Circularly polarized truncated corner square slot antenna for K_u-band applications

U. Keshwala[a], S. Rawat[b], and K. Ray[c,*]

a. *Electronics & Communication Engineering, Amity University Uttar-Pradesh, 201301, India.*
b. *Electronics & Communication Engineering, Manipal University Jaipur, Rajasthan, 303007, India.*
c. *Amity School of Applied Science, Amity University Jaipur, Rajasthan, 303007, India.*

Abstract. The present study presents a novel microstrip line-feed compact square slot Circular-Polarization (CP) antenna for K_u-band applications. The proposed square slot antenna with circular trimmed corners was fabricated with the FR-4 substrate with the defected ground on the opposite side of the patch. The Axial Ratio Band-Width (ARBW) was considerably enhanced by adding a shorting pin and the Impedance Band-Width (IBW) was improved by etching the pentagon-shape slot in the defected ground. The antenna offered the wide CP IBW of 4.96 GHz (13.6 GHz–18.56 GHz), simulated ARBW of 4.85 GHz (14.51–19.30 GHz), and positive gain in the K_u-band. The presented antenna is appropriate for K_u-band applications.

1. Introduction

In addition to transmitting and receiving independently of orientation, the Circular-Polarization (CP) antennas are under growing reformation and they have drawn the attention of researchers in the area of wireless communication due to their resistance to multipath reflections [1]. In recent years, space and wireless communication has experienced an expeditious advance. To support high data rates in wireless applications, the low-cost, low-profile, and high-bandwidth printed antennas are a key component. By taking these points into account, the requirement of high-bandwidth CP antenna is expected.

Commonly, the CP performance can be acquired by using many specific feed arrangements and slight modifications in patch geometry [2,3]. When dual feeding is applied at orthogonal positions in addition to equal amplitudes and 90° phase difference, the CP can be achieved [4]. The other way to obtain CP is by cutting a particular thin slot in the patch or by trimming the two opposite corners of the square patch [5]. Various types of feeding techniques like microstrip line [6], Co-Planar Waveguide (CPW) feed [7], inset feed, and mutual coupling [8] in the form of dual-feed or single-feed can be used to attain CP. Wide CP can be achieved by a bent feeding microstrip line of single-feed type [9]. Some other methods and techniques to procure CP are loading Shorting Pin (SP) [10,11] and chip resistor loading [12].

The most commonly used and a simple technique among all the above-discussed techniques is the single-feed CP without any external phase shifter. Numerous techniques, patch geometries, and configurations have been explored, analyzed, and delineated using a single

*. *Corresponding author. Tel.: +919829142468*
E-mail addresses: usha_keshwala30@yahoo.com (U. Keshwala); sanyog.rawat@gmail.com (S. Rawat); kanadray00@gmail.com (K. Ray)

feed for CP radiation characteristics. In [13], CPW feed CP broadband antenna with 64.7% bandwidth was reported. CP bandwidth between 3172–6211 MHz was obtained by embedding two inverted-L grounded strips and a 45° bent strip around corners of the ground. The Impedance Band-Width (IBW) was enhanced by tuning stubs. A CP monopole antenna with performance ability in two bands was proposed in [14] with IBW of 3.7 GHz in the lower band frequency range (2.9–6.6 GHz) and 1 GHz in the upper band (7.7–8.7 GHz). A slanting edge Defected Ground Structure (DGS) and two orthogonal arms were used to acquire CP.

A single-feed square patch antenna with four T-shape or Y-shape slots at the edges of the patch and a center slot was proposed [15]. By varying the dimensions of T-slots or Y-slots and the center slots, other frequency ratios of CP were also possible. High gain with CPW feed CP antenna was reported in [16] by Kushwaha and Kumar. The gain was improved (3–4 dB) by incorporating Frequency Selective Surface (FSS) and adding a reflector to the IBW, as a result of which the 3 dB Axial Ratio Band-Width (ARBW) was improved. 40×40 mm^2 Asymmetric modified Bow-Tie (ABT) and Symmetric modified Bow-Tie (SBT) slotted circular patch antennas with circular polarization were presented for wideband applications [17]. A ferrite-based wideband circular patch antenna designed on a two-layer, ferrite-dielectric substrate with a wideband circular polarization characteristic was proposed in [18].

A parametric assimilation technique was applied for radiation pattern correction of a mutually coupled circular dipole antenna array [19]. Modeling of the Positive-Intrinsic-Negative (PIN) diode Radio Frequency (RF) switch on a High-Frequency Structure Simulator (HFSS) was presented for the reconfigurable antenna applications [20]. The resonating frequency of the antenna was significantly lowered by using an arrow-shape slot radiating structure. Most of the above antennas reported have narrow CP bandwidth or complex design structures. However, recently, a novel design of CP square slot antenna using two parasitic patches on a single substrate has been presented for 1.74 and 2.82 GHz applications [21]. Also, a dual-sense square slot CP antenna fed by a two-port coplanar waveguide was proposed in [22].

In this article, a compact square slot CP antenna for K_u-band is proposed. The proposed antenna structure is a square slot ones with two opposite truncated corners.

2. Configuration

The front view and back view of the proposed antenna design geometry are shown in Figure 1(a) and (b), respectively. The antenna was printed on an FR-4 substrate of size 34×35 mm^2, thickness 1.59 mm, permittivity $\varepsilon = 4.3$, and loss tangent (δ) 0.025. The conducting DGS and square patch with two circular trimmed corners and center slots were printed on opposite sides of a substrate. The antenna was fed by a 50 Ω microstrip line of width W_1. A pentagon-shape slot was etched on the ground to optimize the performance bandwidth of the antenna.

The evolution process of the antenna design is delineated in Figure 2 with four antenna designs from the start. The four steps for the designing the antenna considered in the proposed work are Step 1 (Antenna I), Step 2 (Antenna II), Step 3 (Antenna III), and Step 4
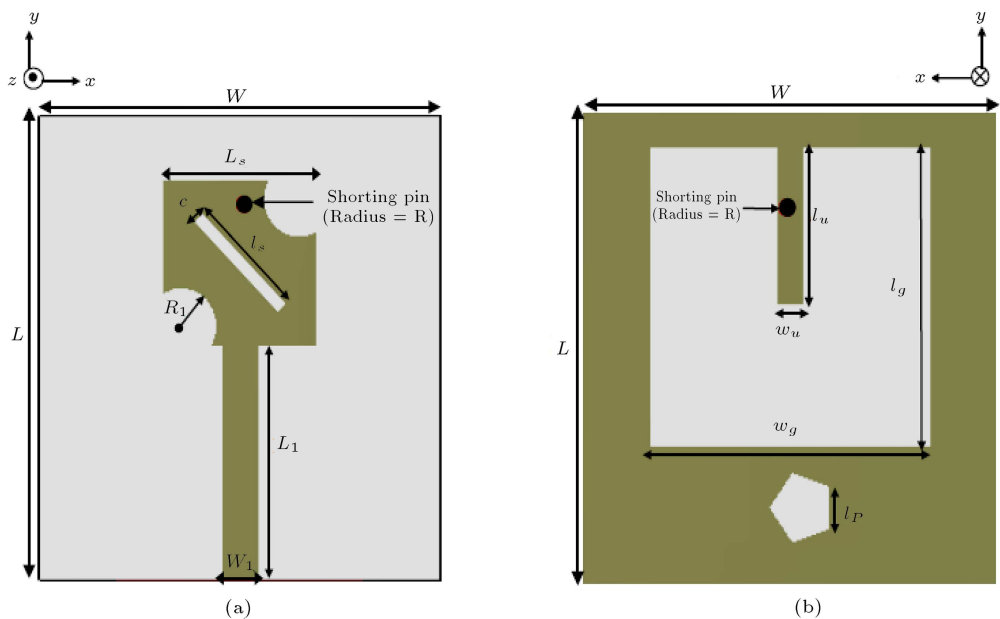

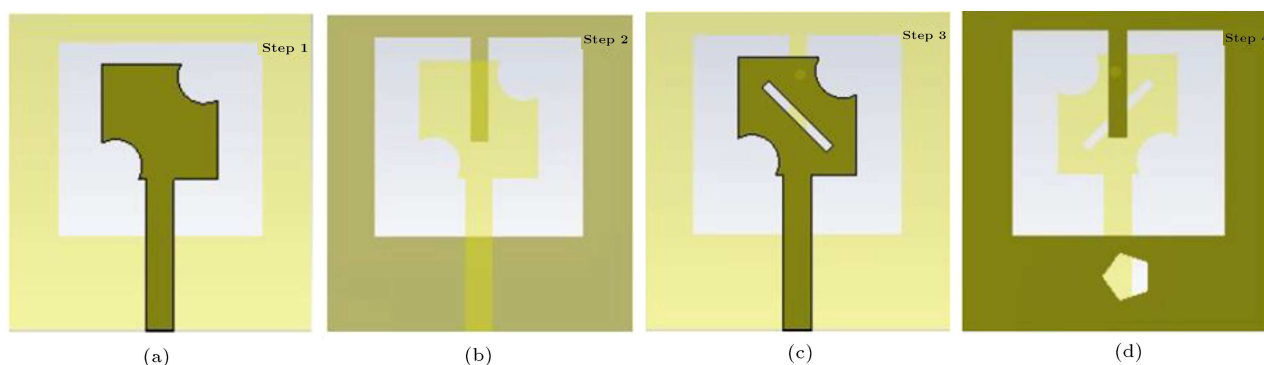**Figure 1.** Proposed antenna design; (a) Front view and (b) back view.

Figure 2. Evolution steps of the proposed antenna geometry.

Table 1. Performance characteristics of the four antenna designs.

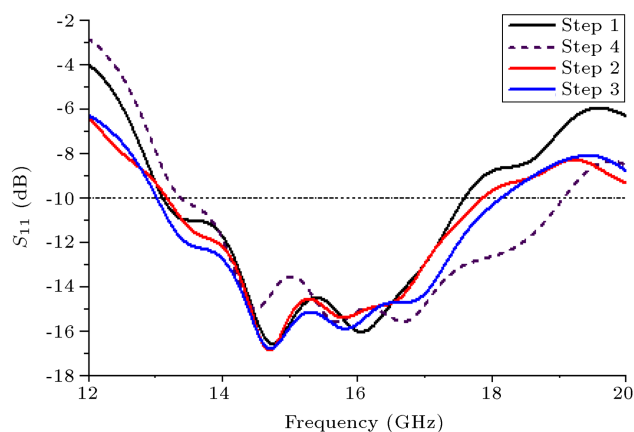| Antenna design	Bandwidth (GHz)	ARBW (GHz)
Step 1	13.3–17.6 (4.5 GHz)	14.5–16.1
Step 2	13.3–17.67 (4.3 GHz)	14.7–16.7
Step 3	13.3–17.7 (4.5 GHz)	14.5–19.6
Step 4 (proposed design)	13.37–19.05 (5.68 GHz)	14.51–19.30
Proposed design	Common band between IBW and ARBW 14.51–19.05 GHz (4.54 GHz)	

Figure 3. Simulated S_{11} for the four different steps of antenna design.

Figure 4. ARBW for the four different steps of antenna design.

(Antenna IV). The antenna presented in step four is the final antenna design with optimized geometrical parameters for K_u-band communication. The four prototypes from Step 1 to Step 4 are listed in Table 1 with performance characteristics. The characteristic graphs for reflection coefficient (S_{11}) and axial ratio in the antenna designs are presented in Figures 3 and 4, respectively. By observing the simulated results, the optimized IBW and ARBW were obtained in Step 4 of antenna design.

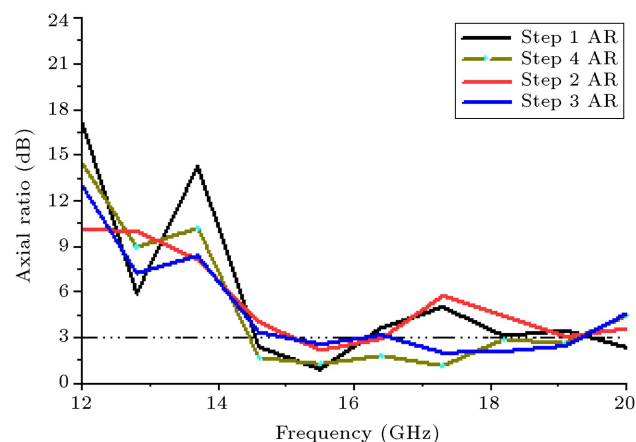To analyze and investigate the optimum performance of the antenna design, several design parameters were considered and parametric analysis was done with the same parameters.

3. Results and discussions

CP is achieved by trimming two opposite corners of a square patch monopole. CP is in the K_u-band range. The corners of a square patch are trimmed by etching circles of radius R_1 mm at opposite ends, as shown in Figure 5. The center of the circle coincides with the corner of the square patch when kept at Center 2. The two orthogonal circles were moved inward and outward
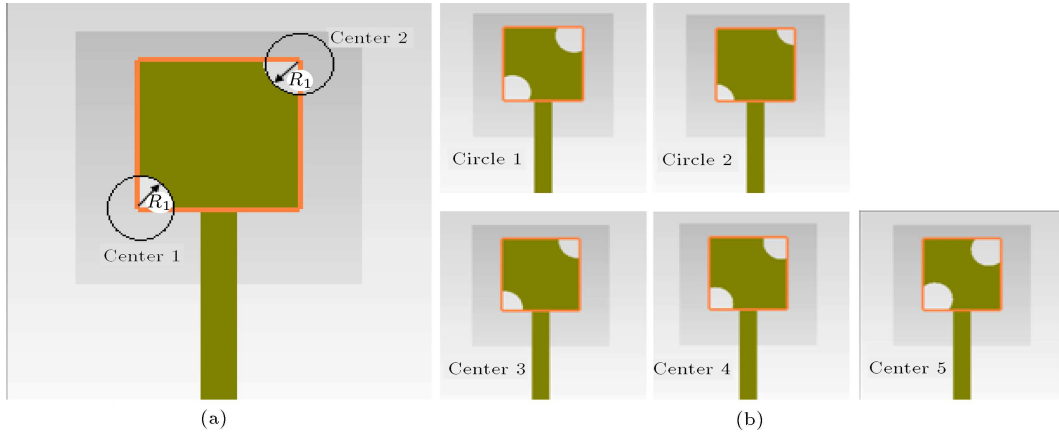
Figure 5. (a) Square monopole for CP with trimmed corner and (b) position of circles for different centers of circles.
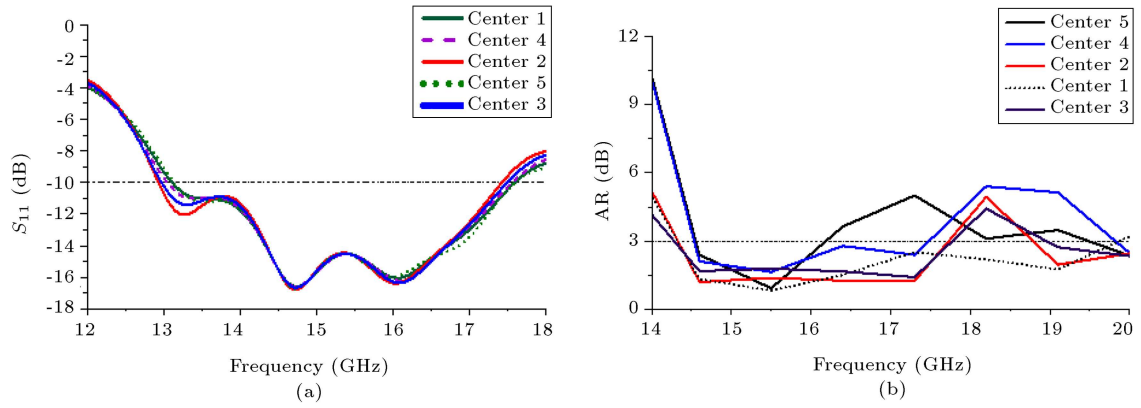

Figure 6. (a) S_{11} for different positions of circle at opposite corners and (b) axial ratio for different positions of circle at opposite corners.

from the initial position to obtain the optimum CP bandwidth. The IBW and ARBW for different positions of circles are presented in Figure 6(a) and (b), respectively. By considering the values obtained for the ARBW characteristics, the optimum results were obtained with Centre 1. The minimum AR variation was obtained for the given range for Centre 1, which can be later enhanced by additional modifications in the antenna design.Due to disturbance on one diagonal, the fundamental mode of the conventional square patch is divided into two orthogonal modes with two different frequencies given by Anantha et al. [23]:

$$f_1 = f_r \left(1 - 2\frac{\Delta s}{s} \right), \tag{1}$$

$$f_2 = f_r, \tag{2}$$

where s is the total area of the square patch, Δs is the area of truncation, and f_r is the resonating frequency of an antenna. The condition to be satisfied for the patch to generate circular polarization is:

$$\frac{\Delta s}{s} = \frac{1}{2Q_o}, \tag{3}$$

where Q_o is the unloaded quality factor of the antenna patch. When the truncation area is quite enough to generate orthogonal modes with equal amplitudes and phase difference of $\pm 90°$, the CP can be achieved. The truncation in the presented antenna is done by etching a circular shape at the diagonal of the patch, as shown in Figure 5.

To further enhance the ARBW, a rectangular slot is added to the ground as shown in Step 2 of antenna design in Figure 2(b). In Step 3, a thin diagonal rectangular slot in the patch is etched according to the following equations [2]:

$$c = \frac{l_s}{10} = \frac{W}{27.2} = \frac{L}{27.2}, \tag{4}$$

$$l_s = \frac{W}{2.72} = \frac{L}{2.72}. \tag{5}$$

The significant improvement in 3 dB ARBW is achieved by adding a SP in Step 3 of the antenna design, as shown in Figure 2(c). Due to the shunt inductive effect produced by the SP, the ARBW is enhanced [24,25]. The parametric analysis is done for the three different radii and positions of the SP in
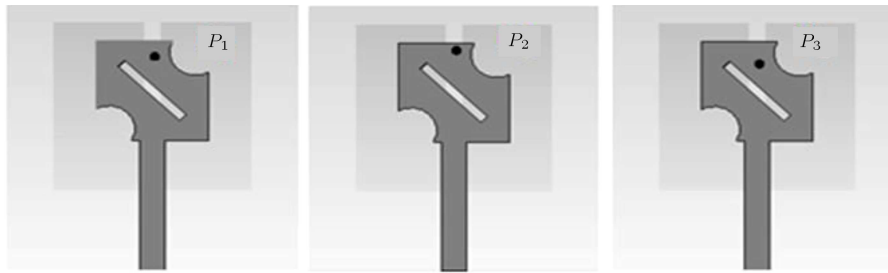
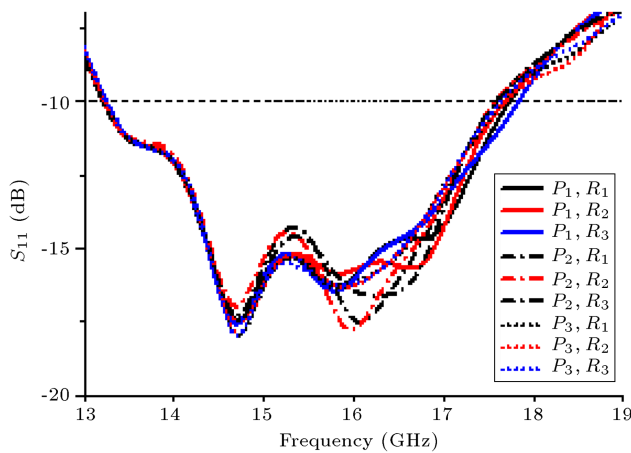**Figure 7.** Three different positions of shorting pin (0.6 mm radius).

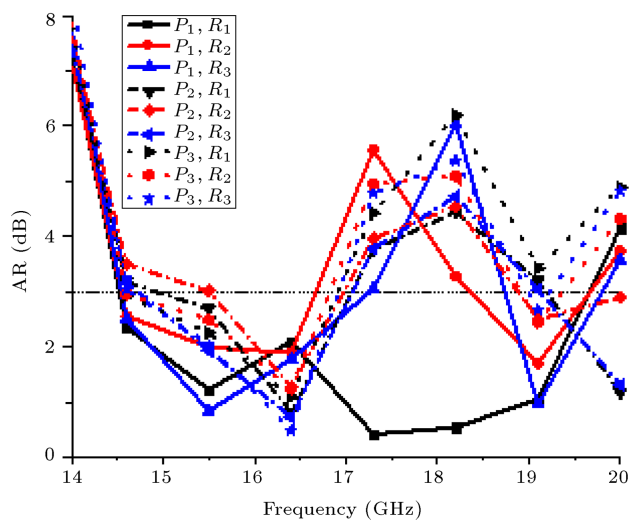**Figure 8.** S_{11} for shorting pin position and radius variation.

Figure 9. Axial ratio for shorting pin position and radius variation.

antenna geometry. The antenna patch of width W is placed at the XY plane with the center at (0, 23.5). The three positions of the SP are P_1 ($P_1(x = 0.3, y = 28.1)$), P_2 ($P_2(x = 0.3, y = 29.1)$), and P_3 ($P_3(x = 0.3, y = 27.1)$) and SP radii are $R_1 = 0.6$ mm, $R_2 = 0.4$ mm, and $R_3 = 0.8$ mm. The three different positions of the SP with a radius of 0.6 mm are shown in Figures 7 and 8. Figure 9 shows the antenna

characteristics obtained in terms of S_{11} and AR for the above-mentioned positions of SP and radii.

The best optimum results in terms of IBW and ARBW are attained for the SP position P_1 and SP radius $R_1 = 0.6$ mm. The obtained ARBW is 4.85 GHz (14.51–19.30 GHz) and IBW is 4.49 GHz (13.23–17.72 GHz). In the present antenna, the ARBW is higher than IBW. To further improve the IBW in the range of ARBW, a pentagon-shape slot is etched in the ground plane and named as Step 4 of the design (for the proposed antenna), as shown in Figure 2(d). The addition of a pentagon slot in the ground leads to considerable improvement in the IBW as compared to the case without slot design. The parametric analysis for various side lengths (l_p) of the pentagon is done by keeping the center of the pentagon the same, the results of which are presented in Figure 10(a) and (b) in terms of IBW and ARBW, respectively. It is clear from the obtained results that the bandwidth is optimum when the side length of the pentagon is $l_p = 3.2$ mm. Thus, variation is made to the center of the pentagon slot by keeping the pentagon side length $l_p = 3.2$ mm. The center of the hexagon slot is moved horizontally and vertically and the corresponding IBW and AR are observed graphically; for this case, the results are presented in Figure 10(c) and 10(d), respectively. The pentagon slot with the center position of ($x = -1$, $y = 6$) gives the optimum results.

The comparison of the results for IBW and ARBW in the same conditions is shown in Figure 10(e). It can be clearly noticed that the IBW is increased from 4.49 GHz (13.23–17.72) to 5.68 GHz (13.37–19.05 GHz) without disturbing the ARBW. The antenna is simulated on the Computer Simulation Technology (CST) microwave studio software [26]. The front view and back view of the final fabricated antenna design (Step 4) are shown in Figure 11. The surface current distribution of the designed antenna at 15.7 GHz is presented in Figure 12(a)–(d). The dispersal of current at 0° and 180° is the same in magnitude but opposite in direction. A similar pattern for current distribution is observed with 90° and 270°.

The normalized radiation patterns of an antenna at resonating frequencies of 14.5 GHz, 15.7 GHz, and 16.8 GHz are shown in Figure 13. Multilobe
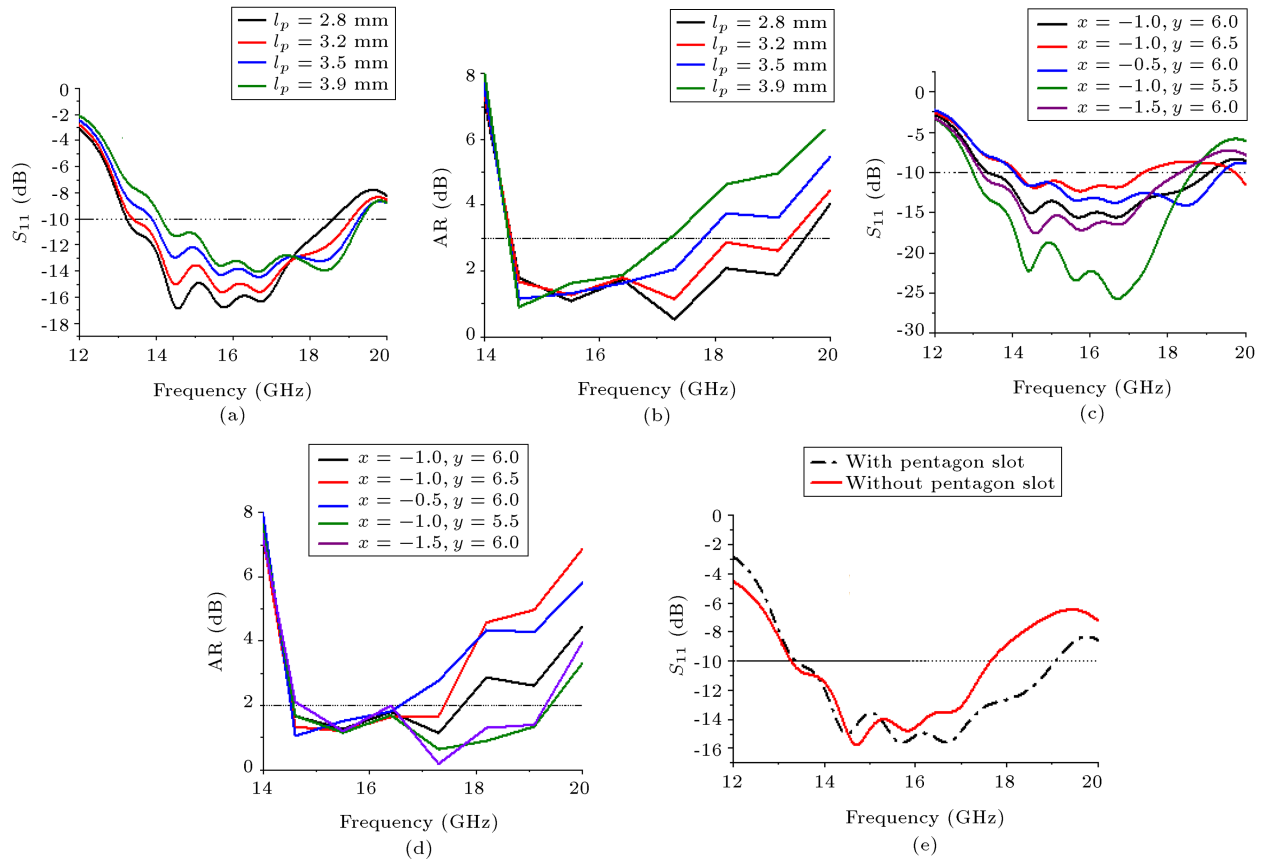
Figure 10. Parametric analysis of the pentagon: (a) S_{11} variation for side length l_p, (b) axial ratio variation for side length l_p, (c) S_{11} variation for the center of the pentagon, (d) axial ratio variation for the center of the pentagon, and (e) S_{11} comparison with and without pentagon slot.
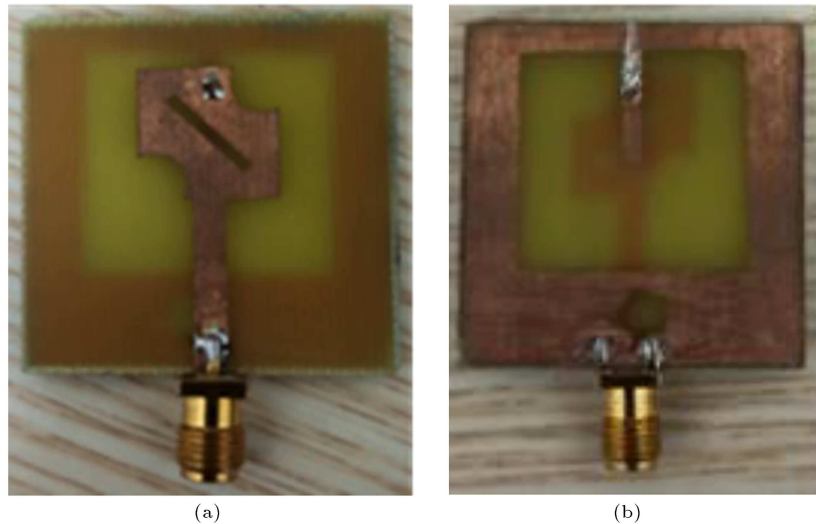

Figure 11. Fabricated antenna (front view and back view).

co-polarization and cross-polarization for E-field are achieved at 14.5 GHz. Co-polarization and cross-polarization with the main lobe at 120° are acquired at 15.7 GHz. At 16.8 GHz, the main lobe is at 48° for co-polarization and 45° for cross-polarization. The difference between the magnitudes in the co-polar and cross-polar patterns is less than 3 dB, which shows that circular polarization is good at these frequencies. Figure 14 shows the gain of the antenna. The maximum gain of 3.54 dBi is obtained at 17.25 GHz. Figure 15 represents the AR of the proposed antenna. It can be observed that ARBW ranges between 14.51–
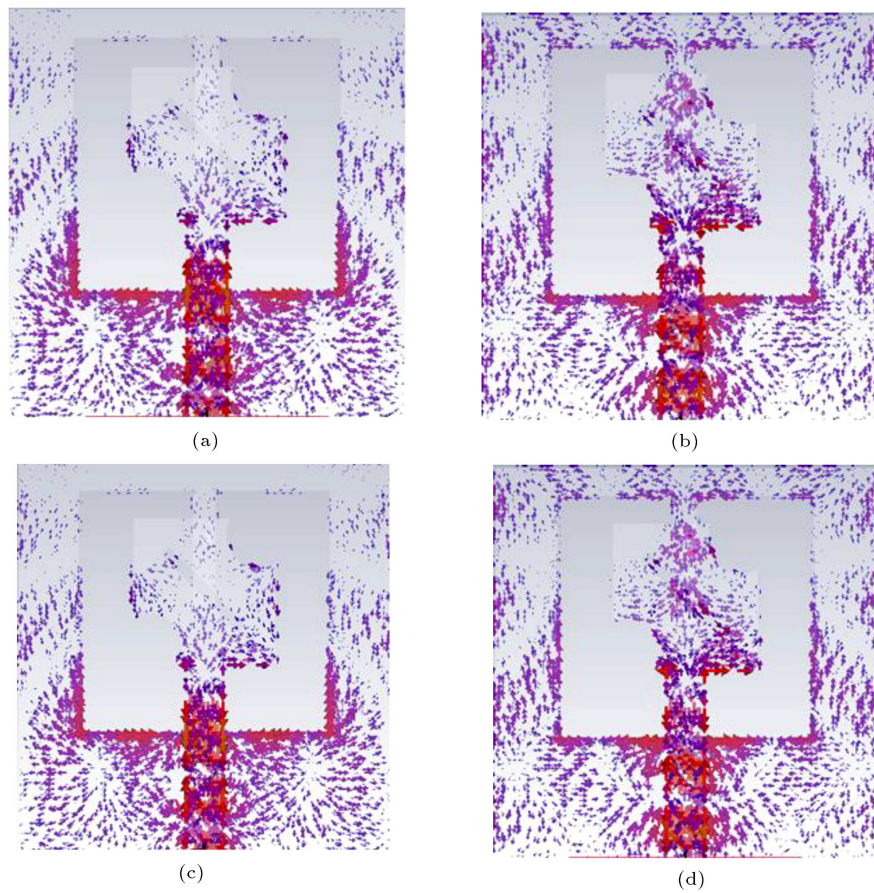
Figure 12. Surface current distribution in the proposed antenna at 15.7 GHz: (a) 0°, (b) 90°, (c) 180°, and (d) 270°.
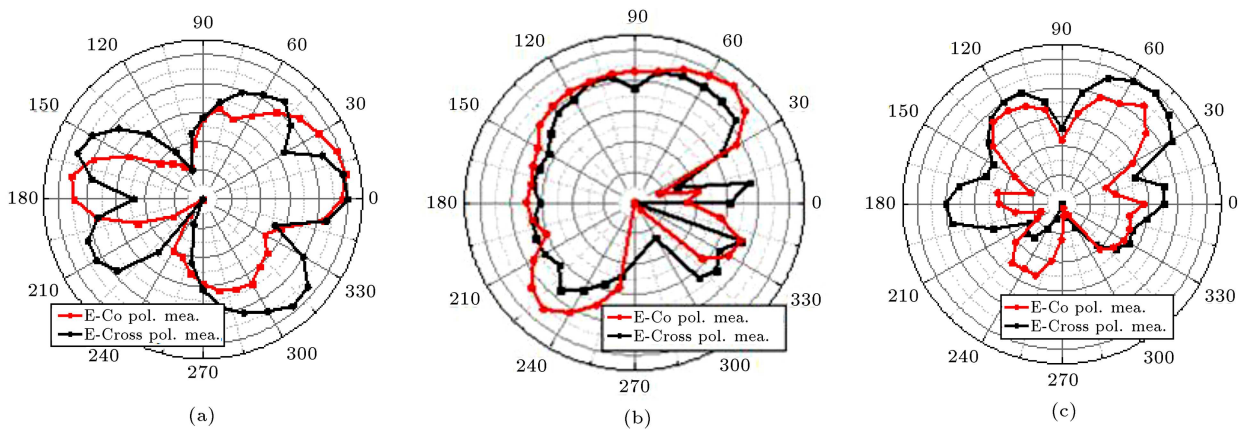

Figure 13. Radiation pattern foe E-Co and E-Cross polarization at resonating frequencies of (a) 14.5 GHz, (b) 15.7 GHz, and (c) 16.8 GHz.

19.30 GHz. To get more insight into antenna characteristics, the simulated and measured return losses are presented in Figure 16. The measured return loss graph is in accordance with the simulated return loss with slight variations. The antenna achieved a measured IBW of 4.96 GHz (13.6 GHz–18.56 GHz) compared with the simulated IBW of 5.68 GHz (13.37–19.05 GHz). The optimized antenna parameters are presented in Table 2. Table 3 compares the proposed antenna characteristics with the existing ones in the antenna CP work reported in this paper [4–16].

4. Conclusions

A novel microstrip line fed Circular-Polarization (CP) antenna was proposed for K_u-band applications. The presented antenna design had a very compact size of $34 \times 35 \times 1.6$ mm^2 and simple geometry. The antenna
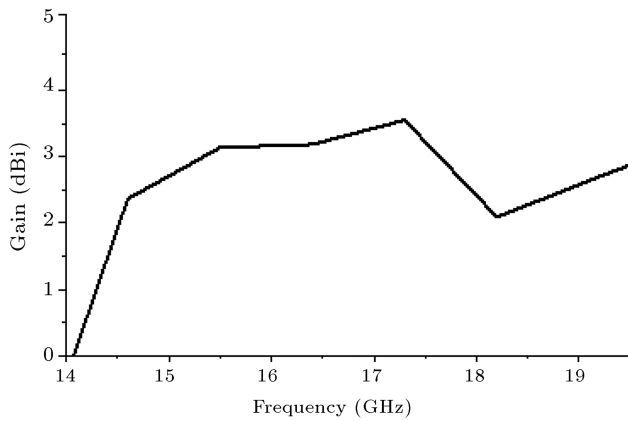
Figure 14. Simulated gain of an antenna.

Table 2. Optimized dimensions of the antenna.

Parameter	Value (mm)	Parameter	Value (mm)
L	35	l_s	10
W	34	l_u	11.5
L_s	13	c	1
R	0.6	w_u	2
W_1	3	l_g	22
R_1	3	w_g	23
L_1	17	l_p	3.2

was of very low cost as it was fabricated on the FR-4 substrate. The low-cost compact-size antenna achieved a very high CP Impedance Band-Width (IBW) of 4.96 GHz (13.6 GHz–18.56 GHz) and simulated Axial Ratio Band-Width (ARBW) of 4.85G GHz (14.51–19.30 GHz) in the K_u-band. The antenna had a
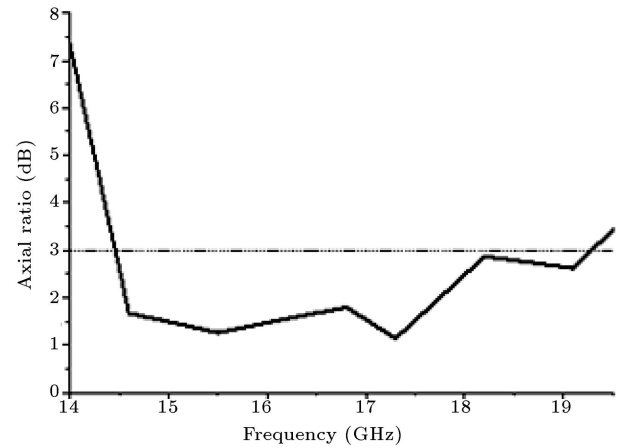

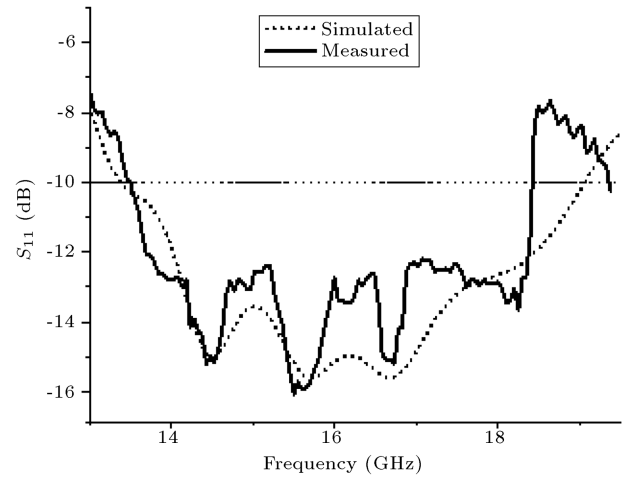**Figure 15.** Variation of axial ratio with frequency in the proposed design.

Figure 16. Simulated and measured S_{11} of the antenna.

Table 3. Comparison of the present work with the existing CP antenna literature.

Reference	Antenna size	IBW	ARBW
[4]	100×100 mm^2	986 MHz (49%) with center frequency of 2007 MHz	1.525–2.16 GHz (0.635 GHz) (35%)
[5]	50×60 mm^2	2.29–2.4 GHz (130 MHz)	2.340–2.370 GHz (0.03 GHz)
[6]	60×60 mm^2	3.67–4.14 GHz (0.47 GHz) 4.45–6.0 GHz (1.55 GHz)	3.00–3.840 GHz (0.84 GHz) 4.30–5.150 GHz (0.85 GHz)
[10]	24×21 mm^2	3.34–4.57 GHz (1.39 GHz)	4.311–4.384 GHz (0.73 GHz)
[11]	100×100 mm^2	2.09–2.65 GHz (0.56 GHz)	2.180–2.610 GHz (0.43 GHz)
[12]	70×63 mm^2	1.209–2.697 GHz (1.48 GHz)	1.740–2.260 GHz (0.52 GHz)
[13]	40×40 mm^2	2.25–6.75 GHz (4.50 GHz) 8.25–10.25 GHz (2.0 GHz)	3.172–6.211 GHz (3.039 GHz)
[14]	32×39 mm^2	2.90–6.60 GHz (3.70 GHz) 7.70–8.70 GHz (1.00 GHz)	4.08–6.5 GHz(2.42 GHz) 8.10–8.40 GHz (0.30 GHz)
[16]	45×50 mm^2	2.20–4.80 GHz (2.28 GHz)	2.20–4.180 GHz (1.98 GHz)
Proposed antenna	34×35 mm^2	13.6–18.56 GHz (4.96 GHz)	14.51–19.30 GHz (5.16 GHz)

wide bandwidth with a positive maximum gain of 3.54 dBi at 17.25 GHz. Low cost, simple geometry, wide bandwidth, compact size, and positive gain make the antenna a suitable candidate for K_u-band applications.

References

1. Fuguo Z., Qi, L., and Steven, G., *Circularly Polarized Antennas*, Wiley-IEEE Press, United Kingdom (2013).

2. Balanis, C.A., *Antenna Theory Analysis and Design*, John Wiley & Sons, Inc., Hoboken, New Jersey (2005).

3. Kumar, G. and Ray, K., *Broadband Microstrip Antennas*, Artech House, Boston, London (2003).

4. Wong, K.-L. and Chiou, T.-W. "Broad-band single-patch circularly polarized microstrip antenna with dual capacitively coupled feeds", *IEEE Trans. Antennas Propag.*, **49**(1), pp. 41–44 (2001).

5. Shekhawat, S. and Sharma, V. "Circularly polarized square patch microstrip antenna with Y-shaped slot for wi-max application", *Eur. J Adva. Eng. Tech.*, **1**(1), pp. 61–68 (2014).

6. Nasimuddin, A. and Arokiaswami, J. "Circularly polarized slot antennas with wideband performance", In *2015 Asia-Pacific Microwave Conference (APMC)*, Nanjing, China (2015).

7. Kim, S.-W., Kim, G.-S., and Choi, D.-Y. "CPW-Fed wideband circular polarized antenna for UHF RFID applications", *Int. J of Antennas Propag.*, **12**, pp. 1–7 (2017).

8. Sung, Y.J. "Circularly polarized Mercedes-Benz logo antenna for GPS applications", *Microw. Opt. Technol. Lett.*, **58**(10), pp. 2308–2311 (2016).

9. Sze, J.-Y. and Chen, W.-H. "Axial-ratio-bandwidth enhancement of a microstrip-line-fed circularly polarized annular-ring slot antenna", *IEEE Trans. Antennas Propag*, **59**(7), pp. 2450–2456 (2011).

10. Rawat, S. and Sharma, K.K. "Stacked configuration of rectangular, and hexagonal patches with shorting pin for circularly polarized wideband performance", *Cent. Eur. J. Eng.*, **4**, pp. 20–26 (2013).

11. Wu, J., Ren, X., Wang, Z., et al. "Broadband polarized antenna with L-shaped strip feeding and shorting-pin loading", *IEEE Antennas Wirel. Propag. Lett.*, **13**, pp. 1733–1736 (2014).

12. Cao, W., Zhang, B., Yu, T., et al. "A single-feed broadband circular polarized rectangular microstrip antenna with chip-resistor loading", *IEEE Antennas Wirel. Propag. Lett.*, **9**, pp. 1065–1068 (2010).

13. Rezaeieh, S.A. Şimşek S., and Pourahmadazar, J. "Design of a compact broadband circularly-polarized slot antenna for wireless applications", *Microw. Opt. Technol. Lett.*, **55**(1), pp. 413–418 (2013).

14. Jhajharia, T., Tiwari, V., Bhatnagar, D., et al. "A dual-band CP dual-orthogonal arms monopole antenna with slanting edge DGS for C-band wireless applications", *AEU – Int. J. Electron. C.*, **84**, pp. 251–257 (2018).

15. Yang, K.-P. and Wong, K.-L. "Dual-band circularly-polarized square microstrip antenna", *IEEE Trans. Antennas Propag*, **49**(3), pp. 377–382 (2001).

16. Kushwaha, N. and Kumar, R. "Design of a wideband high gain antenna using FSS for circularly polarized applications", *AEU - Int. J. Electron C.*, **70**(9), pp. 1156–63 (2016).

17. Darimireddy, N.K., Reddy, R.R., and Prasad, A.M. "Asymmetric and symmetric modified bow-tie slotted circular patch antennas for circular polarization", *ETRI Journal*, **40**(5), pp. 561–569 (2018).

18. Mashhadi, M., Komjani, N., Rejaei, B., et al. "Ferrite-based wideband circularly polarized microstrip antenna design", *ETRI Journal*, **41**(3), pp. 289–297 (2019).

19. Das, A., Mandal, D., and Kar, R. "An optimal radiation pattern synthesis and correction of mutually coupled circular dipole antenna array", *Sci. Iran.*, **29**(3), pp. 1455–1474 (2020).

20. Kumar, J., Basu, B., and Talukdar, F.A. "Modeling of a PIN diode RF switch for reconfigurable antenna application", *Sci. Iran.*, **26**(3), pp. 1714–1723 (2019).

21. Saini, R.K., Bakariya, P.S., and Kumar, P. "Coplanar waveguide fed dual-band dual-sense circular polarized square slot antenna", *Int. J.RF Microw. C.E.*, **28**(9), e21503 (2018).

22. Saini, R.K. and Dwari, S. "Dual-band dual-sense circularly polarized square slot antenna with changeable polarization", *Microw. Opt. Technol. Lett.*, **59**(4), pp. 902–907 (2017).

23. Anantha, B., Merugu L., and Rao, P.V.D.S. "Reconfigurable corner truncated square microstrip patch antennas for wireless communication applications", *IETE J. Res.*, **66**(2), pp. 241–255 (2018).

24. Zhang, X. and Zhu, L. "High-gain circularly polarized microstrip patch antenna with loading of shorting pins", *IEEE Trans. Antennas Propag.*, **64**(6), pp. 2172–2178 (2016).

25. Patil, J.B. and Karia, D.C. "Comparative study of Roger and FR-4 based circularly polarized microstrip patch antenna with injecting a single set of shorting pins", In *9th International Conference on Computing Communication and Networking Technologies (ICC-CNT)*, Bengaluru, India (2018).

26. CST Microwave Studio Simulator, Version 14.

Biographies

Ushaben Keshwala is presently working as an Assistant Professor in the Electronics and Communication Engineering Department, Amity University Uttar Pradesh, India. She graduated with a BEng in Electronics and Communication from G.H. Patel College

of Engineering and Technology, V.V. Nagar, Gujarat, India in 2007. She did her MTech degree in the Electronics and Communication Engineering at Amity University Uttar Pradesh, India, in 2013. She is pursuing the PhD degree in the research field of planar antennas for wireless and satellite communication systems. She has published more than 10 research papers in peer-reviewed international journals, book series, and IEEE conferences. Her current research interest includes nature-inspired antennas and pseudo-random number generation for communication systems.

Sanyog Rawat is presently associated with the Electronics and Communication Engineering Department, Manipal University Jaipur. He has been active in teaching and research for more than 16 years. He received BEng in Electronics and Communication, MTech in Microwave Engineering, and PhD in the field of Planar Antennas. He has published more than 80 research papers in peer-reviewed international journals, book series, and IEEE conferences. He has supervised nearly 30 MTech theses and five PhD dissertations and is currently guiding six PhD scholars. He has organized several workshops, seminars, and national and international conferences. He has been empaneled

in the editorial boards of various national and international journals. His current research interests include reconfigurable RF printed circuits and passive and active microwave integrated circuits. He has visited countries like Japan, Thailand, Malaysia, UAE, and Indonesia for academic and research work. He is also a member of several academic and professional bodies, e.g., he is a senior member of IEEE and life member of IE and ISLE.

Kanad Ray is an IEEE Senior Member who received the MSc degree in Physics from Calcutta University and the PhD degree in the same field from Jadavpur University, West Bengal, India. He has been a Professor of Physics, Electronics, and Communication and is currently working as the Head of the Department of Physics, Amity School of Applied Sciences, Amity University Rajasthan (AUR), Jaipur, India. His current research areas of interest include cognition, communication, electromagnetic field theory, antenna and wave propagation, microwave, computational biology, and applied physics. He has been serving as an editor for various Springer book series. He was an Associate Editor of the Journal of Integrative Neuroscience (The Netherlands: IOS Press).