Frequency/Isolation Reconfigurable Compact Novel Quad-Element MIMO Configuration for WLAN/WiMAX Applications

Kabir Das Ayinala
Dept. of Electrical Engineering
National Institute of Technology Rourkela,
Rourkela, India
518ee7017@nitrkl.ac.in

Prasanna Kumar Sahu
Dept. of Electrical Engineering
National Institute of Technology Rourkela,
Rourkela, India
pksahu@nitrkl.ac.in

***Abstract* — A compact novel quad-element MIMO antenna with frequency and isolation reconfigurable feature is introduced for WLAN and WiMAX services. The antenna elements are based on circular curve-shaped monopoles having a compact area of 12 mm × 22 mm. The decoupling structure is an inverted L-shaped Defective Ground Structure (DGS, etched on the ring-shaped common ground plane, which acts as a bandstop filter. The presented MIMO design has a compact size of 34 mm × 34 mm. The reconfigurable frequency capability between the frequency bands of 3.3 - 3.7 GHz and the 4.4 - 5.7 GHz is achieved by switching the integrated Positive-Intrinsic-Negative (PIN) diodes between ON and OFF states. Simultaneously, the reconfigurable isolation ability between these bands is obtained by controlling the DGS decoupling elements' lengths by switching the incorporated PIN diodes between the OFF and ON states. The introduced decoupling structure accomplished good decoupling levels of 15 and 19 dB across the targeted frequency bands of WiMAX (3.4 – 3.6 GHz) and WLAN (5.15 – 5.35 GHz). The diversity ability of the MIMO configuration in terms of ECC and TARC is below 0.085 and -10 dB across both the operating bands.**

Keywords— Defective ground structure, isolation, MIMO, PIN diode, reconfigurable

I. INTRODUCTION

To fulfill the massive demands of extremely higher data throughput and link quality, the most widely used wireless applications, such as WLAN and WiMAX, integrated quad-element Multiple-Input Multiple-Output (MIMO) configurations. Furthermore, compactness and multi-band characteristics are also the key requirements for space-constrained portable wireless devices to provide wireless connectivity for multiple wireless services. The MIMO configurations with its principles of multiplexing and diversity enhance the channel capacity and reliability without consuming additional bandwidth and transmitter power [1]. However, compact MIMO designs with closely packed elements suffer from a strong mutual coupling. Hence, various authors have been proposed different decoupling techniques for dual-band MIMO antennas to mitigate the undesired mutual coupling. The MIMO designs reported for WLAN and WiMAX applications in [2], [3] utilize separate ground planes for antenna elements to achieve necessary isolation. However, independent ground planes are practically not feasible as these may not ensure a similar reference voltage level, which leads to misinterpretation of the signals [4]. The design in [5] has a large footprint (80 × 80 mm^2), and the quad-element MIMO configuration in [6] operated with two ports only in each of the targeted bands.

Frequency reconfigurable MIMO structures are another important class of antennas that can simultaneously achieve compactness and multi-band characteristics more easily than multi-band antennas. Several MIMO configurations with reconfigurable ability are already proposed in the literature [7-11]. In [7], MIMO configuration with simultaneous isolation & frequency, and in [8], MIMO design with three switchable operations is proposed for WLAN and WiMAX applications. In another design [9], a MIMO configuration with 2.4 and 3.5 GHz switchable modes is proposed to encompass 4G/LTE applications. However, the designs in [7-9] are operated with only two elements. In [10], a quad-element design with a compact size of 46 × 20 mm^2 has been proposed with a DGS decoupling element for WLAN applications. However, in the lower band of 2.4 GHz, the design is operated with two ports. In [11], a 40 × 40 mm^2 large footprint 4-element MIMO design with two wide switchable bands is presented for WLAN and Ku- band wireless applications. However, the design is unsuitable for practical applications as it uses separate grounds

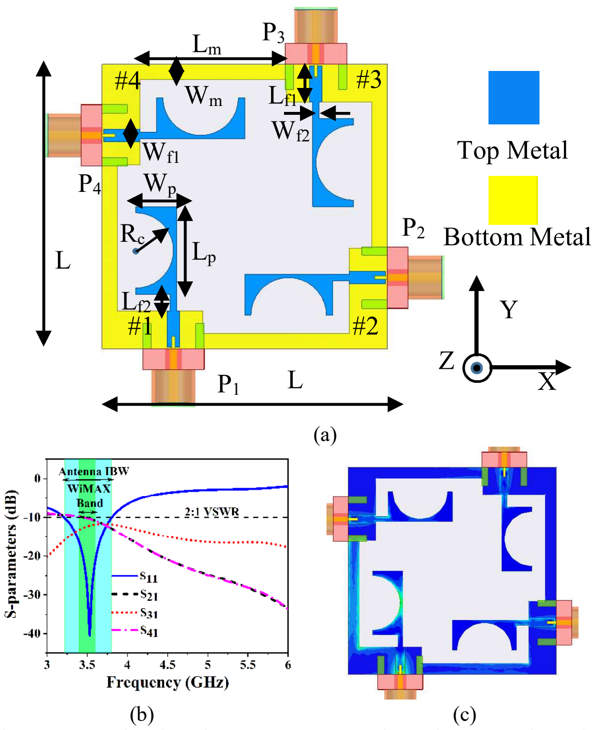


Fig. 1. Lower-band (WiMAX) MIMO configuration (a) Schematic (b) S-parameters (c)Surface current distribution at 3.5 GHz. Dimensions (mm): L=34, L_{f1}= 4.5, L_{f2}= 2, W_{f1}= 1.5, W_{f2}= 0.8, L_p=10.5, W_p=5.7, R_c=4.5, L_m=17.5, W_m=1.6.

TABLE 1. COMPARISON OF THE PRESENTED MIMO STRUCTURE WITH THE SIMILAR MIMO STRUCTURES.

Ref.	Number of ports	Design footprint (mm^2)	Operating bands (GHz)	Isolation (dB)	Gain (dBi)	ECC	Decoupling structure	CG
[8]	2	48.5 × 25	3.17–3.77, 5.13–5.88	16	3.0, 2.2	< 0.05	Polarization diversity	No
[9]	2	120 × 60	2.0 – 2.7, 2.57 -4.27	16	3.7, 4.2	< 0.056	Space diversity	Yes
[10]	4	46 × 20	2.4 – 2.5, 4.9 -5.725	14	-0.5, 2.57	< 0.2	Reconfigurable open-ended slots	Yes
This work	**4**	**34 × 34**	**3.3 – 3.7, 4.4 – 5.7**	**15**	**2.57, 3.5**	< 0.085	**Reconfigurable DGS-DFs**	**Yes**

for isolation enhancement. Therefore, the literature reveals that the implementation of common ground sharing multi-band quad-element MIMO designs with enhanced isolation is a difficult task.

In the presented work, a novel compact common ground plane quad-element MIMO configuration with simultaneous reconfigurable radiator and DGS- based isolation structure is proposed for WLAN and WiMAX frequency bands. The integrated PIN diodes in the radiated structure of circular curve-shaped monopole control the resonant length to switch the operating bands. The PIN diodes across the decoupling slots etched on the ring-shaped common ground plane provide good isolation in the selected operating band. The presented MIMO antenna provides decent isolation with a compact size of $0.37\lambda_0 \times 0.37\lambda_0$. It is more compact than the similar MIMO designs reported in the literature, as shown in Table 1. It reports a very good antenna and diversity performance across both the targeted frequency bands. It is designed over an FR-4 substrate ($\epsilon_r = 4.4, tan\delta = 0.02$) of thickness 0.8 mm using HFSS electromagnetic simulator.

II. QUAD-ELEMENT MIMO CONFIGURATION WITH BSF-BASED DECOUPLING STRUCTURE

In the design evolution of quad-element MIMO antenna configuration with BSF-based decoupling structure, initially,

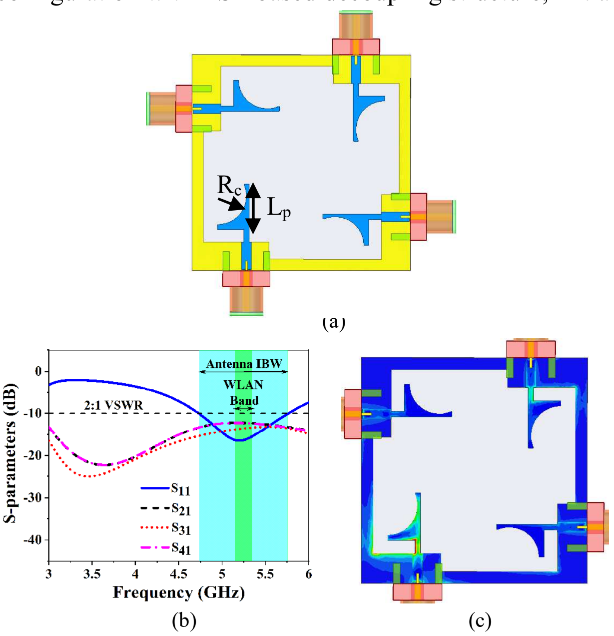


Fig. 2. Higher-band (WLAN) MIMO configuration (a) Schematic (b) S-parameters (c)Surface current distribution at 5.2 GHz (R_c=4.5 mm, L_p= 6.5 mm)

MIMO configuration without decoupling element and later with decoupling element is demonstrated. Fig. 1(a) shows the schematic of lower-band (WiMAX) quad-element MIMO configuration without etching DGS slot for isolation improvement. It uses semi-circular curve-shaped monopole radiators with partial ground planes interconnected with a metallic strip ($L_m \times W_m$) to obtain the continuous ground plane. The curve-shape of the monopole increases the resonant length to provide a certain level of miniaturization compared to the rectangular monopole. The MIMO antenna operates at 3.5 GHz and reports mutual coupling of 10 dB when element #1 is excited, as shown in Fig. 1(b). The higher coupling level is attributed to the strong surface current coupling between the elements through the metallic connected strips. This is demonstrated with the surface current distribution at 3.5 GHz in Fig. 1(c).

For higher (WLAN) band similar MIMO configuration with nearly quarter-circular curve-shaped antenna elements is implemented, as depicted in Fig. 2(a). The S-parameters plotted in Fig. 2(b) show the structure resonates at 5.2 GHz and achieves minimum isolation of 12.5 dB between the elements. This lower isolation is demonstrated with its surface current distribution at its resonant frequency in Fig. 2(c). The MIMO configurations of WiMAX and WLAN bands with common ground planes show poor isolation, which is essentially ameliorated to provide decent diversity ability by incorporating an appropriate decoupling structure.

As poor isolation is due to the coupling of surface currents through the metallic strips, a suitable microstrip bandstop filter (BSF) based on an inverted L-shaped open-ended quarter wavelength slot is considered, as displayed in Fig. 3(a). The S-parameters of the BSF for two different slot lengths (L_s) are displayed in Fig. 3(b) shows the maximum rejection of the signal between the ports is 28 and 25 dB in the lower (WiMAX) and higher (WLAN) bands, respectively. The current distribution at 3.5 and 5.2 GHz in Figs. 3 (c) and (d) demonstrate its principle of trapping electromagnetic energy.

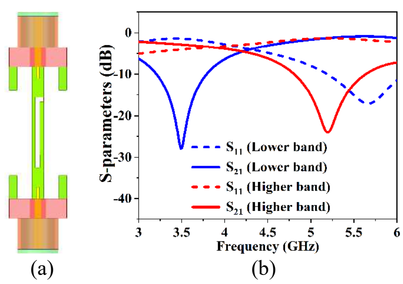
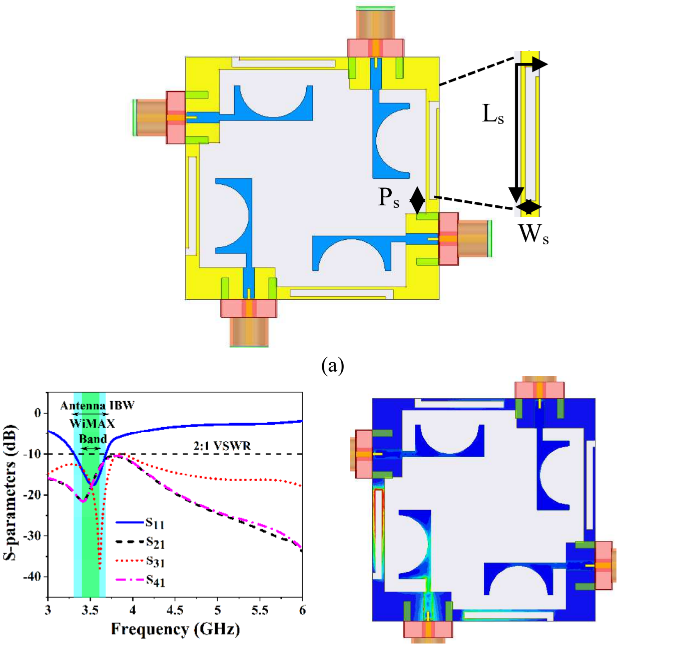


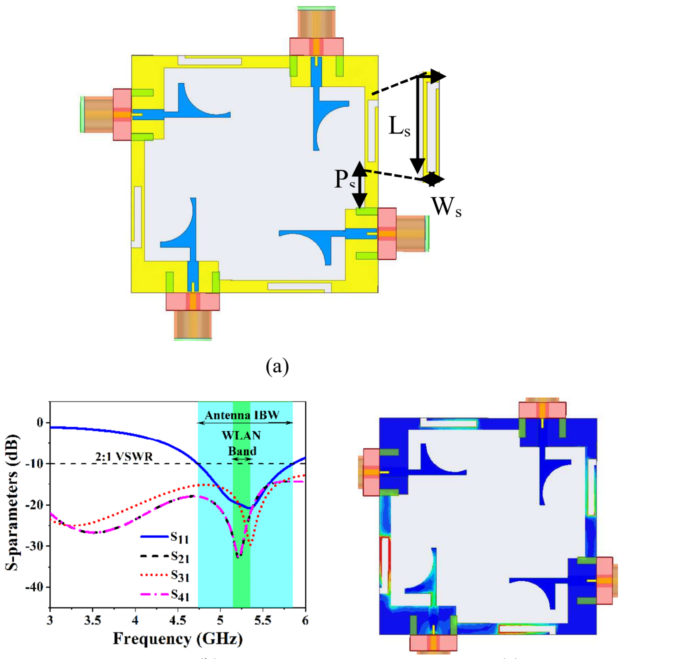
Fig. 3. Bandstop filter characteristics. (a) Schematic (b) S-parameters (c) Current distribution at 3.5 GHz (d) Current distribution at 5.2 GHz.



(a)

(b) (c)

Fig. 4. Lower-band (WiMAX) MIMO antenna system with decoupling structure (a) Schematic (b) S-parameters (c) Surface current distribution at 3.5 GHz. L_s = 14.5 mm, W_s = 1 mm, P_s = 2 mm.



(a)

(b) (c)

Fig. 5. Higher-band (WLAN) MIMO antenna system with decoupling structure (a) Schematic (b) S-parameters (c) Surface current distribution at 5.2 GHz. L_s = 9.1 mm, W_s = 1 mm, P_s = 6.4 mm.

The implemented DGS slot-based BSFs with a slot length of L_s = 14.5 mm $\left(\approx \frac{\lambda_g}{4}\ at\ 3.5\ \text{GHz}\right)$ are etched on the metallic strips between the elements of the WiMAX MIMO configuration, as shown in Fig. 4(a). The S-parameters in Fig. 4(b) show that the isolation is improved to 22 and 38 dB between the orthogonal and aligned elements. The improvement in isolation is demonstrated with the surface current distribution in Fig. 4(c). It clearly shows the trapping of surface current across the BSF slot to decouple the elements. Similarly, decoupling elements with a slot length of L_s = 9.1 mm $\left(\approx \frac{\lambda_g}{4}\ at\ 5.2\ \text{GHz}\right)$ are introduced between the elements of the WLAN MIMO configuration, as shown in Fig. 5(a). The decoupling elements provide peak isolation of 33 and 30 dB between the orthogonal and aligned elements within this band, as depicted in Fig. 5(b). The current distribution at 5.2 GHz in Fig. 5(c) shows how effectively the decoupling element prevents electromagnetic propagation from one element to another.

III. PROPOSED QUAD-ELEMENT RECONFIGURABLE MIMO CONFIGURATION

Finally, the proposed frequency/isolation reconfigurable quad-element MIMO configuration is implemented by combining the WiMAX and WLAN quad-element MIMO configurations using PIN diodes, as shown in Fig. 6. The reconfigurable frequency feature is accomplished by employing four PIN diodes ($D_{f1} – D_{f4}$) on the monopole radiators to operate at 3.5 and 5.2 GHz bands by changing their resonant length. The isolation reconfigurable ability is obtained by integrating four PIN diodes ($D_{d1} – D_{d4}$) with the decoupling slots to isolate the elements effectively in both the targeted frequency bands. BAR50-02 Infineon type PIN diodes are considered for the implementation of the proposed MIMO antenna. As per its datasheet, it provides forward resistance (R_f) of 3 Ω in ON state and 0.15 pF capacitance (C_p) and 5 kΩ reverse resistance (R_p) in OFF state. The reconfigurable MIMO structure operates in

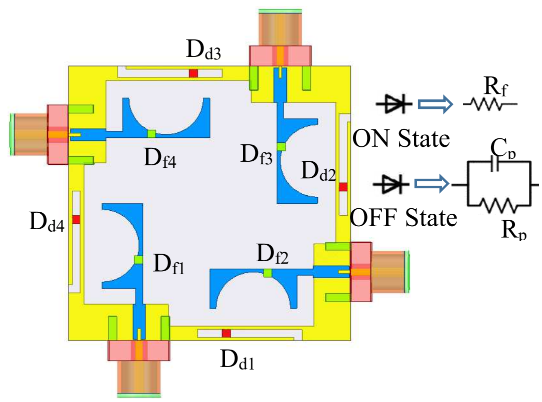
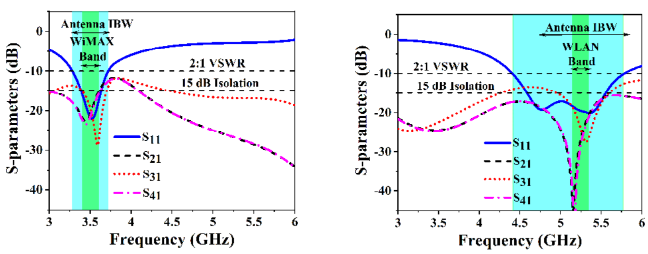


Fig. 6. Schematic of proposed reconfigurable quad-element MIMO design.



(a) (b)

Fig. 7. S-parameters of the presented reconfigurable MIMO configuration when (a) D_{f1} to D_{f4} - ON and D_{d1} to D_{d4} – OFF (WiMAX band) (b) D_{f1} to D_{f4} - OFF and D_{d1} to D_{d4} – ON (WLAN band).

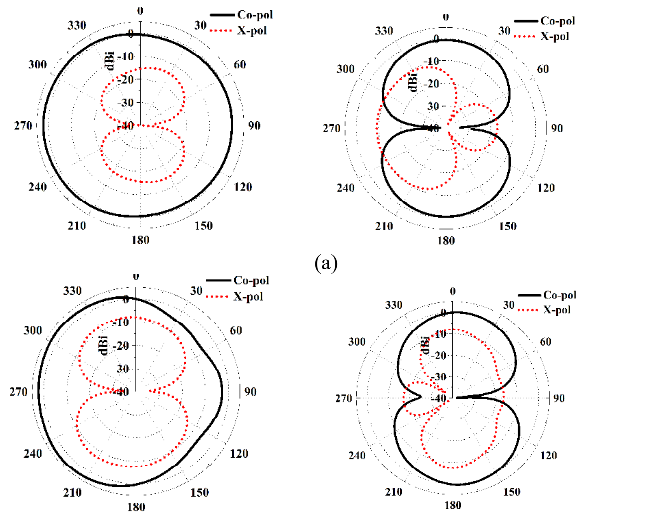


Fig. 8. 2-D radiation patterns of the introduced MIMO design in the principal planes (XZ and YZ) at (a) 3.5 GHz (b) 5.2 GHz.

the WiMAX band with enhanced isolation when PIN diodes D_{f1} - D_{f4} are ON and D_{d1}- D_{d4} are OFF. However, when the diodes D_{f1} – D_{f4} are OFF and D_{d1} – D_{d4} are ON, the proposed structure works in the WLAN band. Figs. 7(a) and (b) depict the S-parameters of the proposed MIMO geometry operated in WiMAX and WLAN bands. The antenna achieves a 2:1 VSWR bandwidth of 11.4% (3.3–3.7 GHz) and 25.7% (4.4–5.7 GHz) in the lower and higher bands. The isolation structure provides isolation below 15 and 19 dB within the targeted WiMAX (3.4-3.6 GHz) and WLAN (5.15–5.35 GHz) bands.

The 2-D patterns of the MIMO design when element #1 is excited are provided in Fig. 8. As noticed, patterns are similar to the dipole antenna in both perpendicular principal planes (XZ and YZ) in both bands. Furthermore, the antenna provides a decent peak gain of 2.57 and 3.5 dBi and peak efficiencies of 71 and 75% at the working frequencies of 3.5 and 5.2 GHz.

IV. DIVERSITY PERFORMANCE

The presented reconfigurable MIMO antenna diversity performance is verified by computing its key performance parameters of Envelope Correlation Coefficient (ECC) and Total Active Reflection Coefficient (TARC). The parameter ECC represents the level of similarity between the MIMO antennas, which is computed for isotropic/uniform channel environments as follows [8].

$$\rho_e(i,j) = \frac{\left|\sum_{n=1}^{N} S_{i,n}^{*} S_{n,j}\right|^2}{\prod_{k=i,j}\left[1-\sum_{n=1}^{N} S_{k,n}^{*} S_{n,k}\right]\eta_k} \quad (1)$$

Where i, j varies from 1 to N (number of ports) and η_k is the efficiency of k^{th} element. The proposed MIMO design achieves ECC < 0.085 across both the bands, which is far below the standard value of 0.5 required for good diversity ability, as shown in Fig. 9(a). The TARC provides effective antenna bandwidth for multi-antenna systems, which is calculated in terms of S- parameters and excitation phase difference (θ) between the ports using the expressions reported in [5]. Fig. 9(b) shows the calculated TARC values are below the specified level of -10 dB across both the working bands

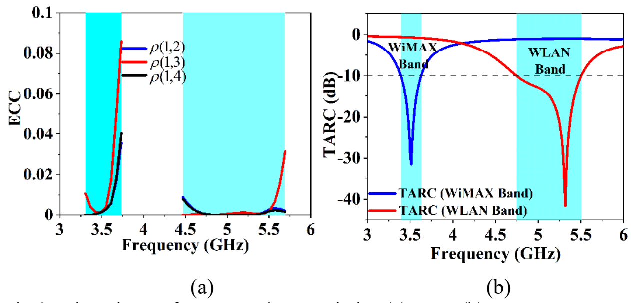


Fig.9. Diversity performance characteristics (a) ECC (b) TARC.

V. CONCLUSION

A novel compact quad-element MIMO configuration with simultaneous frequency/isolation reconfigurable feature is proposed for WiMAX and WLAN frequency bands. It has a compact area of $0.14\lambda_0^2$ (λ_0 is the maximum operating free-space wavelength). It accomplishes an antenna bandwidth of 0.4 GHz (3.3 – 3.7 GHz) and 1.3 GHz (4.4 – 5.7 GHz) in lower and higher bands. It reports good isolation levels of 15 and 19 dB in the targeted bands. The MIMO antenna shows good radiation performance with peak gains of 2.57 and 3.5 dBi in the lower and higher bands. The calculated diversity parameters of ECC and TARC ensure excellent diversity ability. The compact feature of the MIMO antenna with excellent radiation and diversity/MIMO performance characteristics makes it an appropriate candidate for portable wireless devices.

REFERENCES

[1] M. A. Jensen and J. W. Wallace, "A review of antennas and propagation for MIMO wireless communications," *IEEE Trans. Antennas Propag.*, vol. 52, no. 11, pp. 2810–2824, 2004.

[2] L. Malviya, R. K. Panigrahi, and M. V. Kartikeyan, "A 2 x 2 dual-band MIMO antenna with polarization diversity for wireless applications," *Prog. Electromagn. Res.*, vol. 61, pp. 91–103, 2016.

[3] S. Roy, S. Ghosh, and U. Chakarborty, "Compact dual wide-band four/eight elements MIMO antenna for WLAN applications," *Int. J. RF Microw. Comput. Eng.*, vol. 29, no. 7, pp. 1–15, 2019.

[4] M. S. Sharawi, "Current Misuses and Future Prospects for Printed Multiple-Input, Multiple-Output Antenna Systems," *IEEE Antennas Propag. Mag.*, vol. 59, no. 2, pp. 162–170, 2017.

[5] D. Sarkar, K. Saurav, and K. V. Srivastava, "A compact four element CSRR-loaded antenna for dual band pattern diversity MIMO applications," in *2016 46th European Microwave Conference (EuMC)*, 2016, pp. 1315–1318.

[6] A. Birwal, S. Singh, B. K. Kanaujia, and S. Kumar, "Low-profile 2.4/5.8 GHz MIMO/diversity antenna for WLAN applications," *J. Electromagn. Waves Appl.*, vol. 34, no. 9, pp. 1283–1299, 2020.

[7] J. Lim, Z. Jin, C. Song, and T. Yun, "Simultaneous Frequency and Isolation Recon fi gurable MIMO PIFA Using PIN Diodes," vol. 60, no. 12, pp. 5939–5946, 2012.

[8] N. V. Shahmirzadi and H. Oraizi, "Design of reconfigurable coplanar waveguide- fed planar antenna for multiband multi-input – multi-output applications," pp. 1591–1597, 2016.

[9] A. Pant, M. Singh, and M. S. Parihar, "A frequency reconfigurable/switchable MIMO antenna for LTE and early 5G applications," *AEU - Int. J. Electron. Commun.*, vol. 131, no. January, p. 153638, 2021.

[10] S. Soltani, S. Member, P. Lotfi, S. Member, R. D. Murch, and A. Abstract, "A Port and Frequency Reconfigurable MIMO Slot Antenna for WLAN Applications," *IEEE Trans. Antennas Propag.*, vol. 64, no. 4, pp. 1209–1217, 2016.

[11] U. D. Yalavarthi, "Reconfigurable orthogonal quad-port MIMO antenna for DSRC, WLAN, RADAR and Ku-band applications," *AEU - Int. J. Electron. Commun.*, vol. 136, p. 153766, 2021.