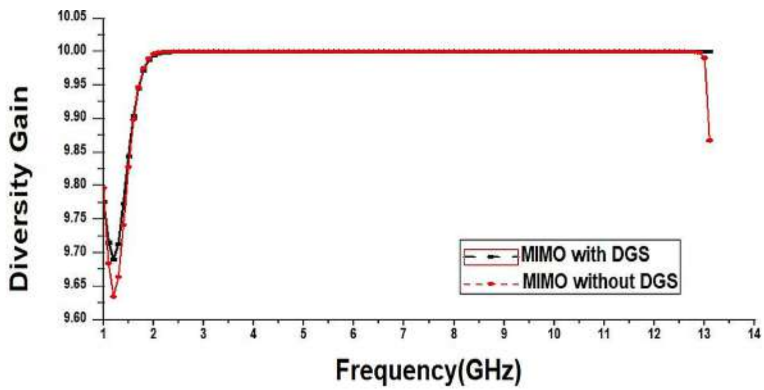


**Figure 8.** DG comparison plot for 2 element MIMO antenna

The amount of correlation between adjacent antennas in MIMO configuration is indicated by ECC. ECC values less than 0.5 are desirable for better diversity performance between adjacent radiators in the MIMO antenna. Higher values of ECC lead to higher correlation and mutual coupling between the radiators in the MIMO antenna. Similarly diversity gain (DG) also tells about isolation between the radiators in the MIMO antenna. DG values close to 10 are desirable. For the present 2 element MIMO antenna, in both cases ECC and DG are up to the mark. In fact with DGS performance is improved. Table 2 shows the comparison of ECC and DG in both cases.

**Table 2.** comparison of ECC and DG for 2 element MIMO antenna

| Frequency (GHz) | ECC | | DG | |
|---|---|---|---|---|
| | Without DGS | With DGS | Without DGS | With DGS |
| 2 | 0.0325 | 0.0287 | 09.98 | 09.99 |
| 6 | 0.0019 | 0.0016 | 09.99 | 10.00 |
| 8 | 0.0019 | 0.0010 | 10.00 | 10.00 |
| 10 | 0.0000 | 0.0000 | 10.00 | 10.00 |

Figure 9 and 10 shows the surface current distribution of 2 element MIMO antenna at 10.1GHz in two cases. Clearly from figure 9 it can be observed that surface currents in the ground plane cause mutual coupling between the antennas. When DGS is kept between the antennas, it minimizes the effect of surface current and there by reduces the mutual coupling between the antennas in the 2 element MIMO antenna.

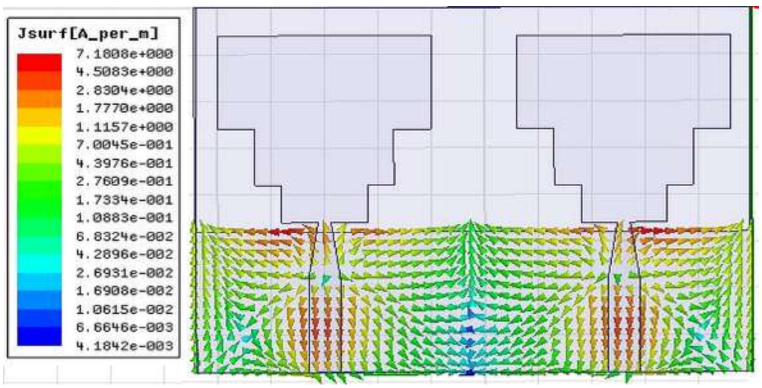


**Figure 9.** Surface current distribution for MIMO antenna without DGS

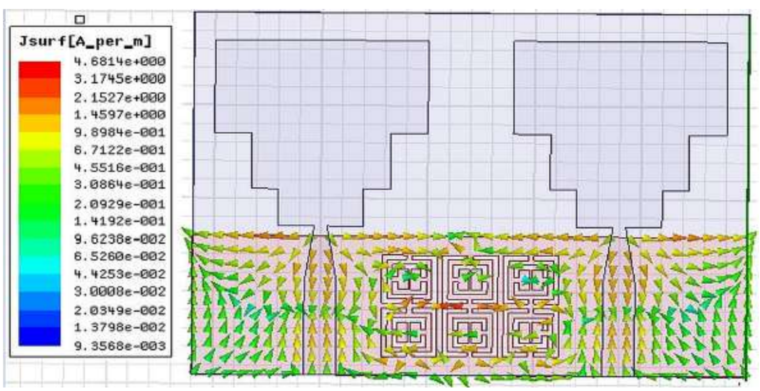


**Figure 10.** Surface current distribution for MIMO antenna with DGS

Figures11 and 12 shows the Gain 3D polar plots for the MIMO antenna, for single port excitation at 10.1GHz and 11.5GHz respectively in two cases. At 10.1GHz, the peak gain without DGS is 6.05dBi. It is 6.14dBi with DGS. With DGS the gain has improved little bit at 10.1GHz. At 11.5GHz the peak gain is 6.01dBi without DGS and it is 17.85dBi with DGS. The peak gain has drastically improved at 11.5GHz.

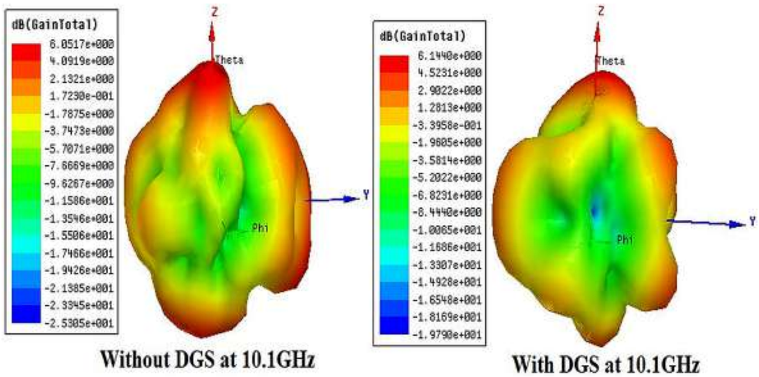


**Figure 11.** Gain 3D polar plot for MIMO antenna for single port excitation

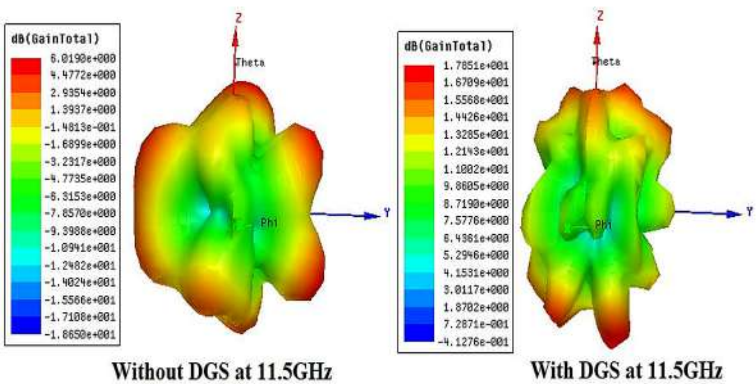


**Figure 12.** Gain 3D polar plot for MIMO antenna for single port excitation

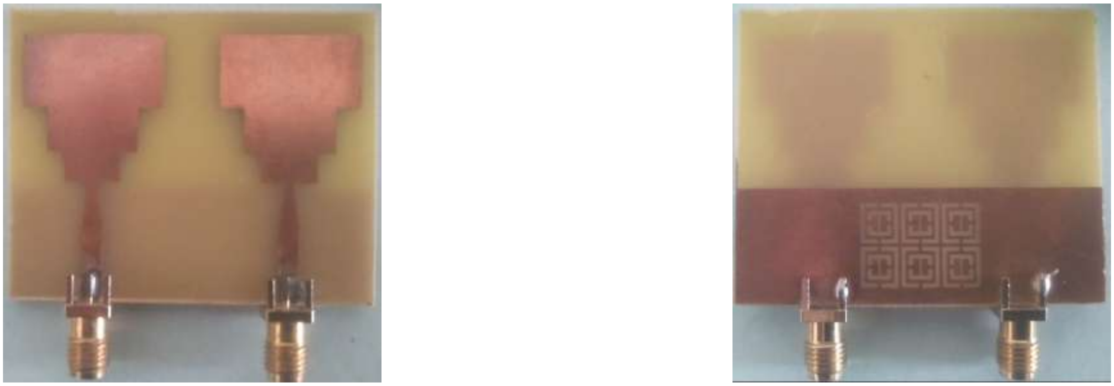

**Figure 13.** (a) Front view (b) Back view

Figures 13(a) and (b) shows the front and rear views of the fabricated 2 element MIMO antenna.

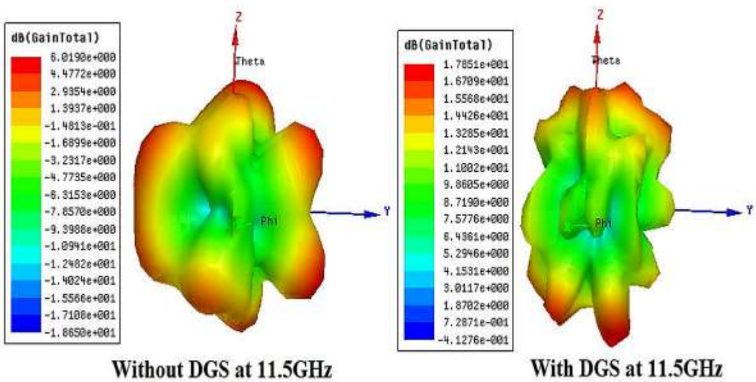


**Figure 14.** Mutual coupling comparison plot

Figure 14 shows the comparison plot of mutual coupling between the simulated and measured values. 5 to 10% deviation is observed within X-band between simulated and measured values.

## Comparison with Existing Works

**Table 3.** Comparison of current work with few existing works

| Reference | Technique Used | Operating band/ frequency | Isolation (S21) | Remarks |
|---|---|---|---|---|
| This Work | Double-couplet DGS between patch antennas | 10.1 GHz | -34 dB | Compact UWB MIMO with strong decoupling at X-band |
| [20] A. Ali et al., 2022 | S-shaped DGS | 3.57–4.48 GHz | -28 dB | Circularly polarized MIMO |
| [21] H. Xing et al., 2020 | Zigzag groove DGS | 5.8 GHz | -28.8 dB | Low ECC, improved isolation |
| [22] A. Sherila, 2025 | DGS + stub slot | 3.5 GHz | -30.6 dB | For 5G MIMO application |
| [23] Z. Zhang et al., 2018 | Fractal + arc DGS | 8–12 GHz | -20 dB | X-band MIMO antenna |
| [24] R. Anitha, 2014 | Ground-slot DGS | Varies | -18 dB | Early DGS-based isolation method |

Table 3gives the comparison of current work with some of the existing works. All have used different DGS structures. Current work uses double-couplet DGS technique and provides strong isolation between the elements of MIMO antenna.

## Conclusions

An ultra-wide band two element MIMO antenna is designed. Double-couplet matted DGS structure is placed between the two elements of MIMO antenna. By placing DGS the overall performance of the MIMO structure is improved. Low ECC values and DG values closer to 10 are obtained. Band width is improved by 1GHz and mutual coupling between the elements of MIMO structure is reduced especially with in the X-band. 13.6dB reduction in mutual coupling is observed at 10.1GHz. Not only that, Gain for single port excitation has improved with DGS in the X-band. By varying the cell size in the DGS structure, the mutual coupling can be reduced over other frequencies significantly with in the ultra-wide band. The measured values are close to simulated values with 5-10% deviation.

## References

[1] Federal Communications Commission, "First report and order: Revision of Part 15 of the Commission's rules regarding ultra-wideband transmission systems," FCC, Washington, DC, USA, 2002.

[2] R. M. Merrill, J. L. Volakis, and A. F. Peterson, "Ultra-wideband antennas: Design and applications," IEEE Antennas Propag. Mag., vol. 48, no. 6, pp. 25–38, Dec. 2006.

[3] D. M. Pozar, Microwave Engineering, 4th ed. Hoboken, NJ, USA: Wiley, 2012.

[4] A. Goldsmith, Wireless Communications. Cambridge, U.K.: Cambridge Univ. Press, 2005.

[5] S. Blanch, J. Romeu, and I. Corbella, "Exact representation of antenna system diversity performance from input parameter description," Electron. Lett., vol. 39, no. 9, pp. 705–707, May 2003.

[6] M. S. Sharawi, "Printed multi-band MIMO antenna systems and their performance metrics," IEEE Antennas Propag. Mag., vol. 55, no. 5, pp. 218–232, Oct. 2013.

[7] L. Liu, S. W. Cheung, and T. I. Yuk, "Compact MIMO antenna for portable devices in UWB applications," IEEE Trans. Antennas Propag., vol. 61, no. 8, pp. 4257–4264, Aug. 2013.

[8] Y. Ding, Z. Du, K. Gong, and Z. Feng, "A compact dual-band MIMO antenna with high isolation," IEEE Trans. Antennas Propag., vol. 61, no. 4, pp. 2081–2084, Apr. 2013.

[9] S. Zhang, K. Zhao, Z. Ying, and S. He, "Adaptive quad-element multi-wideband antenna array for user-effective LTE MIMO mobile terminals," IEEE Trans. Antennas Propag., vol. 61, no. 8, pp. 4275–4283, Aug. 2013.

[10] F. Yang and Y. Rahmat-Samii, "Microstrip antennas integrated with electromagnetic band-gap structures," IEEE Trans. Antennas Propag., vol. 51, no. 10, pp. 2936–2946, Oct. 2003.

[11] D. Guha and Y. M. M. Antar, Microstrip and Printed Antennas: New Trends, Techniques and Applications. Hoboken, NJ, USA: Wiley, 2011.

[12] J.-S. Park, J.-H. Kim, J.-H. Lee, and J.-H. Lee, "A compact UWB MIMO antenna with improved isolation using defected ground structure," IEEE Antennas Wireless Propag. Lett., vol. 15, pp. 127–130, 2016.

[13] T. Alam, M. R. I. Faruque, and M. T. Islam, "Isolation enhancement of UWB MIMO antenna using defected ground structure," Microw. Opt. Technol. Lett., vol. 61, no. 2, pp. 413–419, Feb. 2019.

[14] D. Ahn et al., "A design of the low-pass filter using the novel microstrip defected ground structure," IEEE Trans. Microw. Theory Techn., vol. 49, no. 1, pp. 86–93, Jan. 2001.

[15] S. Choi, K. Chung, and J. Choi, "Wideband MIMO antenna with DGS for UWB applications," Prog. Electromagn. Res. C, vol. 67, pp. 45–55, 2016.

[16] M. S. Khan et al., "A compact UWB MIMO antenna with enhanced isolation using parasitic stubs and DGS," AEU–Int. J. Electron. Commun., vol. 82, pp. 470–478, 2017.

[17] A. Diallo, C. Luxey, P. Le Thuc, and R. Staraj, "Effect of mutual coupling on efficiency of small antenna systems," IEEE Trans. Antennas Propag., vol. 60, no. 2, pp. 652–660, Feb. 2012.

[18] C. A. Balanis, Antenna Theory: Analysis and Design, 3rd ed. Hoboken, NJ, USA: John Wiley & Sons, 2005.

[19] W. L. Stutzman and G. A. Thiele, Antenna Theory and Design, 3rd ed. Hoboken, NJ, USA: John Wiley & Sons, 2013.

[20] A. Ali, J. Iqbal, M. A. Khan et al., "Mutual coupling reduction through defected ground structure in circularly polarized dielectric resonator based MIMO antennas for sub-6 GHz 5G applications," Micromachines, vol. 13, no. 7, p. 1082, 2022.

[21] H. Xing, X. Wang, Z. Gao, X. An, and H. Zheng, "Efficient isolation of an MIMO antenna using defected ground structure," Electronics, vol. 9, no. 8, p. 1265, 2020.

[22] A. Sherila, "MIMO antenna design with defected ground structure and stub slot for 5G application," Journal of Telecommunications and Electronics Engineering, vol. 7, no. 2, pp. 188–198, 2025.

[23] V. S. Kushwah and G. S. Tomar, "Design of Microstrip Patch Antennas Using Neural Network," 2009 Third Asia International Conference on Modelling & Simulation, Bundang, Indonesia, 2009, pp. 720-724, doi: 10.1109/AMS.2009.12.

[24] Z. Zhang, K. Wei, J. Xie et al., "The MIMO antenna array with mutual coupling reduction by defected ground structures," Radioengineering, vol. 27, no. 4, pp. 969–975, 2018.