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A low-profile wideband circularly polarized MIMO antenna with pattern and polarization diversity

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Research Paper

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Abstract

The present work describes a unique planar low-profile wideband circularly polarized Multiple-Input and Multiple-Output (MIMO) antenna operating in the X-band, with pattern and polarization diversity over the entire axial-ratio bandwidth (ARBW). The design is unique in the sense that a simple grounded stub introduced between two linearly polarized monopole antennas has been used to realize wideband circular polarization, pattern diversity, and high isolation between antennas. The ARBW of the MIMO antenna is 2.45 GHz (8.11–10.56) 3 dB and its impedance matching bandwidth is 3.52 GHz (8.07–11.59). The isolation is better than 20 dB. The antenna can be easily adapted to operate other frequency bands by simple frequency scaling. It has been fabricated on an FR-4 substrate and its performance has been compared against several existing available antennas.

Introduction

In modern communication systems, Multiple-Input and Multiple-Output (MIMO) antennas are used for receiving and sending many data signal instantaneously over the same radio channel [1–6]. The pattern diversity antennas can discriminate a large portion of the angular space, while the polarization diversity is useful for immunizing the system from polarization mismatch, which could be a source of fading in the signal. Isolation between the antennas, working at the same frequency, is a critical factor to consider when designing the MIMO system. Several methods have been suggested to improve the isolation, albeit at the cost of enlarged size and added design complexity of the structure [1, 2, 7–9]. Although most of the MIMO antennas are designed in the WLAN band (2.4/5.8 GHz) [1–5], other designs have also been reported in the UWB band [6, 10–13]. In some scenarios, one antenna works with linear polarization (LP), while the other operates with circular polarization (CP) [1, 2]. Furthermore, antennas could be LP [5, 10–12, 14–17]. However, both antennas are often chosen to be circularly polarized for a robust system [3, 4, 18]. These antennas are suffered from a narrow CP or axial ratio band. To discriminate large portion of the signal and make use of angular space pattern diversity is exploiting [1, 2, 5, 6, 11, 12, 14, 17]. Some of the antennas are designed for UWB band with pattern diversity and isolation is improved by using stub in the ground or simple metallic line between the radiating elements [11, 12, 19], while these antennas are linearly polarized. Various types of EBG and metamaterial structures have been employed to reduce the mutual coupling between the radiating elements; this would result in large size and complex structure [7–9].

This work describes the design of a *wideband LHCP/RHCP MIMO antenna* in the X-band, which exhibits both the pattern and polarization diversity. Wideband CP with both pattern and polarization diversity is realized by inserting single stub in the ground between the two radiating elements, and this stub also provides high isolation between them. The 3 dB axial-ratio bandwidth (ARBW) of the antenna is 2.45 GHz (8.11–10.56), its impedance matching bandwidth (IMBW) is 3.52 GHz (8.07–11.59), and its isolation is better than 20 dB. All the simulations have been carried out by using the 3D EM simulator ANSYS HFSS.

Antenna design

The proposed MIMO antenna has been designed on low-cost substrate FR-4 having $\varepsilon_r = 4.4$, loss tangent = 0.02, and thickness $h = 0.8$ mm. The detailed dimension with the layout and fabricated antenna structure is shown in Fig. 1. Antenna design starts from the rectangular patch which is step-1 (antenna-1), and then by truncating diagonally from the upper side of the antenna-1 which is step-2 (antenna-2). Next, we truncate the lower portion of the patch to obtain the antenna-3 (step-3), which provides impedance matching from 8.6 to 11.5 GHz, and narrow band CP at center frequency 10.92 GHz. Stub in the ground plane further

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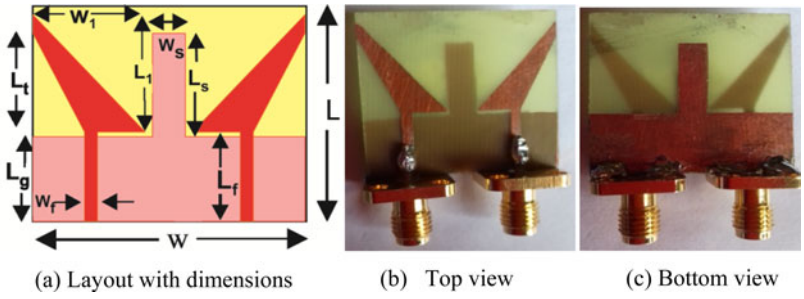


Fig. 1. Proposed antenna structure. (a) Layout with dimensions; (b) top view; (c) bottom view.

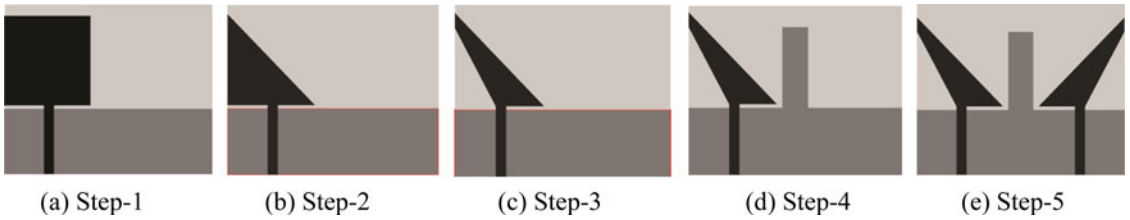


Fig. 2. Design steps of the proposed MIMO antenna. (a) Step-1; (b) step-2; (c) step-3; (d) step-4; (e) step-5.

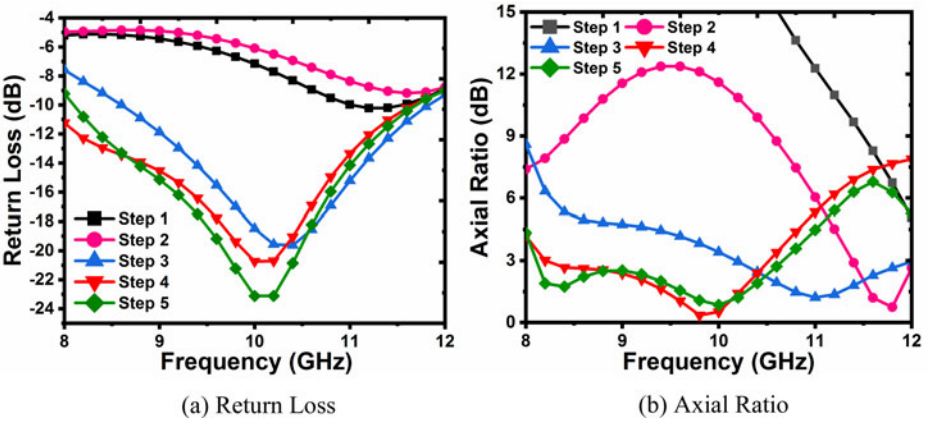


Fig. 3. Simulated return loss and axial ratio with design steps. (a) Return loss; (b) axial ratio.

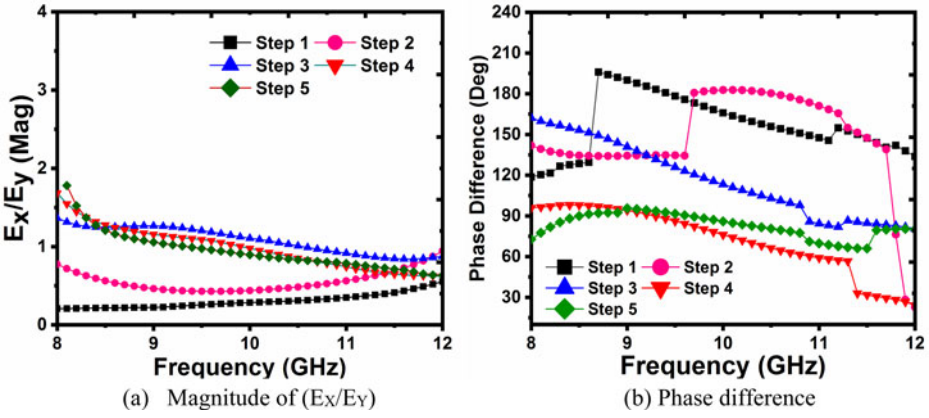


Fig. 4. Electric field components magnitude (E_X/E_Y)/ phase difference. (a) Magnitude of (E_X/E_Y); (b) phase difference.

improves the axial ratio band as well as impedance matching band, which is step-4 (antenna-4). For MIMO application, another similar antenna is placed on the other side of the stub, which is step-5 (final antenna-5). The main objective of the stub in the ground plane is to provide wideband CP, pattern diversity, and high isolation between the two antennas. Proposed MIMO antenna has two monopole antennas, which are facing each other with a small spacing of 5 mm ($\approx 0.16\lambda_0$ at $f_c = 9.83$ GHz). Both the antennas have common ground, and both are fed by microstrip line of width (W_f) and length (L_f).

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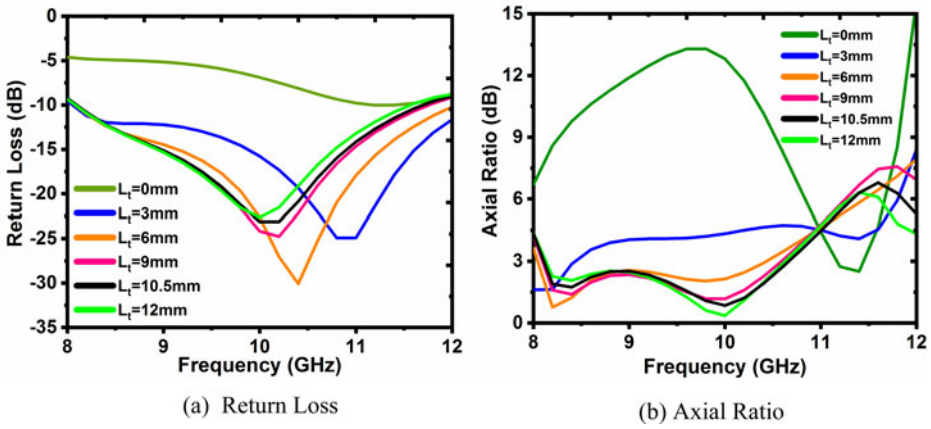


Fig. 5. Effect of truncation length L_t of step-5. (a) Return loss; (b) axial ratio.

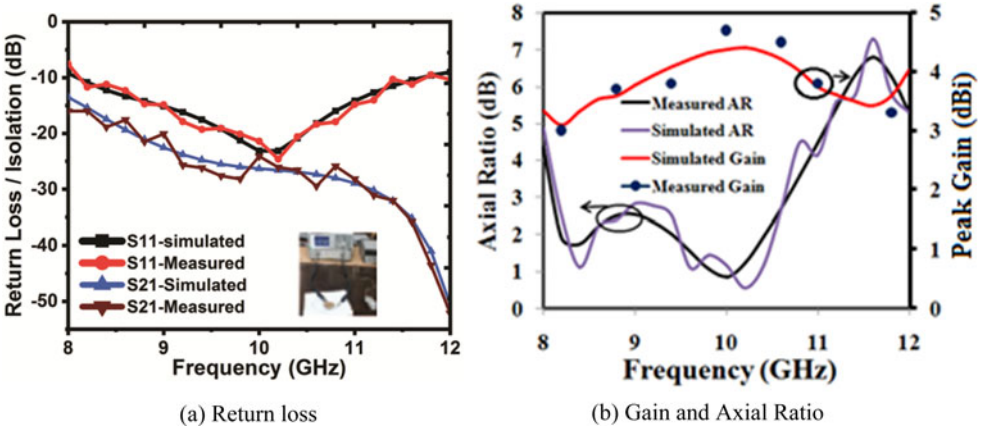


Fig. 6. Simulated and measured return loss, axial ratio and gain. (a) Return loss; (b) gain and axial ratio.

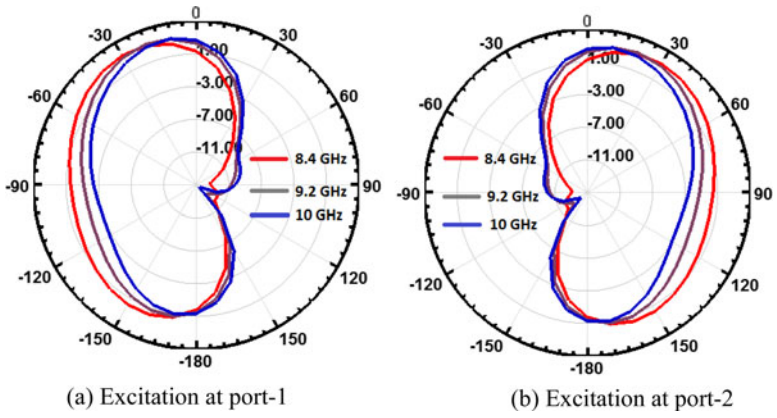


Fig. 7. Radiation pattern at 8.4, 9.2, 10 GHz showing pattern diversity. (a) Excitation at port-1; (b) excitation at port-2.

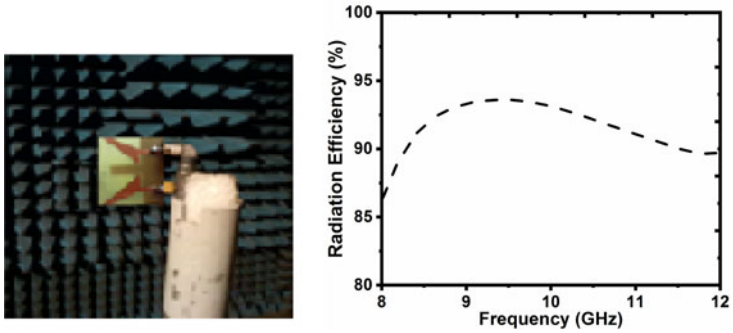
The dimensions of the proposed antenna structure are as follows: $W = 29$ mm, $L = 23$ mm, $W_1 = 12$ mm, $L_1 = 12.5$ mm, $W_s = 3.5$ mm, $L_s = 11$ mm, $L_g = 9$ mm, $W_f = 1.4$ mm, $L_f = 9.5$ mm, and $L_t = 10.5$ mm. These diagonal truncation and ground stub change the radiation pattern to directional pattern. Since these antennas are facing each other, hence their radiation patterns are in opposite direction thus pattern diversity is observed. The final antenna is antenna-5, which is designed in five systematic steps, illustrated in detail in Fig. 2.

Simulated performances of the proposed antennas (from antenna-1 to antenna-5) are compared in Fig. 3. The IMBW (S_{11}) starts improving from antenna-3 to antenna-5, while the axial ratio starts improving from antenna-2 to antenna-5.

Antenna-4 and antenna-5 have IMBW as 3.52 GHz (8.07–11.59 GHz) while ARBW is 2.45 GHz (8.11–10.56 GHz), which is wideband, shown in Figs 3(a) and 3(b).

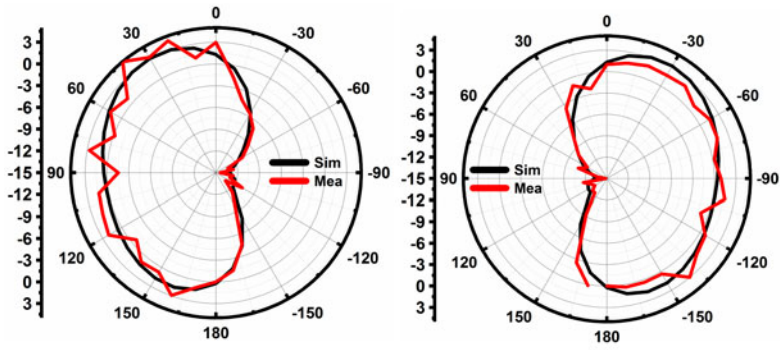
To realize the CP, we need to excite simultaneously two orthogonal horizontal mode and vertical mode with a 90° phase difference (PD). To understand the generation of CP, the two electric far-field components (E_X and E_Y) should have the same amplitudes but with 90° PD. The amplitude ratio of the electric far-field components (E_X/E_Y) and their PD from step-1 to

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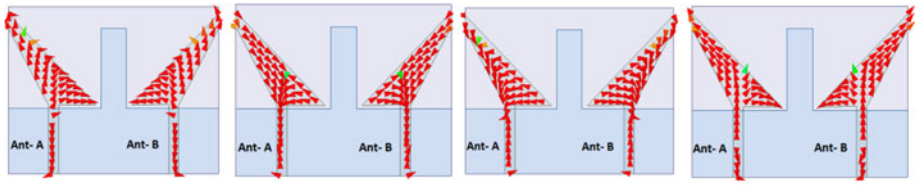
(a) Gain measurement (b) Radiation Efficiency

Fig. 8. Gain measurement and efficiency. (a) Gain measurement; (b) radiation efficiency.



(a) Excitation at port-1 (b) Excitation at port-2

Fig. 9. Simulated and measured radiation pattern at 8.4 GHz showing pattern diversity. (a) Excitation at port-1; (b) excitation at port-2.



(a) ωt = 0⁰ (b) ωt = 90° (c) ωt = 180° (d) ωt = 270°

Fig. 10. Surface current distribution at 8.4 GHz. (a) ωt = 0°; (b)ωt = 90°; (c) ωt = 180°; (d) ωt = 270°.

step-5 are illustrated in detail in Figs 4(a) and 4(b). The electric far-field components (E_X and E_Y) of antenna-4 and antenna-5 have identical amplitude and both have 90° PD from 8.11 to 10.56 GHz, as may be seen in Fig. 4 while antenna-1 to antenna-3 have no identical amplitude and 90° PD at the same time. The relationship between the far-field components demonstrates the generation of CP in the entire axial ratio band.

Parametric study

ARBW is mainly controlled by the truncation of lower side length L_t of step-4 shown in Figs 1(a) and 2(d). The ARBW starts improving with an increase in length L_t of the truncation. There is no significant effect on the IMBW while ARBW is improved with length L_t, which is presented in Fig. 5. Truncation in the lower side excites simultaneously two orthogonal horizontal mode and vertical mode with a 90° PD. This can be understood with the help of two electric far-field components (E_X and E_Y), which have the same amplitudes with 90° PD for L_t = 10.5 mm within the entire axial ratio frequency band shown in Fig. 4. Hence these two electric far-field components (E_X and E_Y) are responsible for the generation of CP.

Simulated and measured results

Both simulated and measured results are compared in Fig. 6. It can be noted that the isolation is high which can be seen in Fig. 6(a). It is better than −20 dB, obtained without employing extra decoupling structure. The wideband CP, pattern diversity, and isolation are achieved by simply adding one stub in the ground plane which can be seen in Fig. 2(d). There is no electric field coupling between both the antennas, hence it provides a pretty well pattern diversity within the axial ratio band as shown in Fig. 7. Both measured and simulated ARBW is 2.45 GHz (8.11–10.56) while its IMBW is 3.52 GHz (8.07–11.59) as shown in Figs 6(b) and 6(a).

The simulated and measured gain of the antenna varies from 3 to 4.8 dBi as shown in Fig. 6(b). Figure 8(a) shows the gain measurement in the anechoic chamber. The radiation efficiency is varying from 85 to 93%, which is high within the whole ARBW

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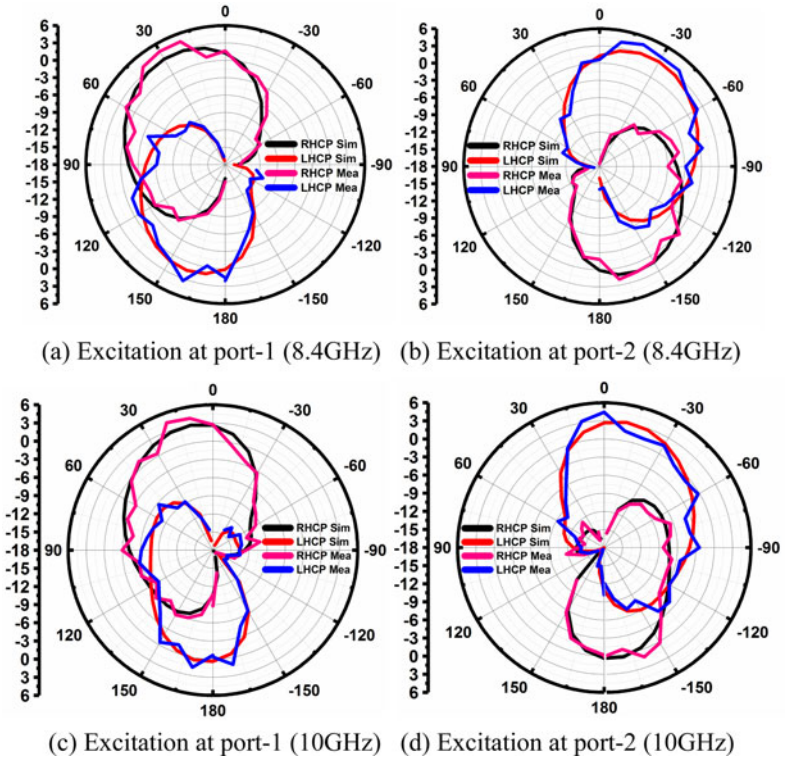


Fig. 11. Simulated and measured LHCP/RHCP radiation pattern at 8.4 and 10 GHz, showing polarization diversity. (a) Excitation at port-1 (8.4 GHz); (b) excitation at port-2 (8.4 GHz); (c) excitation at port-1 (10 GHz); (d) excitation at port-2 (10 GHz).

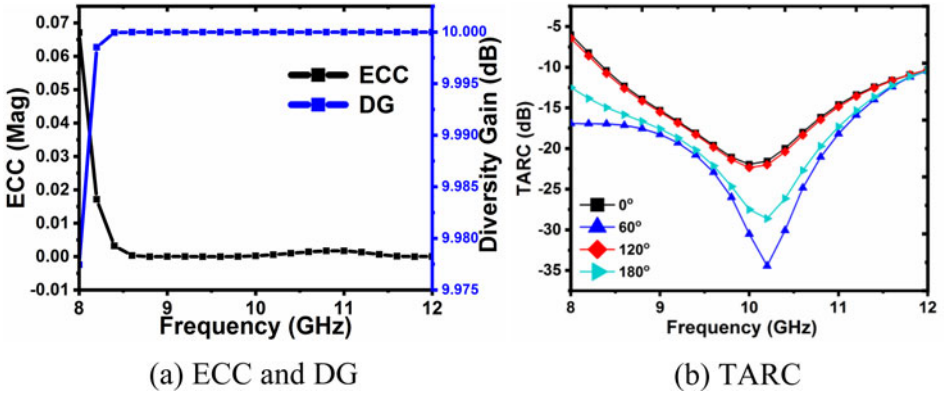


Fig. 12. Simulated and measured performances. (a) ECC and DG; (b) TARC.

as shown in Fig. 8(b). This indicates that the proposed antenna is highly efficient.

Isolation between two monopoles is better than −20 dB, it further improves with frequency. The 2D simulated radiation pattern shows the pattern diversity phenomena in the proposed antenna structure. Figure 9 shows the simulated and measured radiation pattern for 8.4 GHz which illustrates the pattern diversity. The simulated surface current distribution on the surface of antenna-A and antenna-B is shown in Fig. 10.

The rotating surface current verifies the CP of both the antennas, when each port of the antennas is excited individually. Antenna-A radiates LHCP while antenna-B radiates RHCP when both of them excited separately. Simulated and measured LHCP/RHCP radiation patterns are at 8.4 and 10 GHz, showing polarization diversity shown in Fig. 11. The proposed antenna radiates LHCP wave when port-1 is excited while it radiates RHCP wave when port-2 is excited.

To estimate the diversity performance of the proposed MIMO antenna, the envelop correlation coefficient (ECC), Diversity Gain (DG) and total active reflection coefficient (TARC) are calculated. Figure 12 shows simulated ECC using far-field pattern, DG, and TARC. ECC mostly preferred to find the correlation in the received signals while DG provides an enhancement in the system with several antennas compared to a system with single antenna. ECC is calculated from the far-field pattern. The ECC of the proposed antenna is nearly equal to zero while the acceptable ECC is <0.5 and DG is 10 dB, which are shown in Fig. 12(a). TARC plot is shown in Fig. 12(b), which shows stable characteristics as high isolation observed between port-1 and port-2. Hence our antenna has acceptable ECC, DG, and TARC. Our proposed antenna is compared in Table 1 with the earlier published works, which shows its performance is comparable. It has wide band axial ratio and IMBW with polarization and pattern diversities. The efficiency of the proposed antenna varies from 85 to 93%.

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Table 1. Performance comparison

Ref.	IMBW	ARBW	Diversity		Isolation (dB)	Gain (dB)	Efficiency %
			Pattern	Polarization			
1	1.3 GHz	250 MHz	Yes	Yes	>−14	2.5–4.3	96
2	90 MHz	80 MHz	Yes	Yes	>−15	3.8	85–90
3	1.02 GHz	900 MHz	Yes	Yes	>−18	3.0–4.0	70–93
4	1.0 GHz	375 MHz	No	Yes	>−20	4.8–5.0	86–95
5	84 MHz	NA	Yes	No	>−53	2.08	NA
Our	3.52 GHz	2.56 GHz	Yes	Yes	>−20	3.0–4.8	85–93

Conclusion

A wideband circularly polarized MIMO antenna with pattern and polarization diversity is presented in this paper. The ARBW is 2.45 GHz (8.11–10.56) while its IMBW is 3.52 GHz (8.07–11.59). The proposed antenna structure is simple and useful for X-band, and it has both pattern diversity and polarization diversity within the entire axial ratio band. The isolation without using extra decoupling structure between the antennas is better than −20 dB. The performance of the proposed antenna has been compared with those of the recently published works and is shown to be favorable. Compared to legacy circularly polarized MIMO antennas, the proposed antenna has better impedance matching, 3 dB ARBWs, and both pattern and polarization diversity. The simulated and measured results verify the design concept.

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