Wireless Personal Communications (2022) 123:407–420
https://doi.org/10.1007/s11277-021-09137-0

Ultra-Wideband Compact Circularly Polarized Antenna

Ekta Thakur[1] · Naveen Jaglan[1] · Samir Dev Gupta[1]

Accepted: 8 September 2021 / Published online: 14 September 2021

Abstract
In this research work, a circularly polarized (CP) monopole antenna is designed for Ultra-Wideband (UWB) applications. The CP UWB antenna is be made up of a reformed ring patch and ground plane. The slots and stubs are inserted in the ground to achieve CP in the UWB antenna. This antenna attained an Axial Ratio Bandwidth (ARBW) of 5 GHz (4.0–9.0 GHz) that lies in the UWB frequency range that is from 3.1 to 10.6 GHz. The designed antenna has a radiation efficiency of around 80% for the complete UWB frequency range. The CP UWB antenna is designed and fabricated using the FR4 with a compact size of $32 \times 30 \times 1.6$ mm^3 and with a peak gain of 6.8 dBi. Tested results are in good resembles with simulated ones.

Keywords Ultra-wide band (UWB) · Circular polarization(CP) · Impedance bandwidth (IB) · Axial ratio bandwidth (ARBW) · Compact size

1 Introduction

Ultra-Wide Band (UWB) technology is used in most of the communication systems because of wide Impedance Bandwidth (IB), simple fabrication method, low power dissipation, higher transmission data rates, low cost, multipath cancellation. The UWB [1–5] ranges from 3.1 to 10.6 GHz is used for numerous wireless applications. The biggest challenge for wireless communication systems is the polarization mismatch loss between the transmitter and the receiver [6]. To overcome the polarization mismatch loss and multiple path interference it is essential to propose a UWB antenna with circular polarization (CP) features. In general, compared to the linearly polarized antenna, the circularly polarized antenna has many advantages such as eliminating polarization mismatch and reducing multipath interference [7]. Normally, CP wave in the UWB antenna can be produced by two orthogonally placed electric fields or magnetic fields with identical amplitude and 90° phase difference. Different techniques are used to generate the CP wave in the UWB antenna such as by employing couplers, phase shifters, or modified antenna structures. With the growing demand for the CP UWB antenna, the ARBW of the CP antenna required to be improved. A CP antenna can be obtained by using two feeding techniques: single feed

✉ Naveen Jaglan
naveenjaglan1@gmail.com

[1] Jaypee University of Information Technology, Waknaghat, Solan, Himachal Pradesh, India

and multi-feed. For ease, we have chosen a single fed monopole antenna. With the growing demand CP UWB antenna for high data wireless communication systems, the ARBW needs to enhance. Although the impedance bandwidth of the single fed monopole antenna is small due to the high Q factor of the antenna [8]. Therefore, designing a compact single fed monopole antenna with a wide axial ratio is a great task. Further, to obtain wide ARBW different stub [8] and slots [9] is reported in the literature. Various CP Antenna with different patch shape, for example, S-model [10], arc- slot antenna [11] and X-shaped [12], meandered- [13], hook [14], modified circular ring [15] antenna has been also suggested with wide 3 dB ARBW. In this editorial, a ring-shaped planar antenna is suggested with wide ARBW. A slot is etched under the feed line and the strip is extended from the ground to obtain a wider axial ratio. The proposed antenna has impedance bandwidth of 3–11 GHz, whereas the ARBW is 4–9 GHz. Further, the entire ARBW is coincided by impedance bandwidth, thus CP characteristics are satisfactory for the suggested antenna. In the interim, the suggested antenna has a simpler compact size with wider ARBW than the above-mentioned antenna. The design process and measured outcomes are analyzed and discussed in detail in the succeeding divisions.

2 Circular Polarized UWB Antenna

2.1 Design and Analysis

Figure 1 depicts the layout of the CP UWB antenna. The suggested structure comprises of the ring-shaped patch with the outer and inner radius of R1 and R2, respectively, Table 1 presents the dimension of the suggested CP UWB Antenna. A slot and stub are incorporated in the ground to enhance the ARBW. The proposed structure is simulated and fabricated using FR-4 substrate whose ε_r is 4.4 and height (h) is 1.6 mm Ansoft HFSS v.13 software is used to simulate the suggested antenna. EP 2006 PCB Prototype machine is used to fabricated the suggested antenna. The antenna parameters like S parameters and radiation pattern are evaluated using the Agilent N5230C vector network analyzer and microwave shield anechoic chamber respectively. Figure 2 indicates the archetype of the circularly polarized UWB antenna. The measured and simulated VSWR is depicted in Fig. 3.

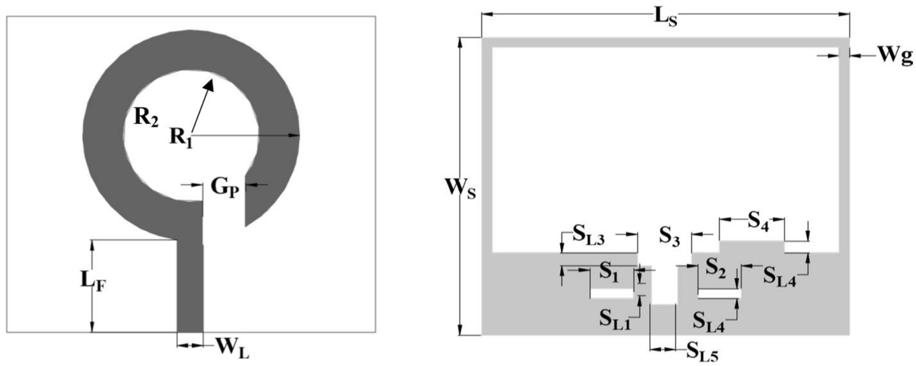
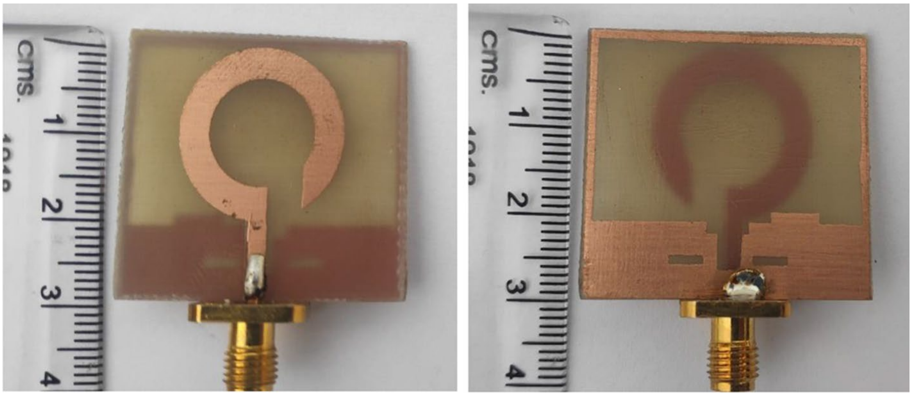


Fig. 1 Proposed Circular polarized ultra wide band antenna

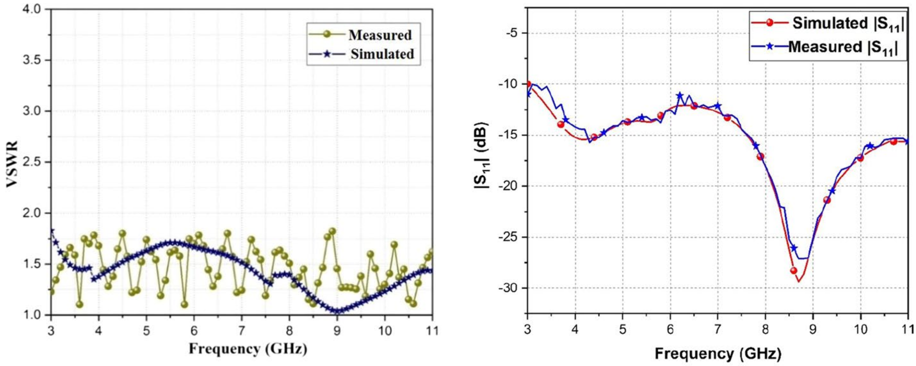
Table 1 Dimensions of suggested antenna

Parameter	S_3	S_{L3}	S_2
Units (mm)	5	1.3	4
Parameter	S_{L2}	S_1	S_{L1}
Units (mm)	1	1	4
Parameter	S_{L4}	S_4	L_G
Units (mm)	1.2	4	8.3
Parameter	S_{L5}	G_P	L_F
Units (mm)	5	4	8.7
Parameter	W_s	L_s	W_L
Units (mm)	34	30	2.4
Parameter	R_1	R_2	G_P
Units (mm)	10	6.3	4



(a) **(b)**

Fig. 2 **a** Uppermost view, **b** Foot view



(a) **(b)**

Fig. 3 Tested and simulated VSWR and return loss

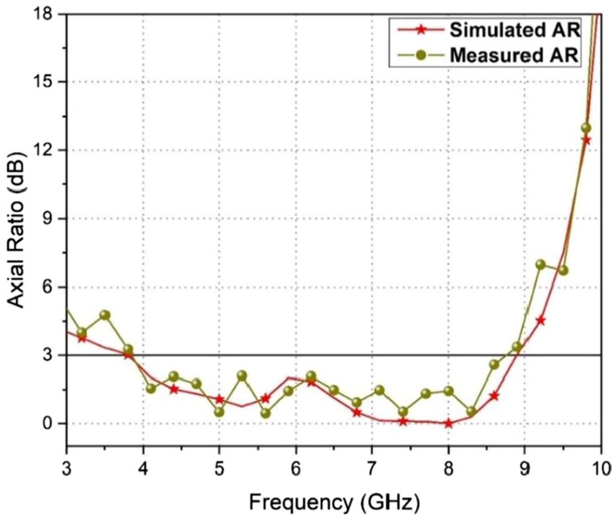


Fig. 4 Tested and simulated Axial ratio

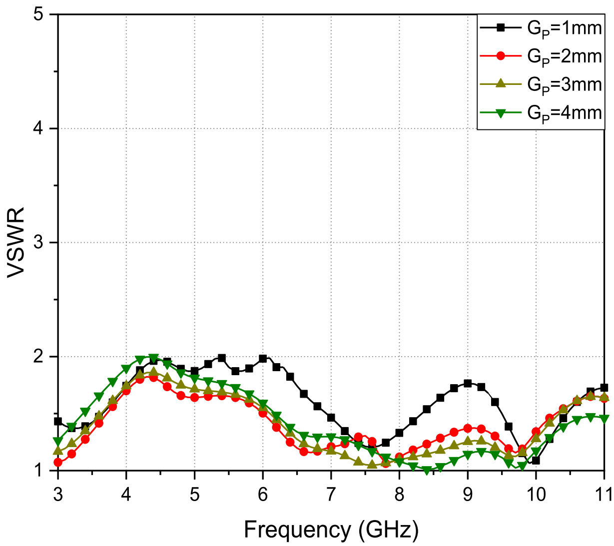


Fig. 5 Variation of VSWR for different ring slot width (Gp)

Figure 4 displays the deviation of the simulated and tested axial ratio with frequency. It can be seen that 3 dB ARBW of the suggested structure is 4–9 GHz coincided by 10 dB impedance bandwidth. Figures 5 and 6, shows that, it has marginal effect on impedance matching, although by increasing slot length from $S_1 = 1–4$ mm, the upper band of the axial ratio moves from 7.6 to 9 GHz, which increases overall ARBW.

2.2 Variations in the ground slot(S_1)

Figures 7 and 8 depict the simulated VSWR and axial ratio for different values of $S_1 = 2$, 3, and 4 mm respectively. It is observed that there is a negligible variation on

Fig. 6 Axial ratio for different ring slot width(Gp)

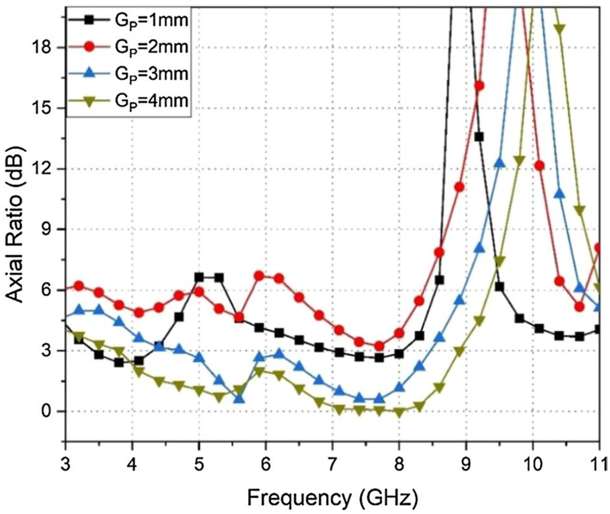
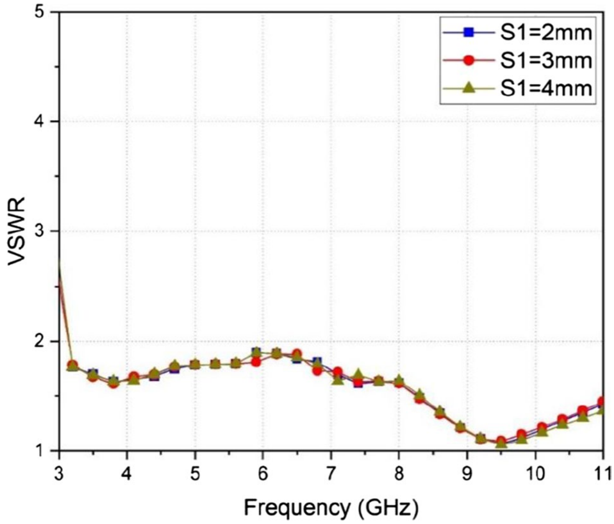


Fig. 7 Deviation of VSWR for dissimilar ground slot length (S_1)



VSWR, whereas, in Fig. 8, significant variation is seen in the Axial ratio for different ground slot which improves overall ARBW length (S_1). As the slot length increased from $S_1 = 2$–4 mm, the lower band of the axial ratio moves from 5.5 to 4 GHz,. By varying S_2 the same variation is observed in VSWR and the axial ratio of the suggested CP UWB antenna.

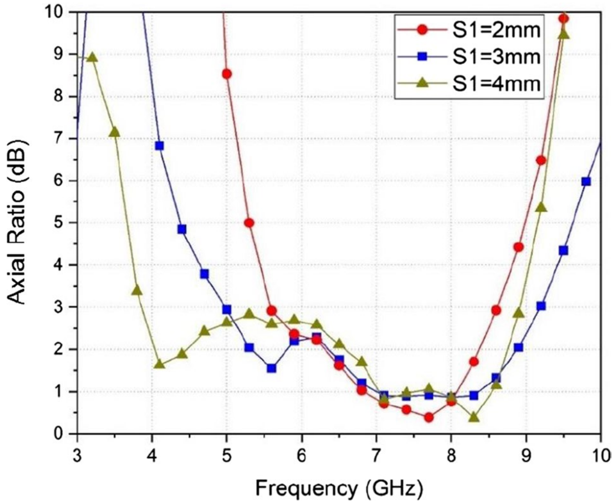


Fig. 8 Deviation of Axial ratio for dissimilar ground slot length (S_1)

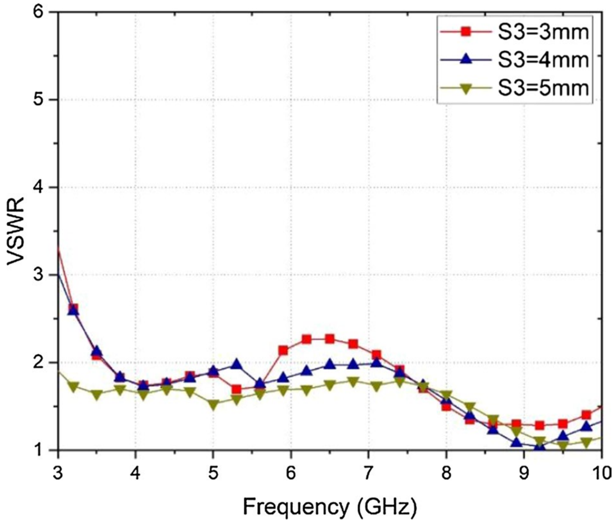


Fig. 9 Deviation of VSWR for dissimilar the slots length (S_3)

2.3 Variation of the slot length(S_3)

Figure 9 indicates the deviation of VSWR for different slot lengths (S_3). It is seen that there is a little deviation on impedance matching, as slot length S_3 increase from 3 to 5 mm.

Figure 10. presents the deviation of the axial ratio with frequency. Two CP mode approaches each other as S3 decrease to 5 mm and proposed structure shows the maximum bandwidth of AR. Thus, the two CP modes get unite by varying the length of the slot.

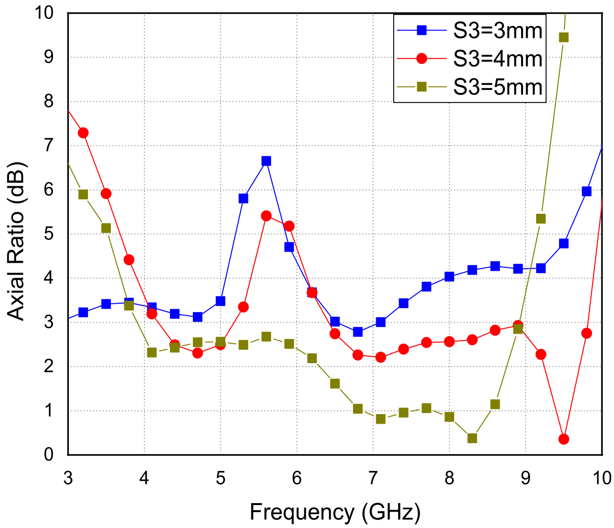


Fig. 10 Deviation of Axial Ratio for dissimilar the slots length (S_3)

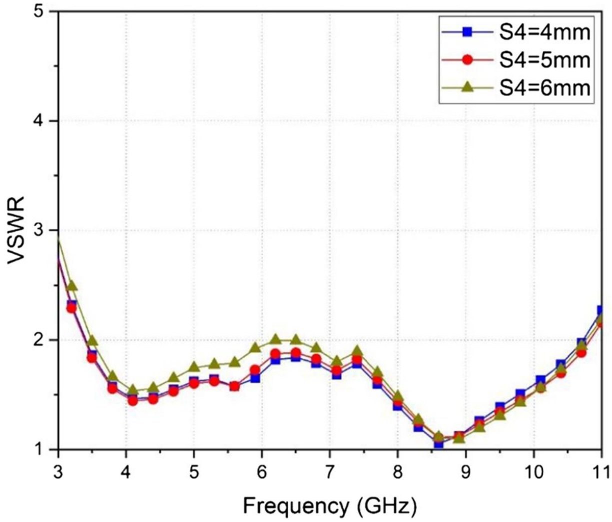


Fig. 11 Deviation of VSWR for dissimilar ground slot length (S4)

2.4 Variations in the ground slot(S4)

Figure 11 indicates the deviation of VSWR with frequency for different ground slot lengths (S_4). It is perceived that there is a minimal variation on VSWR, whereas, in Fig. 12, significant variation is seen in the axial ratio for different ground slot length (S_4). As the slot length increased from $S_4=4$–6 mm, the upper band of the axial ratio moves from 8.3 to 9.1 GHz, which improves the overall ARBW.

Figures 13 and 14 indicates the deviation of return loss and axial ratio for different ground slot lengths (S_{L5}). It is perceived that there is significant variation on both return loss and axial ratio. As the slot length increased from $S_4=3$–5 mm, the return loss and axial ratio improves significantly.To understand the circular polarization mechanism the surface current distribution is analyzed with phase change from 0° to 270°. The current

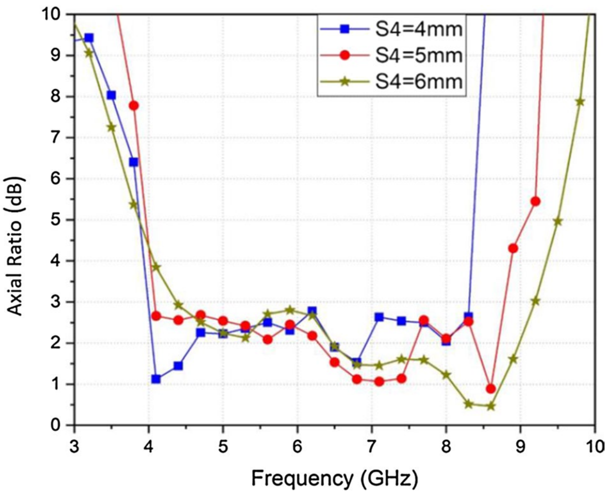


Fig. 12 Deviation of Axial ratio for dissimilar ground slot length (S4)

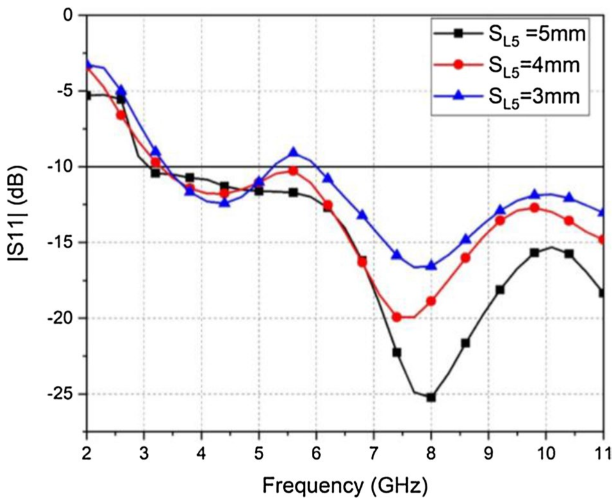
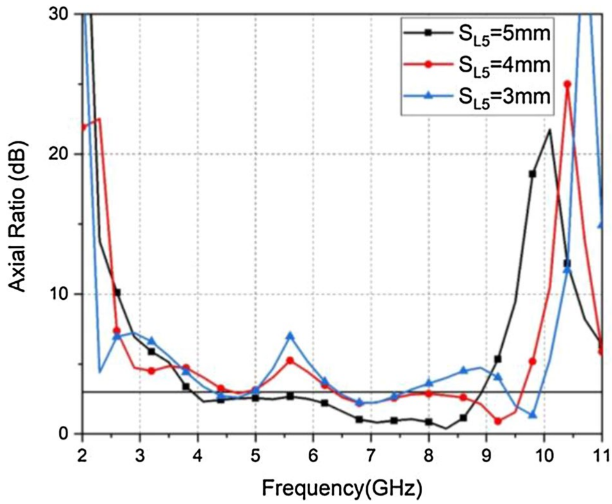


Fig. 13 Deviation of return loss for dissimilar ground slot length (S_{L5})

circulations of the proposed structure at 5.5 GHz at dissimilar time pause: w(t) = 0°, 90°, 180°, and 270° is demonstrated in Fig. 15. The predominant vector direction is in −Y direction for 0°, while for 90° the predominant vector direction is −X direction. For 180° and 270°, the predominant vector direction is reverse to 0° and 90°. It is observed from the figure that as the phase increase from 0° to 270°, with the identical amplitude and 90° phase difference the current moves in the left-handed or clockwise direction, as observed from the + Z direction. Thus, it is noticed that the suggested circularly polarized UWB antenna can radiate left-hand CP (LHCP) wave as observed from + Z direction and right-hand CP (RHCP) from the − Z direction. Figure 16 indicates the simulated and tested H plane and E plane at 5 GHz and 7 GHz. In + Z direction the radiated wave is LHCP and in the − Z direction the radiated wave is RHCP.

Figure 17 illustrates the radiation efficiency of the suggested CP UWB antenna.Fig. 18 indicates the gain variation with the frequency of the suggested antenna. Good constancy can

Fig. 14 Deviation of Axial ratio for dissimilar ground slot length (S_{L5})



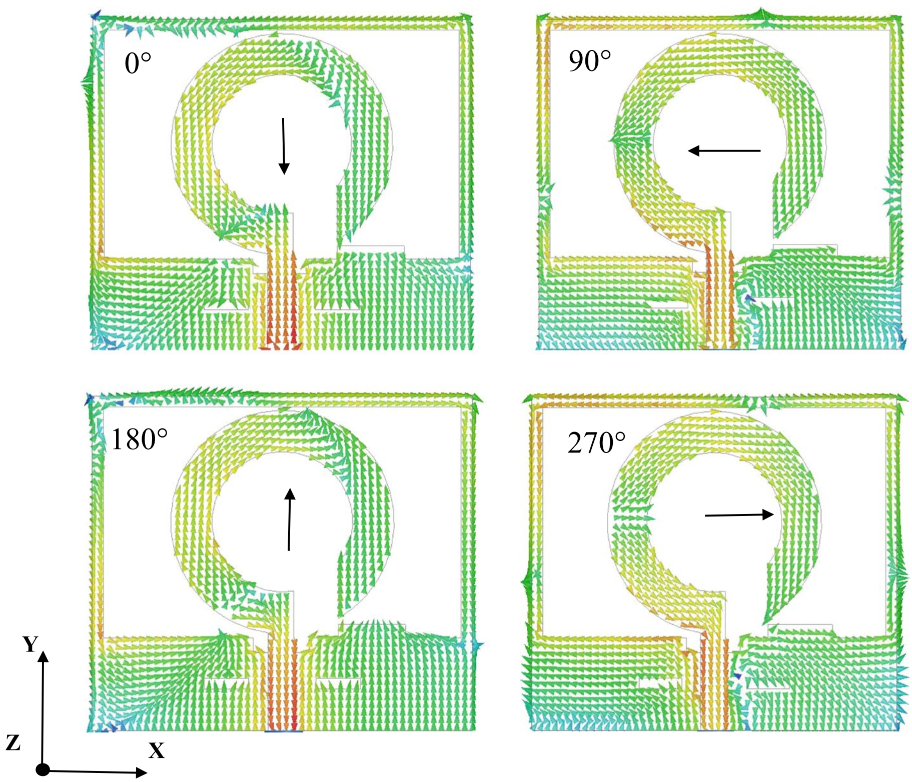


Fig. 15 Current density at 6 GHz with the dissimilar phase of 0°, 90°, 180°, and 270°

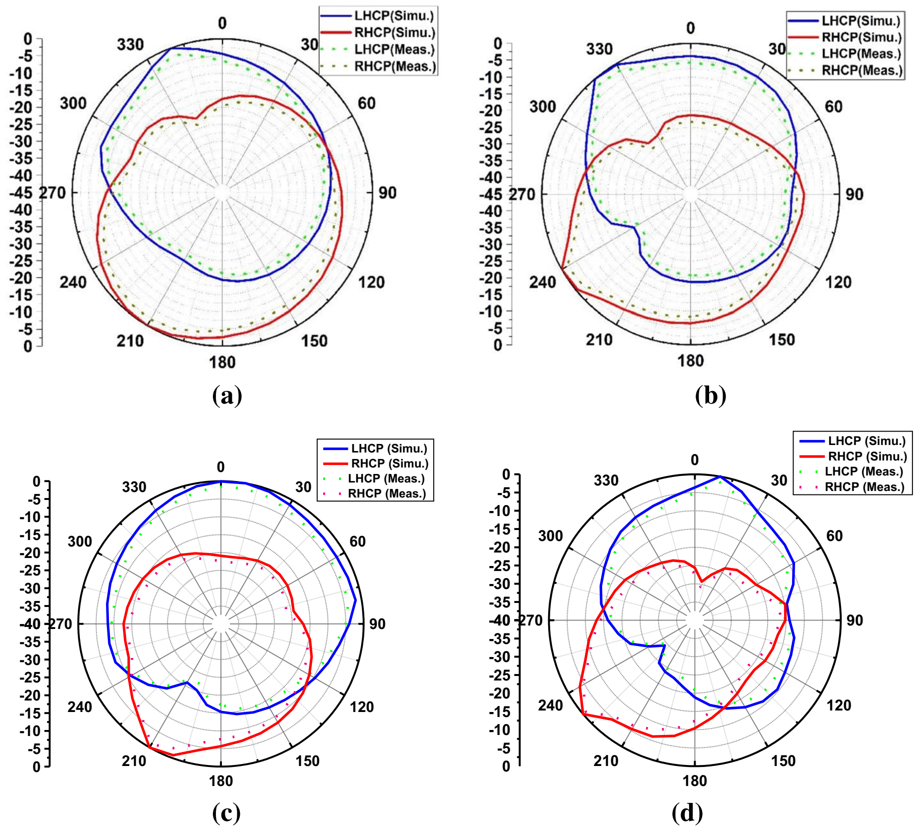


Fig. 16 Radiation plot **a** E-plane and **b** H-plane at 5 GHz **c** E-plane and **d** H-plane at 7 GHz

Fig. 17 The plot of radiation efficiency

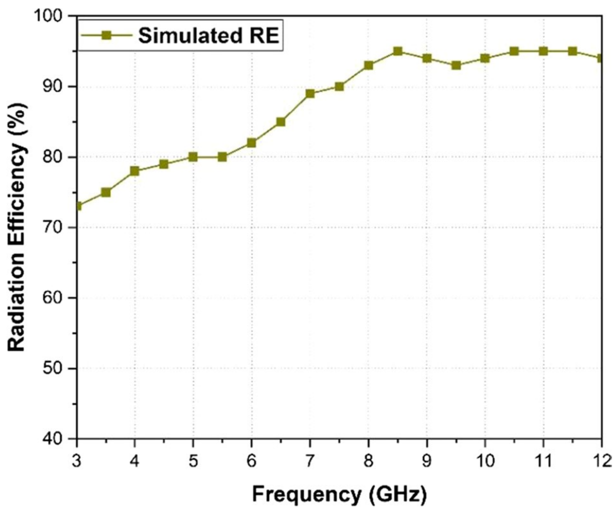


Fig. 18 Variation of antenna gain with frequency

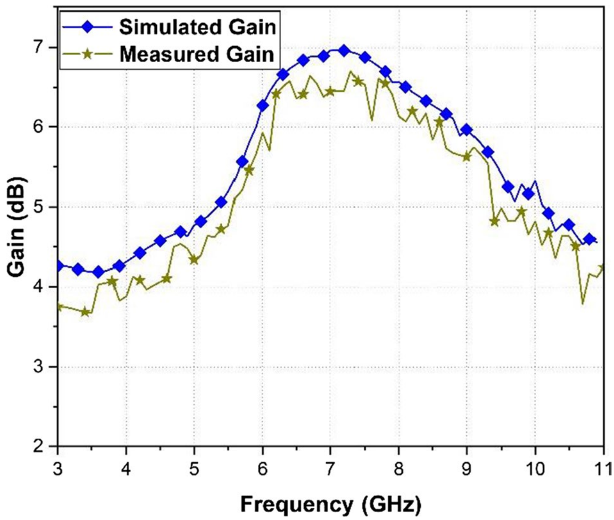


Table 2 Performance comparison of the suggested antenna

S. No.	Reference	Impedance bandwidth (GHz)	Polarization	Axial ratio bandwidth (GHz)	Dimensions (mm × mm)
1	Proposed antenna	3–11	LHCP	4–9	32 × 30
2	[15]	3–11	LHCP	4–9.5	34 × 30
3	[16]	2.25–7.35	LHCP	2.05–6.55	49 × 55
4	[17]	2.4–14	LHCP	4.3–6.75	60 × 50
5	[18]	2.67–13	LHCP	4.9–6.9	60 × 60
6	[19]	4.56–8.5	RHCP	4.75–8.45	40 × 40
7	[20]	5.02–10.84	LHCP	5.07–9.22	40 × 40
8	[21]	2.08–3.75	LHCP	2.28–3.76	46.6 × 70
9	[22]	1.84–2.43	LHCP	1.89–2.43	50 × 50
10	[23]	1.48–4.24	RHCP	2.05–3.9	55 × 50
11	[24]	0.85–4.15	LHCP	1.20–3.40	100 × 100
12	[25]	1.78–5.64	RHCP	2.85–5.21	54 × 54
13	[26]	2.4–7.4	LHCP	4.9–6.9	39 × 32

be attained compared to simulated and tested results. The tested gain of the antenna varies in between 4.5 and 7 dB for complete UWB. Table 2 indicates the performance evaluation of the suggested structure with those recent antennas in the publication. It is noticed that the proposed structure has a small size with wider impedance bandwidth and ARBW than the existing antenna.

3 Conclusion

In this letter, a compact ring-shaped CP UWB antenna has been effectively simulated and tested. The CP UWB antenna is attained by inserting a slot in the ground that generates rotating surface current to produce CP characteristic's in this antenna. The surface current moves in the clockwise direction when observed from + Z direction and LHCP is obtained. Simulated and tested results confirm that the suggested CP UWB antenna obtains impedance bandwidth of 3–11 GHz and ARBW of 4–9 GHz as observed from + Z direction. So, suggested antenna is a decent applicant for wideband CP application like WiMAX (3.3–3.6 GHz), 5G (3.4–3.7 GHz), C-band (3.7–4.2 GHz), Aeronautical Radio Navigation band (4.2- 4.7 GHz), WLAN (5.15–5.825 GHz), downlink of X-band satellite communications (7.25–7.75 GHz) and X-band satellite link (9.6–11.2 GHz) within the UWB frequency range.

Acknowledgements Sincere thanks to Prof. Binod K. Kanaujia (Jawaharlal Nehru University) for approving the easy access of the laboratory facilities.

Author Contributions Authors have contributed a compact circular polarised ultra wide band antenna.

Funding The authors did not receive support from any organization for the submitted work.

Declarations

Conflict of interest The authors have no conflict of interest to declare that are relevant to the content of this article.

References

1. Irene, G., & Rajesh, A. (2018). Penta-band reject inside cut koch fractal hexagonal monopole UWB MIMO antenna for portable devices. *Progress In Electromagnetics Research C, 82*, 225–235.
2. Nguyen, D. T., Lee, D. H., & Park, H. C. (2012). Very compact printed triple band-notched UWB antenna with quarter-wavelength slots. *IEEE Antennas and Wireless Propagation Letters, 11*, 411–414.
3. Babashah, H., Hassani, H. R., & Nezhad, S. M. A. (2019). A compact UWB printed monopoleMIMO antenna with mutual coupling reduction. *Progress In Electromagnetics Research C, 91*, 55–67.
4. Chamani, Z., & Jahanbakht, S. (2017). Improved performance of double- T monopole antenna for 2.4/5.6 GHz dual-band WLAN operation using artificial magnetic conductors. *Progress In Electromagnetics Research M, 61*, 205–213.
5. Tripathi, S., Yadav, S., & Mohan, A. (2014). Hexagonal fractal ultra-wideband antenna using Koch geometry with bandwidth enhancement. *IET Microwaves, Antennas and Propagation, 8*, 1445–1450.
6. Ooi, T. S., & Rahim, S. K. A. (2010). 2.45 GHz and 5.8 GHz compact dualband circularly polarized patch antenna. *Journal of Electromagnets Waves and Application, 24*, 1473–1482.
7. Zhang, Y. P. (2011). 60-GHz antenna-in-package technology. *IET Microwaves, Antennas and Propagation, 5*, 1743–1750.
8. Weng, W. C., Sze, J. Y., & Chen, C. F. (2014). A dual-broadband circularly polarized slot antenna for WLAN applications. *IEEE Transactions on Antennas and Propagation, 62*, 2837–2841.
9. Karamzadeh, S., Rafii, V., Kartal, M., & Saygin, H. (2016). Compact UWB CP square slot antenna with two corners connected by a strip line. *Electronics Letters, 52*, 10–12.
10. Tang, H., Wang, K., Wu, R., Yu, C., Zhang, J., & Wang, X. (2017). A novel broadband circularly polarized monopole antenna based on C-shaped radiator. *IEEE Antennas and Wireless Propagation Letters, 16*, 964–967.
11. Li, G. H., Li, H. Q., Li, T. L., & Liang, C. H. (2013). CPW-fed S-shaped slot antenna for broadband circular polarization. *IEEE Antennas and Wireless Propagation Letters, 12*, 619–622.

12. Gyasi, K. O., Wen, G. J., & Inserra, D. (2018). A compact broadband cross-shaped circularly polarized planar monopole antenna with a ground plane extension. *IEEE Antennas and Wireless Propagation Letters, 17*, 335–338.
13. Jhajharia, T., Tiwari, V., Yadav, D., Rawat, S., & Bhatnagar, D. (2018). Wideband circularly polarized antenna with an asymmetric meandered-shaped monopole and defected ground structure for wireless communication. *IET Microwaves, Antennas and Propagation, 12*, 1554–1558.
14. Elwi, T. A., Imran, A. I., & Alnaiemy, Y. (2015). A miniaturized lotus shaped microstrip antenna loadedwith EBG structures for high gain-bandwidth product applications. *Progress In Electromagnetics Research C, 60*, 157–167.
15. Manas, M., Bhattacharjee, S., & Mitra, M. (2019). Circularly polarized planar monopole antenna for ultrawideband applications. *International Journal of RF and Microwave Computer-Aided Engineering, 29*, 1–9.
16. Hu, B. Y., & Nasimuddin, S. X. (2015). Broadband circularly polarized moon-shaped monopole antenna. *Microwave and Optical Technology Letters, 57*, 1135–1139.
17. Tang, H. K., Wang, R., Wu, C. Z., Yu, J., & Wang, X. (2017). A novel broadband circularly polarized monopole antenna based on C-shaped radiator. *IEEE Antennas and Wireless Propagation Letters, 16*, 964–967.
18. Panahi, A., Bao, X. L., Ruvio, G., & Ammann, M. J. (2014). A printed triangular monopole with wideband circular polarization. *IEEE Transactions on Antennas and Propagation, 63*(1), 415–418.
19. Han, R. C., & Zhong, S. S. (2016). Broadband circularly-polarized chifre-shaped monopole antenna with asymmetric feed. *Electronics Letters, 52*, 256–258.
20. Martin, F., Falcone, F. B., Marques, J. R., & Sorolla, M. (2003). Miniaturized coplanar waveguide stop band filters based on multiple tuned split ring resonators. *IEEE Microwave and Wireless Components Letters, 13*, 511–513.
21. Zhang, H., Jiao, Y. C., & Lu, L. (2017). Broadband circularly polarized square-ring-loaded slot antenna with flat gains. *IEEE Antennas and Wireless Propagation Letters, 16*, 29–32.
22. Hoang, T. V., Le, T., Li, T. Q., & Park, H. C. (2016). Quad-band circularly polarized antenna for 2.4/5.3/5.8-GHz WLAN and 3.5-GHz WiMAX applications. *IEEE Antennas and Wireless Propagation Letters, 15*, 1032–1035.
23. Hu, B. Y., & Nasimuddin, S. X. (2015). Broadband circularly polarized moon-shaped monopole antenna. *Microwave and Optical Technology Letters, 57*, 1135–1139.
24. Kumar, Y., Gangwar, R. K., & Kanaujia, B. K. (2018). Compact broadband circularly polarized hook-shaped microstrip antenna with DGS plane. *International Journal of RF and Microwave Computer-Aided Engineering., 28*(6), e21275.
25. Chiu, C. Y., Yan, J.-B., & Murch, R. D. (2007). Compact three-port orthogonally polarized MIMO antennas. *IEEE Antennas and Wireless Propagation Letters, 6*, 619–622.
26. Xu, R., Li, J., & Liu, Y. J. (2018). A design of broadband circularly polarized C-shaped slot antenna with sword-shaped radiator and its array for L/S-ban applications. *IEEE Access, 6*, 5891–5896.

Ekta Thakur received her B. Tech degree in Electronics and Communication Engineering from Bahra University and M. Tech degree in Electronics and Communication Engineering from Jaypee University of Information Technology, Solan in 2016. Currently, she is pursuing her Ph.D. degree from Jaypee University of Information Technology, Solan. Her main research interests include, Ultra-wide band antennas, Band notched antennas, Meta-materials, MIMO systems, Electromagnetic band gap structure and circular polarized UWB Antenna.

Naveen Jaglan was born in 1989, obtained B.Tech (Hons.) and M.Tech (Hons.) degrees in Electronics and Communication Engineering from Kurukshetra University, Kurukshetra, India in 2009 and 2011 respectively. He obtained his Ph.D. dissertation entitled "Design and Development of Microstrip Antennas integrated with Electromagnetic Band Gap structures" from Jaypee Institute of Information Technology, Sec-62, Noida, U.P., India in June 2017. He has authored/co-authored several research papers in referred international journals and conferences. His research has included microwave communications, planar and conformal microstrip antennas including array mutual coupling, artificial materials (metamorphic, metamaterials), EBG, PBG, FSS, DGS, novel antennas, UWB antennas, MIMO systems, numerical methods in electromagnetics, Composite Right/Left Handed (CRLH) transmissions and High-k dielectrics. His skill includes modelling of antenna and RF circuits with Ansoft HFSS/CST Microwave Studio/ADS Momentum, measurements using Vector Network Analyzer and Anechoic Chamber.

Samir Dev Gupta obtained his B.E. (Electronics) from Bangalore University (University Visvesvaraya College of Engineering, Bangalore), M.Tech (Electrical Engineering) from I.I.T. Madras, M.Sc. (Defence Studies) from Madras University, and Ph.D. from J.I.I.T. Noida. He is currently designated as Director and academic head of Jaypee University of Information Technology (JUIT) Waknaghat, Solan, H.P., India. He has over three and a half decades of work experience in the areas of avionics, communication, radar systems and teaching at UG & PG level. His teaching career spans over 22 years and 6 months includes in addition to teaching at JIIT, Noida since December 2002, teaching at Institute of Armament Technology under Pune University, now Defence Institute of Advanced Technology (Deemed University) for PG programmes and training & development needs of Indian Air Force (I.A.F.) and Defence Research & Development Organization (D.R.D.O.), Air Force Technical College (A.F.T.C.), Bangalore where graduate engineers from IIT's, NIT's and Indian & foreign Universities undergo Aeronautical Engineering (Electronics) course for about 18 months prior joining Technical Officers' branch of the I.A.F. and Advanced Stage Trade Training Wing at Guided Weapon Training Institute, Baroda He was also a recognized postgraduate teacher in microwave communication at Pune University. His research interest is in the area of conformal microstrip patch antenna for aircraft systems. His publications in referred journals and conferences are well cited. His previous assignments includes, Deputy Director at Air Headquarters and were involved in planning, coordinating and directing maintenance, modification of aircraft and helicopter systems, modifications and induction of advance electronic systems into I.A.F., Commanding Officer of an 8 GHz LOS microwave communication unit, Senior Engineer looking after maintenance of airfield navigation aids, techno-logistic management of ground based communication equipment as Aeronautical Engineering (Electronics) Branch officer of the I.A.F., Chairman Communication Advisory Committee at I.A.T. Pune. He is qualified for first & second line servicing of Mirage-2000 aircraft. Work experience on Mirage Mission Simulator and fly by wire systems of Mirage-2000 aircraft. Led and supervised highly qualified and skilled engineering officers and technicians of I.A.F. in maintenance and operation of missile, radar and communication systems. Experienced in management of resources to achieve time bound targets and objectives viz. successfully implemented contract with international and national agencies for induction of Unmanned Aerial Vehicle, Portable Laser Designating Systems and up gradation of aircraft simulators for the I.A.F. Prior to joining JUIT Waknaghat as Director and academic head, he was a Professor in the department of ECE at Jaypee Institute of Information Technology (JIIT), Noida. He also initiated training and placement process for JIIT, Noida. Successfully placed first and second batch students of Jaypee Education System in top-notch national and multinational organizations through campus recruitment. He has been associated at JIIT, Noida in students' welfare and discipline as Associate Dean of Students and Chairman Proctorial Board respectively.