Isolation Enhancement Between MIMO Elements Using Slotted Ground And M-Shaped DGS

K. V. Prasad[#], M. Venkata Siva Prasad^{*}, M. Himaja[#]
1. Assistant Professor & Research Scholar, ECE, V R Siddhartha Engineering College, Vijayawada & ANU College of Engineering and Technology, Guntur.
2. Professor, ECE, R V R & J C College of Engineering, Chowdavaram, Guntur
3. Assistant Professor, ECE, R V R & J C College of Engineering, Chowdavaram, Guntur

Article Info Abstract — MIMO antennas, due to their compact size, are widely used for wireless Page Number: 1760 – 1776 applications. The isolation or mutual coupling (MC) between MIMO elements is **Publication Issue:** still a research problem. The spacing between the elements will be minimized to Vol. 71 No. 3s2 (2022) accomplish system compactness, which allows for high MC between the elements. This paper presents a new 2-element MIMO design with slotted patch elements using M-shaped DGS for the MC reduction. The feed used is strip-line feed, and the design is simulated using HFSSv15. With a slot cut in all the square patch's four directions, the MIMO design is simulated using HFSS. The ground plane design will alter the antenna parameters to the required level based on the parametric patch analysis. The structure comprises two elements on a 50×36 mm2 FR4 substrate. The effects of slots on gain and bandwidth are demonstrated. An M-shape DGS and a slot cut in all directions reduce this new design's MC. The proposed structure resonates at 3.5 GHz (WiMAX), 5.9 GHz (WLAN), 7.9 GHz (SATCOM applications at X-band), and 9.3 GHz (Radar, Cellular mobiles, and commercial WLAN) in the entire Ultra-Wide Band (UWB) range and therefore achieves multi-Article History band characteristics. The spacing between elements is 11mm. A 20 dB MC Article Received: 22 April 2022 reduction is achieved at the operating multi bands. The proposed design structure Revised: 10 May 2022 achieves ECC < 0.04 and DG > 9.985. Accepted: 15 June 2022 Keywords- Defected Ground Structure (DGS), Diversity Gain (DG), Envelope Publication: 19 July 2022 Correlation Coefficient (ECC), MIMO, Patch, Slits

I. **INTRODUCTION**

In [1], a compact monopole antenna is designed for UWB frequency. The proposed design with substrate dimensions $25 \times 18 \times 1.6 \text{ mm}^3$ utilizes two kite-shaped elements in coalesced form with the tapered slotted ground. The parametric analysis of the kite-shaped patch and the tapered base is made, an Impedance Bandwidth (IBW) of 14.2 GHz is accomplished, and the gain is in the range of 2.28 to 5.0 dBi for the entire UWB. In [2], a hexagonal-shaped MIMO antenna is analyzed and studied, covering the S-band, WLAN, UWB, and X-band. The substrate used is FR4 with dimensions $0.18\lambda_0 \times 0.37\lambda_0$. The distance between the two patches is $0.053\lambda_0$. Triangular-shaped-edge-cuttings are made in the design bottom, and DGS is used. Isolation is enhanced by 20 dB with an E-shaped tree arrangement and parasitic elements. Various MIMO parameters like ECC, DG, and Total Active Reflection Co-efficient (TARC) are measured for the operating frequency bands. In [3], a compact Minkowski design for reducing MC in between two elements is analyzed. The proposed MIMO design, which resonates at 2.5, 3.5, 5.2, and 7 GHz frequencies, shows the reduction in MC with 54, 50, 40, and 44 dB at the resonating frequencies. In [4], the miniaturization of the antenna design with gain enhancement

is proposed with Modified Minkowski Fractal DGS (M-MFDGS) for three patch antennas with different feeding techniques. The design with strip-line feeding provides 70 % patch area reduction with a gain of 1.43 dBi. The design with proximity-coupled feeding achieves a higher gain and bandwidth (5.11 dBi and 110 MHz). The design with aperture coupled feeding provides a gain of 5.91 dBi. In [5], a compact patch with M-MFDGS for 2.4 GHz WLAN application is proposed. Incorporating capacitive M-MFDGS, without changing the dimensions of the patch, the operating frequency is shifted from 4.16 GHz to 2.4 GHz. The design dimensions are 0.15 λ 0 × 0.13 λ 0, with IBW of 5.20 %, and gain of 1.4 dBi centered at 2.41 GHz. This design is suitable for portable wireless applications. In [6], a four-port monopole design is analyzed for MIMO applications. To enhance bandwidth, the structure is studied by making an arrow-shaped slot etched on the radiator and stepped ground. In [7-8], a band-notched miniaturized Printed Log Periodic Dipole Array (PLPDA) with a meander fractal concept is proposed for wide-band applications. This concept is applied to all the elements in the PLPDA. Using the sub-sectional tapered concept, band notch characteristics are obtained in the WLAN band, WiMAX band, and a broad bandwidth with this meander fractal concept. The proposed design, fabricated on a RO3003 substrate, is best applicable for short-range, high-speed wireless communications. In [9], a modified radiating patch with high-gain broadband using a Poly tetra fluoro ethylene (PTFE) substrate is proposed. Dimensions for the design are $0.52\lambda_0 \times 0.51\lambda_0$. Gain and BW effects are analyzed using a slot and five slits on the proposed antenna element design. In [10], resistor-loaded paired parallel-coupled resonators (PCRs) are used for isolation enhancement in MIMO elements. The spacing between array elements is $0.125\lambda_0$ and isolation greater than 25 dB is achieved within the UWB.

In [11], to achieve better data rates with enhanced gain for the 5G communications, the antenna design is made with a substrate, Polymethacrylate. This substrate provides a high gain compared to all the other substrates used in the antenna design. A gain of 10.054 dB with a bandwidth of 80 MHz is achieved with this substrate. The patch antenna with this substrate is preferred for 5G cellular base station (BS) antenna for the frequency range of 3.3 GHz to 3.7 GHz. These high gain antennas are designed with two simple techniques: Simple shorting pin and chip impedance shorting. The overall geometry of the patch antenna is reduced with a simple shorting pin technique with improved gain, and the narrowband effect can be minimized by implementing the chip impedance shorting method. The design with high gain is best suitable for 5G cellular communications. In [12], a novel design structure, Spiro Meander Line Uniplanar Compact Electromagnetic Band Gap (SMLUC-EBG), is presented. This design is proposed to minimize MC between elements for WLAN applications. The spacing between the elements is $0.14\lambda_0$ and isolation of 20.3 dB is achieved with the proposed design. In [13], a circular patch antenna for WLAN application is presented with an eroded ground plane, and it is electromagnetically coupled. The eroded ground plane minimizes the physical area of the circular patch and can be utilized for WLAN services. The miniaturized antenna provides excellent reflection characteristics at a 2.4 GHz frequency. In [14], a circular annular ring patch by embedding an Electromagnetic Band Gap (EBG) structure reduces surface waves. An Mshaped EBG is utilized on the ground with vias at the center of each EBG, and this EBG is inscribed in the $6 \times 6 \text{ mm}^2$ patch. This proposed design can be utilized for the Mobile Satellite Service (MSS) band, UMTS, and WCDMA. In [15], a dual-band patch for WLAN and WiMAX applications are presented with narrow vertical slots. The proposed antenna with two

vertical slots resonates at 3.5 GHz WiMAX and 5.3 GHz WLAN bands. Particle Swarm Optimization (PSO) method is incorporated to optimize the proposed design dimensions. This design provides better radiation properties at the two bands, making it appropriate for dualband implementation. In [16], threefold stubs are etched to reduce MC between elements. This design consists of two polyhedron annulus patch elements, threefold fork-shaped stubs (TFSS), a conventional dielectric substrate, and a microstrip line feeder. By using this TFSS, the performance parameters are improved. MC was improved by 42 dB when the TFSS and polyhedron annulus patch elements were introduced. In [17-18], three patch antennas are designed with direct, proximity, and aperture coupled feeding for X-band portable applications by loading the M-MFDGS technique. The overall physical size of the patch with these feeding techniques and M-MFDGS reduces up to 67 % and overall volumetric reduction of 84 %. The gain of this proposed design is about 6.2 dBi at 10 GHz. In [19], a compact design with the partial ground and parasitic elements and a rectangular slot on the I-shape element is proposed. The FR-4 substrate dimensions of the proposed technique are $15 \times 20 \times 1.6 \text{ mm}^3$. This design provides bandwidth enhancement. Simulated results show that the IBW was achieved at three resonant frequencies. This antenna design is suitable for Wi-Fi, WiMAX, and X band. In [20], a novel periodic defected ground structure of S-shape (PDGS) to reduce MC between elements is proposed with three S-shaped DGS structures placed between the elements, and the spacing is 50 mm. With this arrangement, a 40 dB reduction in MC is achieved. PDGS interrupts the far-field and induces current between the elements, and etched PDGS minimizes the surface current considerably within a restricted substrate area.

In [21], compact EBG integrated MIMO is proposed for WLAN and WiMAX to reduce MC between the elements, and the proposed design operates within the range 2.01-3.92 GHz. The proposed MIMO design has very low ECC, good DG, very low Channel Capacity Loss (CCL). In [22], a DGS used to suppress MC in MIMO design is presented, and this design eliminates the phased array scan blindness. By analyzing, the surface waves will get squashed in the substrate using back-to-back U-shaped DGS. In [23], a compact UWB-MIMO with low MC is introduced and is designed with $50 \times 30 \text{ mm}^2$. In this design, F-shaped stubs maintain isolation between the elements. This design has S21 < -20 dB, better ECC, DG, over the UWB frequency. In [24], in a slot array, a metamaterial is used for steering the surface waves so as to reduce MC. Both Complementary Split Ring Resonator (CSRR) and complimentary fishnet structures are used to minimize MC. An isolation improvement of 14 dB is obtained throughout 2 GHz bandwidth, with a 3.4 mm slot gap. In [25], a novel fractal DGS to minimize MC between coplanar elements is proposed, and the bandgap characteristic of the design is studied. Results show that isolation enhancement of >35 dB is obtained. In [26], a compact design for UWB is investigated. This design implementation is performed with a patch and parasitic elements at the top, and DGS is etched on the substrate bottom. The proposed design dimensions are $20 \times 20 \times 1.6$ mm³ with an efficiency of 79.8 %, respectively. It is best suitable for WiMAX, WLAN. In [27], a MIMO antenna design for reducing MC is proposed. Six parallel metal strips are introduced between two patches to reduce MC between the elements, and -42 dB is achieved with metal strips at 5.8 GHz frequency. In [28], an effective technique of utilizing metallic pins at the square element edges to alter the antenna polarization is proposed. The measurements indicate that the isolation enhances from 2.8 dB to 20 dB at 3.5 GHz. In [29], to reduce the MC, an EBG is used as an isolator and is of about 30.5 dB and

provides low ECC. In [30], a compact design with improved isolation consists of slot antennas with $22 \times 26 \text{ mm}^2$. A T-shape slot is etched on the ground to provide better impedance matching and reduce the MC. The design provides MC of < -18 dB over the UWB. In [31], dual-band MIMO elements that operate at 3.7 and 4.1 GHz is presented. The MIMO element spacing is about 0.034 λ 0. The design consists of a decoupling surface and H-shaped DGS. The isolation is greater than 30 dB in both 3.7 and 4.1 GHz bands from the decoupling structure and the DGS.

In [32], a UWB-MIMO design that provides good dual-band suppression with port isolation is presented. This design utilizes a fractal-shaped patch, parasitic neutralization stubs, ground, and notches to achieve band notches at WiMAX and X-band. In [33], a four-port monopole is presented using arrow-shaped slot etching and step etching to enhance isolation and bandwidth. The ECC obtained was less than 0.001 and the efficiency was greater than 85.70 %. In [34], a slit embedded mushroom EBG and periodical CSRRs are implemented to reduce surface waves between elements. An H-shape DGS is introduced to reinforce the decoupling effect, and a 12 dB MC reduction is realized. In [35], a 2-element miniaturized MIMO design with reduced MC is accomplished. MIMO antenna is simulated with four T-shaped slots on the patch with 50×25 mm² on Flame Redundant-4 epoxy. A T-shape stub and slot method reduce the MC of the proposed method. This provides multi-band characteristics for the applications like WiMAX, WLAN, X-band SATCOM and Radar, Cellular radio, and WLAN. In [36], different isolation techniques for MIMO antennas are discussed. In [37], a slot-shaped EBG design with cell dimensions, 6.3×6.3 mm² is proposed. This proposed design analyses the surface wave effects in the antenna array resonating at 5.8 GHz frequency. The slot-shape unit cell will modify $S_{11} < -10$ dB and $S_{12} < -51$ dB and changes the current distribution to avoid surface waves. This structure is best suitable for the WLAN application.

The article is implemented as follows: The antenna analysis with different parameters is described in Section 2. Section 3 represents the analysis of the design proposed. Simulation and measurement results are described in Section 4. The conclusion is presented in section 5.

II. **PROPOSED METHOD**

Figure 1 represents a MIMO design with slits on all four sides of the patch. The proposed structure simulation is performed on FR-4 substrate with Ws × Ls ($36 \times 50 \text{ mm}^2$), tan $\delta = 0.002$, $\varepsilon_r = 4.4$. The height of the substrate is 1.6mm. An M-shaped DGS between two radiators for isolation enhancement is shown in Figure 1. This design uses Lp × Wp (Lp=Wp) patch element, four slits on all the sides with L length and N width. The proposed structure is excited with strip-line feed, and inter-element spacing is approximately 11 mm, between the two MIMO elements. The MIMO evolution is shown in Figure 2An easy way to comply with the conference paper formatting requirements is to use this document as a template and simply type your text into it.

$$\epsilon_{reff} = \left(\frac{\epsilon_r + 1}{2}\right) + \left(\left(\frac{\epsilon_r + 1}{2}\right)\left(1 + \frac{12h}{w}\right)^{-\frac{1}{2}}\right)$$
[1]

surface wave suppression condition is given by,

$$\frac{h}{\lambda_0} \le \frac{0.3}{2\pi\sqrt{\varepsilon_0}}$$
[2]

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$$L_{e} = \frac{c}{2f_{0}\sqrt{\varepsilon_{eff}}}$$
[3]
Patch length, $Lp = L_{e} - 2\Delta L$
[4]
Slit length $L=M=\lambda/4$
[5]
ameter, $D \simeq (\lambda/4)$
[6]

Diameter, $D \simeq (\lambda/4)$

Equations 1, 3, and 4 indicate the substrate's effective permittivity, the patch element's effective length, and the antenna element's length. Equation 2 shows the condition for suppressing the surface waves beneath the substrate. As it is a square patch, length and width are identical.



Figure 1. A proposed MIMO structure

Figure 1 depicts a MIMO antenna fed with strip-line, uses four cross-shaped slots on four sides of the antenna element, with two different sizes, length L and width N. The design evolution of the MIMO is represented in Figure 2.



Figure 2: Formation steps for the proposed MIMO antenna

The antenna design is simulated using HFSS 13.0 and fabricated on FR-4 substrate with a thickness (height) of 1.6mm, length and width, Ws × Ls. An M-shaped DGS between two cross-shaped elements is indicated in Figure 1. The design implements a patch with different sizes of cross-shaped slots are etched on the 4 directions of the patch with length L (where L=M) and width N. The edge-to-edge distance between the elements is 11 mm.

The optimized parameters are listed in Table 1. As the notations provided in the Table 1, Ls and W_s indicates the substrate length and width. L_p and W_p denotes the patch length and width. A, B, C, E, F, and G denotes the slotted ground dimensions. D indicates the diameter of the

circle. L, M, and N provides the slit length and width. I, J, and K denotes the M-shaped DGS length and width. d denotes the edge-to-edge spacing between the patch elements. H denotes the feedline height. Multiple slits are introduced for the MIMO element, and the design operates for the UWB with specific applications at WiMAX, WLAN, X-band SATCOM, and commercial WLAN. The simulated S_{11} and S_{12} plots for the proposed technique are shown in Figure 3.



Figure 3: Proposed S_{11} and S_{12} of the design.

Finally, the proposed design with $|S_{11}| < -10$ dB, resonating from 2.5 GHz to 12 GHz, is plotted in Figure 2(h). Isolation of < -20 dB is observed. The simulation is performed for all the evolution design steps of the proposed design, and S_{11} for the iterations is shown in Figure 4.



Table 1. Proposed design Parameters

Parameter	Ls	Ws	Lp	Wp	Α	В	C	D	Е	F	G
Value (mm)	50	36	15	15	18	11.5	10	4	6.25	2	5.5
Parameter	н	I	J	K	L	М	N				
Value (mm)	20	1.7	5	4	3	3	1	1			

III. PROPOSED ANTENNA ANALYSIS

All paragraphs must be indented. All paragraphs must be justified, i.e., both left-justified and right-justified.

A. Effect of Slits on patch element:

The concept of DGS used in MIMO is proposed in ref. [11], [13], [14], [17] and in [21]. Defected Ground Structure (DGS) acts as a band stop filter that blocks the surface currents flowing in the desired frequency from one radiator to another. From the design analysis, the proposed DGS provides good MC reduction. The S-parameters with and without Slotted ground and M-shaped DGS are compared in Figure 5 and Figure 6. From Figure 5, using an M-shaped DGS and the slits on the patch, the peaks at which the antenna resonates are 3.51 GHz, 7.95 GHz, and 9.45 GHz. S12 >–15 dB is achieved over the UWB range.

B. Slotted ground and DGS effects on the proposed design:

Figures 5 and 6 shows S_{11} and S12 parameters with and without M-shape DGS and slotted ground.



Figure 5: Simulated S₁₁ with and without M-shaped DGS and slotted ground



Figure 6: S12 of the proposed design with and without slotted ground and M-shape DGS. A slotted ground is used to enhance isolation. From the S₁₁ plot, the peaks at which the antenna resonates are 3.51 GHz, 7.95 GHz, and 9.45 GHz using a slotted ground. Etching slots on the ground edges enhance S₂₁ with the slotted ground structure. MC is reduced at the resonating peaks that make S₂₁ > -15 dB.

IV. PARAMETRIC ANALYSIS OF THE DESIGN PROPOSED:

Isolation improvement of the design is analyzed based on the parametric analysis by performing the slit length variation on the patch element and varying the distance between the patch radiators. The scattering parameters $|S_{11}| \& |S_{12}|$ for different distances are analyzed in figure 7. In this design, parametric analysis has been done by varying one parameter, and all other parameters remain unchanged to evaluate S-parameters.

A. Effect of Slits on patch element:

The distance variation affects S_{11} with d= 7.5mm to d = 11mm, and the S_{11} variation to the distance between the patches is shown in Figures 7 & 8. From Fig. 7, distance, d =11 mm, will resonate the antenna at 3.5 GHz, 5.9 GHz, 7.9 GHz and 9.3 GHz and S_{11} at these resonating frequencies are -42.62 dB, -45.84 dB, -40.23 dB and -34.56 dB and S_{12} at these frequencies are -45.26 dB, -44.83 dB, -41.25 dB and -42.31 dB and are depicted in Figure 8. The spacing between the elements, d = 11 mm, S_{11} & S12, is >-40 dB, demonstrating a strong MC reduction between the radiating elements.



Figure 7: S_{11} for distance variation of the MIMO design



Figure 8: S12 with different distances for the proposed antenna

When the distance between the patches varies from d=7mm to d=11mm, S_{11} and S_{12} are greater than -20 dB, and the optimized distance is d=11 mm, which reduces the MC at the resonating frequencies.

B. Effect on varying slit lengths L, M, and N:

Slit lengths L, M, and width N variations on the patch will significantly change the antenna analysis parameters like S_{11} , S_{12} , gain, and directivity. Figure 9 shows that S_{11} increases by 15 dB, with L, M, and width N variation.



Figure 9. S11 for different slit lengths and widths of the MIMO design.

V. RESULTS: SIMULATION AND MEASUREMENT

This section presents the simulated and measured results for the design proposed. The proposed design analyses the envelope correlation co-efficient, diversity gain, and radiation efficiency. *A. Scattering parameters and Radiation* analysis *of the design:*

The design is validated by fabricating the antenna, and the results measured are attained with Keysight (9916A) VNA. Figure 10 shows the measured and simulated S-parameters. The proposed design IBW is 7.6 GHz, with S21 below -35 dB.



Figure 10. S₁₁ and S12 of the proposed MIMO design (Simulated and Measured)

Radiation plots at the resonant frequency are depicted in figure 12. A gain of 4.55 dBi is achieved for the prototype fabricated, and the simulated gain is 5.50 dBi, as shown in Figure 13. Figure 14 demonstrates the co-polarization and cross-polarization plots in H-plane. Figure 15 depicts the co-polarization and cross-polarization plots in E-plane, which indicates the desired orthogonal polarization of the proposed design radiation pattern. Figure 16 shows the fabricated model of the proposed design. A comparison of different techniques with the proposed design is shown in Table 2. Table 2 indicates the comparison of the proposed design with the existing works. As seen from Table 2, the proposed design resonates at four different frequencies over the UWB range compared to other related works.



Figure 11. Measurement setup for the measurements of the proposed design.

Figure 11 shows the measurement setup for measurements of the proposed design. The measurements are taken by considering the Horn antenna as a transmitter and the proposed structure as a receiver. The distance between the two antennas is maintained at $2D^2/\lambda$, where D is the substrate width, and λ is the wavelength of the smallest resonating frequency of the UWB range. The equivalent circuit is proposed in Figure 17. After simulating the equivalent circuit, R= 1K Ω , L= 5.5nH, and C= 10pF. The figure reveals that the UWB band is a parallel combination of R, L, and C for the entire 3.1-10.8 GHz. The two parallel LC circuits in parallel represent the M-shape DGS structure.

B. MIMO Parameters for the Proposed Structure:

The validation of the design is done by analyzing Envelope Correlation Co-efficient (ECC) and Diversity Gain (DG). The simulation and measured parameters are compared. ECC analysis is performed using S-parameters as mentioned [29]; ECC is < 0.05 and is shown in Figure 18. DG with 9.9 dB is shown in Figure 19.

The ECC based on S12 is given in equation (7) in terms of field-based equation and specifies the radiation patterns of two radiating elements correlation.

$$\rho_{e} = \frac{\left| \int_{0}^{2\pi} \int_{0}^{\pi} (XPR \cdot E_{\theta 1} \cdot E_{\theta 2}^{*} \cdot P_{\theta} + E_{\varphi 1} \cdot E_{\varphi 2}^{*} \cdot P_{\varphi}) d\Omega \right|^{2}}{\int_{0}^{2\pi} \int_{0}^{\pi} (XPR \cdot E_{\theta 1} \cdot E_{\theta 2}^{*} \cdot P_{\theta} + E_{\varphi 1} \cdot E_{\varphi 2}^{*} \cdot P_{\varphi}) d\Omega \times \int_{0}^{2\pi} \int_{0}^{\pi} (XPR \cdot E_{\theta 1} \cdot E_{\theta 2}^{*} \cdot P_{\theta} + E_{\varphi 1} \cdot E_{\varphi 2}^{*} \cdot P_{\varphi}) d\Omega}$$

$$(7)$$

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Figure 12. 2-Dimensional radiation plots at the design's resonating frequencies in E-and H-Planes (red color & blue color: simulated and measured in E-Plane, pink color, and green color: simulated and measured in H-Plane).

The formula gives DG based on the ECC:



Figure 13. Simulated and measured gain of the proposed MIMO design.



Figure 14. Co- and cross-polarization at 3.45 GHz.



Figure 15. Co and cross-polarization at 3.45 GHz.



Figure 16. Fabricated Design, (a) front view, (b) back view.



Figure 17: Equivalent circuit of the proposed design



Figure 18. Simulated ECC.



Figure 19. Simulated and measured DG.

Table 2. Comparison of the proposed and previous related works.

		P	P	real here here	
Ref	Antenn	S ₁₁	S ₁₂	Freque	Substrate
•	a	(dB)	(dB)	ncy	used
	Dimens			(GHz)	
	ions				
	(mm)				
[2]	$28 \times 58 \times$	>-10	>-20	UWB	FR-4
	1.6			(2.1-	
				12.9)	
[3]	60×40	-48	-54 &	2.4 &	FR-4
	× 1.6	& –	-40	5.2	
		19			
[4]	34×80	>-15	>-15	3.1-	FR-4
	× 1.6			10.9	
[9]	22×34	-	-	8.97	FR-4
	× 1.6	18.29	55.12		
[10	15×20	>-10	-	(2.34–	FR-4
]	× 1.6			2.46),	
				4.61–	
				5.92	
				and 9–	
				9.9	
[11	30×30	-35	-56	2.57	Rogers
]	× 3.81				TMM 6
[12	28×55	>-10	-29	(2.35-	FR-4
]	× 1.6			2.5)	
				and	
				(3.2-	
				3.85)	
[14	30×50	>-10	>-20	UWB	FR-4
1	× 1.6				

30×30	-35	-35	2.2	Rogers
× 3.81				TMM 6
30×36	>-10	-42	5.8	Rogers
× 3.8				RT/duroi
				d 5880
36×50	>-10	>-15	3.1–	FR-4
× 1.6	at 3.5,	at 3.5,	10.6	
	5.9,	5.9,		
	7.9	7.9		
	and	and		
	9.3	9.3		
	$30 \times 30 \times 3.81$ $30 \times 36 \times 3.8$ $36 \times 50 \times 1.6$	$\begin{array}{c ccc} 30 \times 30 & -35 \\ \times 3.81 & & \\ 30 \times 36 \\ \times 3.8 & & \\ \hline & \\ 36 \times 50 & > -10 \\ \times 1.6 & \text{at } 3.5, \\ 5.9, \\ 7.9 \\ and \\ 9.3 & \\ \end{array}$	$\begin{array}{c ccccc} 30 \times 30 & -35 & -35 \\ \times 3.81 & & & \\ \hline & & & \\ 30 \times 36 & > -10 & -42 \\ \times 3.8 & & & \\ \hline & & \\ 36 \times 50 & > -10 & > -15 \\ \times 1.6 & \text{at } 3.5, & \text{at } 3.5, \\ 5.9, & 5.9, & 5.9, \\ 7.9 & 7.9 & \\ and & and \\ 9.3 & 9.3 \end{array}$	$\begin{array}{c ccccccccccccccccccccccccccccccccccc$



Figure 20. Radiation efficiency (RE) (%) of the proposed design.

Irrespective of the antennas used, DG depends on BER, and the radiation efficiency is shown in Figure 20 and reveals that the RE > 95 %. The efficiency is calculated using a formula. Efficiency = $(1 - |TARC|^2) * Radiation efficiency$ [9]

VI. CONCLUSIONS

A slotted MIMO with M-shape DGS and slotted ground with $36 \times 50 \text{ mm}^2$ is analyzed. Two slotted MIMO antenna elements operate for the UWB band. To validate the design, fabrication of a two-element structure is done and tested. The edge-to-edge gap is 0.215 λ o. An M-shaped DGS and slotted ground improve isolation at 3.45, 5.89, 7.95, and 9.30 GHz with S₁₂>-15 dB. Isolation enhancement is improved by etching an M-shape DGS on the slotted ground, and the gain is 4.95 dBi, DG > 9.9 dB, and ECC < 0.05, for the entire UWB.

REFERENCES

 R N Tiwari, Prabhakar Singh, Binod Kumar Kanaujia, Amit Kant Pandit, "A Coalesced Kite Shaped Monopole Antenna for UWB Technology", Wireless Personal Communications, vol. 114, pp. 3031-3048, Oct. 2020

- [2] Tathababu Addepalli and Vaddinuri R. Anitha, "Design and Parametric Analysis of Hexagonal Shaped MIMO Patch Antenna for S-Band, WLAN, UWB, and X-Band Applications", Progress in Electromagnetics Research C, vol. 97, pp. 227–240, Dec. 2019.
- [3] K. Vasu Babu, B. Anuradha, "Design of multi-band Minkowski MIMO antenna to reduce the mutual coupling", Journal of King Saud University – Engineering Sciences, vol. 32, pp. 51–57, Jan. 2020.
- [4] Amiya Bhusana Sahoo, Guru Prasad Mishra and Biswa Binayak Mangaraj, "Design and Performance Study of Single and Multi-Layered Fractal Based Miniaturized Patch Antennas for 2.4 GHz Applications", Journal of Microwaves, Optoelectronics and Electromagnetic Applications, vol. 20, pp. 274-296, June 2021.R. M. Osgood, Jr., Ed. Berlin, Germany: Springer-Verlag, 1998.
- [5] Guru Prasad Mishra, Biswa Binayak Mangaraj, "Highly compact microstrip patch design based on improved capacitive Minkowski fractal defected ground structure", International Journal of Electronics and Communication, AEU, vol. 115, Feb. 2020.
- [6] Watcharaphon Naktong and Amnoiy Ruengwaree, "Four-Port Rectangular Monopole Antenna for UWB-MIMO Applications", Progress in Electromagnetics Research B, vol. 87, pp. 19–38, Mar. 2020.
- [7] Deepak Mathur, N. K. V. (2022). Analysis & amp; Prediction of Road Accident Data for NH-19/44. International Journal on Recent Technologies in Mechanical and Electrical Engineering, 9(2), 13–33. https://doi.org/10.17762/ijrmee.v9i2.366
- [8] Manas Ranjan Jena, Sanjana Sahoo, Guru Prasad Mishra & Biswa Binayak Mangaraj, "Miniaturized band-notched printed LPDA design with meander fractal dipole for UWB communication", International Journal of Electronics, Taylor, and Francis, Pp: 21-44, Apr. 2020.
- [9] S. Sahoo, G P Mishra, Manas Ranjan Jena, and Biswa Binayak Mangaraj, "Sub-sectional Tapered Printed-LPDA Design with WLAN, WiMAX Notch Bands for UWB Communication Systems", International Conference on Intelligent Computing and Communication Technologies, ICICCT 2019, Pp:717-727.
- [10] K. Mondal and P. P. Sarkar, "Gain and Bandwidth Enhancement of Microstrip Patch Antenna for WiMAX and WLAN Applications" IETE Journal of Research, vol. 67, pp. 726-734, Jan 2019.
- [11] Jung-Dong Park, Muhibur Rahman and Hsiang Nerng Chen, "Isolation Enhancement of Wide-Band MIMO Array Antennas Utilizing Resistive Loading", IEEE Access, vol. 7, pp. 81020-81026, July 2019.
- [12] Rajiv P, G.P.Mishra, B.B. Mangaraj and Ashutosh Narayan, "An Improved Compact Antenna Design Proposed for 5G Cellular Band", International Journal of Sensors, Wireless Communications and Control, vol. 10, pp. 886-899, 2020.
- [13] Niraj Kumar and Usha K. Kommuri, "MIMO Antenna Mutual Coupling Reduction for WLAN Using Spiro Meander Line UC-EBG", Progress in Electromagnetics Research C, vol. 80, pp. 65–77, Jan. 2018.
- [14] Chauhan, T., and S. Sonawane. "The Contemplation of Explainable Artificial Intelligence Techniques: Model Interpretation Using Explainable AI". International Journal on Recent and Innovation Trends in Computing and Communication, vol. 10, no. 4, Apr. 2022, pp. 65-71, doi:10.17762/ijritcc.v10i4.5538.

- [15] Amiya Bhusana Sahoo, Biswa Binayak Mangaraj, "A miniaturized electromagnetically coupled patch antenna design using an eroded ground plane", Microwave and Optical Technology Letters, vol. 62, pp. 3589-3600, June 2020.
- [16] Jayashree P. Shinde, Pratap N. Shinde, "M-shape electromagnetic-bandgap structures for enhancement in antenna performance", International Journal of Electronics and Communications- (AEU), vol. 70, pp. 842-849, June 2016.
- [17] Amiya B Sahoo, G P Mishra and B B Mangaraj "Optimal Design of Compact Dual-Band Slot Antenna Using Particle Swarm Optimization for WLAN and WiMAX Applications," Recent Advances in Electrical and Electronic Engineering, vol. 12, pp. 425-431, Oct. 2019.
- [18] Chuanhui Hao, Hongmei Zheng, Jingjing Zhang, and Xubao Sun, "The Deployment of Stub Structures for Mutual Coupling Reduction in MIMO Antenna Applications", Progress in Electromagnetics Research Letters, vol. 92, pp. 39–45, June 2020.
- [19] Guru P. Mishra, Amiya B. Sahoo, Smeeta Hota, Biswa B. Mangaraj, "Direct and electromagnetically coupled compact microstrip antenna design with modified fractal DGS", International Journal of RF and Microwave Computer-Aided Engineering, vol. 29, pp. 1-18, June 2019.
- [20] Gill, D. R. (2022). A Study of Framework of Behavioural Driven Development: Methodologies, Advantages, and Challenges. International Journal on Future Revolution in Computer Science & Amp; Communication Engineering, 8(2), 09–12. https://doi.org/10.17762/ijfrcsce.v8i2.2068
- [21] Guru Prasad Mishra, Biswa Binayak Mangaraj, "Miniaturized microstrip patch design based on highly capacitive defected ground structure with a fractal boundary for X-band microwave communications", IET Microwaves, Antennas and Propagation, vol. 13, pp. 1593-1601, August, 2019.
- [22] Vishal Asnani and Sudeep Baudha,"Triple Band Microstrip Patch Antenna Useful for Wi-Fi and WiMAX", IETE Journal of Research, March 2019.
- [23] Kun Wei, Jianying Li, Ling Wang, Zijian Xing, and Rui Xu, "S-shaped periodic defected ground structures to reduce microstrip antenna array mutual coupling", Electronics Letters, vol. 52, pp. 1288–1290, July 2016.
- [24] Ashim Kumar Biswas, Ujjal Chakraborty, "Reduced mutual coupling of compact MIMO antenna designed for WLAN and WiMAX applications", International Journal of RF and Microwave Computer-Aided Engineering, vol. 29, pp. 1-10, Dec. 2018.
- [25] S. Xiao M.-C. Tang Y.-Y. Bai S. Gao B.-Z. Wang, "Mutual coupling suppression in microstrip array using defected ground structure", IET Microwaves, Antennas & Propagation, vol. 5, pp. 1488–1494, September 2011.
- [26] Amjad Iqbal, Omar A. Saraereh, Arbab Waheed Ahmad and Shahid Bashir, "Mutual Coupling Reduction Using F-Shaped Stubs in UWB-MIMO Antenna", IEEE Access, vol. 6, pp. 2755-2759, December 2017.
- [27] Satyabrat Hota, Sudeep Baudha, B. B. Mangaraj, & Manish Varun Yadav, "A novel compact planar antenna for ultra-wideband application", Journal of Electromagnetic Waves and Applications, vol 34, pp. 1-13, Nov. 2019.
- [28] J. . Hermina, N. S. . Karpagam, P. . Deepika, D. S. . Jeslet, and D. Komarasamy, "A Novel Approach to Detect Social Distancing Among People in College Campus", Int J Intell Syst Appl Eng, vol. 10, no. 2, pp. 153–158, May 2022.

- [29] Jeet Ghosh, Debasis Mitra, and Shouvick Das, "Mutual Coupling Reduction of Slot Antenna Array by Controlling Surface Wave Propagation", IEEE Transactions on Antennas and Propagation, vol. 67, pp. 1352-1357, February 2019.
- [30] Kun Wei, Jian-Ying Li, Ling Wang, Zi-Jian Xing, and Rui Xu, "Mutual Coupling Reduction by Novel Fractal Defected Ground Structure Bandgap Filter", IEEE Transactions on Antennas and Propagation, vol. 64, pp. 4328-4335, October 2016.
- [31] Xu-bao Sun and Mao Yong Cao," Low mutual coupling antenna array for WLAN application", Electronics Letters, vol. 53, pp. 368–370, March 2017.
- [32] Md Abdullah, Qinlong Li, Wei Xue, G Peng, Y He and X Chen, "Isolation enhancement of MIMO antennas using shorting pins", Journal of Electromagnetic Waves and Applications, vol. 33, pp. 1249-1263, April 2019.
- [33] Ashim Kumar Biswas, Aparna Kundu, Anup K. Bhattacharjee, and Ujjal Chakraborty, "Isolator-Based Mutual Coupling Reduction of H-shaped Patches in MIMO Antenna Applications", Advances in Computer, Communication, and Control, 1st ed. Vol 41, Lecture Notes in Networks and Systems, Springer, Singapore 2019, pp. 361-366.
- [34] Chao-Ming Luo, Jing-Song Hong, Member, IEEE, and Lin-Lin Zhong," Isolation Enhancement of a Very Compact UWB-MIMO Slot Antenna with Two Defected Ground Structures", IEEE Antennas and Wireless Propagation Letters, Vol. 14, 2015.
- [35] Gill, R. . (2022). Subalgebras over p-Adic Domains. International Journal on Recent Trends in Life Science and Mathematics, 9(1), 37–46. https://doi.org/10.17762/ijlsm.v9i1.140
- [36] W Naktong and A Ruengwaree, "Four-Port Rectangular Monopole Antenna for UWB-MIMO Applications", Progress in Electromagnetics Research B, vol. 87, pp. 19–38, March 2020.
- [37] Asutosh Mohanty, Sudhakar Sahu, "High isolation two-port compact MIMO fractal antenna with Wi-Max and X-band suppression characteristics", International Journal of RF and Microwave Computer-Aided Engineering, vol. 30, Oct. 2019.
- [38] R. Anitha, V.P. Sarin, P. Mohanan and K. Vasudevan, "Enhanced isolation with defected ground structure in MIMO antenna", Electronics Letters, Vol. 50, pp. 1784–1786, November 2014.
- [39] Yang, Zhuo, Jun Xiao, and Qiubo Ye "Enhancing MIMO antenna isolation characteristic by manipulating the propagation of surface waves", IEEE Access, vol. 8 pp. 115572-115581, June 2020.
- [40] Kudumu V. Prasad and Makkapati V. S. Prasad, "Mutual Coupling Reduction between Slotted-T MIMO Elements for UWB Applications", Progress in Electromagnetic Research C, vol 107, pp. 203-217, Jan. 2021.
- [41] V Saritha, C. Chandrasekhar, "A study and review on frequency band notch characteristics in re-configurable MIMO-UWB antennas", Wireless personal communications, vol. 118, pp 2631-2661, Feb. 2021.
- [42] Prasad V Kudumu, Venkata Siva Prasad Mokkapati, "A Slot-shaped EBG structure for improving the Isolation between Patch Arrays," International Journal of Microwave and Optical Technology, vol 15, pp. 269-278, May 2020.