Low Profile CPW Fed Compact Square Slot Antenna with Wide Axial Ratio Bandwidth

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***Abstract*—A CPW fed circularly polarized square slot antenna that gives rise to a wide axial ratio bandwidth is designed and studied in this article. More than 18.8% (7.7GHz-9.31GHz), 3dB ARBW can be achieved by utilizing L shaped grounded strip in the upper right side and square in opposite to this in the lower left side. To further enrich the 3 dB ARBW of the proposed slot antenna, three slots on the outer periphery (two horizontal and one vertical) are engraved from the ground. These perturbation structures are responsible for current rotation and increment in ARBW. With the optimized value of various parameters, a 3dB ARBW of 73.05% (4.17-8.97GHz, 4.8GHz) concerning central frequency 6.57GHz and IBW of 87.8% (3.56-9.14GHz, 5.58GHz) concerning central frequency 6.35GHz is attained. Also, superb CP radiation patterns have been detected in the direction of main beam (broad-side), with RHCP and LHCP in the +Z and -Z directions, respectively. The overall dimension of offered antenna is 20mm ×20mm×1.0mm.**

Keywords— CPW feed, square slot antenna, axial ratio, impedance bandwidth, radiation pattern

I. INTRODUCTION

In wireless communication circularly polarized (CP) antenna is broadly famous because of its ability of forecasting polarization mismatch and adaptability of the orientation angle between transmitting and receiving antennas. In many communication system applications, it becomes quite difficult to manage the alignment or orientation of the antenna [1-2]. CP behaviour is accomplished when an antenna transmits two orthogonal vectors (electric field) with a ninety-degree phase and equal amplitude. Since the fabrication of the slot antenna is easy in comparison to other techniques and looking at its low profile, it is best for acknowledgment of CP operations [3]. However, the issue is the narrow impedance/ axial ratio bandwidth that restricts the use of such offered antennas. To conquer the issue of restricted impedance and axial-ratio bandwidths (ARBWs), different shapes/slots and structures have been proposed [4-9].

In many cases, alteration in conventional structure can't ensure high ARBW. Scholars working in the antenna field finding the new way and procedures to beat this issue, without influencing other antenna features. An outline of efforts and focus committed to this issue by researchers and specialists in recent times is as per the following. In [10], Wang *et al* applied slots and stubs in square slot ground as a perturbed element in place of L strip and attain the wide 2dB ARBW of (54.2% from 5.65-9.85GHz) in place of conventional 3dB ARBW. However, the size of the antenna is 40 × 40 × 0.8 mm^3. In [11], Jhajharia *et al* proposed a reconfigurable dual-band CP antenna using PIN diode for C band wireless applications. An ARBW of 4.5% (4.3–4.5GHz) and 17.69% (5.1–6.09GHz) is achieved with this design. However, the design is somewhat complex. In [12], Birwal *et al* presented a dual sense CP design modified with the P shape dual-port along with semi-circular and triangular structures in the ground plane and attain 75.23% (2.67–5.89GHz) ARBW, however, the volume of the antenna is 48 × 48 × 1.5 mm^3. The overview of the recent development in CP antenna is studied by Banerjee *et al* [13]. In their review authors included the different aspects of CP antennas along with technical and conceptual analysis of some of the novel designs.

In this article, the design and analysis of a compact square slot CPW fed antenna are presented. The offered design is simple that consists of symmetric L strip and three open wide slots at an optimized location that gives 73% 3dB ARBW for central frequency 6.57GHz (4.17-8.97GHz, 4.8GHz) and IBW (3.56-9.14GHz, 5.58GHz) or 87.8% for central frequency 6.35GHz. In succeeding sections, the antenna design, discussion on results and conclusion are deliberated.

II. ANTENNA DESIGN AND RESULTS

The process step of the proposed antenna configuration is given in Fig. 1(a-c). FR4 substrate having a thickness of 1.0mm with relative permittivity of ε_r = 4.4 and loss tangent of $\tan\delta$ = 0.025 is used for the designing of the antenna. Since this is a CPW fed design so there is no metal conductor at the backside of the substrate. The substrate size which is in actual represents the overall dimension of the antenna is $(L \times W \times h)$. The width of the feed line w_f and gap value 'g' is calculated by the inbuilt feed line calculator in CST [14]. The dimension of the square patch is $(L_p \times W_p)$, which is slotted by another square having dimensions of $(L_{slot} \times W_{slot})$ to enhance the impedance bandwidth. Two horizontal slots, one in the lower-left corner $(S_{x1} \times S_{y1})$ and the other is in the upper left corner $(S_{x2} \times S_{y2})$ in association with one vertical slot in the lower right corner $(S_{x3} \times S_{y3})$ are etched from the CPW ground plane radiator. The patch is modified by applying symmetric L-strip having dimensions $(l_x \times l_y)$ along the x-axis and y-axis. A small square patch of dimension $(a_x \times b_y)$ is protruded at the lower-left corner of the slotted square. All these parameters make a great impact on antenna performance in terms of S_{11} and axial ratio. The final design with all notations is depicted in Fig. 2. To attain the best value of axial ratio bandwidth and S_{11}, extensive simulations are conceded out using the CST Microwave Studio v.17. The optimized value of parameters is tabulated in Table I.

TABLE I. PARAMETERS OF THE PROPOSED CPW-FED SQUARE SLOT ANTENNA

Parameter	Value (in mm)	Parameter	Value (in mm)
$L = L_p$	20	$W = W_p$	20
L_{slot}	7.2	W_{slot}	7.2
$a_x \times b_y$	4.0 × 4.0	$l_x \times l_y$	1.0 × 6.0
$S_{x1} \times S_{y1}$	7.3 × 2.3	$S_{x2} \times S_{y2}$	12.7 × 2.3
$S_{x3} \times S_{y3}$	2.3 ×7..3	w_f	1.5
g	0.2	h	1.0

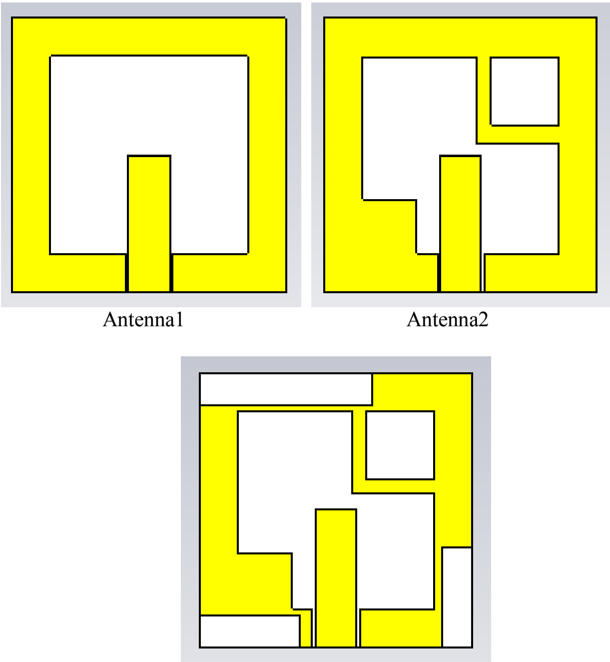


Fig. 1. Step wise evolution of prototype antenna

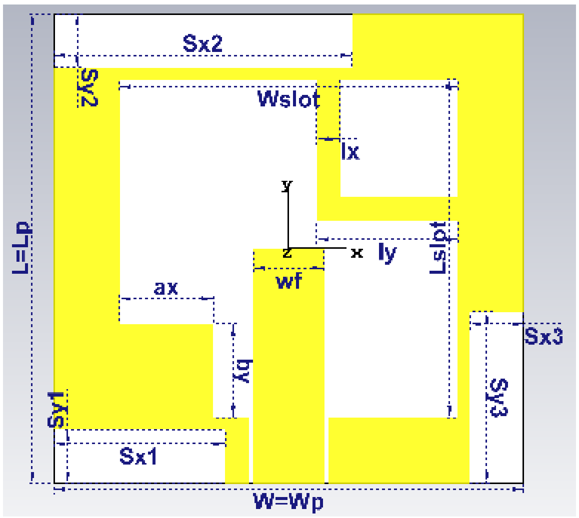


Fig. 2. Outline of the proposed CPW-fed square slot antenna

Fig. 1(a-c) illustrates the stepwise evolution of the prototype antenna. Step 1 is a simple CPW fed square slotted antenna that gives a wide impedance bandwidth. The S_{11} and axial ratio variation of 'Antenna1' is shown in Fig. 3 and Fig. 4 respectively that represent that 'Antenna1' is giving rise 54.5% IBW (3.92-6.85GHz). However, the axial ratio (AR) value, which is a measure of circular polarization is 40dB (much larger than 3dB), depicts that 'Antenna1' is linearly polarized [15]. Here, AR is the ratio of the major and minor semi-axes of the polarization ellipse and expressed as [16]:

$$AR(dB) = 20\log_{10}\left[\frac{E_{x0}}{E_{y0}}\right] \tag{1}$$

A pure CP behaviour can be achieved if the AR value is equal to 1 or 0 decibel (dB). However, in practice, it is quite challenging to attain this value. Hence, a range of frequency ($f_h - f_l$) up to which AR ≤ 3 dB is taken to quantify CP for practical applications. The 3dB ARBW is defined as:

$$ARBW = \frac{f_h - f_l}{f_{min}} \tag{2}$$

To achieve the wide ARBW in association with wide IBW, following the [17], in step 2, a L shaped grounded strip structure $(l_x \times l_y)$ and a square patch of dimension $(a_x \times b_y)$ is loaded at the upper right corner and lower-left corner of the square slot respectively for improving the ARBW as shown in Fig.1(b). The S_{11} and axial ratio variation of 'Antenna2' are shown in Fig. 3 and Fig. 4 respectively it is observed that antenna is behaving as CP radiator in this case and gives rise 18.8% (7.7GHz-9.31GHz), 3dB ARBW. The -10dB IBW value is 5.32GHz (3.78-9.1GHz), which is 82.7% with respect to mid-frequency 6.43GHz. The improved performance is achieved due to the introduction of L shaped strip and square that acts as the perturbation structures. Since these structures alter the path of the magnetic currents in the slots in such a way that two orthogonal resonant modes with an identical amplitude and a quarter phase difference can be excited.

To further improve the ARBW of 'Antenna2', following [18], two horizontal slots, one in the lower-left corner $(S_{x1} \times S_{y1})$ and other is in the upper left corner $(S_{x2} \times S_{y2})$ in association with one vertical slot in the lower right corner $(S_{x3} \times S_{y3})$ are embedded in the CPW ground plane in 'Antenna2'. In the final design 'Antenna3', these embedded slots predominantly responsible for the rotation of current and results in more 87.8% (3.56-9.14GHz), -10dB IBW and 73% 3dB ARBW (4.17-8.97GHz).

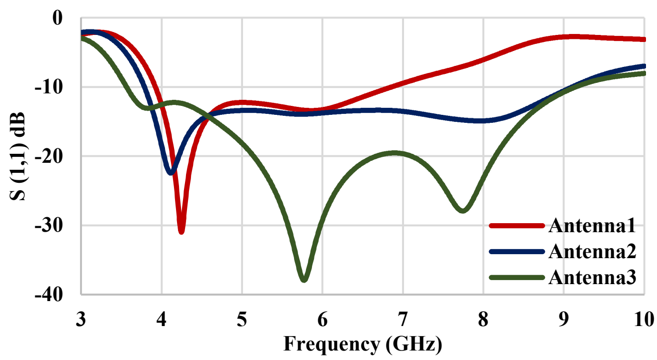


Fig. 3. S_{11} variation with frequency for 'antenna1', 'antenna2' and 'antenna3'

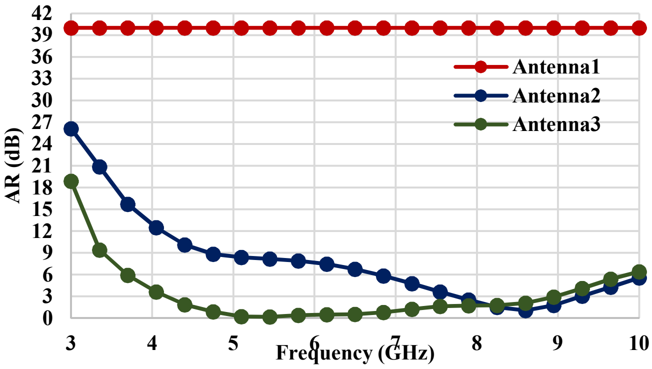
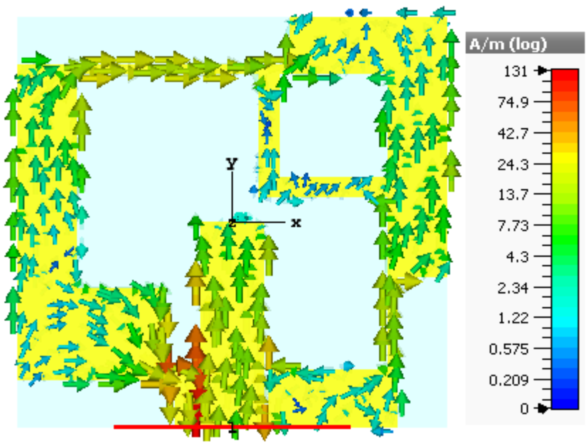


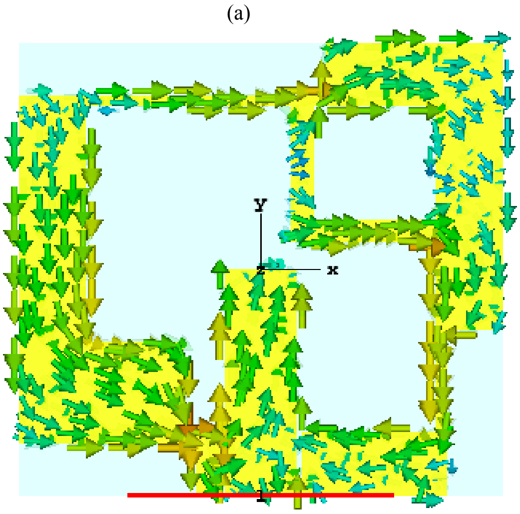
Fig. 4. Variation of AR value with frequency for 'antenna1', 'antenna2' and 'antenna3'

III. CP Mechanism

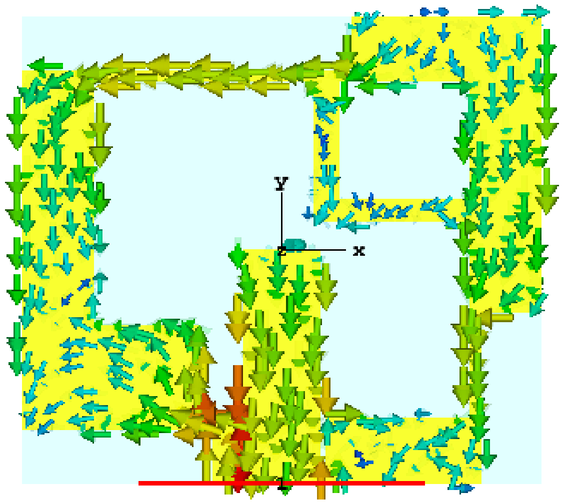
To understand the CP mechanism of offered antenna, surface current distributions at two resonances 5.76GHz and 7.76GHz at the different instant of time are illustrated in Fig. 5(a-d) and Fig. 6(a-d) respectively. It is easy to reveal from these figures that the current vector is rotating anticlockwise as the phase of excitation progresses, and results in the RHCP polarization rotation.



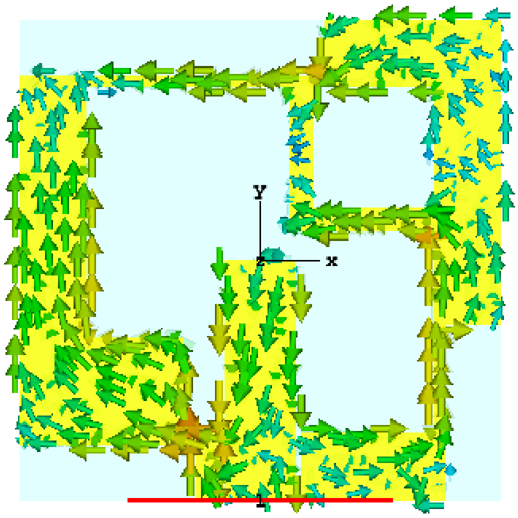
(a)



(b)

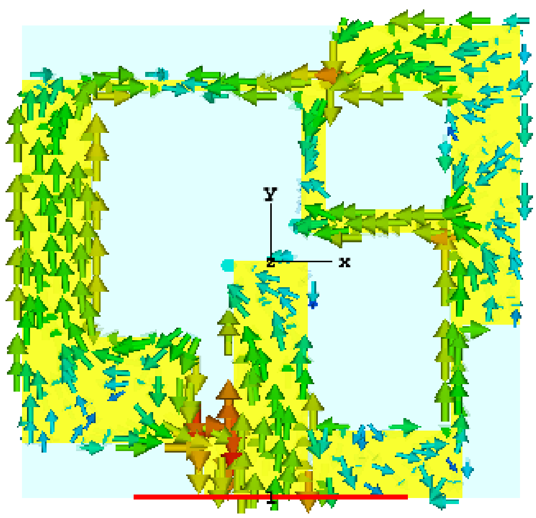


(c)

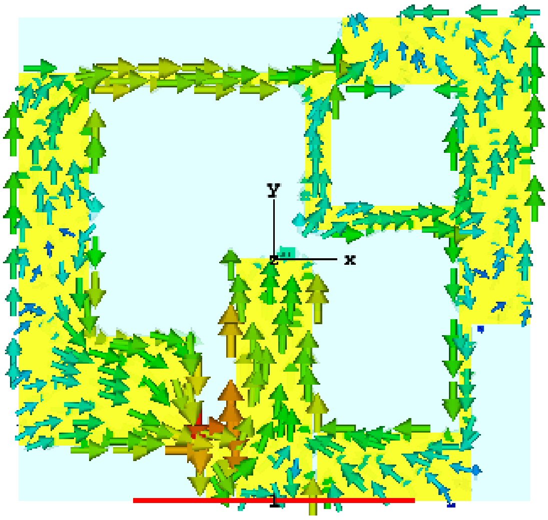


(d)

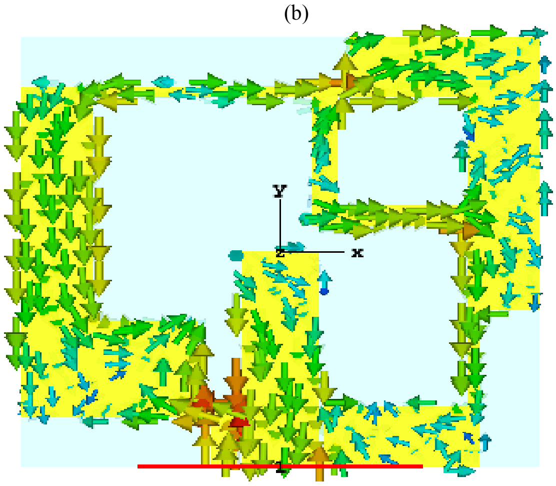
Fig. 5. Surface current distributions (simulated) at 5.76GHz (a) 0 (b) 90 (c) 180 and (d) 270



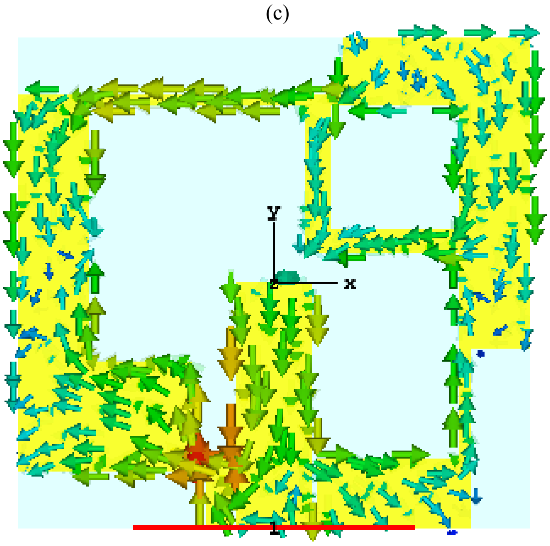
(a)



(b)

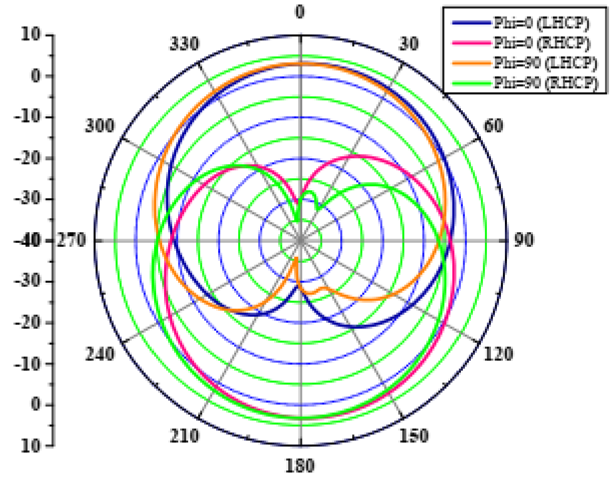


(c)

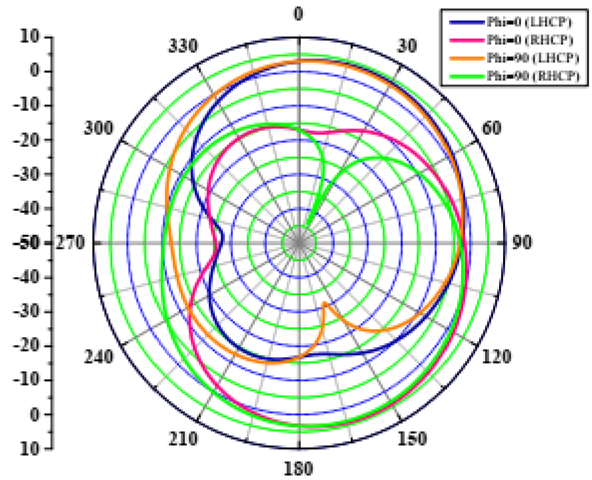


(d)
Fig. 6. Surface current distributions (simulated) at 7.76GHz
(a) 0 (b) 90 (c) 180 and (d) 270

The normalized simulated radiation patterns at resonant frequencies 5.76GHz and 7.76GHz for phi equal to zero degrees and ninety degrees are shown in Fig. 7(a-b). It is perceived that the cross-polarization (LHCP) level is nearly 20dB down in reference to the direction of the main beam. It seems that the CP beam directions are slightly tilted away from the boresight directions which is probably due to the asymmetric nature of the radiator in reference to the feed strip.



(a)



(b)

Fig. 7. Simulated radiation pattern of the antenna at frequency (a) 5.76GHz and (b)7.76 GHz

A comparison of the proposed wideband CP antenna with other published articles on the wideband CP antenna is given in Table II. The result achieved in [19-20] is close to the offered results, however, the size is double and fivefold in comparison to the proposed design. Also in [21], the author achieved the dual CP band but at the cost of antenna size. In [22], the achieved IBW and ARBW are near to half of the offered design but the overall size of the antenna is compact as the substrate height is very less. Recently in [23], Jaiverdhan *et al* presented a square slot antenna design that has high IBW but the ARBW is not comparable to the offered design also the volume of the antenna is large in comparison to the proposed antenna. In conclusion, the proposed antenna is compact in size and gives rise to maximum ARBW among the given references make it useful for wireless communication systems.

TABLE II. COMPARISON IN PERFORMANCE OF VARIOUS SQUARE SLOT CP ANTENNAS

Reference	−10 dB Reflection Coefficient Bandwidth (in GHz)	3 dB AR Bandwidth (in GHz)	Overall Dimension (mm × mm ×mm)
[19]	63.22% (2.65 - 5.10 GHz)	31.14% (3.66 - 5.01 GHz)	89 ×100×1.6
[20]	73.39% (5.02–10.84 GHz)	58.08% (5.07–9.22 GHz)	40 ×40×1.6
[21]	15.6% (2.24□2.62GHz) and 42.4% (3.26 □ 5.18 GHz)	15.7% (2.24- 2.62GHz) and 45.5% (3.26-5.18GHz)	50 ×50×1.52
[22]	37.2% (7.0-10.2 GHz)	31.82% (7.4-10.2GHz)	24 × 22 × 0.25
[23]	118% (2.93–11.43 GHz)	22.2% (4.87–6.09 GHz)	25 ×25×0.8
Proposed	87.8% (3.56-9.14GHz)	73% (4.17-8.97GHz)	20 ×20×1.0

IV. Conclusions

A wideband circularly polarized square slot antenna is discussed in this article that gives 73.05% axial ratio bandwidth and 87.8% impedance bandwidth. The minimum axial ratio value is found at frequency 5.45GHz which is 0.195dB. The offered antenna is compact in size and gives stable and steady radiation patterns in the frequency range of interest. The offered design radiates RHCP waves. The simulated maximum efficiency and gain values are 88% and 3.7dBi respectively. These outcomes suggest that this antenna can be an expected candidate for present-day wireless communication systems.

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