Wideband Circularly Polarized Planer Inverted-F Antenna using Reactive Impedance Surface

Tejaswi Jadhav, Shraddha Deshpande

***Abstract:** A wideband circularly polarized (CP) planar inverted-F antenna (PIFA) is proposed and designed using reactive impedance surface (RIS) for mobile communication. PIFA with RIS is used for CP radiation, size reduction and wideband of the proposed CP-PIFA. It is a different technique for improving the various performance parameters of the antenna, that is, narrow bandwidth, size reduction, and the axial ratio (AR). The structure of circular polarized PIFA is designed, analyzed, geometrically optimized, and implementation of the antenna to operate at 2.4 GHz WLAN bands. Finally, a proposed CP-PIFA is analyzed and simulated using full 3D electromagnetic high-frequency structure simulator (HFSS). The measured impedance bandwidth of designing an antenna (S11) 10-dB is 1399 MHz (1.542-2.943 GHz) 58.29\%, simulated 3-dB axial ratio bandwidth is 870 MHz (1.639-2.50 GHz) 36.25\%, measured voltage standing wave ratio (VSWR) is 1.02 and the realized gain is 8.1 dB for the 2.4 GHz WLAN bands.*

***Keywords:** Planar Inverted-F Antenna, Reactive Impedance Surface, Wideband, Circular Polarization, Axial Ratio.*

I. INTRODUCTION

Nowadays, the development of wireless applications in our day to day life, increasing the need for mobile subscribers to design better mobility, low cost, lesser phase sensitivity, miniature and bright weight antenna. However, the wireless device usually suffers from narrow impedance and circularly polarized (3-dB axial ratio) bandwidth. The circularly polarized PIFA offer more elasticity for the mobile devices and wireless communication due to their tactlessness near the phase change caused by multi-path effects or device orientation. It has integrated the compact volume, which is existing in an advanced compact handset [1] 2-D meandered current paths and the capacitive load for the ground plane for antenna size reduction and improving antenna impedance bandwidth [2].

Revised Manuscript Received on November 30, 2019.
* Correspondence Author
Tejaswi Jadhav*, Research Scholar, Electronics Department, Walchand College of Engineering, Sangli, Maharashtra, India. Email: tejaswi.jadhav@walchandsangli.ac.in
Shraddha Deshpande, Electronics Department, Walchand College of Engineering, Sangli, Maharashtra, India. Email: shraddha.deshpande@walchandsangli.ac.in

Finite ground planes contribute significantly to the bandwidth and radiation for PIFA [3] loaded shorting elements of the CP patch antenna to achieve symmetric size reductions and broadside radiation [4]. Asymmetric-cross slotted the patch used for the miniaturization and the circular polarization [5]. Metamaterials based low profile antenna using reflection phase regions for circular polarization [6], [7]. The notched frequency can be adjusted by slit length in the L-shaped stub [8]. The novel PIFA with wideband impedance bandwidth [9] and new approach cuboid ridge inductive loading patch for improving the CP performance [10]. The metamaterials based RIS has used in the slot-loaded patch for optimization of the antenna [11]. HIS consists of periodically arranged 6 × 6 nested concentric square patches on the top layer of the substrate to produce two in-phase reaction bands [12]. L-shaped stub microstrip antenna with OSA fed and a multilayer based an AMC reflector novel using metamaterials structure RIS [13]. The lattice of 4 × 4 periodic metallic square structure patch with RIS [14] the partially reacting surface (PRS) and the reactive impedance surface (RIS) used in the wideband microstrip antenna [15]. The asymmetrical fractal boundaries patch antenna is using a mushroom unit cell (MUC) and RIS [16]. Novel hexagonal ring-based RIS for the circularly polarized antenna [17] and the 4×4 patch array antenna using the RIS layer which is operated to change the ground plane [18].

The mobile communication system, smaller antenna sizes, is essential to meet the need for miniaturization. Thus, bandwidth improvement and size reduction are becoming considerations for mobile applications of PIFA. The unique property of PIFA is low profile internal antennas for handset terminals and to easy manufacture which is applicable in the various areas like military, space, and commercial applications. However, the benefits of the PIFA will still be offset by some inherent disadvantages such as lower gain, smaller bandwidth less power-handling capability and polarization. To minimize these drawbacks of PIFA using exact analysis methods, simulation, optimal design techniques, and implementation of the innovative new concepts to the successful development of a CP-PIFA using RIS.

In this work, a compact, wideband circular polarization planar inverted-F antenna using RIS has the leads of the compact or small size and appropriate design for mobile applications. PIFA has lesser bandwidth, lower gain, which is problematic to the mobile communication.

So the improvement in the impedance bandwidth of the CP-PIFA increases at the expense of size by increasing the height of conducting patch and substrate (dielectric) height to lower the quality factor, etc. Apart from these, more limitations are observed so minimize above drawbacks in the PIFA introduces the new proposed CP-PIFA using RIS. The RIS, known as metamaterials, has been exposed current the capability to reduce the size of antennas when allocation as the substrate for the proposed antenna. However, the space of conservative RIS substrates is much bigger than that of the reduced antenna. The HFSS 15 simulation tools are used to simulate the designed proposed CP-PIFA. The compact CP-PIFA using RIS is designed, fabricated, measured, and tested.

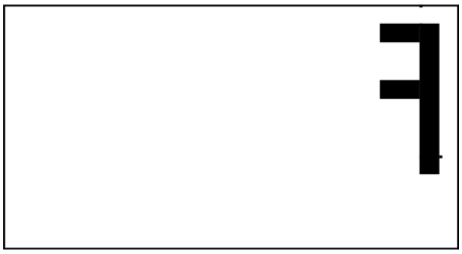


Fig. 1.Top view of the CP-PIFA

II. ANTENNA DESIGN

The meta-material (MM) square unit cell is an artificial substrate of the planner antenna. It has used as a periodic metallic thin structure with the asymmetric square-shaped array structure whose period is identical and same size [19]. RIS structure, which contains square periodic metal patches on the substrate, a ground plane and the thickness of the dielectric substrate of h1. An intervallic structure of RIS has acquired through its square-shaped unit cells. The top view of the CP-PIFA is as shown in Fig. 1. PIFA is an F-shaped, the shorted pin which contains a fixed ground plane, a coaxial connector probe, a top radiator, length of PIFA is one-fourth wavelength, and a shorting technique to the ground plane. In the design of proposed CP-PIFA, the required parameters are resonance frequency (f0), the dielectric substrate FR4 (εr = 4.4) with loss tangent (δ = 0.02) and the height of substrate (h). Fig. 2 shows the cross-sectional interpretation of the CP-PIFA. The proposed antenna has two dielectric substrates h1 and h2, which height h1 = 1.59 mm and h2 = 1 mm. RIS structure of antenna has sandwiched between two dielectric substrates. The feed point of conventional PIFA (radiator patch) and the ground plane of the antenna have directly connected by using surface mount sub-miniature (SMA) connector. The feed location of PIFA is one side corner of the antenna. Therefore SMA connector on feeding probe does not directly contact with metallic periodic unit cells of the RIS. The metallic periodic square unit structure of the RIS is as shown in Fig.3 under the radiator patch. The RIS covers an array structure of the proposed antenna 5 × 6 periodic metallic square unit cells. The RIS structure contains the periodic arrangement of the square unit cells overhead of the ground surface of the dielectric substrate. The RIS structure is beneficial for the bandwidth improvement, size reduction, and circular polarization of the antenna. PIFA and design of RIS are discussed in the next subsection.

A. Conventional PIFA

The conventional PIFA is consisting of patch element (top side), a ground surface (bottom side), a microstrip feed, a shorting pin, and the dielectric substrate. The conventional PIFA antenna shape is look-like English character F, hence it is called an inverted- F antenna. The conventional PIFA dimensions of radiating patch are 24.88 ×2.33×1 mm, and the ground surface of the CP-PIFA is 56.4 mm × 41.68 mm.

B. *RIS for Proposed CP-PIFA*

The top view of the RIS structure 5 × 6 arrays of the proposed CP- PIFA is as shown in Fig. 3. The simple characteristics of RIS based on meta-surface are explained in this reference [6].

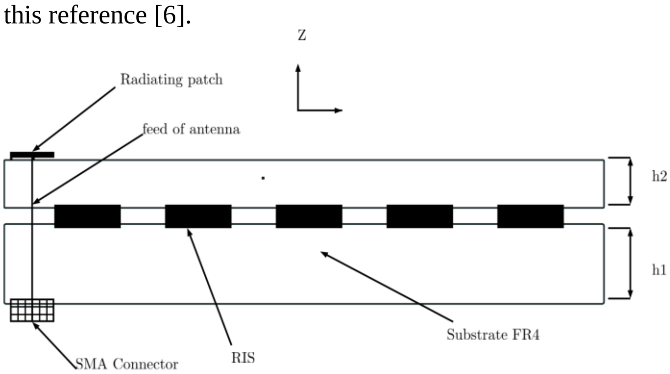


Fig. 2.Cross sectional view of CP-PIFA

The metamaterials-based RIS is periodically metallic square unit cells, relaxed the two-dimensional arrangement constructed on the ground backed dielectric substrate to improve the impedance bandwidth, size reduction, and the circular radiation pattern. The periodic structure of RIS has designed with exciting a transverse electromagnetic (TEM) mode. The perfect magnetic conductor (PMC) and perfect electric conductor (PEC) boundaries are around the metallic unit cell of RIS. The perfect electric (PE) and the perfect magnetic (PM) conductor are used for achieving the greatest optimal bandwidth and the size reduction. The metallic unit cell surface expending with the PEC and PMC boundaries through the single-mode waveguide port is excited by a plane wave. The metallic periodic unit cell surface size is the same and fixed. The reflection phase change of the PEC surface and the PMC surface is 180◦ and 0◦ respectively, which is back, radiated waves of the patch striking its surface. The performance parameters of the radiating metallic patch are enhanced to tuning the resonance frequency in the inductive surface, although keeping the total size of RIS unit cells is kept fixed. The operating wavelength of CP-PIFA is kept much larger than the metallic unit cells of RIS. The conventional PIFA is the planner antenna using the high dielectric substrate (FR4) over a low loss tangent. The main reason of size reduction is the robust electromagnetic coupling among the conventional PIFA, the PEC (PMC) and the ground surface, thus the conning significant near field region, which, the expanse of the electromagnetic energy inside the dielectric substrate of the proposed antenna. As a result, the comprehensive miniaturization of the PIFA has improved the cost of corporate features such as low profile, narrow bandwidth and the lesser impedance matching of the CP-PIFA due to the undesirable characteristic impedance matching. The last few years, the enhancing of antenna required the infinite impedance surface (PMC), and the zero impedance surface (PEC) but the opposite and the proximity image current of the PE surface has removed the radiated field surface from the CP-PIFA. The perfect magnetic surface is problematic to improve poor antenna efficiency, narrow bandwidth, input impedance, and moderately lossy field.

The image cancellation of an antenna is difficult in PEC and the dissipative loss of CP-PIFA is problematic in PMC. The purely reactive impedance with RIS decreases the mutual coupling between the PIFA and the ground surface of the antenna. Therefore the RIS used above the ground plane of the antenna, it is significantly recovering the performance of antenna than PEC and PMC surface and also improve the narrow bandwidth, size reduction, and reduces the back radiation of the antenna.

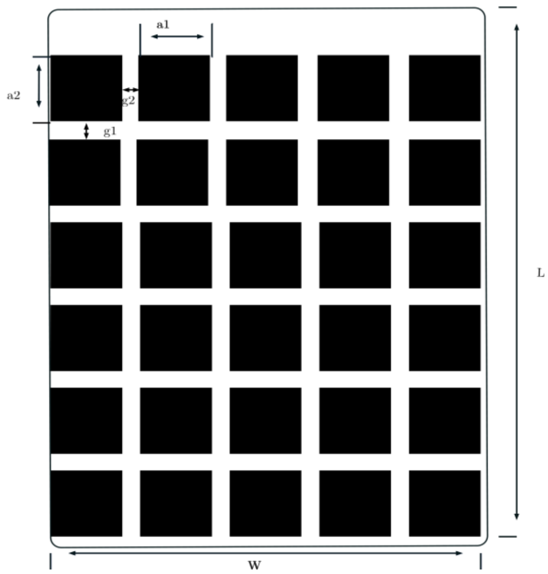


Fig. 3.Top view metallic square patch of the 5×6 RIS array

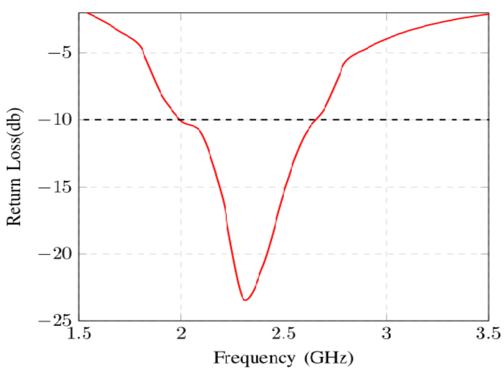


Fig. 4.Return Loss (S11) of the CP-PIFA

The main three drawbacks of RIS have used the ground surfaces: a) reduce the mutual coupling between the PIFA and the ground surface of the antenna, that improving the performance of impedance matching of antenna. (b) It combines the capacitive (inductive) performance of the PIFA with the inductive (capacitive) performance of the RIS, therefore, it is beneficial for size reduction, and (c) improving the front to back ratio of the proposed antenna. The metallic square unit cell which made up of inductive RIS on the PEC top of the dielectric substrate can store the magnetic energy. Therefore, it is growing the inductive and capacitive reactance of the radiating patch and compensating the electric or magnetic energy stored near the CP-PIFA. Also, it is an ensuing the geometric size reduction of an antenna.

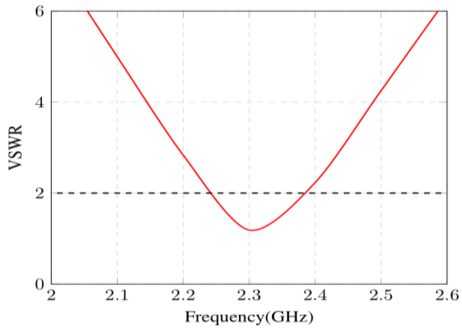


Fig. 5.VSWR of the CP-PIFA

The combination of periodic structure works an equivalent to a parallel inductive and capacitive circuit which is then provided desired the impedance characteristics and improving the bandwidth with the same sizes of the radiating antenna and substrate over RIS.

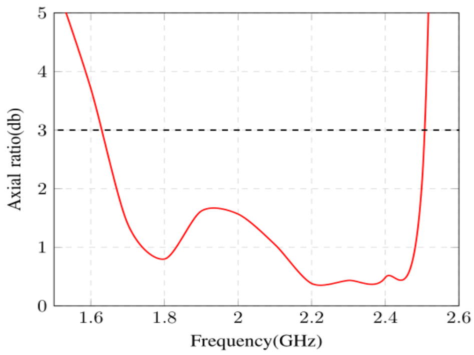
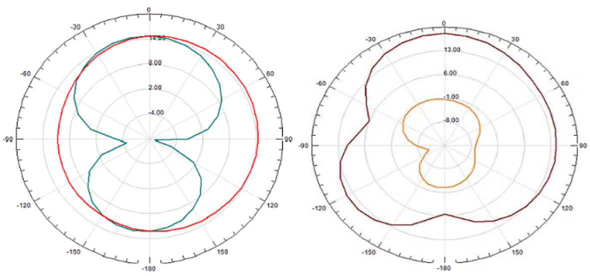


Fig. 6. Axial ratio plot.

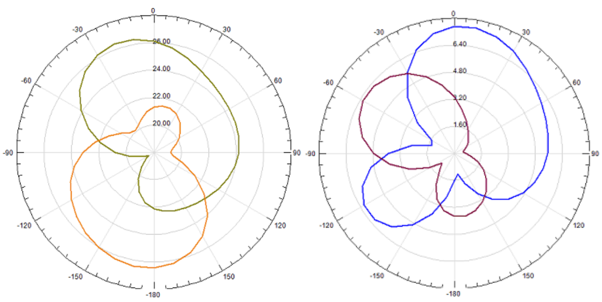
C. *Design RIS for CP-PIFA*

CP-PIFA using RIS is designed for circular polarization and miniaturization of the antenna. In the CP-PIFA design, the metallic square unit surface is printed on the top side of a dielectric substrate (FR4). The RIS structure has 5 × 6 arrays of the proposed CP- PIFA. The metallic square unit cells are printed on the top side of a dielectric substrate (FR4). The RIS has the periodic metallic square unit cell is arranged one after another combined with the dielectric substrate for the wave propagation. The proposed antenna having permittivity of the dielectric substrate ($\varepsilon r = 4.4$ and $\delta = 0.002$) and the thickness (h=1.59 mm). The periodic metallic square unit cell surface is perpendicular to its plane. All sides of the RIS have boundary conditions. The lateral measurements of CP-PIFA are fixed same as the ground surface dimension for PIFA configuration. The feed location (one side-feed) and the radiator patch of the proposed antenna are given for the better impedance matching. The adjacent dimension of the periodic metallic unit cells is set to have a1 = 0.8 mm, a2 = 0.9 mm, g1 = 0.342 mm and g2 = 0.28 mm. The geometric ground plane size of RIS is 56.4 mm × 41.68 mm.



(a) (b)

Fig. 7. (a) E Plane (b) H Plane



(a) (b)

Fig. 8. (a) X-Z Plane (b) Y-Z Plane

III. SIMULATION RESULTS AND DISCUSSION

The simulated return loss, voltage standing wave ratio (VSWR), axial ratio (AR), the radiation pattern, and the gain of the proposed CP-PIFA using RIS is discussed in this section. The proposed CP-PIFA antenna is fabricated, tested, and concluded that the RIS surface enhances the CP radiation and wide bandwidth. The obtained simulation result of the reflection coefficient (S11) is as shown in Fig. 4. The simulated |S11| -10 dB impedance bandwidth is 510 MHz ranges from (2.0641 2.5748 GHz) and -6 dB impedance bandwidth is 880 MHz ranges from (1.9 2.78 GHz) which covers the target center frequency of 2.4 GHz. Voltage standing wave ratio (VSWR) of the proposed CP-PIFA is as shown in Fig. 5. It is noticed that the value of VSWR is almost 1.1880 at a frequency of 2.4 GHz, which is very efficient in a fabrication process. The smaller the VSWR is, the better the antenna is matched to the transmission line and the more power is delivered to the antenna. It implies that almost all input power of an antenna could be transmitted to the patch and better impedance matching. Fig. 6 illustrates the axial ratio (AR) characteristics of CP-PIFA. Simulated -3 dB axial ratio bandwidth ranges from (1.6299 - 2.5053 GHz) 35.24% for 2.4 GHz WLAN bands. When AR < 1dB, it indicates the good circular polarized antenna. The axial ration implies all input power of an antenna has transmitted to the patch, so it is beneficial for impedance matching. The radiation pattern of the antenna (co-planar and cross-plane) in the $\theta = 0^\circ$ and $\varphi = 90^\circ$ of the XY plane is as shown in Fig. 7(a) and (b). The CP PIFA radiation pattern of E-plane and H-plane has simulated in HFSS. The radiation pattern of the antenna depends on the electric field or the magnetic field of the CP-PIFA. When port 1 of an antenna is excited in the HFSS simulation then the CP-PIFA radiates for the circular polarization, then the wave direction along the Z-axis (+Z direction and -Z direction). Fig. 8 (a) and (b) shows the simulated both RHCP and LHCP patterns, the radiation patterns of the X-Z plane and the Y-Z plane, which is a good agreement. In this figure shows Maximum radiation direction deviates of CP-PIFA from Z-axis, towards the right plan of XZ and the left plane of YZ. Fig.9 shows the front-back ratio of the CP-PIFA. This parameter is important in circumstances where interference or coverage in the reverse direction needs to be minimized.

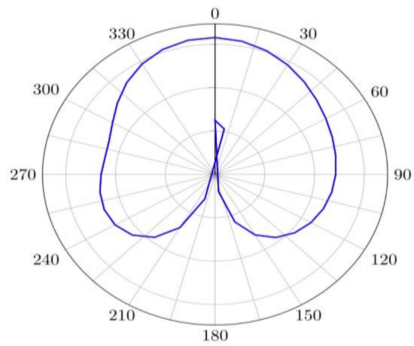


Fig. 9.Back radiation of CP-PIFA.

The peak gain of the proposed CP-PIFA for the mobile application as shown in Fig. 10. The simulated result of gain is 8.1db, which is suitable for the good circular polarized antenna.

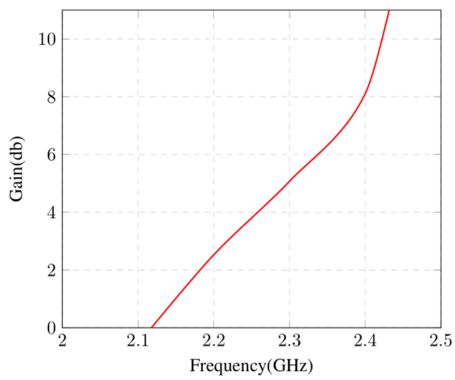


Fig. 10.Gain of CP-PIFA

IV. EXPERIMENTAL RESULTS

The return loss and VSWR of the proposed CP-PIFA using RIS are measured in the vector network analyzer (VNA). Fig.11 and Fig 12 illustrates the obtained simulated and fabricated results of performance parameters like return loss and VSWR. Measured impedance bandwidth < -10 dB is 587 MHz (2.3758-2.9635 GHz) 24.48% and impedance bandwidth < -6dB is 1076 MHz (2.126-3.2020GHz) 45%with respect to 2.4 GHz WLAN bands. The measured results of the proposed antenna have slightly increased as compared to the simulated results of the return loss (S11) and VSWR because of the small air gap between patch and ground substrate which has prepared in the fabrication procedure. The fabrication antenna is beneficial for a mobile application.it is shows the good impedance matching for proposed antenna. Fig.13 has shown the photograph of fabricated CP-PIFA using RIS. The top view of the fabricated antenna shows the original conventional PIFA and the periodic metallic cell structure in a photograph known as RIS.

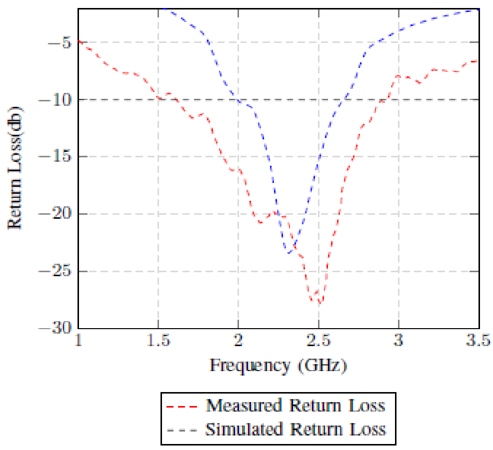


Fig. 11.Simulated and measured Return Loss of CP-PIFA

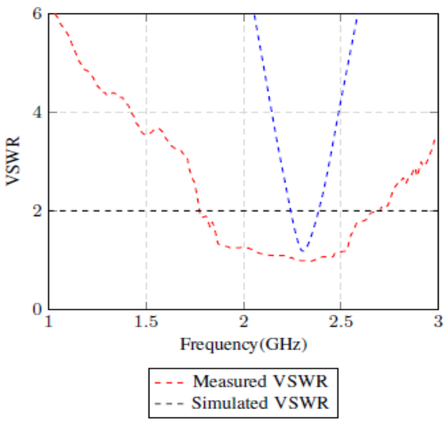


Fig. 12.Simulated and measured VSWR of CP-PIFA

Fig. 13.Photograph of fabricated CP-PIFA with RIS

V. CONCLUSION

A wideband circularly polarized PIFA using reactive impedance surface (RIS) has designed for the wireless mobile application. The RIS improves return loss, VSWR, radiation pattern, gain, axial ratio, and the circular polarization of the CP-PIFA. Good impedance matching and wideband is achieved by using the RIS plane. The measured impedance bandwidth of designing antenna S11 10-dB impedance bandwidth is 1399 MHz (1.542-2.943 GHz) 58.29%, simulated 3-dB axial ratio bandwidth is 870 MHz (1.639-2.50 GHz) 36.25%, measured VSWR is 1.02 and the realized gain is 8.1 dB for 2.4 GHz WLAN bands. RIS has improved the front to back ratio and minimize the back radiation of CP-PIFA. Therefore the CP-PIFA is useful for wireless application such as Bluetooth and the 5G mobile application.

REFERENCES

1. X.-Z. Lai, Z.-M. Xie, X.-L. Cen, and Z. Zheng, “A novel technique for broadband circular polarized pifa and diversity pifa systems,” *Progress In Electromagnetics Research*, vol. 142, pp. 41–55, 2013.
2. C. Y. Chiu, K. M. Shum, and C. H. Chan, “A tunable via-patch loaded pifa with size reduction,” *IEEE transactions on antennas and propagation*, vol. 55, no. 1, pp. 65–71, 2007.
3. N. L. Bohannon and J. T. Bernhard, “Design guidelines using characteristic mode theory for improving the bandwidth of pifas,” *IEEE Transactions on Antennas and Propagation*, vol. 63, no. 2, pp. 459– 465, 2014.
4. H. Wong, K. K. So, K. B. Ng, K. M. Luk, C. H. Chan, and Q. Xue, “Virtually shorted patch antenna for circular polarization,” *IEEE Antennas and Wireless Propagation Letters*, vol. 9, pp. 1213–1216, 2010.
5. K. Agarwal, A. Alphonse et al., "Compact asymmetric-cross slotted microstrip antenna on reactive impedance surface," in 2012 *IEEE AsiaPacific Conference on Antennas and Propagation. I*EEE, 2012, pp. 51–52.
6. Y. Dong, H. Toyao, and T. Itoh, “Compact circularly-polarized patch antenna loaded with metamaterial structures,” *IEEE transactions on antennas and propagation*, vol. 59, no. 11, pp. 4329–4333, 2011.
7. K. Agarwal, A. Alphonse et al., "Design of compact circularly polarized microstrip antennas using meta-surfaces," in 2013 *European Microwave Conference. IEEE*, 2013, pp. 1067–1070.
8. N. Jeevanandham, K. Agarwal, A. Alphonse et al., "Dual-band circularly polarized hexagonal-slot antenna," in 2012 9th *European Radar Conference. IEEE*, 2012, pp. 508–511.
9. Y. Yao, X. Wang, X. Chen, J. Yu, and S. Liu, "Novel diversity/Mimo pifa antenna with broadband circular polarization for multimode satellite navigation," *IEEE Antennas and Wireless Propagation Letters*, vol. 11, pp. 65–68, 2012.
10. A. Motevasselian and W. G. Whittow, "Patch size reduction of rectangular microstrip antennas using a cuboid ridge," *IET Microwaves, Antennas & Propagation*, vol. 9, no. 15, pp. 1727–1732, 2015.
11. L. Bernard, G. Chartier, and R. Sauleau, "Wideband circularly polarized patch antennas on reactive impedance substrates," *IEEE Antennas and Wireless Propagation Letters*, vol. 10, pp. 1015–1018, 2011.
12. D. Chandu, R. K. Barik, and S. Karthikeyan, "Triple-band circularly polarized antenna on a two-layered high impedance surface with two in-phase reflection bands," in 2017 47th *European Microwave Conference (EuMC). IEEE*, 2017, pp. 600–603.
13. K. Agarwal, A. Alphonse et al., "Wideband circularly polarized AMC reflector backed aperture antenna," *IEEE Transactions on antennas and propagation, vol. 61,* no. 3, pp. 1456–1461, 2012.
14. J. Chatterjee, A. Mohan, and V. Dixit, "Broadband circularly polarized h shaped patch antenna using reactive impedance surface," *IEEE Antennas and Wireless Propagation Letters, vol. 17, no.* 4, pp. 625–628, 2018.
15. S. Jagtap, A. Chaudhuri, N. Chaskar, S. Kharche, and R. K. Gupta, “A wideband microstrip array design using ris and prs layers,” *IEEE Antennas and Wireless Propagation Letters,* vol. 17, no. 3, pp. 509–512, 2018.
16. S. Nelaturi and N. V. S. N. Sarma, "A compact microstrip patch antenna based on metamaterials for wi-fi and WiMAX applications," *Journal of Electromagnetic Engineering and Science,* vol. 18, no. 3, pp. 182–187, 2018.
17. G. Samanta and S. R. Bhadra Chaudhuri, “Design of a compact cp antenna with enhanced bandwidth using a novel hexagonal ring based reactive impedance substrate,” *Progress In Electromagnetics Research*, vol. 69, pp. 115–125, 2018.
18. Z. Zhang, W. Chen, J. Fu, P. Li, B. Lv, and Z. Wang, “Circularly polarized patch array antenna based on reactive impedance surface,” *IET Microwaves, Antennas & Propagation,* vol. 12, no. 14, pp. 2213–2217, 2018.
19. S. X. Ta and I. Park, “Low-profile broadband circularly polarized patch antenna using metasurface,” *IEEE Transactions on Antennas and Propagation*, vol. 63, no. 12, pp. 5929–5934, 2015.

AUTHORS PROFILE

Tejaswi Jadhav is presently working as Lecturer in Electronics at Government Residence Women Polytechnic Tasgaon, Maharashtra, India. She has received her Bachelor in Engineering degree in Electronics and Communication discipline from Shivaji University, India. She is completed her Master's Degree in Electronics and currently perusing PhD in Electronics from Walchand college of Engineering, Sangli, Maharashtra, India. She has 10 years of Academic Experience. She is Life time member of ISTE. Her research area includes Communication and Microwave.

Prof (Mrs.) Shraddha Deshpande is presently working as Professor in Walchand college of Engineering, Sangli, Maharashtra, India. She joined as Lecturer in 1986 in Department of Electronics Engineering. She has received Ph. D. from IIT Bombay, Mumbai in 2010. Her areas of interest are Control systems, Artificial Neural Networks and Optimization Techniques. Currently five research scholars are working under her guidance.