

RESEARCH ARTICLE



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Broadband circular polarized patch antenna with harmonic suppression

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Abstract

Background/Objectives: To develop Circular Polarized (CP) patch antenna with improved bandwidth and harmonic suppression for RF energy harvesting system. **Methods/Statistical analysis:** A $\lambda/4$ resonator is introduced and coupled in proximity to the radiating patch for bandwidth enhancement and high order harmonic suppression. Compared with other dual-resonance patch antennas, the proposed antenna has attractive low-profile property and simple structure. The CP can be achieved by putting arc shape slits at edge of circular patch. The structure, working principle and results we are described. **Findings/Applications:** The operating bandwidth is from 1.68 GHz to 2.95 GHz (52.91%) with a reflection coefficient less than -10 dB with Axial Ratio bandwidth of 550MHz (2.21 GHz -2.76 GHz) while harmonic suppression over wide frequency range from 1 to 12 GHz is achieved. The experimental and simulated results is good matching except some slight variation. **Novelty/Applications:** New techniques for both bandwidth enhanced and harmonic suppression and up to 4th higher order harmonics has been suppressed. Proposed structure offers wideband CP Antenna with harmonic suppression.

Keywords: RF energy harvesting; microstrip patch antenna; harmonic suppression; circular polarization

1 Introduction

With the development of antenna technology, one of the focusing issues nowadays is integrating antennas and filters. Suppressing the wideband high order harmonic attracts more and more researchers' attention. Integrating filter at input front end of antenna is the common method to suppress high order harmonics⁽¹⁾. Applying filters can contribute to other issues such as increasing the size, weight, and cost of the wireless device. In this way, some alternative solutions that do not increase cost or complexity for the device can be attractive. Thus, solutions that use the antenna itself to filter these higher-order modes become interesting^(2,3).

Several studies are being developed for design designing antennas able to attenuate or suppress unwanted frequencies. To suppress the second and third harmonics a spur-line filter was inserted in the antenna microstrip feed line⁽⁴⁾. Defected ground structures (DGS) was used in patch antenna to suppress higher order harmonics⁽⁵⁻⁸⁾.

Transverse slot orthogonal to the microstrip feedline is introduced as the harmonic suppression unit⁽⁹⁾. To improve the both bandwidth and the harmonic suppression long stub used⁽¹⁰⁾. A pair of $\lambda/4$ stepped-impedance resonators (SIRs) in each port which is to enhance bandwidth and suppress harmonics used⁽¹¹⁾.

In RF Energy Harvesting System due to Linear polarization of antenna, it does not get maximum ambient RF energy. Thus using Circular Polarized (CP) antenna, we can avoid wrong polarization which results collect maximum RF energy^(12–14). A circularly polarized (CP) microstrip antenna with embedded slots is designed which efficiently attains harmonics suppression⁽¹⁵⁾. CP Antennas offers lots of applications in modern-day wireless communication^(16,17).

The antenna structures in^(2–14), with higher order mode suppression. However, these antennas have very low bandwidth; some antenna cannot be circular polarized.

In this work, we design a new antenna with harmonic rejection operate at 2.45 GHz. The harmonic rejection has been accomplished by using $\lambda/4$ resonator with partial gnd and a capacitive feed line. This structure can achieve harmonic suppression function so that harmonics up to 4th order can be suppressed. The measured results show good agreement with the simulated results

2 Material and Methods

2.1 Geometry and design

The structure of the proposed CP patch antenna is shown in Figure 1. This antenna is designed on a substrate with a relative permittivity of 4.4 and thickness of $h = 1.5$ mm. The size of the resonator is (L_r) that of the $\lambda/4$ resonator is chosen. The radius of circular patch (a) is calculated by below equations⁽¹⁸⁾.

$$\text{Lambda } (\lambda) = c/f = 3 \times 10^8 / 2.4 \times 10^9$$

$$(\lambda) = 125\text{mm at } 2.4\text{GHz}$$

The radius of circular patch is given by,

$$a = F \left\{ 1 + \frac{2h}{\pi F \epsilon_r} \left[\ln \left(\frac{\pi F}{2h} \right) + 1.7726 \right] \right\}^{-1/2} \quad (1)$$

Where,

$$F = \frac{8.791 \times 10^9}{f_r \sqrt{\epsilon_r}}; f_r \text{ in GHz, } h \text{ in mm} \quad (2)$$

$$Z_0 = \frac{60}{\sqrt{\epsilon_r}} \ln \left(8 \left(\frac{H}{W_f} \right) + 0.25 \left(\frac{W_f}{H} \right) \right) \quad (3)$$

We get $W_f = 2.8\text{mm}$

Feed and resonant length is given by

Feed length (L_{50}) = $\lambda/4 \times \sqrt{4.4}$

Resonant length (L_r) = $\lambda/4$

$L_s = L + 2 \times 6h = 28.4 + 2 \times 6 \times 1.6 = 49\text{mm}$

$W_s = W + 2 \times 6h = 38 + 2 \times 6 \times 1.6 = 59\text{mm}$

For the purpose of bandwidth enhancement, the resonance of the $\lambda/4$ resonator with partial gnd, which is close to the TM₁₀ resonance of the patch antenna, is introduced. This can efficiently improve the operating bandwidth. In addition, to achieve a better impedance matching, the partial gnd plane is used as shown in [Figure 1]. The length of the resonator can be tuned to suppress the certain high-order resonance of the patch antenna. Finally, by optimization, the size parameters of this proposed CP patch antenna are as shown in Table 1. [Figure 2] shows traditional CP antenna and [Figure 3] shows proposed CP antenna

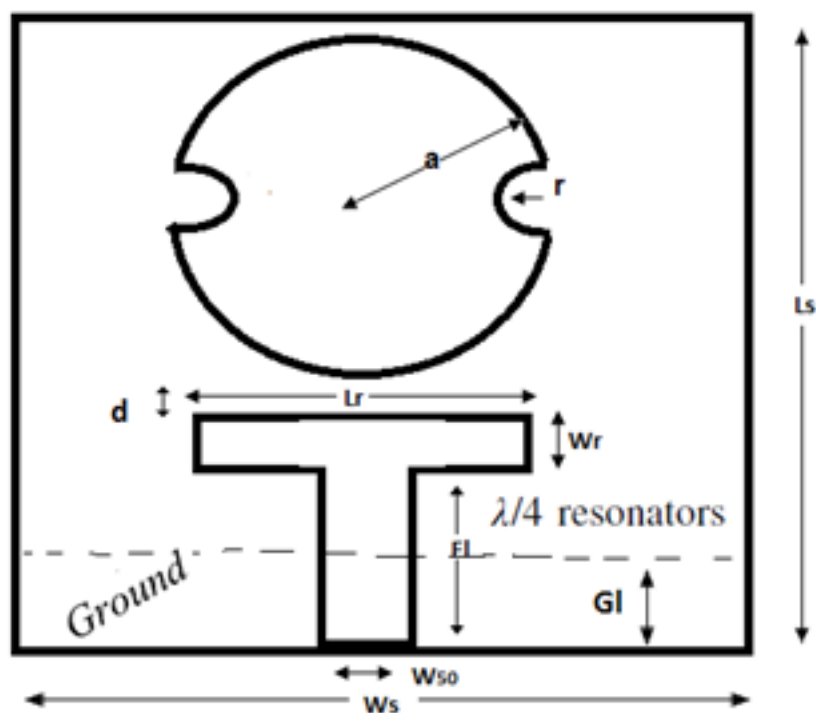


Fig 1. Geometry of the proposed wideband CP antenna

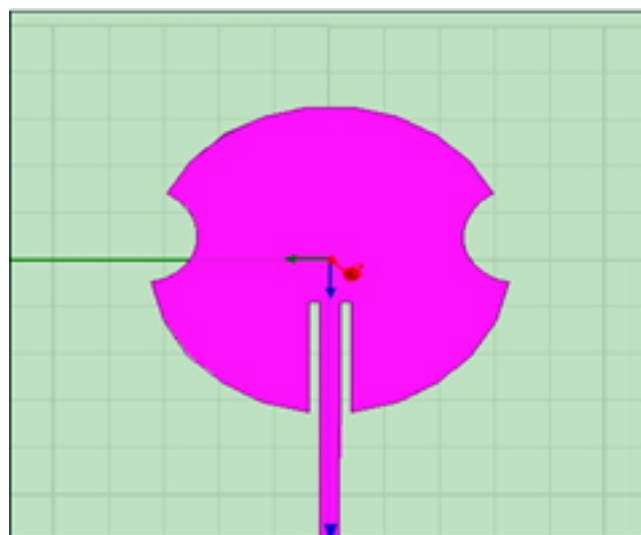


Fig 2. Traditional circular polarized patch Antenna

Table 1. Optimized dimension of proposed CP antenna

Parameters	Ls	Ws	a	Lr	Wr
Dimensions (mm)	56.0	56.0	14.5	29.0	1.0
Parameters	Fl	W50	d	Gl	r
Dimensions (mm)	18.5	2.8	1.5	12.0	5.0

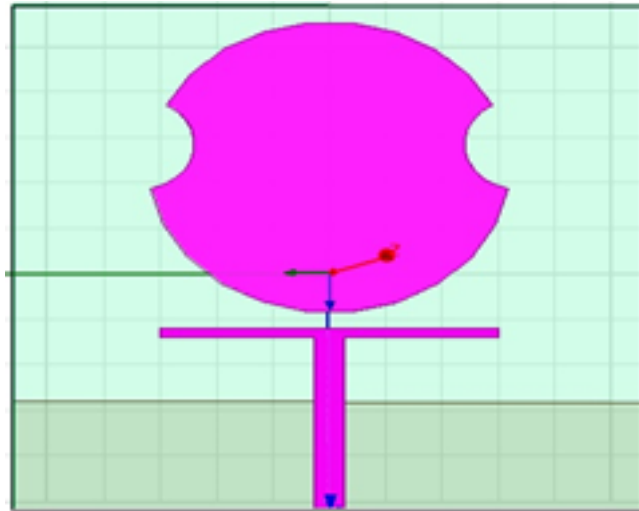


Fig 3. Proposed circular polarized antenna

3 Results and Discussion

3.1 Effect of simulated return loss of the proposed CP antenna and traditional CP antenna

The Simulation results of proposed CP antenna has been carried out in HFSS. [Figure 4] presents the simulated reflection coefficient of the proposed CP antenna, the traditional CP antenna after introducing the capacitive coupling feed, high-order resonant modes at 5.0GHz, 7.1GHz, 9.5GHz, and 11.0 GHz are significantly suppressed.

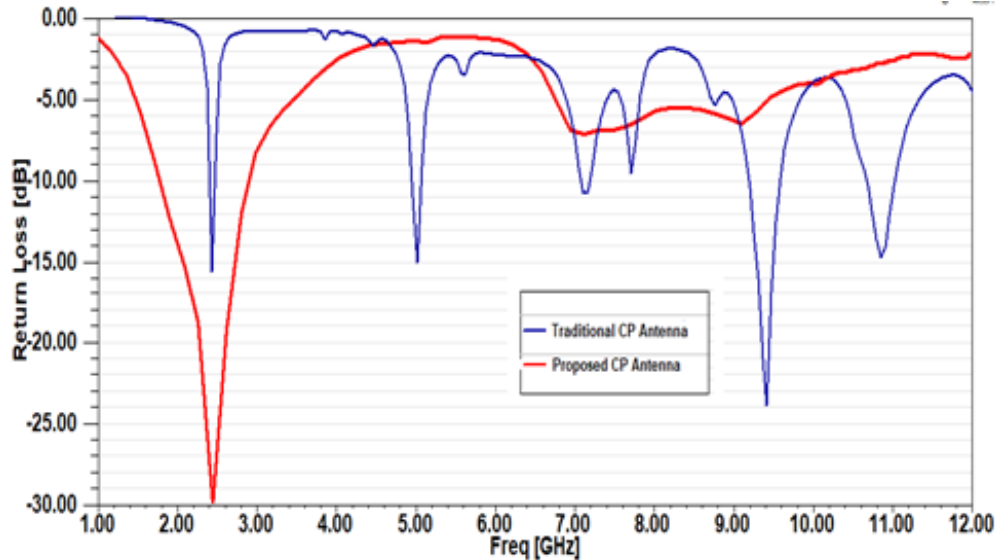


Fig 4. Simulated return loss of the proposed CP antenna and traditional CP antenna

3.2 Effect of coupling gap (d) on return loss

Meanwhile, effect of coupling gap (d) can be observed in [Figure 5], which indicates that the gap is important parameter of the proposed CP patch antenna for wider bandwidth. Comparing the results of coupling gap $d = 1.0\text{mm}$, 1.5mm and 2.0 mm . The optimum gap $d = 1.5\text{mm}$ (blue graph), we got maximum bandwidth in proposed CP antenna.

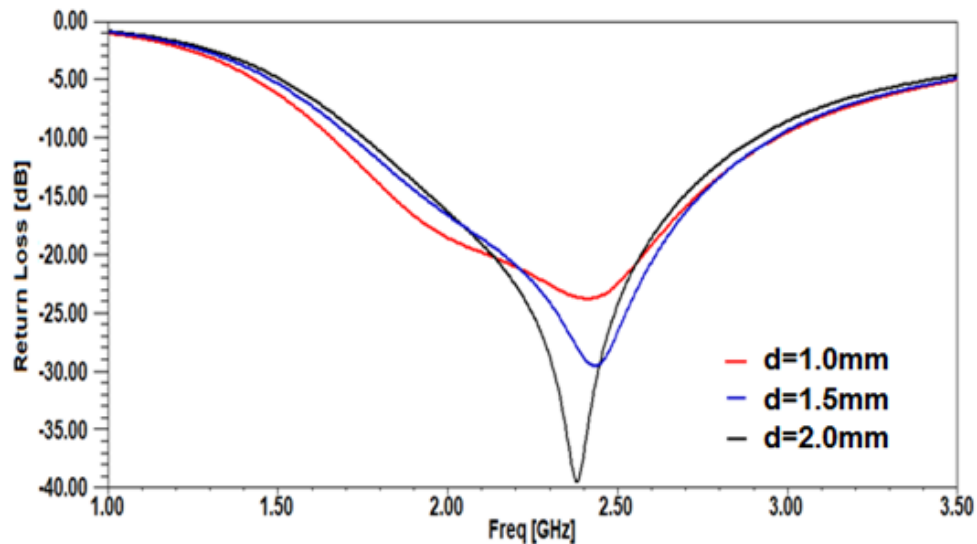


Fig 5. Effect of coupling gap (d) on return loss

3.3 Effect of resonator length (Lr) on return loss

The effect of resonator length (Lr) can be observed in [Figure 6], which indicates that the resonator length is important parameter of the proposed CP patch antenna for controlling resonating frequency. If the resonator length is increasing, then freq shift to at lower side around 2.3GHz (blue graph) and decreasing resonant length the freq shift to higher side at 2.6GHz (green graph). The optimized resonator length Lr = 29mm (red graph), we got desired freq 2.45GHz.

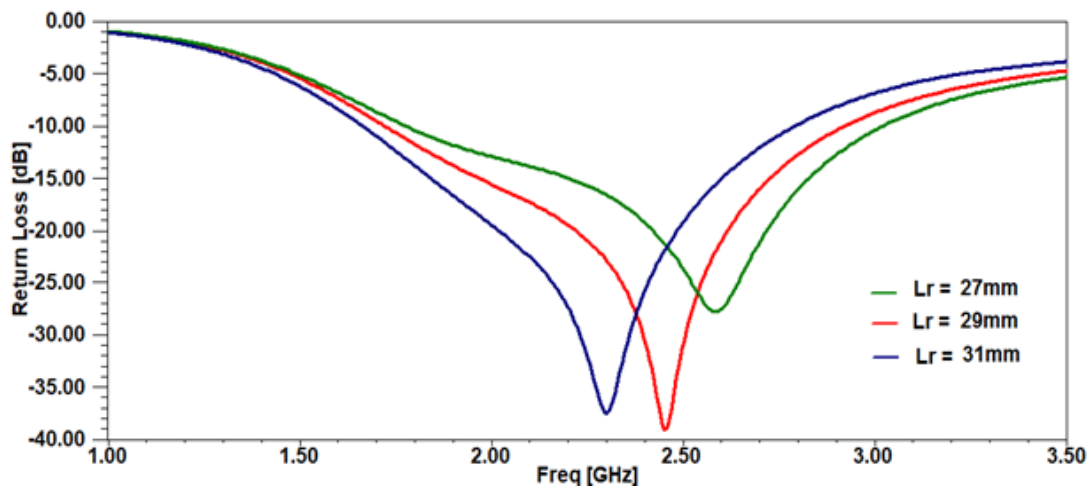


Fig 6. Effect of resonator length (Lr) on Return Loss

3.4 Effect of radius of circular patch (a) on return loss

The effect of radius of circular patch (a) can be observed in [Figure 7], which indicates that the radius of circular patch is important parameter of the proposed CP patch antenna for better impedance matching. If the radius of antenna is increasing, then the return loss is -22.5 dB at 2.40GHz (blue graph) and decreasing radius of antenna the return loss is -36.5dB at 2.5GHz (green graph). The optimized radius of antenna a = 14.5mm (red graph), we got freq minimum return loss -39.3 dB at 2.45GHz.

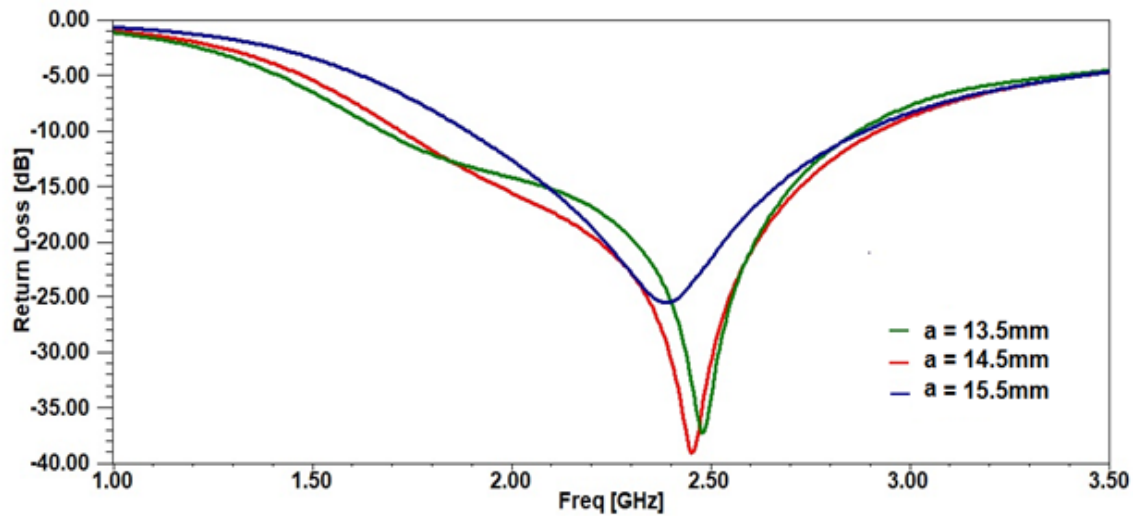


Fig 7. Effect of radius of circular patch (a) on return loss

3.5 VSWR of Proposed CP Antenna

[Figure 8] VSWR of Proposed CP Antenna. The Simulated bandwidth of the proposed CP antenna in terms of VSWR is 1.68-2.95 GHz (52.91%).

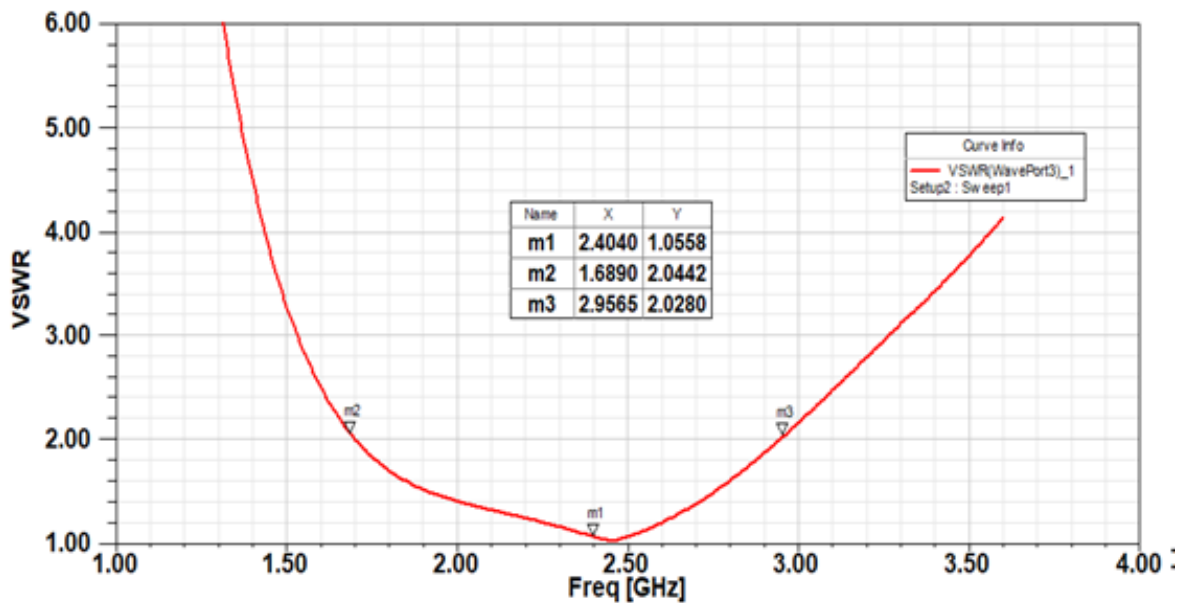


Fig 8. VSWR of proposed CP antenna

3.6 Radiation pattern E and H plane of proposed CP antenna

[Figure 9] it is observed that the radiation patterns of proposed CP antenna are bidirectional in E-plane & omnidirectional in H plane at freq 2.45GHz. It can be observed that the gain of the proposed CP antenna is 2.5 dBi at 2.45 GHz.

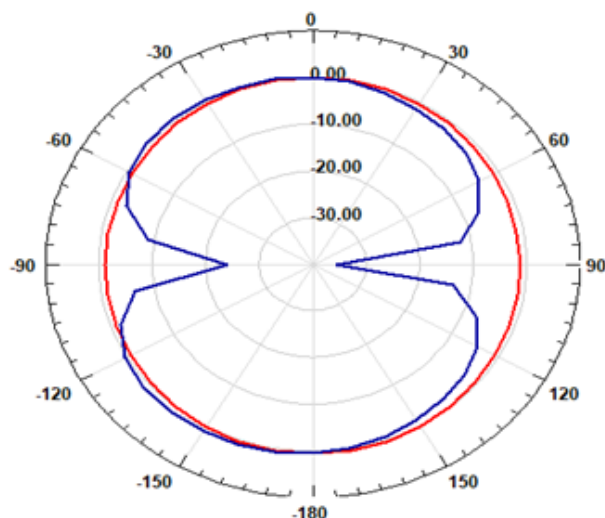
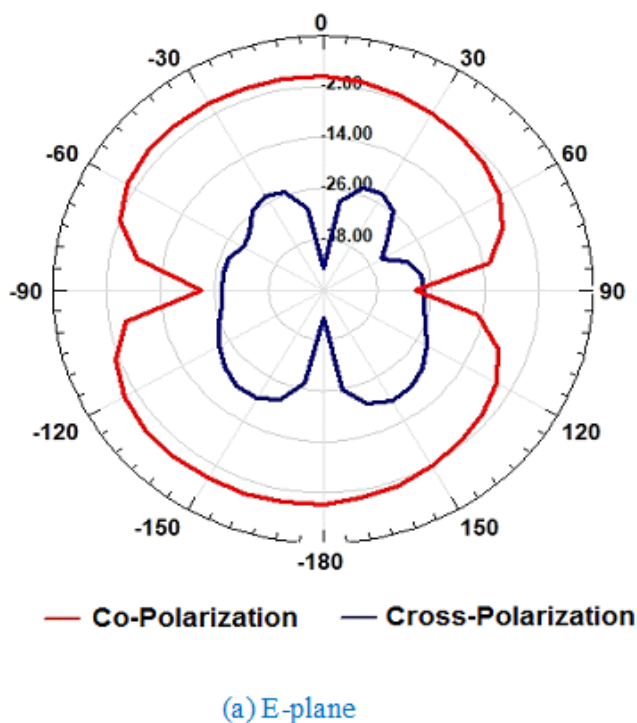


Fig 9. Radiation pattern E and H plane of proposed CP antenna

3.7 Co and cross polarization in E and H plane of proposed CP antenna

[Figure 10] The simulated co- and cross-polarized radiation patterns of proposed CP antenna in E-plane & H-plane at the resonant frequency 2.45 GHz are plotted in [Figure 10]. It shows that the CP antenna has a bidirectional radiation pattern in E-plane and omnidirectional in H-plane [Figure 10a], illustrates simulated co- and cross-polarized radiation patterns of proposed antenna in E-plane, at the resonant frequency 2.45 GHz. The cross-polarization level is more than 40 dB below than the co-polarization level. [Figure 10b], illustrates simulated co- and cross-polarized radiation patterns of proposed antenna in H-plane, at the resonant frequency 2.45 GHz. The cross-polarization level is more than 42 dB below than the co-polarization level.



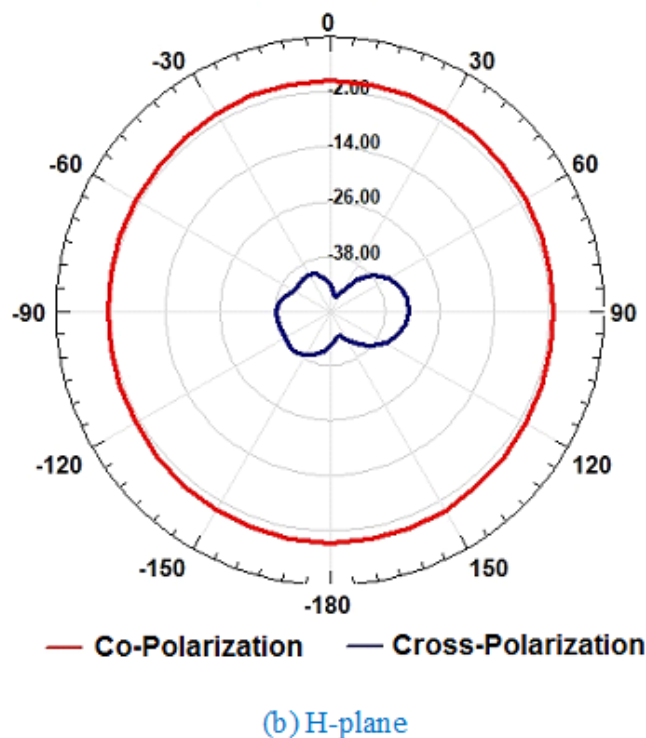


Fig 10. Co-Cross polarization of proposed CP antenna at 2.45GHz(a) E-plane and (b) H-plane.

3.8 Axial ratio of proposed CP antenna

[Figure 11] The proposed CP antenna has axial ratio (AR) bandwidth of 550 MHz i.e. 22.91% covering the frequency range of (2.21GHz - 2.76GHz). The antenna has a good performance in term of AR.

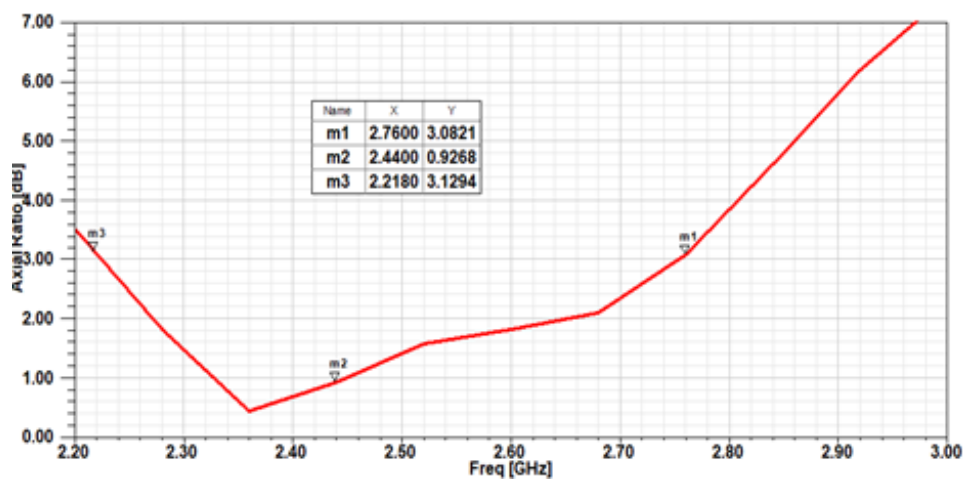


Fig 11. Axial ratio of proposed CP antenna

3.9 Surface current distributions

The current distribution of the Proposed Vs. traditional CP antenna at 5.0 GHz and 9.5GHz is presented in [Figure 12]. Red colour indicates maximum current along the edge of radiating patch. This means that in proposed CP antenna there is no second

and third harmonics present.

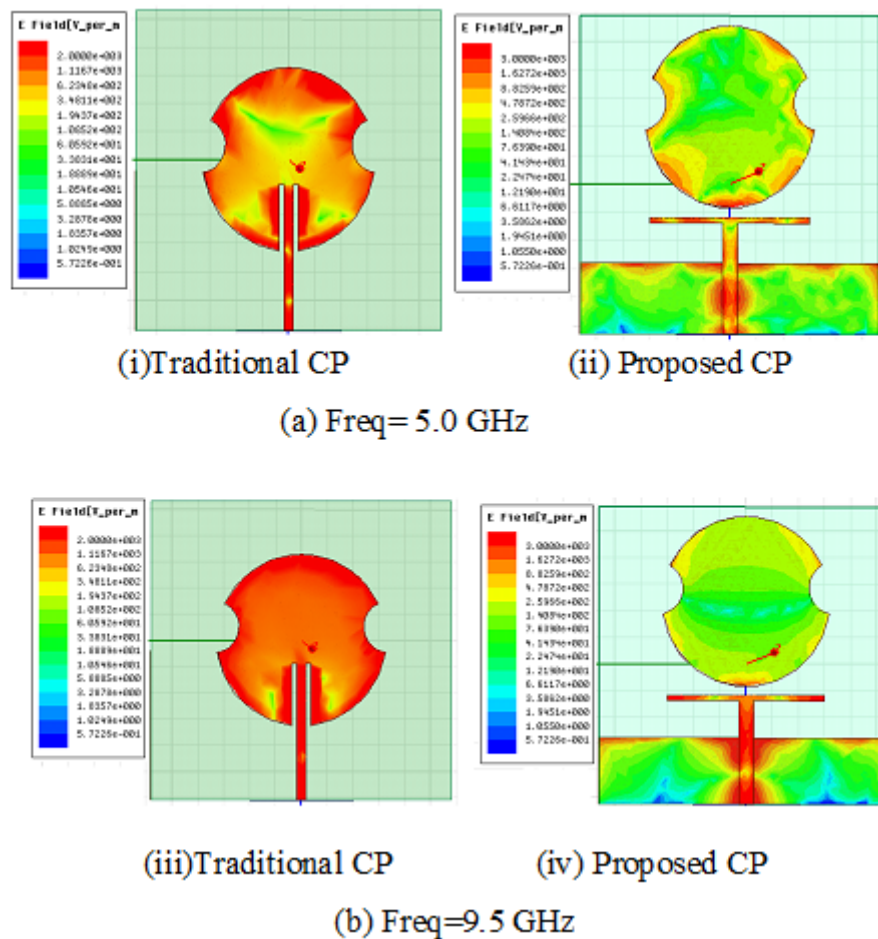


Fig 12. Surface 3 current distributions (a) 5.0GHz (b) 9.5GHz

3.10 Comparison Table

As seen the [Table 2], To improve the performance of this antenna, a pair of $\lambda/4$ microstrip line resonators is introduced. Traditional CP patch antenna, and proposed CP patch antenna are described. It concludes that proposed CP patch antenna technique's both bandwidth & harmonics suppression of antenna are improved.

Table 2. Comparison table of traditional Vs proposed CP antenna

Sr. No.	Results	Freq (GHz)	Return Loss (dB)	VSWR	BW (MHz)	Gain (dB)
1.	Traditional CP Patch Antenna	2.45	-15.60	1.39	70	4.6
2.	Proposed CP Antenna	2.44	-29.87	1.06	1260	2.5

3.11 Measurement results

The Proposed CP Patch antenna has been fabricated and tested using VNA. The Measurement results of proposed circular patch antenna getting bandwidth of 1220MHz at freq 2.47GHz. It shows there is harmonic reduction through entire freq band form 1-10GHz. The simulated Vs measured return loss proposed circular patch antenna has been shown in [Figure 13].

The Measured return loss characteristics of the proposed patch antenna in [Figure 10], indicated that the return loss is below -10 dB in the operating freq band from 1.94GHz–3.16GHz and fractional percentage BW is around 50.83 %.

[Figure 14] shows fabricated Prototype Proposed CP Patch antenna.

Comparison of the proposed CP antenna with reported state of art designs are listed in [Table 3]. The proposed CP antenna offers large bandwidth as compared to all other antennas reported table in ⁽¹⁻⁵⁾ ⁽⁹⁾ ⁽¹¹⁾ ⁽¹²⁾ & ⁽¹⁶⁾. The proposed antenna offers Circular Polarization (CP) compared to antenna reported table in ⁽¹⁻⁵⁾. Also, upto 4th higher order harmonic suppression achieved in proposed antenna.

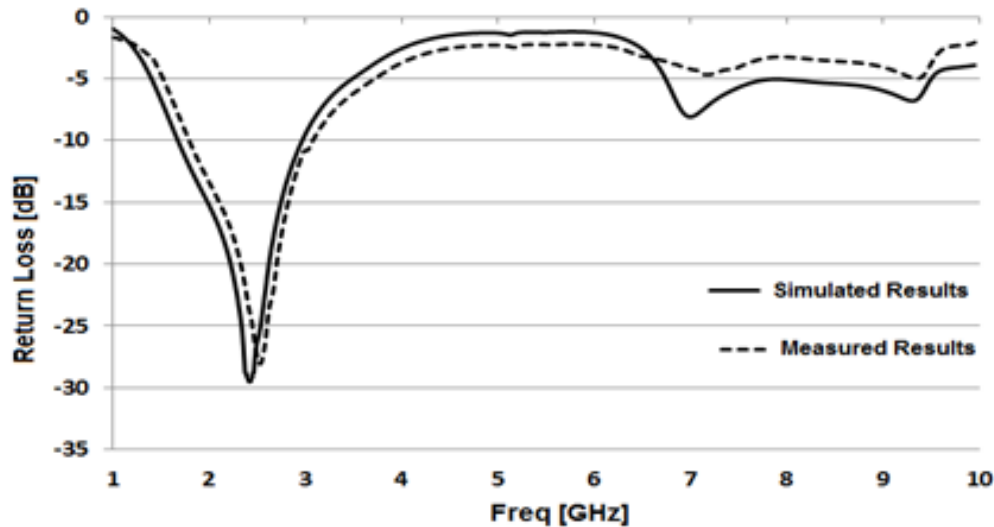
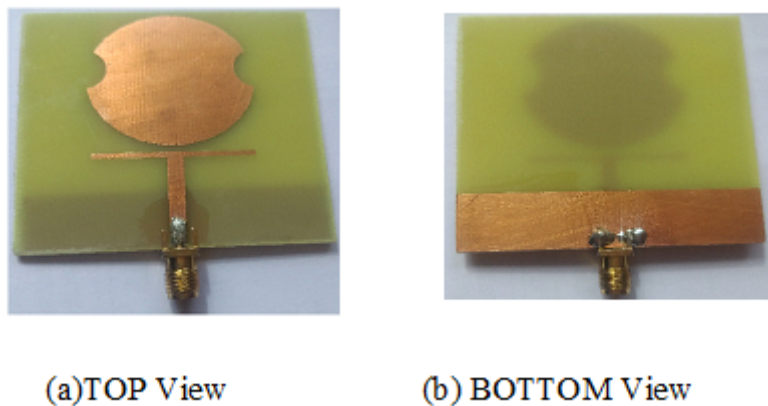


Fig 13. Simulated Vs Measured Return loss of proposed CP antenna



(a) TOP View

(b) BOTTOM View

Fig 14. Fabricated prototype proposed CP patch antenna

Table 3. Comparison of proposed CP antenna with other state of art designs

Year and Reference	No. of higher order modes Suppressed	Fundamental Frequency (GHz)	BW (MHz)	Polarization	Techniques used
2020 ⁽¹⁾	2	2.4	100	Linear	Defected Ground Structure(DGS)
2019 ⁽²⁾	3	2.4	80	Linear	DGS
2019 ⁽³⁾	2	3.5	90	Linear	Defected Microstrip Structure (DMS)

Continued on next page

Table 3 continued

2017 ⁽⁴⁾	3	2.4	80	Linear	Spur-Line Filter
2018 ⁽⁵⁾	2	2.4	80	Linear	DGS
2018 ⁽⁹⁾	3	2.4	500	Linear	Slotted
2018 ⁽¹¹⁾	2	3.5	200	Circular	$\lambda/4$ Stepped-Impedance resonators (SIRs)
2018 ⁽¹²⁾	2	2.4	300	Circular	Slot and stubs multilayer
2018 ⁽¹⁶⁾	3	2.4	90	Circular	Slot with differential feed
Proposed work	4	2.4	1260	Circular	$\lambda/4$ resonator with capacitive feed and partial gnd

4 Conclusion

A Circular Polarized microstrip-fed patch antenna with improved bandwidth and harmonic suppression has been proposed. Compared with the conventional microstrip-fed antenna, a $\lambda/4$ resonator and partial gnd are introduced, respectively, to enhance the impedance bandwidth and harmonic suppression. The bandwidth of proposed CP antenna around 1260MHz (1.69-2.95GHz) is 18 times higher than traditional CP antenna. The proposed CP antenna has axial ratio (AR) bandwidth of 550 MHz i.e. 22.91% covering the frequency range of (2.21GHz - 2.76GHz). The experimental and simulated results offer good matching except some slight variation.

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