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DGS-Engineered Quad-Element UWB MIMO Antenna for Ultra-Wideband Applications

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ABSTRACT

This paper presents the design and simulation analysis of a compact four-element ultra-wideband (UWB) multiple-input multiple-output (MIMO) antenna incorporating a defected ground structure (DGS) for improved isolation and reduced mutual coupling. The antenna proposed in this paper is designed on an FR-4 dielectric substrate with a dielectric constant of 4.4 and simulated with HFSS software, with overall dimensions of 88 mm × 82 mm. Four identical modified monopole radiating elements are arranged orthogonally to provide spatial diversity. An interconnected DGS configuration is incorporated into the bottom ground plane to influence surface current distribution to improve isolation between adjacent radiating elements. The simulated results demonstrate wideband impedance matching over the frequency range of 3–11 GHz, with the reflection coefficient (S_{11}) remaining below −10 dB throughout the operating band. Deep resonances are observed at 5.9 GHz and 9.69 GHz, with corresponding S_{11} values of approximately −49 dB and −37 dB, respectively. The transmission coefficient (S_{21}) remains below approximately −23 dB across the operating band, indicating inter-element isolation exceeding 23 dB. Furthermore, the ECC calculated remains below 0.012 and DG nearly 10 dB, indicating low correlation between antenna elements. At two representative resonant frequencies, the radiation characteristics are shown to be co-polarization dominant as compared to cross-polarization components. A comparison has been done with earlier reported UWB MIMO antenna configurations with proposed configuration in terms of impedance bandwidth, isolation, substrate dimensions, The results indicate the potential of the antenna proposed in this paper for compact and lower correlation UWB MIMO wireless communication applications.

Keywords: *Ultra-Wideband (UWB), Multiple-Input Multiple-Output (MIMO), Defected Ground Structure (DGS), Mutual Coupling, Isolation, Envelope Correlation Coefficient (ECC), FR-4 Substrate*

1. INTRODUCTION

Ultra-wideband (UWB) systems promise high data rates at low fabrication cost, yet dense multipath environments cause reflection and diffraction that degrade conventional single-antenna links[1]. Multiple-input multiple-output (MIMO) architecture was proposed to ease multipath fading and raise transmission quality [1], but the space available in modern

portable front-ends is severely limited [1]. This tension - wide bandwidth and high isolation demanded simultaneously from a shrinking footprint - frames the problem this study addresses [2].

Ideally, MIMO elements sit at least a half-wavelength apart [3]. In practice, strong surface currents, space radiation, and surface waves couple closely spaced radiators [3],and packing many elements into limited space reduces isolation and inflates the envelope correlation coefficient (ECC), degrading diversity performance [4]. The consequences are direct: correlation erodes the diversity benefit [3], and regulating mutual coupling has become the critical concern in MIMO antenna development [3].

A wide range of tools has been employed – DGS, EBG structures, slots, neutralization lines, parasitic elements, and orthogonal placement [3]. Layouts of orthogonal four-elements utilizing slotted ground achieve isolation greater than 20 dB and ECC below 0.005 [5]. Mesh-like DGS structures utilizing parasitic elements achieve ECC below 0.002 [2]. Yet, many solutions offer high isolation at the cost of bandwidth or add complexity to fabrication, EBG based quad-elements only present isolation of 17.5 dB [6], while some DGS approaches also present frequency shift issues [7]. Others have narrower bands or larger footprints [8].

Table 1. Reported approaches to mutual-coupling reduction.

Approach	Reported Isolation	Key Limitation	Source
F-shaped ground stubs (2-port)	>20 dB	Two elements only	[1]
Ground stub + EBG (2-port)	>25 dB	Two elements only	[9]
EBG quad-element	>17.5 dB	Modest isolation	[6]
Parasitic decoupling (4-port)	>20 dB	Complex multilayer	[10]
DGS quad-element	>20 dB	Bandwidth trade-off	[11]

The research checks if a DGS-engineered quad-element UWB MIMO antenna can get isolation above 20 dB, ECC less than 0.005, and diversity gain near 10 dB throughout the entire UWB band without compromising compactness. The conceptual model is based on DGS theory, which states that etching of the ground plane will interfere with the confined surface current distribution and alter the effective capacitance and inductance of transmission lines [7], and trap surface coupling currents [12]. According to prior work, DGS with ECC below 0.02 may reduce the mutual coupling. Also, quad-port DGS designs can provide isolation greater than 25 dB [7]. A quad-element DGS design that simultaneously optimises bandwidth, isolation, gain, and ECC has not been explored yet [11] – the scope of this paper. Practically, such antennas are meant for UWB communication, sub-6 GHz 5G, IoT terminals, and short-range sensing [5].

The paper is written in three stages. First, the demand for UWB-MIMO is established. Second, the isolation-versus-footprint is identified. Finally, the DGS-engineered quad-element design and its simulated and measured diversity metrics are put into occupation. The DGS-engineered quad-element design is comparatively evaluated against reported designs [2][6].

2. LITERATURE REVIEW

Obtaining very high data rate (VHD) in a UWB system at low fabrication cost is possible. Undesirably, the reflection and diffraction from a multipath environment highly degrade the link with a single antenna [1]. MIMO architecture is advanced to mitigate multipath fading and improve transmission quality [1]; however, the space available at modern mobile front-ends is very limited [1]. The literature has identified a key tension: broader bandwidth and lower correlation between antenna elements are the two key features of modern device antennas [2], and satisfying both at once is genuinely difficult [4].

Ideally, MIMO elements sit at least a half-wavelength apart [3]. In practice, strong surface currents, space radiation, and surface waves couple closely spaced radiators [3], and packing many elements into limited space reduces isolation and inflates ECC [4]. The consequences are direct: correlation degrades the diversity benefit [3], making mutual-coupling regulation the critical concern in MIMO antenna development [3]

A broad toolkit has emerged, spanning DGS, EBG structures, slots, neutralization lines, parasitic elements, and orthogonal placement [3][1]. The comparison below exposes a pattern: strong isolation is routinely reported, but often at the cost of element count, bandwidth, or footprint.

Table 2. Comparison of reported UWB MIMO decoupling approaches.

Study	Elements	Isolation	ECC	Key Limitation
[1]	2	>20 dB	<0.04	Two elements only
[9]	2	>25 dB	<0.001	Two elements only
[6]	4	>17.5 dB	-	Modest isolation
[4]	4	>22 dB	<0.1	Higher ECC
[2]	4	>20 dB	<0.002	Larger 45×45 mm²
[11]	4	>20 dB	<0.016	Large 70×65 mm²

Evidence specific to the DGS is encouraging but fragmented. A zigzag DGS cut mutual coupling by 28.8 dB with ECC under 0.02 [7], and fork-shaped slot DGS trapped surface currents to sustain better than 20 dB isolation across the UWB band [12]. The 4-port DGS designs exhibit a return loss exceeding 25 dB [2], while mesh-like DGS with parasitic elements achieves an ECC lower than 0.002 [2]. Notwithstanding, some contradictions seem evident: certain DGS schemes alter operating frequency [7], EBG quad-element designs report only 17.5 dB [6], while many high-isolation structures are either too large or use split grounds [1]. All of these techniques [1] have a common theme of a trade-off between bandwidth, size, and complexity.

The literature is mature on two-element decoupling and on single-mechanism quad-element designs, but thin on a quad-element DGS architecture that balances bandwidth, isolation, gain, and ECC simultaneously [11]. Orthogonal layouts alone leave parallel-element coupling unresolved, and metamaterial or neutralization-line solutions add fabrication complexity [3] [13]. This study therefore tests whether a DGS-engineered quad-element UWB MIMO antenna can deliver isolation above 20 dB and ECC well below 0.005 across the full band without sacrificing compactness - directly targeting the isolation-versus-correlation objective that prior work addresses only piecemeal [5][10].

3. ANTENNA GEOMETRY

The quad element UWB MIMO antenna is designed on FR-4 dielectric substrate and have an overall dimension of FR-4 substrate having dielectric constant 4.4 with dimensions 88 mm × 82 mm (width × length) are shown in Fig. 1. The antenna proposed here is simulated with Ansys HFSS software. The top layer contains four identical radiating elements arranged orthogonally to one another (90° apart angularly). Each radiating element use a modified monopole shape that is geometrically shaped with a microstrip feed line. The orthogonal layout reduces mutual coupling between adjacent antenna elements without additional structures, while providing spatial diversity.

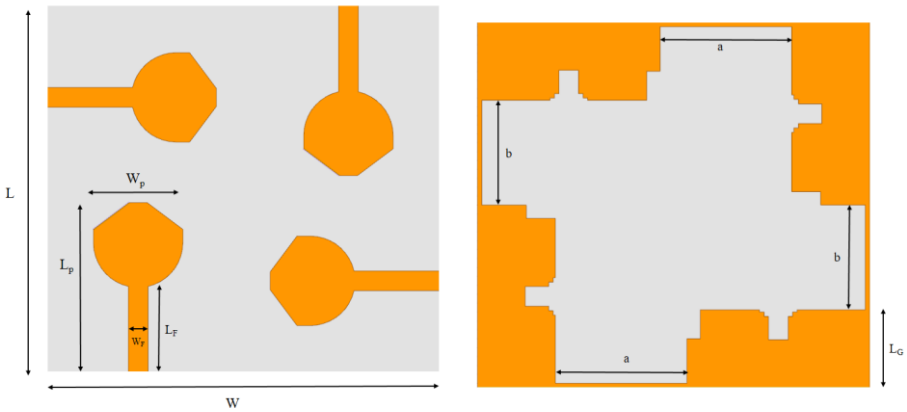


Figure 1: Geometry of the proposed quad-element UWB MIMO antenna: (a) top radiating layer and (b) bottom DGS layer

The bottom layer adopts a defected ground structure (DGS) to improve the impedance matching as well as isolation characteristics of the proposed MIMO configuration. The length (LG) of the partial ground plane of every individual radiating element is 17.5 mm, which corresponds to the optimized ground dimension of a single-element antenna. The individual ground sections are interconnected using 1 mm-wide narrow conductive strips to create a common ground configuration. The connection structure has a horizontal dimension (a) of 29.5 mm along the substrate width and a vertical dimension (b) of 23.5 mm along the substrate length. With this configuration of DGSs, discontinuities are intentionally created in the ground plane to reduce the inter-element coupling of electromagnetic energy

The combination of orthogonally placed radiating elements along with the interconnected DGS-based ground configuration is intended to achieve improved isolation while maintaining wide impedance bandwidth. The physical layout of the antenna proposed in this paper includes the top radiating layer and the bottom DGS layer, is presented in Fig. 1(a) and Fig. 1(b), respectively.

4. RESULTS AND DISCUSSION

4.1 Reflection Coefficient (S_{11})

Fig. 2 represents the S_{11} of the proposed antenna over 3–11 GHz. The antenna maintains an S_{11} below −10 dB throughout the operating band, confirming its wideband impedance matching. Deep resonances are observed at 5.9 GHz and 9.69 GHz, with S_{11} values of approximately −49 dB and −37 dB between port 1 and 2, respectively, indicating excellent impedance matching at these frequencies. In addition, all four ports reflection coefficient values remains well below -10 dB which confirms the impedance-matching behaviour among the four antenna elements.

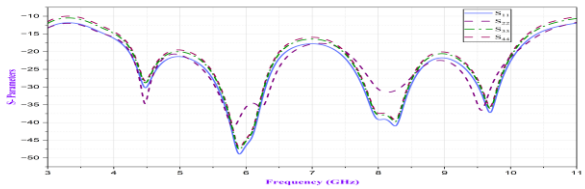


Figure 2: Simulated reflection coefficient (S_{11}) of the proposed antenna

4.2 Mutual Coupling and Isolation Characteristics

Figure 3 illustrates the simulated transmission coefficient (S_{21}), which represents the coupling between ports. The results illustrate that the DGS, placed at the antenna's bottom layer, effectively prevents electromagnetic coupling of the two antenna elements. Over the operational frequency range of 3–11 GHz, the response S_{21} is lower than –23 dB for inter-port isolation greater than 23 dB. Moreover, the isolation is about -56 dB at 3.9 GHz between ports 1 and 2, indicating great suppression of mutual coupling at this frequency. The engineered DGS configuration significantly improves port isolation, as evidenced by the consistently low transmission coefficient across the entire operating band. The importance of this property is especially critical for MIMO antenna systems, as diminished mutual coupling will enable the independent functioning of individual radiating elements.

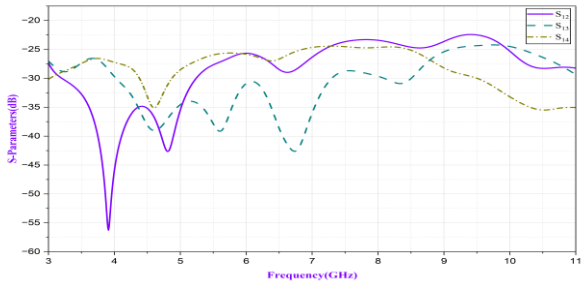


Figure 3: Simulated transmission coefficient (S_{21})

4.3 Radiation Pattern Characteristics

The radiation characteristics of the proposed antenna are further investigated using co-polarization and cross-polarization patterns at selected resonant frequencies of 5.9 GHz and 9.69 GHz. Figures. The radiation patterns in the XZ-plane and YZ-plane at 5.9 GHz are shown in Figures 4 and 5. In both planes, the response of the co-polarized radiation component

is much higher than that of the cross-polarized component. While there are some variations in the radiation pattern depending on the observation plane, the low levels of cross-polarization denote the acceptable polarization characteristics of the proposed antenna.

Similarly, Figs. 6 and 7 illustrate the co-polarization and cross-polarization patterns in the XZ-plane and YZ-plane, respectively, at 9.69 GHz. The results demonstrate that the co-polarized component remains dominant over the cross-polarized component across most angular directions. The radiation patterns exhibit relatively stable radiation characteristics at this higher resonant frequency, with effective polarization discrimination between the two components. The observed radiation behaviour at both resonant frequencies further supports the suitability of the proposed antenna for UWB MIMO applications.

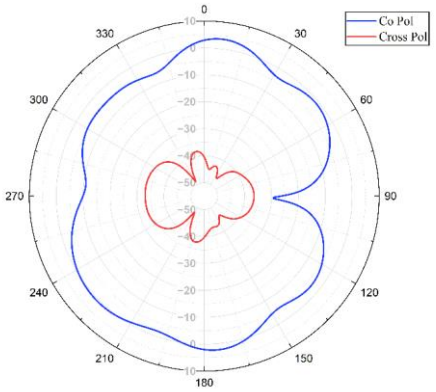


Figure 4: Radiation characteristics in the XZ-plane at 5.9 GHz

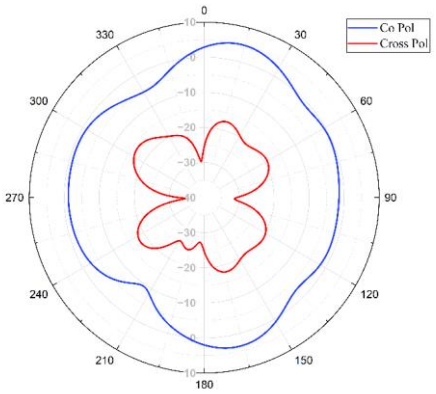


Figure 5: Radiation characteristics in the YZ-plane at 5.9 GHz

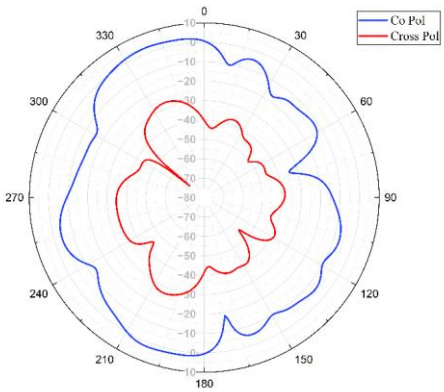


Figure 6: Radiation characteristics in the XZ-plane at 9.69 GHz

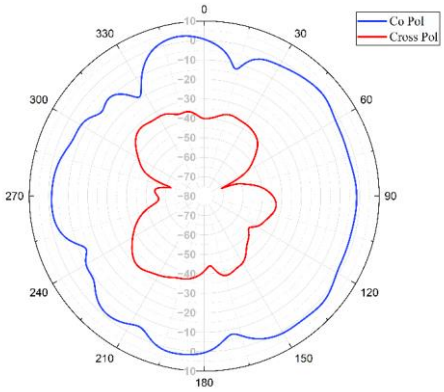


Figure 7: Radiation characteristics in the YZ-plane at 9.69 GHz

4.4 Envelope Correlation Coefficient (ECC)

The plot of ECC as shown in Figure 8 was calculated using the far-field radiation patterns over the entire UWB operating band. The ECC remains below 0.012 throughout the 3–11 GHz band, which is significantly lower than the commonly accepted limit of 0.5 for MIMO antenna systems. This low ECC indicates excellent diversity performance and minimal correlation between the antenna elements, further confirming the effectiveness of the proposed antenna design for UWB MIMO applications.

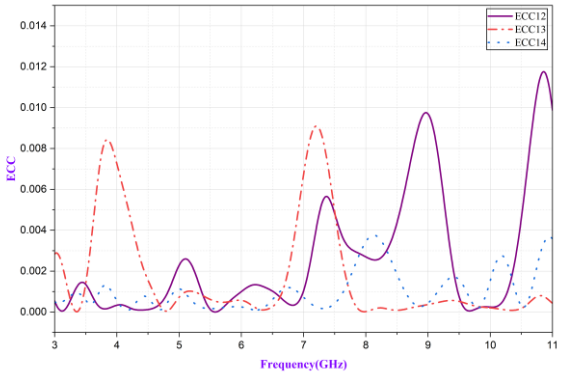


Figure 8: ECC calculated using the far-field method.

4.5 Diversity Gain (DG)

The proposed combination of four UWB MIMO antennas is evaluated with respect to diversity gain for various port combinations. The simulated results show diversity gain values nearing the theoretical value of 10 dB within the working frequency range of 3-11 GHz. Figure 9 shows simulated characteristics of the antenna proposed here.

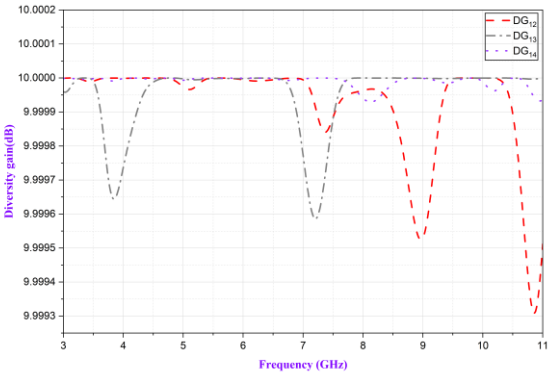


Figure 9: Diversity Gain

5. COMPARATIVE ASSESSMENT OF UWB MIMO ANTENNA PERFORMANCE

Table 3 provides a comparative assessment of the proposed antenna with recently reported designs in terms of key performance indicators, namely, impedance bandwidth, inter-element isolation, and envelope correlation coefficient (ECC). The results prove that the proposed design allows obtaining a good impedance bandwidth, enhanced isolation, and reduced mutual correlation between antenna elements. These characteristics establish its competitive performance relative to existing designs and highlight its potential for UWB wireless communication applications.

Table 3. Comparative evaluation of the proposed UWB MIMO antenna against selected reported designs

References	Substrate Material	Dimensions (mm^2)	Operating Bandwidth	Isolation(dB)	ECC
[14]	FR-4	80x80	2.1-20	<25	<0.02
[15]	FR-4	81x87	3.03–10.74 GHz	<20	<0.1
[16]	FR-4	92x70	3.0–18.0	<15	<0.01
[17]	Split-Ring Composite	136x136	2.2–6.28 GHz	<14	<0.05
This Work	FR-4	88x82	3.0-11	<23	<0.01

6. CONCLUSION

The proposed quad element ultra-wideband (UWB) multiple-input multiple-output (MIMO) antenna incorporating a DGS-engineered ground structure is designed and simulated for improved impedance matching and inter-element isolation. The antenna proposed in this paper is designed on an FR-4 dielectric substrate having a dielectric constant of 4.4, simulated with HFSS software with overall dimensions of 88 mm × 82 mm, employing four orthogonally arranged modified monopole radiating elements. The interconnected DGS configuration is introduced to modify the ground-plane current distribution. Good impedance matching is demonstrated with $S_{11} < -10$ dB throughout the operating band ranging from 3 to 11 GHz. The resonant responses of −49 dB and −37 dB at 5.9 GHz and 9.69 GHz show effective matching at both these frequencies. The value of the transmission coefficient (S_{21}) is always lower than about −23 dB in the working band, which achieves an inter-element isolation of more than 23 dB. The envelope correlation coefficient (ECC) assessed through far-field radiation patterns is measured to be less than 0.012, and the diversity gain is near 10 dB, indicating less correlation between antenna elements and good diversity. The radiation patterns at 5.9 GHz and 9.69 GHz also display dominant co-polarized components in the examined planes compared to the cross-polarized components. The comparative analyses against earlier reported UWB MIMO antenna designs show the proposed antenna has good operating bandwidth, isolation, and low envelope correlation. In short, the simulated performance establishes the viability of the DGS-engineered quad-element antenna for UWB MIMO wireless communication.

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