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Quad Element Reconfigurable Radiation Pattern MIMO Antenna for Indoor Wireless Communication

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Abstract—A quad-element reconfigurable radiation pattern Multiple Input Multiple Output (MIMO) antenna is designed for WLAN and 5G applications suitable for indoor wireless communications. It consists of four radiating elements that operate over triband frequencies 2.4, 3.5, and 5.5 GHz. Moreover, the pattern diversity is obtained by introducing two diagonally crossed slots in the radiator to steer the main beams of the antenna in 8 different angular directions using eight PIN diodes. The overall physical dimension of the proposed antenna is about $0.55 \times 0.55\lambda_0$. In addition, an Acrylonitrile Butadiene Styrene (ABS) enclosure is designed, and the performance of the proposed antenna is evaluated. The measurement results show that the proposed antenna has an impedance bandwidth of 4.18%, 14.13%, and 28.5% at the said frequencies, respectively.

1. INTRODUCTION

Recently, the requirement for modern wireless communication systems is exponentially increasing to meet user demands for digital access worldwide with good coverage and high data rates. Antennas are a quintessential element in the communication system to propagate signals in the wireless medium. These antennas must be cognitive [1] to sense the environmental conditions and be more adaptable for futuristic applications. Specifically, complex indoor environments like shopping halls, hospitals, University campus, and offices suffer from connectivity and coverage issues. These challenges arise mainly due to the materials used in building and the existence of various obstacles which weaken the signals [2]. To overcome these shortcomings, radiation pattern reconfigurable MIMO antennas are prominent solutions [3] which increase the coverage and null out the interferences, producing adaptable radiation patterns for the intended users. Also, it assists the system to combat fading effects, hence improving the overall link reliability. Hence, this pattern reconfigurable MIMO antenna can increase the capacity by allowing the system to select different coverage zones and enhancing the overall system performance.

In the literature, various techniques were reported [4–8], to reconfigure the antenna's radiation patterns like parasitic patches, cavity resonators, structural modifications, and surface current paths. In [4], a pattern switchable monopole antenna was reported for an operating frequency of 2.45 GHz for indoor ceiling mountable antennas. Researchers in [5] designed a pattern reconfigurable antenna with 4 monopole electric radiators at 3.5 GHz for 5G communication applications. Also, a monopole-based pattern switchable antenna [6] was designed with band for satellite communication at 3.5 GHz. A wideband beam switchable antenna [7] was illustrated for the 3 to 6 GHz frequency range. In [8], the researchers reported a quasi-Yagi antenna with and without a reflector to achieve pattern diversity at the 3.5 GHz. In [9], a 2×2 MIMO antenna was designed and evaluated to check the compatibility

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of pattern reconfigurable antennas in indoor scenarios. Note that all the above-reported works are operating at a single frequency, large in size, and less than four angular directions were covered.

The proposed work presents a compact quad-element MIMO antenna with pattern reconfiguration at triband frequencies of 2.4, 3.5, and 5.5 GHz. The radiation pattern switching is obtained by controlling the bias modes of active switches. The developed antenna achieves the peak gain of 5.6 dBi and efficiency more than 70%. Also, the diversity metrics are obtained as isolation of 18 dB, Envelope Correlation Coefficient (ECC) < 0.18, Diversity Gain of 9 dB, Total Active Reflection Coefficient (TARC) > 11 dB, and Channel Capacity Loss (CCL) < 0.33 bits/s/Hz.

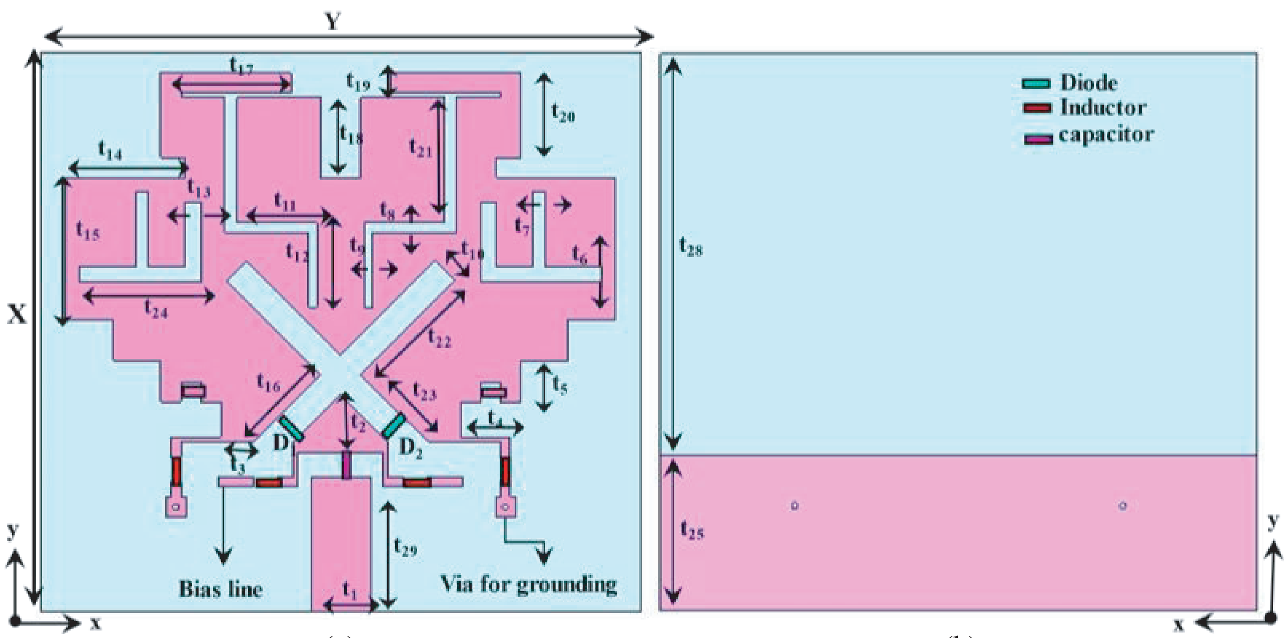
2. ANTENNA DESIGN

The designed pattern reconfigurable antenna is printed on an FR4 dielectric medium possessing $\varepsilon_r = 4.4$, $\tan\delta = 0.014$ with the overall physical dimension as $28 \times 30 \times 1.6\,\text{mm}^3$ and represented in Figure 1. It comprises a Slotted Patch Radiator (SPR), transmission feed line, and ground plane. Further, the length and width of the designed antenna are optimized using the design equations [10, 11],

$$X = \frac{c}{2f_r}\sqrt{\frac{2}{\varepsilon_r + 1}} \tag{1}$$

$$Y = \frac{c}{2f_r\sqrt{\varepsilon_{eff}}} - 2\Delta L \tag{2}$$

where C indicates the velocity of light; f_r denotes the lowest operating frequency; ε_r signifies the effective dielectric constant; ΔL represents the electrical length of the radiator.



(a) (b)

Figure 1. Antenna picture and its dimension details. (a) Front, (b) back view: $X = 28$, $Y = 30$, $t_1 = 3$, $xt_2 = 2.9$, $x_3 = 1.61$, $x_4 = 2.5$, $x_5 = 2.1$, $x_6 = 0.8$, $x_7 = 0.6$, $x_8 = 0.5$, $x_9 = 0.25$, $x_{10} = 1.4$, $x_{11} = 4$. $x_{12} = 3.75$, $x_{13} = 0.8$, $x_{14} = 3.75$, $x_{15} = 7.1$, $x_{16} = 4.77$, $x_{17} = 6.5$, $x_{18} = 4$, $x_{19} = 1$, $x_{20} = 4.25$, $x_{21} = 6.25$, $x_{22} = 6.67$, $x_{23} = 3.4$, $x_{24} = 6.05$, $x_{25} = 7.8$, $x_{28} = 20.2$, $x_{29} = 6.75$ (All dimensions are in mm).

Initially, the antenna evolved from a simple rectangular patch. In later stages, a Dual Diagonally Crossed Slot (DDCS), Dual Inverted F-shaped Slot (DIFS), and Modified U-shaped Slot (MUS) are introduced to resonate at 2.4, 3.5, and 5.5 GHz. In addition, pattern switching is obtained by short and open-circuiting the diodes. Hence, the PIN diodes D_1 & D_2 are utilized to couple the energy from the feed line in two different directions. In mode I (D_1-ON/D_2-OFF), the radiation pattern is tilted to 60°, 45°, and 45° in $+x$ direction at the operating frequencies 2.4, 3.5, and 5.5 GHz, respectively. In mode II (D_1-ON/D_2-OFF), the pattern is steered to 45°, 60°, and 15° in $-x$ direction at the operating frequencies 2.4, 3.5, and 5.5 GHz, respectively. The reflection characteristics of the unit element are presented in Figure 2.

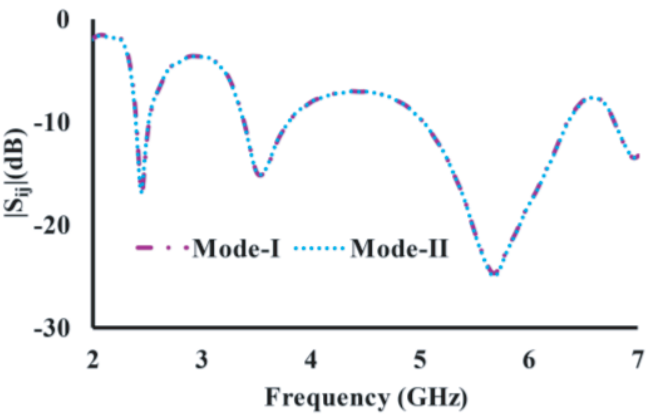


Figure 2. Reflection coefficient of proposed antenna at both modes.

3. RECONFIGURABLE MIMO ANTENNA DESIGN

Indoor scenarios often require coverage optimization due to their dynamic nature in terms of interferences, dense building materials and bulk users. Reconfigurable Radiation Pattern MIMO Antenna (RRPMA) can optimize its radiation patterns to different directions, wherever high user density exists and coverage needed to improve. The proposed RRPMA covers three important wireless standards required in indoor environments such as 2.4, 3.5, and 5.5 GHz. It consists of quad antenna elements with a total size of $68 \times 68 \times 1.6\,\text{mm}^3$. However, the antenna elements are decoupled with a minimum distance of $0.03\lambda_0$ (λ_0 corresponds to the lowest operating frequency 2.4 GHz). Each antenna element is organized in an orthogonal fashion concerning the adjacent elements to further suppress the coupling between the antenna elements. Also, common ground reference level is provided using a thin strip of 0.25 mm. Figure 3 portrays the layout of the proposed RRPMA with dimensions.

In addition, to improve the signal quality and coverage, radiation pattern reconfiguration is achieved by utilizing 8 PIN diodes. Hence, the reflection characteristics of the proposed antenna are analysed for two different cases, case I: D_1, D_3, D_5, D_7 are ON/ (D_2, D_4, D_6, D_8 remains OFF) and case II: D_2, D_4, D_6, D_8 are ON/(D_1, D_3, D_5, D_7 remains OFF) represented Figure 4. All four antenna elements radiate at the same frequencies 2.4, 3.5, and 5.5 GHz. Also, the isolation, gain, and efficiency of the proposed RRPMA are evaluated in Figure 5. The proposed antenna achieves better isolation well below 15 dB, peak gain 5.6 dBi, and efficiency more than 70%. For realizing the developed antenna, the PIN diode BAR50-20V is chosen from Infineon technologies which have a resistance of 1.5 Ω and inductance of 0.6 nH respectively during the forward bias state and low parallel capacitance during the reverse bias state.

3.1. Radiation Characteristics of RRPMA

In the proposed MIMO antenna, the radiation pattern reconfiguration is obtained by incorporating the diagonally crossed slots in the radiator which alters the flow of surface current paths. Hence, the PIN diodes are integrated at the edges of the crossed slots to couple the energy from the feed in two different directions. Moreover, the radiation characteristics of the proposed RRPMA are illustrated in Figure 6. Figure 6(a) depicts all four antenna elements' 2D radiation characteristics at 2.4 GHz. It can be observed that when D_1, D_3, D_5, and D_7 are forward biased, the proposed antenna produces

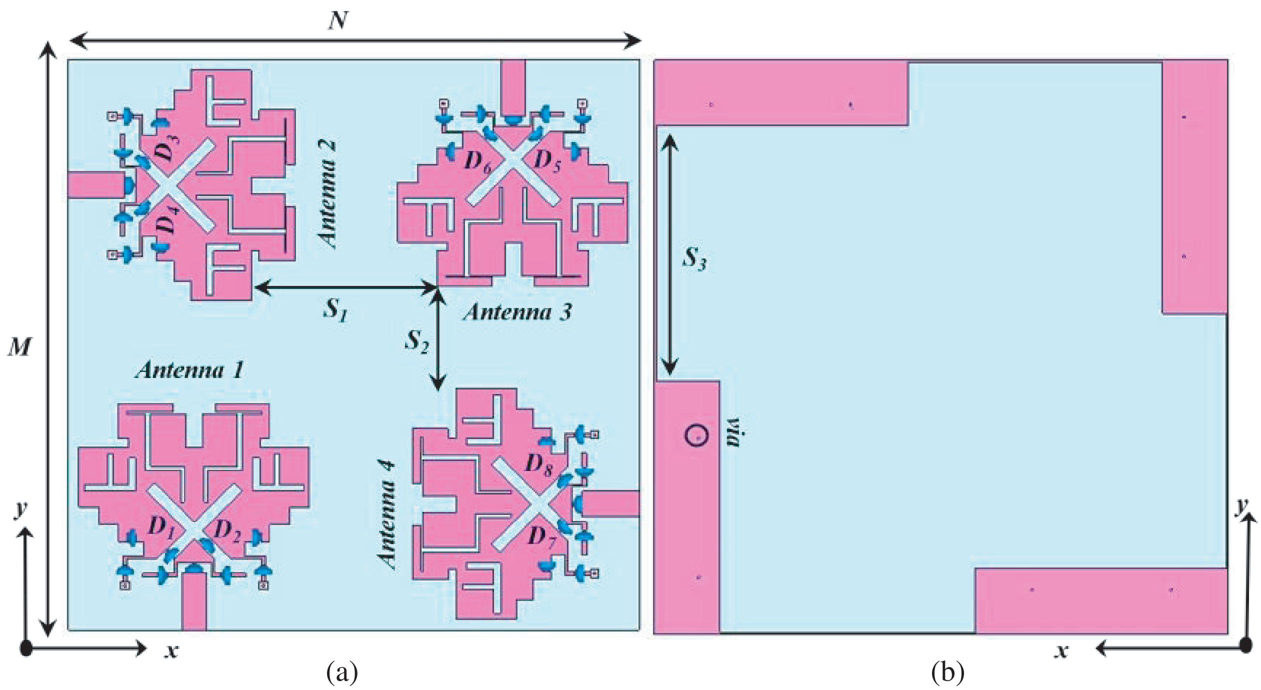


Figure 3. Schematic of the proposed RRPMA: $M = 68$, $N = 68$, $S_1 = 22$, $S_2 = 12.5$, $S_3 = 30$ (All dimensions are in mm). (a) Top view. (b) Back view.

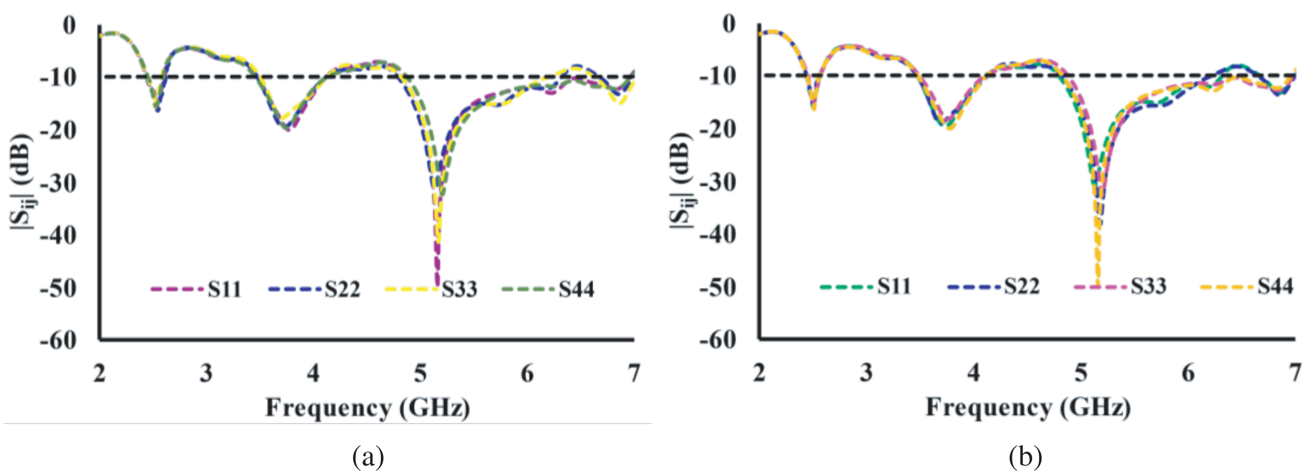
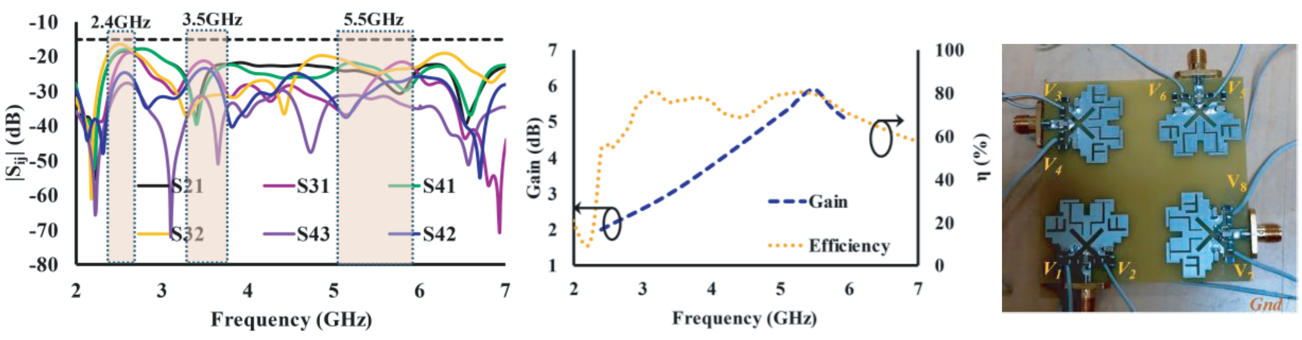


Figure 4. Reflection characteristics of the proposed RRPMA. (a) Case I. (b) Case II.

beams in four different directions such as 90°, 135°, 45°, and 300°. Similarly, when D_2, D_4, D_6, and D_8 are ON, the antenna elements radiate in four different directions such as 270°, 225°, 315°, and 60°. Figure 6(b) shows the beams at 3.5 GHz of the proposed MIMO antenna. When D_1, D_3, D_5, and D_7 are biased, the beams radiate towards four different angular directions such as 90°, 60°, 345°, and 240°. Also, when D_2, D_4, D_6, and D_8 are biased, the beams reconfigured to the directions 270°, 300°, 15°, and 120°. Figure 6(c) presents the beam directions at 5.5 GHz when D_1, D_3, D_5, and D_7 are biased, with the antenna pointing towards 195°, 105°, 15°, and 315°, and when D_2, D_4, D_6, and D_8 are biased, the beams switched to the directions as 15°, 255°, 345°, and 45°. Thus, the proposed antenna is capable to steer the antenna beams to multiple directions at the respective frequencies represented in Table 1.

Hence, in a real-time environment, the antenna is placed inside a plastic enclosure which is transparent to the wireless signals. Therefore, the ABS material is chosen to study the behaviour



(a) (b) (c)

Figure 5. (a) Mutual coupling characteristics. (b) Gain and efficiency. (c) Fabricated prototype of RRPMA.

Table 1. Radiation characteristics of RRPMA and their reconfigurable direction.

	Port-1		Port-2		Port-3		Port-4	
Frequency (GHz)	D_1	D_2	D_3	D_4	D_5	D_6	D_7	D_8
2.4	90°	270°	135°	225°	45°	315°	300°	60°
3.5	90°	270°	60°	300°	345°	15°	240°	120°
5.5	195°	15°	105°	255°	15°	345°	315°	45°

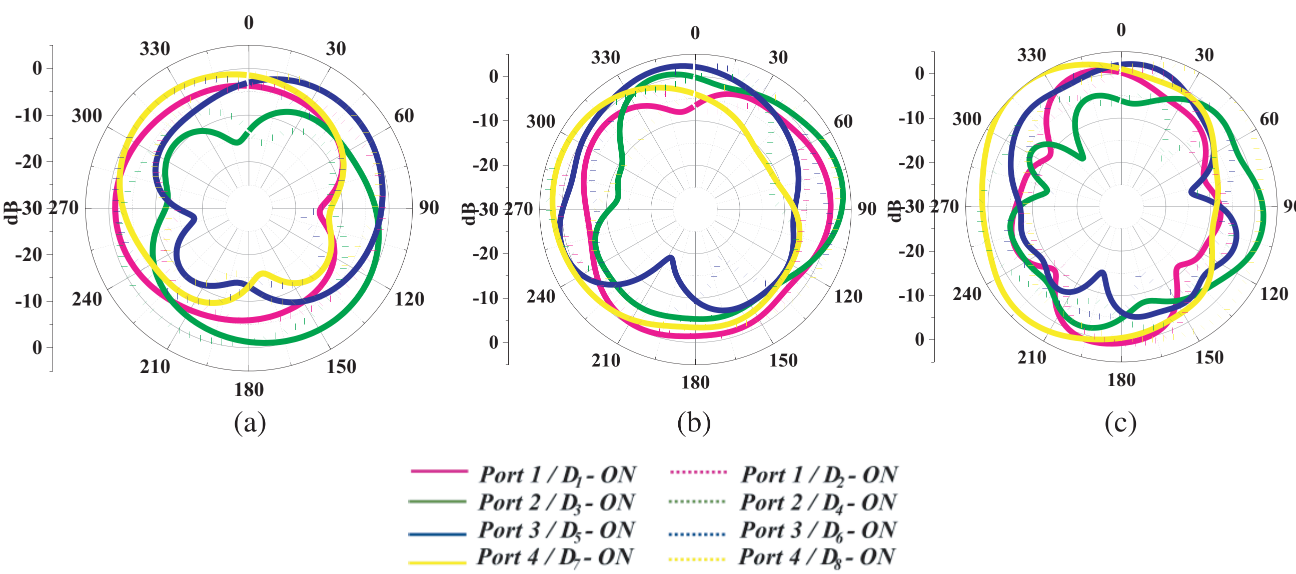
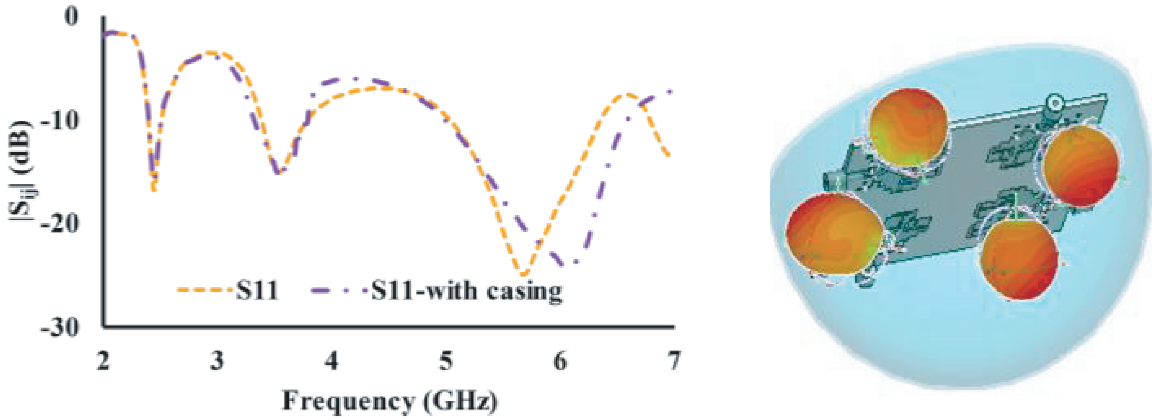


Figure 6. 2D far-field characteristics of proposed RRPMA at φ plane. (a) 2.4, (b) 3.5, (c) 5.5 GHz.

of the antenna inside the plastic casing. The plastic encasing is $70 \times 70\,\text{mm}^2$ in size. The dome-shaped encasing is selected, since it has a wide aperture in small size, provides good radiation, and possesses aesthetic attire. The reflection and radiation characteristics of RRPMA with the enclosure are represented in Figure 7, and the radiation characteristics at 2.4 GHz are shown in Figure 7(b).

Furthermore, the performance of the RRPMA is validated using standard parameters [12, 13] such as isolation, ECC, TARC, and CCL. It is noticed from Table 2 that the proposed antenna achieves



(a) (b)

Figure 7. (a) Reflection characteristics with & without casing. (b) Radiation characteristics of RRPMA with casing.

Table 2. MIMO characteristics of the proposed RRPMA.

Antenna Element	State of diode	Isolation (dB)			ECC			TARC (dB)			CCL (bits/s/Hz)		
		Frequency (GHz)											
		2.4	3.5	5.5	2.4	3.5	5.5	2.4	3.5	5.5	2.4	3.5	5.5
1 (w.r.t 2)	D_1-on	23	25	21	0.03	0.03	0.03	−17	−18	−11	0.31	0.13	0.23
	D_2-on	25	28	26	0.03	0.04	0.015	−11	−20	−11	0.33	0.24	0.33
2 (w.r.t 3)	D_3-on	22	18	21	0.08	0.12	0.035	−12	−19	−10	0.24	0.13	0.28
	D_4-on	18	20	19	0.05	0.18	0.007	−16	−14	−10	0.15	0.07	0.3
3 (w.r.t 4)	D_5-on	29	33	15	0.01	0.02	0.004	−12	−16	−13	0.10	0.27	0.24
	D_6-on	27	30	22	0.07	0.05	0.16	−14	−17	−14	0.01	0.15	0.03
4 (w.r.t 1)	D_7-on	28	19	24	0.01	0.07	0.007	−16	−12	−23	0.11	0.23	0.11
	D_8-on	26	24	26	0.06	0.06	0.012	−12	−18	−11	0.26	0.12	0.26

Table 3. Performance comparison of proposed RRPMA with other related works.

R. No.	Antenna Size (λ) (mm^2)	No. of AE	AE Spacing (λ)	Frequency (f_o) (GHz)	%BW (%)	Gain (dBi)	η (%)	No. of directions covered	ECC
[14]	0.96×0.48	2	-	2.45	8	-	60	2	0.02
[15]	1.2×2.06	2	-	5.25	3.8	5.1	70.1	3	0.03
[16]	0.44×0.61	2	0.25	2.65	3.8	-	85	7	0.05
[17]	1.86×1.44	2	-	3.6	19	5.1	-	4	-
This work	**0.55×0.55**	**4**	**0.03**	**2.4, 3.5, 5.5**	**4.18, 14.13, 28.52**	**1.4, 3.35 5.6**	**70.4 82.4 83.3**	**8**	**0.18**

*AE: Antenna Elements; *η: Efficiency; λ_0: lowest resonant frequency;

isolation greater than 18 dB, ECC $<$ 0.18, TARC $<$ -11 dB, and CCL $<$ 0.33 bits/s/Hz. Table 3 compares the proposed work with other related references.

4. CONCLUSIONS

A reconfigurable radiation pattern MIMO antenna is reported in this research work. It covers three wireless standards which are used in indoor scenarios with a wide bandwidth at the desired operating frequencies such as 2.4, 3.5, and 5.5 GHz. The results show that the proposed antenna has good diversity performance characteristics. Further, an ABS casing is designed, and the antenna performance with enclosure is evaluated. The beam reconfiguration is performed at triband frequencies and covers eight different directions at each frequency. Therefore, the proposed antenna is suitable for indoor wireless scenarios.

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