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A Wideband Circularly Polarized CPW-Fed Diamond Shape Microstrip Antenna for WLAN/WiMAX Applications

Sonu Rana[1], Jyoti Verma[1], and Anil K. Gautam[2, *]

Abstract—This paper presents the design and fabrication of a wideband circularly polarized CPW-fed compact diamond-shaped antenna. To enhance the wideband response and axial ratio in the desired frequency band, the geometry of the proposed antenna is modified. The modified antenna consists of one radiating element that includes two slits, one horizontal rectangular stub, and an improved ground plane. The suggested wide-band antenna has overall measurements of 25 mm × 28 mm × 1.6 mm. The V-shaped slit generates two orthogonal modes in the proposed antenna to excite circular polarization. The rectangular stub improves the wideband response in 2.35–4.62 GHz. The fabricated prototype antenna demonstrates good consistency between simulation and measured results. The suggested antenna resonates over a 2700 MHz transmission bandwidth between 2.35 and 4.62 GHz, making it a good choice for WLAN and WiMAX applications. The average gain in the wideband is 3.1 dBi with better efficiency. It is shown that our suggested approach is a great choice for developing any wideband microstrip antenna for usage in a variety of wireless communication systems.

1. INTRODUCTION

In today's wireless communication systems, circularly polarized microstrip antennas with excellent performance are employed because they can reduce the loss caused by multipath effects and are less effective by cross-polarization interference. Two orthogonal linearly polarized modes with a 90° phase difference should be excited to generate circular polarization in an antenna. Two orthogonal modes can be generated by inserting different perturbations in the patch antenna like strips, slots, slit, stub, asymmetric cross-slot, etc. [1–3]. Various shapes are used to obtain circular polarization in a single-feed patch antenna, like triangular, square, diamond, rectangular, and ring shapes [4, 5].

However, nearly 2-dB axial-ratio bandwidth generated in these antennas is very low. So, work has to be done to improve the axial ratio bandwidth. Nowadays, smartphones, laptops, and computers have been designed to be small, flat, and multifunctional. Therefore, it is difficult to create a single antenna that can accommodate various wireless applications in a broad bandwidth while maintaining the security of data [6–8]. It is difficult for researchers to design circularly polarized wideband antennas using different techniques to satisfy the broadband requirements without significantly compromising other parameters [9, 10]. Wireless LAN (WLAN) connects two or more devices using wireless communication to create a local area network (LAN) that gives users the ability to move around within the area and remain connected to the network. However, not all of the primary WLAN bands have been covered by the majority of designs. The strategies for broadening the operating bandwidth are suggested by researchers with adding a strip [11–13] and modifying the radiating patch and ground plane to U-shaped, T-shaped, multi-resonator, and compact printed wide-slots [14–17].

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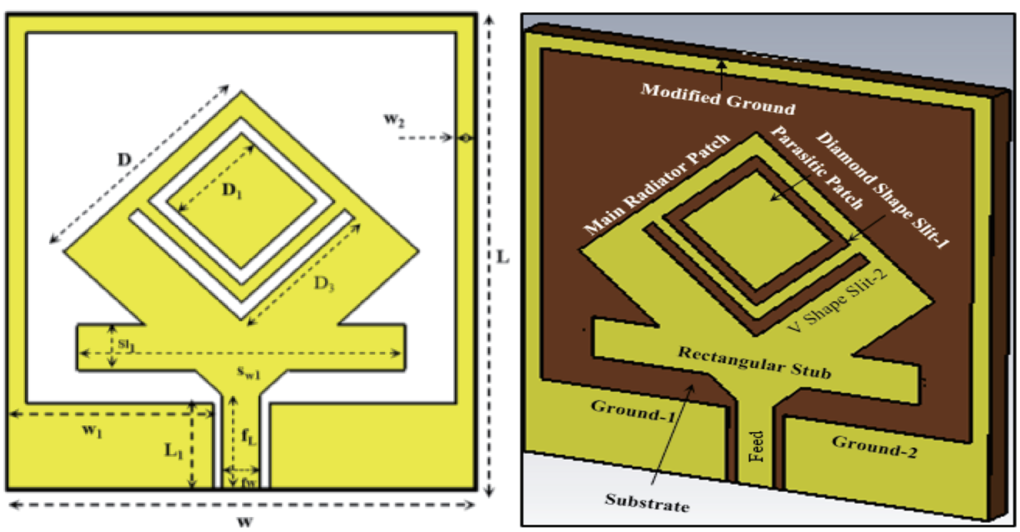
* Corresponding author: Anil Kumar Gautam (gautam1575@yahoo.co.in).
[1] Department of ECE, MRIIRS, Faridabad, India. [2] Department of Electronics and Communication Engineering, G.B. Pant Engineering College, India.

However, there are some limitations that limit the use of these antennas in this system, for example, large physical dimensions and unsuitable radiation patterns. Antennas used for wireless communication must therefore be portable, affordable, simple to make, and simple to install [18–24].

This paper proposes a circularly polarized wideband antenna for WLAN/WiMAX application. The proposed antenna mainly comprises a modified ground with a diamond-shaped microstrip antenna. In the drafting patch, two slits are introduced to improve the wideband as well as the axial ratio. By introducing the two slits and a rectangular stub, wideband behavior from 2.35 to 4.62 GHz is excited. The antenna's gains are consistent across all operating bands. Results from simulations and experiments show that our antenna has good radiation and reflection properties across the whole WLAN/ WiMAX band.

2. ANTENNA LAYOUT

Figure 1 depicts the WLAN/WiMAX compact wideband microstrip antenna 2D and 3D views. The proposed antenna is mounted on an FR-4 substrate whose dielectric constant (ε_r), loss tangent (tan δ), and thickness (h) are 4.4, 0.02, and 1.6 mm, respectively. The overall size of the antenna is $25 \times 28 \times 1.6\,\text{mm}^3$. The antenna structure consists of $50\,\Omega$ coplanar waveguide (CPW) feed. Fig. 1 shows the proposed circularly polarized diamond-shaped CPW microstrip antenna. A horizontal rectangular bar and two slits are introduced in the proposed structure to improve the wide band response. The upper diamond shape slit-I is etched to enhance the wideband operation, and a lower V-shaped slit is added to improve the return loss, wideband, as well as axial ratio. The slit-I is a diamond-shaped ring that was etched at the top corner of the main radiating patch. The diamond ring-shaped slit isolated a parasitic patch in the main structure. The geometrical parameters are described in Fig. 1, and their values are listed in Table 1.



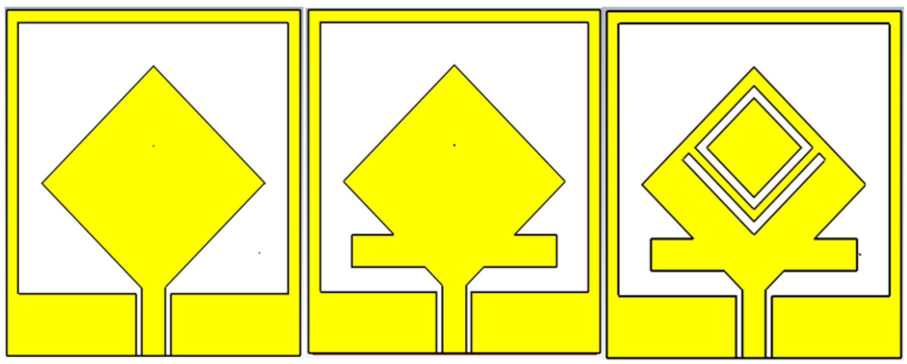
(a) (b)

Figure 1. Proposed circularly polarized diamond-shaped wideband antenna. (a) 2D and (b) 3D view.

A lot of effort has been made here to improve the bandwidth, as well as the axial ratio, where different design evolution stages are explained thoroughly. Initially, a simple CPW antenna was designed at 3.5 GHz. The conductor width (W), the gap (g) between the conductor and ground plane on both sides, and the dielectric constant (ε_r) all contribute to the coplanar waveguide impedance value. To obtain the desired response, large clusters of resonant frequencies should be produced within the desired frequency range by pushing the return loss below 10 dB. To achieve this goal, the coplanar ground shape is modified as shown in Fig. 2 under stage I, and its return loss characteristics show some wideband

Table 1. Optimized Geometrical variables of the proposed diamond shape antenna.

Variables	Dimension (mm)	Variables	Dimension (mm)
L	25	S_{L1}	2.66
W	28	S_{W1}	17.50
W_1	11	D	9.5
L_1	5	D_1	5
W_2	1	D_3	6.05
F_L	7	F_w	2



(a) (b) (c)

Figure 2. Design evolution stages I, II, and III of the proposed diamond shaped antenna. (a) Stage-I. (b) Stage-II. (c) Stage-III.

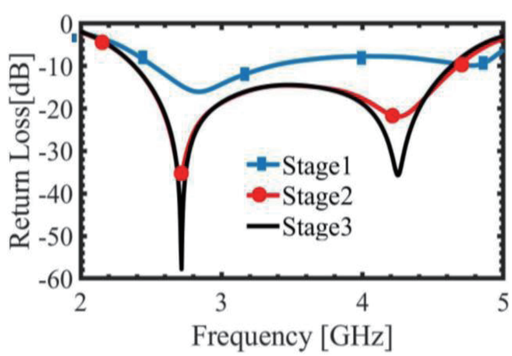


Figure 3. Comparison of return loss characteristics in different evolution stages.

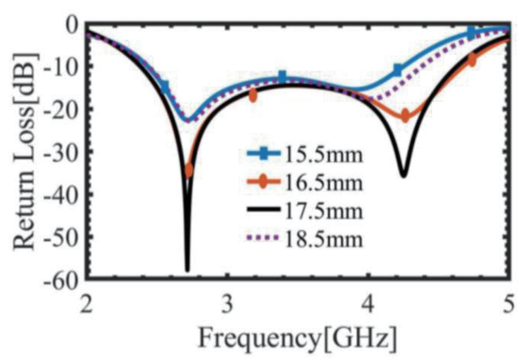


Figure 4. Results of variations of width ($SW1$) of rectangular slit on the S-parameters.

response as shown in Fig. 3. Now, to improve the wideband response a horizontal rectangular stub is inserted in the main radiating patch in the structure. Now the antenna shows good wideband response as shown in Fig. 3 under stage II. Further, the impedance bandwidth was improved by inserting two slits in the main patch which improves not only the return loss but also the axial ratio in the desired band.

A lot of effort is also made on a novel design by modifying the parasitic shape to circle, oval, null, etc., but no improvement is observed, rather it degrades the radiation pattern and axial ratio. So, the parasitic patch remains untouched. Slit II is a V-shaped ring that is placed exactly below slit I to increase the current circulation which further improves the axial ratio in the wideband. The proposed antenna resonates in the wideband from 2.35 GHz to 4.62 GHz with a return loss of better than 20 dB in the entire bandwidth. The axial ratio value is below 2.5 dB in 2.35–4.62 GHz bandwidth. To understand the effect of parameters on antenna performance, a parametric analysis of the circularly polarized CPW antenna is performed. Because a typical microstrip antenna only has one resonance, it is a narrowband antenna in general. The narrowband width performance of the microstrip antenna limits its operation as a wide-band antenna. However, multiband or wideband performance can result from the overlapping resonances of two or more resonant parts. Microstrip antennas must be adjusted to accommodate multi-resonances.

A variety of techniques can be used to generate multiple resonances. The proposed design achieves the wide bandwidth by employing a CPW-fed monopole radiator with a diamond shape. Fig. 4 shows the parametric results on variation in the width of rectangular slit which lies on the lower part of diamond shape main radiator. The slit's width varies from 15.5 mm to 18.5 mm using a parametric sweep. As the width of the rectangular slit increases in both directions with step size 1 mm, it shows good return loss with enhanced bandwidth. So $Sw1 = 17.5$ mm is the optimized width of rectangular stub. Figs. 5, 6, and 7 also show parametric sweep on rectangular stub length, the diameter of the outer diamond shape ring, and the position of the V slit on the radiator below slit-I. As the stub length increases with step size 0.33 mm, the frequency at IInd resonance is shifted to the right, and no effect is noticed at the Ist resonance frequency. The length of stub is varied between 2 mm and 3.33 mm. At 2.66 mm width, wide bandwidth is obtained, so the optimized stub length of 2.66 mm is considered. When the outer radius of the diamond shape is increased with a step size of 0.3 mm, the Ist resonance frequency shifts in the right direction, and $D = 10$ mm will be the optimized dimension for good bandwidth and return loss.

A parametric sweep is also applied on the V slit of the radiator patch to obtain a wideband and enhanced axial ratio as shown in figure. To comprehend the impact of the slit on parameters for antenna performance, parametric analysis of the circularly polarized slit-microstrip antenna is carried out. For the requirement of circularly polarized radiation, two orthogonal modes with a 90° phase shift can be

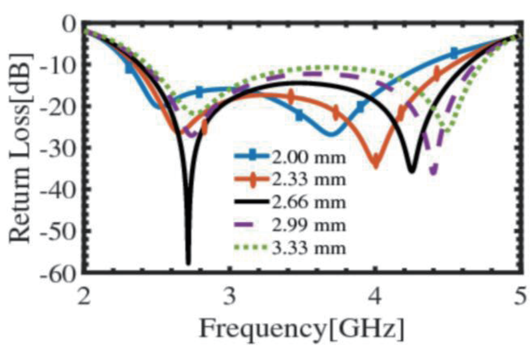


Figure 5. Results of variations of width (S_{l1}) of rectangular slit on the S-parameters.

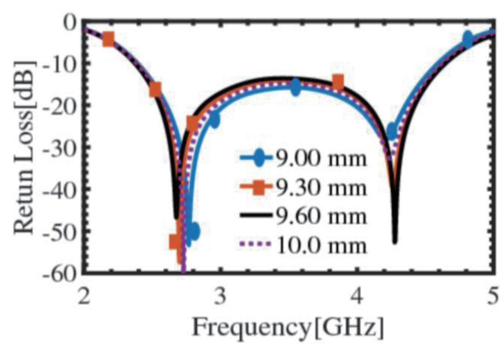


Figure 6. Results of variations in the outer ring (D) of Diamond shape primary patch.

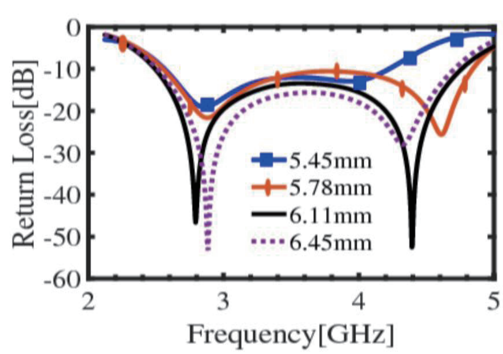


Figure 7. Results of variations in position V Shape Slit for the proposed antenna.

produced by altering the slit II dimensions. The orthogonal mode resonant frequencies for single-feed microstrip antennas should be significantly close to obtain good CP radiation. The feed location and V-shaped slit sites in this investigation are fixed ($P = 15.5$ mm, 11.5 mm). The antenna can be made to receive CP radiation by altering $d1$ in relation to $d3$.

3. RESULT AND DISCUSSION

Experimental results of the proposed antenna demonstrate an excellent wide bandwidth between 2.35 and 4.62 GHz. The electromagnetic simulator CST Studio Suite is used for detailed parametric studies. The proposed diamond-shaped microstrip patch antenna was designed and tested with Agilent vector network analyzer N5230A. The fabricated prototype of the proposed wideband diamond-shaped antenna is shown in Fig. 8. The proposed antenna has a number of benefits, including a compact design, superior gain, and radiation patterns that satisfy the needs of the WLAN/WiMAX and 5G application. This antenna geometry is simple to create and has an optimal size. Investigations are conducted on variations in the size of essential design parameters and also how they affect antenna performance. The experimental results are very close to the simulated ones. The designed antenna's simulated and measured return losses are shown in Fig. 9. The obtained 10 dB bandwidth is 2240 MHz between 2.35 and 4.62 GHz. The 3 dB axial ratio bandwidth is around 2400 MHz obtained as shown in Fig. 10. The gain vs. frequency graph is shown in Fig. 11, and the overall gain is greater than 3.1 dB in operating bandwidth 2.4 GHz to 4.35 GHz. The measured return loss, AR, gain and simulated outcomes are in

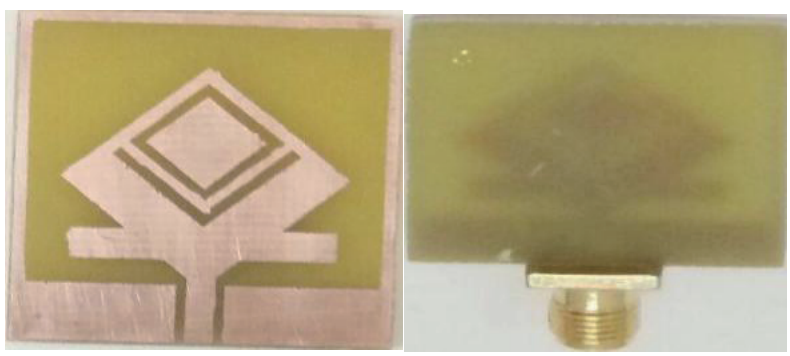


Figure 8. Prototype of front & back view of proposed diamond shape antenna.

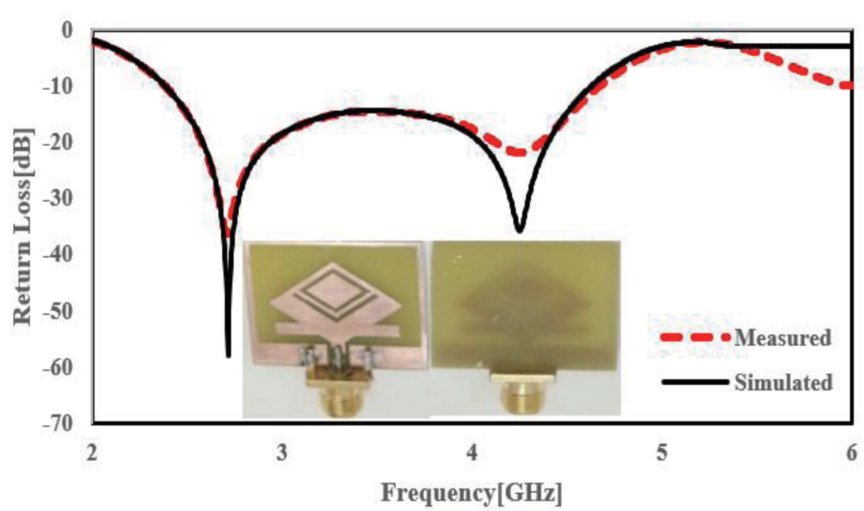


Figure 9. Measured and simulated results of the proposed diamond shape antenna.

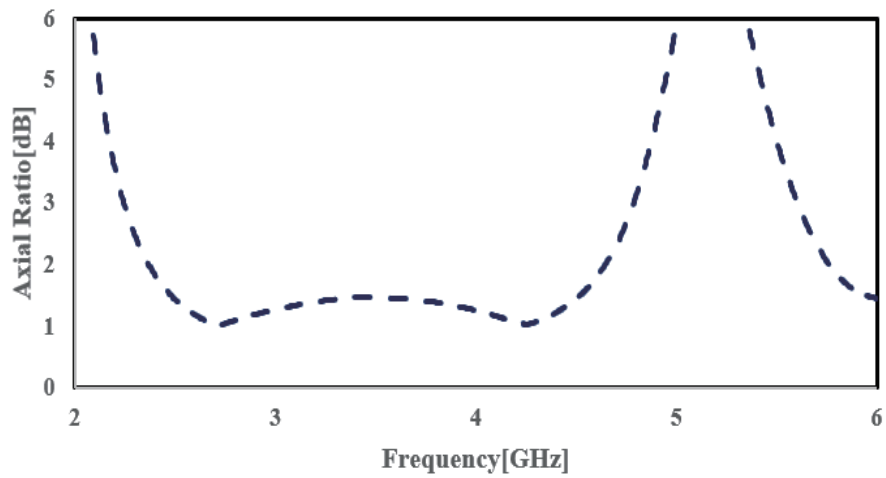


Figure 10. Axial ratio of proposed diamond shape antenna.

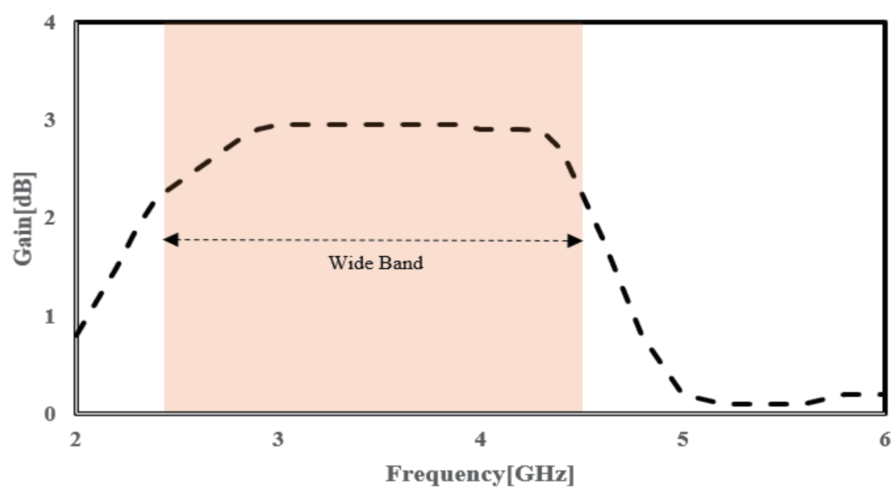


Figure 11. Gain versus frequency graph of proposed diamond shape antenna.

good agreement.

The simulated and measured results of reflection coefficients (S_{11}) are given in Fig. 9 for the proposed diamond shape wide-band antenna. The antenna's simulated operational frequency bands ($|S_{11}|10\,\text{dB}$) range from 2.3 to 4.62 GHz. The antenna, therefore, provides sufficient bandwidth to support all needed WLAN and WiMAX operations. It is evident that the measured and simulated curves have a strong agreement.

The slight discrepancy between the measured and simulated reflection coefficients (S_{11}) is primarily caused by the relative permittivity's (ϵ_r) tolerances, poor welding, and the distinction between the microstrip feed line's characteristic impedance of the SMA connector and the antenna. Fig. 10 presents an excellent axial ratio value below 1.5 dB for circular polarization and the impedance bandwidth of the antenna improved, which results in wider axial ratio bandwidth. The surface current distributions at wide frequency bands, i.e., 2.4 GHz, 3.5 GHz, and 4.5 GHz, are illustrated in Fig. 12. It is found that the external current is scattered towards the outer diamond ring and across the main feed line. The combination of the outer diamond ring and inner diamond patch attached with a horizontal rectangular stub generates a wide band. Throughout the frequency band of interest, the observed radiation patterns are nearly stable radiation patterns, shown in Fig. 13. Fig. 14 displays efficiency variation with frequency. It is discovered that the proposed diamond-shaped antenna's radiation efficiency is nearly constant (78%)

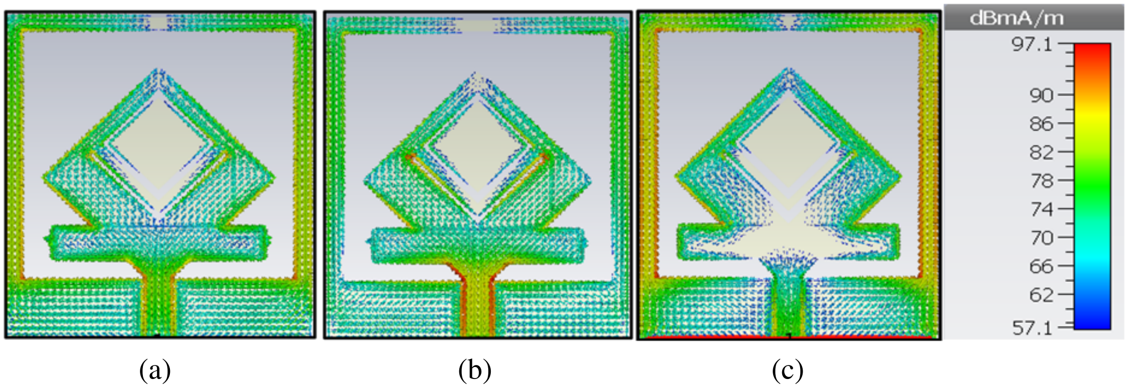


Figure 12. Effect of surface current dispersals of the projected antenna at changed frequencies 2.4 GHz, 3.5 GHz, and 4.5 GHz. (a) 2.4 GHz, (b) 3.5 GHz, (c) 4.5 GHz.

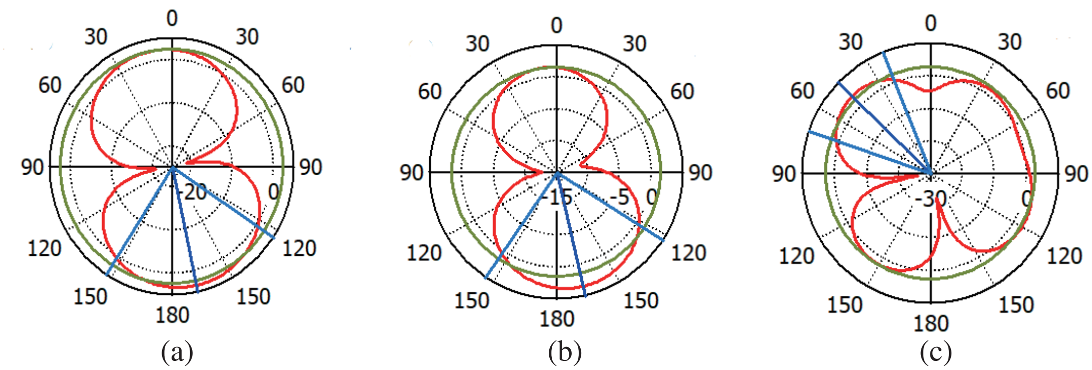


Figure 13. Gain Pattern of Proposed Antenna at (a) 2.4 GHz (b) 3.5 GHz. and (c) 4.5 GHz.

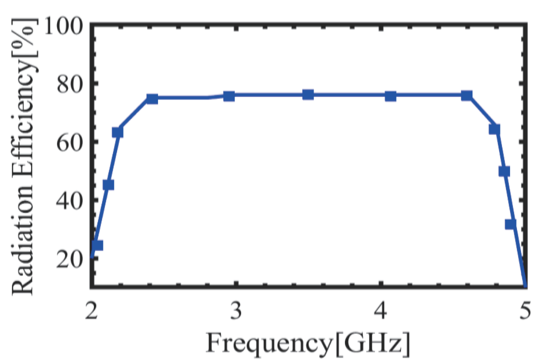


Figure 14. Radiation efficiency of proposed diamond shape antenna.

over a wide band of frequencies between 2.35 and 4.62 GHz.

The majority of linearly and circularly polarized antennas that have been recently proposed for WiMAX/WLAN applications are summarized in Table 2. A critical examination of Table 1 reveals that the suggested circular polarization antenna has compact size, large AR bandwidth, superior gain, and efficiency compared to the other reported antennas.

Table 2. Performance comparison of the proposed WLAN antenna with other reported WLAN antennas.

Ref. number	Size (mm)	Operating bands (GHz)	Polarization	AR bandwidth (GHz)	Gain (dB)
[1]	$33 \times 17 \times 1.6$	2.41–2.54, 5.15–5.35	Linear	Nil	2.4
[2]	$18 \times 20 \times 0.1$	3.3–3.88	Linear	Nil	2.06
[5]	$50 \times 50 \times 1.58$	3.30–3.78, 5.40–5.86	Circular	3.30–3.78, 5.40–5.86	3.03
[8]	$25 \times 23 \times 1.6$	2.71–12.61	Linear	Nil	2.5
[19]	$38 \times 25 \times 1.6$	2.4–6.0 GHz	Linear	Nil	2.85
[20]	$15 \times 15 \times 1.6$	2.25–2.85, 3.4–4.15, 4.45–8	Linear	Nil	2.78
Proposed work	$25 \times 28 \times 1.6$	2.35–4.62	Circular	2.4	3.1

4. CONCLUSION

The compact CPW circularly polarized diamond-shaped microstrip antenna has been presented here for WLAN/WiMAX applications. The antenna prototypes are built and tested. Investigations are conducted on variations in the size of essential design parameters and how they affect antenna performance. The proposed antenna has a number of benefits, including a compact design, superior radiation patterns, and a high gain that satisfies the needs of WLAN/WiMAX 5G application. This antenna geometry is simple to create and has an optimal size. The measured and simulated results show that the proposed antenna has good impedance bandwidths. The modified antenna consists of one radiating element that includes two slits, one horizontal rectangular stub, and an improved ground plane. The rectangular stub and two slits are used to enhance the wideband response and circular polarization in 2.35–4.62 GHz. The fabricated prototype antenna demonstrates good consistency between simulated and measured results. The suggested antenna resonates over a 2700 Mz transmission bandwidth between 2.35 and 4.62 GHz, making it a good choice for WLAN and WiMAX applications. The average gain in the wide band is 3.1 dBi. Furthermore, the obtained radiation patterns show that the proposed antenna has figure-eight patterns in the E-plane. The antenna's gains are stable across all operating bands. The simulated and experimental results show that our antenna has good reflection and radiation characteristics throughout the WLAN/WiMAX.

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