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A Compact 5.3 GHz Circular Polarized Patch Rectenna with CSRR Inspired Ground Plane

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Abstract— In this paper, a compact size metamaterials loaded circular microstrip patch antenna is presented. A complementary split ring resonator is loaded in the ground plane of circular microstrip patch antenna. The unloaded circular microstrip patch antenna resonates at 5.5 GHz, whereas after loading it with complementary split ring resonator, the same antenna resonates near 5.3GHz with reduced size. The effective footprint of the antenna is reduced by nearly 25% compared to the conventional patch antenna. The gain of the metamaterials loaded antenna structure is 3.5 dB. The antenna provides a cross polarization isolation of about ≥15 dB at 5.3 GHz. The antenna also achieves wider axial ratio beam width of 75.5 degrees.

Keyword: *Complementary split ring resonators; Microstrip Patch; Metamaterials; Radiation Pattern.*

I INTRODUCTION

Microstrip antennas are widely used in wireless devices due to its low cost, compact size and ease of fabrication. With increase in demand wireless network, huge devices are deployed for remote sensing applications, biometric applications and other military application in which devices are highly dynamic in the deployed environment. This demands use of circularly polarized (CP) antenna in place of linear antennas. In general, circularly polarized antenna profile is much bigger than conventional linear antenna due to additional mechanism need to induce radiations. These CP antennas are limited by axial ratio beamwidth characteristics which limits its applications. Lots of researches has been carried in circularly polarized antenna to improve axial ratio beamwidth. In [1] by increasing the spacing between the crossed dipoles, the beamwidth is increased and in [2], by extending surface waves to ground plane, the beamwidth is enhanced. In [3], Pin diodes are used to enhance beamwidth by controlling the shunt inductive load. However, the antenna utilized dual feed which increase the antenna profile. Stubs [4] and parasitic patches [5] are also used to perturb the surface current field over the radiating patch and thereby increasing the beamwidth of the antenna. In [6] rhombus shaped slot and an E-shaped slot [7] are etched in the radiating patch to achieve CP radiation. However, the antennas suffer from poor axial ratio beamwidth. Dual slot etched on the radiating patch at its periphery to excite CP radiation is presented in [8]. Metamaterials structures are used to enhance the antenna performances in recent days. In [9] complementary split ring resonators are used to decrease the antenna profile significantly. Most of the antenna CP presented focus either on antenna profile or the axial ratio beamwidth of the antenna. Hence in present study both the antenna profile and the axial ratio beamwidth is studied. A compact CP antenna loaded with complementary split ring resonators (CSRR). The conventional antenna design is studied initially and Later CSRR loading are incorporated in the conventional design to check the performances of the antenna. The proposed model is simulated using HFSS simulator and its performance are compared with other conventional CP antenna models.

II ANTENNA DESIGN PROCEDURE

A. Circular patch antenna

Theoretically the radiating patch of the antenna can be of any shape. For ease of design complexity and fabrication cost, in this work a circular shape is chosen. In general circular patch antenna suffers from narrow bandwidth and poor gain constraints which can be mitigated by use of additional slot in radiating patch (to improve bandwidth) and use of circular patch arrays (to improve gain). In this design, the radii of the circular patch is calculated from equation (1) given below.

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

Where $F = \frac{8.791\times10^9}{F_r\sqrt{\varepsilon_r}}$

a= circular patch radius, F_r= Resonant Frequency; ε_r= relative permittivity and h= substrate height.

In this design a low cost roger TMM3 substrate having a thickness of 0.381mm is chosen. The material has a relative permittivity of 3.27 with loss tangent of 0.002. Based on the substrate thickness and material permittivity the radius of the circular patch (R) is calculated as 7.9mm using equation (1). Figure 1 shows geometry of the circular patch antenna. The length and width of the substrate is chosen to be 40mm x 40mm with a thickness of 1.6mm as shown below. A quarter wave transformer is used to balance the impedance between radiating patch and the input port.

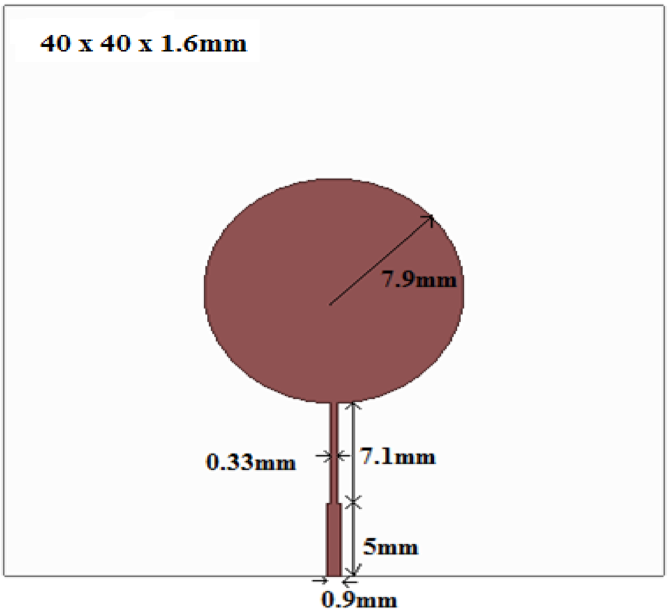

Fig. 1. Geometry of circular patch antenna

B. Circularly polarized patch antenna

In general, the circular patch antenna gives linear polarization. In order to have circular polarization, it is necessary to induce 90-degree phase delay between the electric and magnetic field components. For that two slots separated by 90 degrees apart is used in the radiating element [8]. Figure 2 shows modified circular patch antenna with slots to generated circular polarized radiation. The antenna gives left hand circular polarization. In

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order to have right hand circular polarization, the mirror image of the geometry in which slot is created in right half of the radiating patch is used.

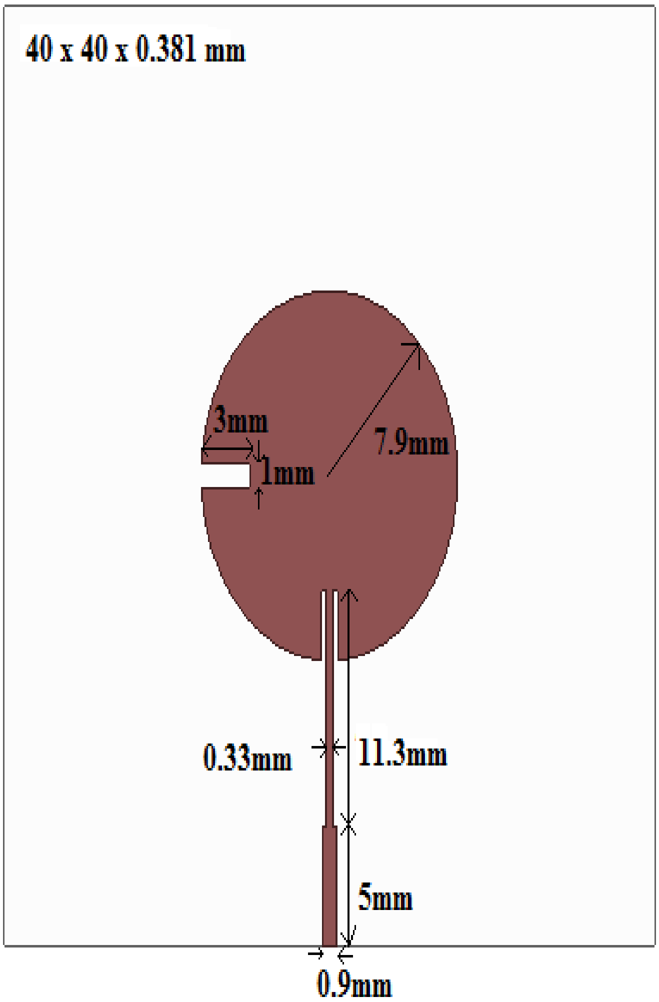


Fig. 2. Circularly polarized antenna [8].

C. Complementary split ring resonators (CSRR)

Circularly polarized (CP) antenna is widely used in miniature devices such as Bluetooth devices, Remote devices where the orientation of the antenna should not affect the performance of the antenna. Hence there is a need for compact CP antenna. One way to reduce the overall size of the antenna is by using Complementary split ring resonators which are planar metamaterials structures that can yield negative value of effective permittivity of a material. The geometry of the Complementary split ring resonators is calculated based on equation given below [10].

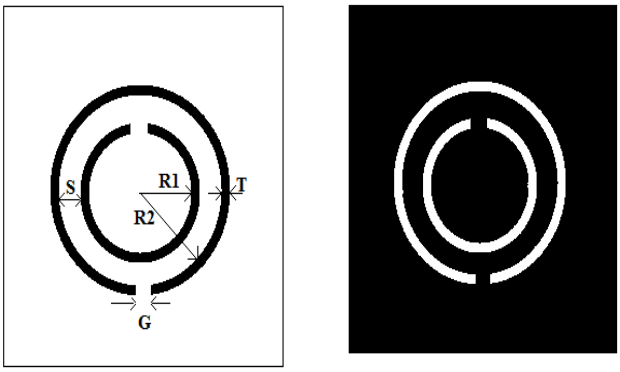
$$n = \frac{1}{kd}cos^{-1}\left[\frac{1}{2S_{21}}(1 - S_{11}^2 + S_{21}^2)\right] \quad (2)$$

$$Z = \sqrt{\frac{(1+S_{11})^2 - S_{21}^2}{(1-S_{11})^2 - S_{21}^2}} \quad (3)$$

$$\varepsilon = \frac{n}{z} \quad (4)$$

$$\mu = nz \quad (5)$$

Where n is the refractive index and z is the wave impedance. For an operating frequency of 5.5GHz the dimension of the Complementary split ring resonators is determined and are shown in Figure 3. The unit cell has a radius of R1= 1.4mm, R2=2.1mm with a spacing between rings S= 0.3 mm, split gap G = 0.8 mm and width T= 0.4 mm.

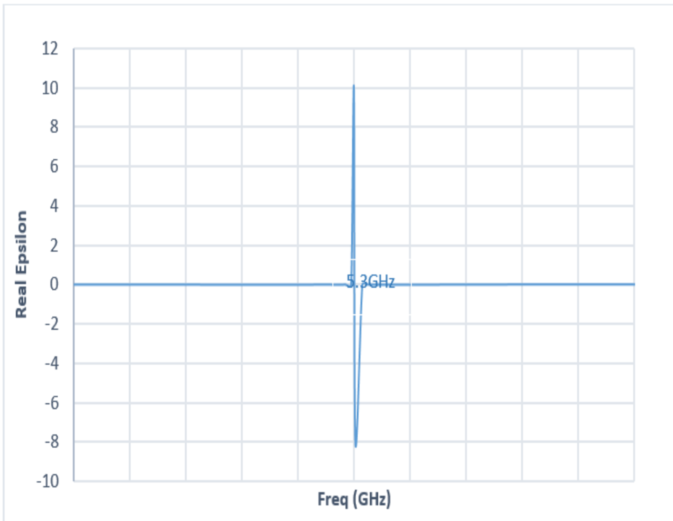


(a) (b)

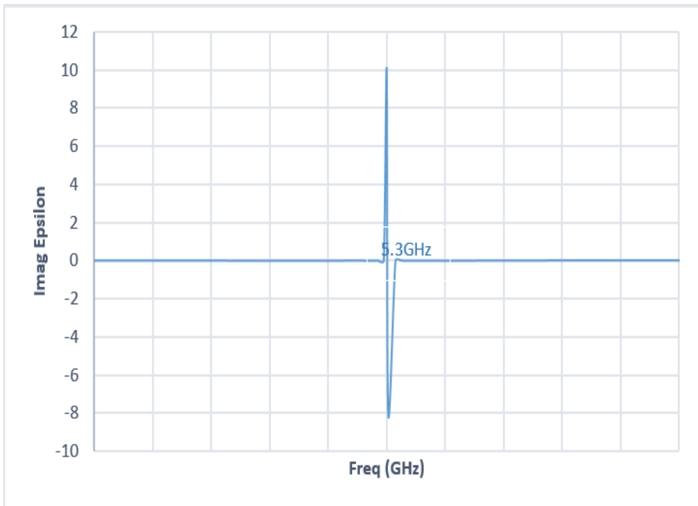
Fig. 3. (a) Split ring resonators (b) Complementary split ring resonators

The performance of the split ring resonator is validated using equation (2) -(7) to check the negative permittivity at operating frequency and are shown in Figure 4.

The CSSR has the advantages of making the patch antenna to high efficiency, electrically small and tunable. And hence its suitable for wireless applications and RF energy applications.



(a)



(b)

Fig. 4. Effective permittivity of spilt ring resonator.

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D. Proposed circularly polarized antenna with CSRR loadings

In order to reduce the antenna size, the designed CSRR is loaded in the ground plane as shown in Figure 5. The CSRR is loaded at 2mm offset position from the center of the ground plane to induce propagation delay in the surface wave fields for CP radiation.

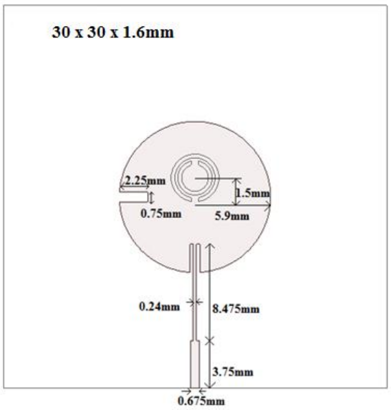


Fig.5. Proposed CP antenna with CSRR load.

III RESULTS AND DISCUSSION

The performances of the antenna are validated using HFSS simulator and are given below. The impedance characteristics of the proposed antenna along with traditional circular patch and CP antenna is shown in Figure 6. It is inferred from Figure 6 that the introduction of slot and CSRR increase the electrical length of the radiating surface and hence shifts the operating frequency towards lower band. The proposed antenna resonates at 5.3 GHz in the ISM band with impedance bandwidth of 120MHz (5.26-5.38GHz).

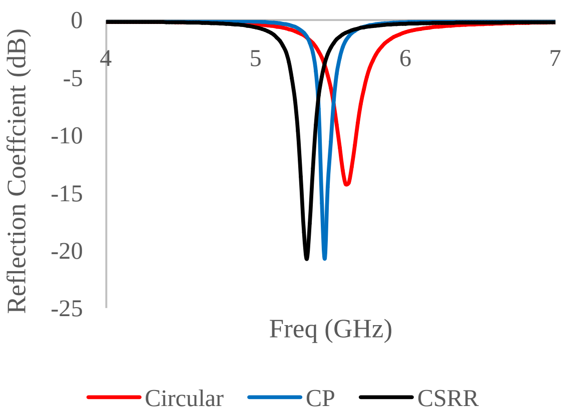
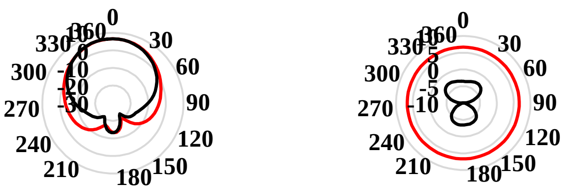


Fig. 6. Reflection Coefficient (dB)

The radiation characteristics of the traditional circular patch is shown in Figure 7.



(a) Elevation Plane (b) Azimuthal Plane

Fig. 7. Radiation pattern of Circular patch.

It is inferred from Figure 7 that circular patch antenna gives unidirectional radiation in elevation plane and omnidirectional pattern in azimuthal plane with a peak gain of 6dBi in the direction of propagation. The radiation characteristics of the circularly polarized patch antenna aong with proposed CSRR loaded CP antenna is shown in Figure 8.

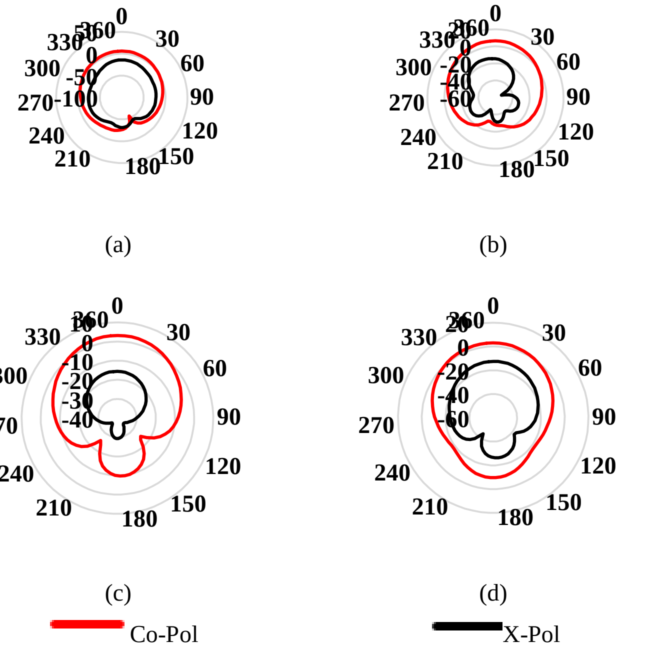


Fig. 8. Radiation pattern (a) CP_E-Plane (b) CP_H-Plane (c) CSRR_E-Plane (d) CSRR_H-Plane

It is inferred from Figure 8, that the CP antenna without CSRR load give a peak gain of 5.85 dBi with cross polarization isolation of >15dB in the operating frequency. Similarly CP antenna with CSRR load gives a peak gain of 3.5dBi with cross polarization isolation of >15dB in the operating frequency. The decrease in frequency is because of bidirectional radiations due to presence of CSRR load in ground plane. It is because of CSRR slot acts as a secondary radiator and hence radiates in other directions. This results in bidirectional radiation pattern. Figure 9 shows axial ratio plot for the proposed CP antenna with CSRR load. The antenna gives wider axial ratio bandwidth (3dB) of 75.4 degree in the resonant frequency. The axial ratio is 1.97

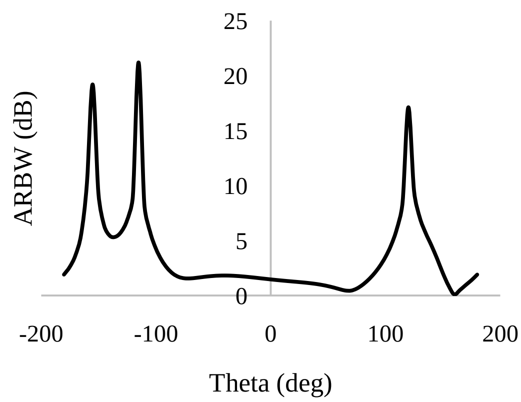


Fig. 9. 3dB axial ratio beamwidth

Performance comparison of proposed antenna with other conventional antenna is shown in Table 1. It is observed that the proposed antenna is compact and gives better axial ratio beamwidth along with sufficient gain in the operating band.

Table.1. Performance comparison of proposed antenna with other conventional antenna

Parameter	**Size (mm)**	**Gain**	**3dB Axial ratio Beamwidth**
[6]	50 x 50 x 1.6	5.16 dB	95 Deg
[7]	40 x 40 x 0.381	5.85 dB	79.8 Deg
Proposed	30 x 30 x 1.6	3.5 dB	75.5 Deg

IV CONCLUSION

In this paper a compact circularly polarized patch antenna loaded with CSRR is presented. The antenna s fabricated on single layer FR4 substrate and are fed by 50 ohm SMA connector. The antenna is designed to operate at 5.3GHz ISM band and gives a peak gain of 3.5dBi with better cross polarization isolation ≥15dB in the operating frequency. Compare to other conventional antenna, the proposed antenna reduces the overall antenna profile by 25%. The antenna also achieves wider axial ratio beam width of 75.5 degree and thus makes it suitable for wireless applications.

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