Progress In Electromagnetics Research M, Vol. 78, 175–184, 2019

Single Feed Circularly Polarized Antenna Loaded with Complementary Split Ring Resonator (CSRR)

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Abstract—In this paper, complementary split ring resonator (CSRR) based single feed rectangular microstrip antennas are designed for circular polarization. In the first antenna design, two CSRRs are loaded on ground, and for the second design, two CSRRs are loaded on patch with identical orientation of meta-resonators in both cases. CSRRs are used to diminish the resonance frequency of the antenna, and thus the antenna size miniaturization can be achieved. Overall dimensions of the two antennas are $(50 \times 50 \times 1.6)\,\mathrm{mm}^3$, and the impedance bandwidth for $S_{11} < -10\,\mathrm{dB}$ exhibits between 2.3 and 2.4 GHz which is useful for wireless communication service. The characteristics of the proposed antennas, i.e., reflection coefficient, axial ratio, gain, and radiation patterns, are observed and compared for the two cases. The proposed two antennas have been designed and simulated using CST Microwave studio 14. The circularly polarized antenna with CSRRs loaded on patch has been fabricated for experimental verification of the simulated results. Measured reflection coefficient, gain, and radiation pattern are in good agreement with the simulated result.

1. INTRODUCTION

Circularly polarized antenna is getting much attention in modern WLAN, satellite and mobile communication. Circularly polarized antenna is considered as better choice than linearly polarized antenna because of more polarization flexibility between transmitter and receiver and reduced fading effect [1]. For compact antenna design single feed CP antenna is always preferred over dual feed configuration as it is free from any additional feeding circuit [2].

Most common techniques of obtaining circular polarization in a single feed patch antenna are either placing a diagonal slot at the centre of the square patch, truncating diagonally opposite corners of the square patch or employing diagonal feed in a nearly square patch [3, 4]. Beside these conventional methods, a pair of stubs or notches on the opposite edges in a square patch [2, 5] and asymmetric U or V shaped slits along the diagonals can produce circular polarization [6]. Miniaturization of patch area up to 1/16 of the conventional patch is achieved by placing an additional complementary split ring resonator (CSRR) loaded metal layer between the patch and ground [7]. In [8] a modified CSRR is embedded on the ground plane to achieve wider bandwidth of the antenna. A four ports concentric square ring MIMO antenna with CSRRs etched from the ground plane is presented for higher isolation between identical polarized elements [9]. Dual and multiband band antennas for WiMAX, GSM and WLAN applications have been proposed using CSRRs loaded on the patch and the ground plane [10, 11]. In [12] a dual band RHCP antenna having a stack radiating patch accompanied with CSRRs, tuning stubs and notches is shown. Dual and triple band antennas with varying polarization and a novel CP antenna using two identical CSRRs loaded on rectangular patch have been proposed in [13]. An implantable CP antenna in the ISM band with four C-shaped slots and a CSRR loaded at the centre

Received 5 September 2018, Accepted 13 January 2019, Scheduled 11 February 2019
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is presented for real time glucose monitoring [14]. In [15] a circularly polarized compact wideband aperture coupled microstrip antenna loaded with metamaterial structure is reported.

In this paper, two designs of single feed rectangular microstrip antenna (RMSA) are demonstrated for circular polarization. In the first design, two circular CSRRs are embedded on the ground plane of the antenna (RMSA), and for the second design, CSRRs are loaded on the radiating patch. Both antennas are designed and simulated using CST Microwave studio 14 [16]. Section 2 presents the basic metamaterial unit and its circuit model. Design configurations of the two antennas are represented in Section 3. Simulation results are discussed in Section 4. Measured results are shown in Section 5 for comparison with simulated results.

2. CSRR ELEMENT

The basic properties of metamaterials are discussed in [17]. Pendry et al. first proposed an artificial μ-negative structure that consists of array of split ring resonators (SRRs) [18], and later Smith et al. experimentally confirmed negative permeability of SRR unit [19]. SRR behaves as a magnetic dipole when it is excited by an axial magnetic field. The complementary split ring resonator (CSRR) is complementary dual element SRR behaving as an electric dipole. Both SRR and CSRR can be considered as parallel L-C resonant circuit which has same resonance frequency, i.e., $f = 1/2\pi\sqrt{\mathrm{LC}}$. Equivalent circuit models of SRR and its dual part CSRR have already been shown in [20]. Fig. 1 shows the unit element of CSRR and its circuit model.

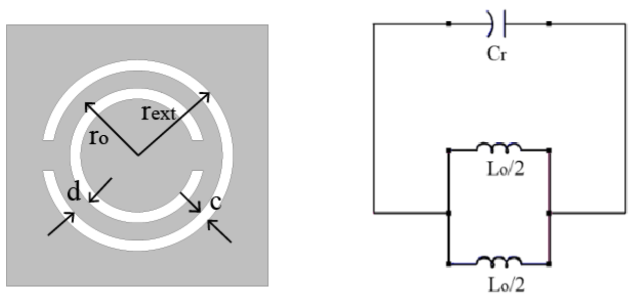

Figure 1. Basic CSRR unit and its equivalent circuit model.

Because of unconventional properties, metamaterial units are employed in antenna design for bandwidth and gain enhancement [21]. Also their sub-wavelength resonance benefits the size reduction of the antenna [22, 23]. The ground plane of the patch antenna loaded with CSRRs is reported for gain enhancement [24], and also dual band operation is achieved [25]. CSRR elements are etched periodically from the ground plane of the patch to reduce resonance frequency and increase the impedance bandwidth [26]. Triangle [27] and hexagon [28] shaped CSRRs are loaded on the radiating patches to achieve multiband operation. Ultra-wideband antennas with single [29] and dual notched bands [30] in WiMax/WLAN frequency band have also been proposed recently where CSRRs are loaded on patch. In this paper, CSRRs sub wavelength resonance due to its negative permittivity is utilized for achieving circular polarization. By loading CSRRs either on ground or on patch, an additional resonance can be produced which is close to the patch intrinsic resonance. The mutual orthogonal characteristics of these two resonances can produce circular polarization when the phase difference between them is reached near 90° which is done by adjusting the positions of the CSRRs in ground/patch.

3. ANTENNA DESIGN

Initially, a rectangular microstrip antenna (RMSA) is designed with patch dimension of $(26 \times 25)\,\mathrm{mm}^2$ as shown in Fig. 2. The RMSA is designed on an FR4 substrate with dielectric constant 4.3, thickness 1.6 mm, and loss tangent 0.02. In the first antenna design, two circular CSRRs of identical size are

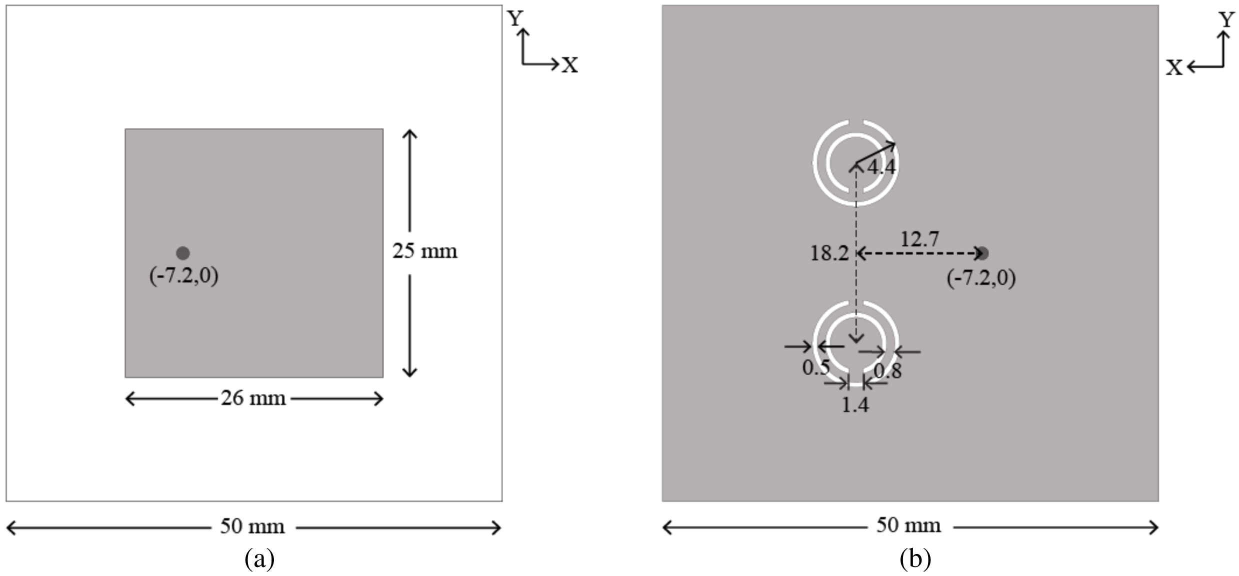

Figure 2. Geometry of the RMSA antenna with CSRRs loaded on ground (a) Top view and (b) Bottom view.

etched from the ground plane. The coaxial feed position and CSRRs relative position are determined to achieve the desired antenna characteristics. For the second antenna design, two CSRRs are loaded on the radiating patch. Substrate and ground plane dimensions for both antennas are $(50 \times 50)\,\mathrm{mm}^2$. Both antennas exhibit circular polarization, and two CSRRs face back load in both antennas depending on the direction of the ring splits.

3.1. Antenna Design with CSRRs Loaded Ground

When two face to back CSRRs are loaded on the ground plane of an RMSA with orthogonal feed position to the ring splits, two degenerate modes with orthogonal polarization are generated at nearby frequencies. Fig. 2 represents the top view and bottom view of the antenna. CSRR itself is a resonating element instead of a good radiator, so it will couple the field to patch. The coupled field between CSRRs and patch is polarized in the y-z plane while the patch inherent radiation is polarized in x-z plane.

3.2. Antenna Design with CSRRs Loaded Patch

The radiating patch loaded with CSRRs can also yield circular polarization due to resonances at two close frequencies. While one of these resonances is patch intrinsic radiation polarized in x-z plane, the other resonance is caused by coupling of the field between CSRRs and patch having polarization in y-z plane. Top and bottom views of the antenna are presented in Fig. 3.

4. SIMULATED RESULTS

Figure 4 represents the reflection coefficient plots of these two CP antennas. Reflection coefficient plot of an unloaded RMSA with same patch size is also shown in Fig. 4 to get an insight of the effect of CSRRs. The centre frequency of the operating band ($S_{11} < -10\,\mathrm{dB}$) for RMSA, RMSA loaded with CSRR on ground and patch are 2.68 GHz, 2.36 GHz, and 2.34 GHz, respectively. The simulated percentage impedance bandwidths for $S_{11} < -10\,\mathrm{dB}$ of the RMSA and RMSA loaded with CSRRs on ground and patch are 3.28%, 5.92%, and 5.22%, respectively. It is clear that the CSRR loaded path or ground will cause a moderate decrease in resonance frequency and increase in impedance bandwidth.

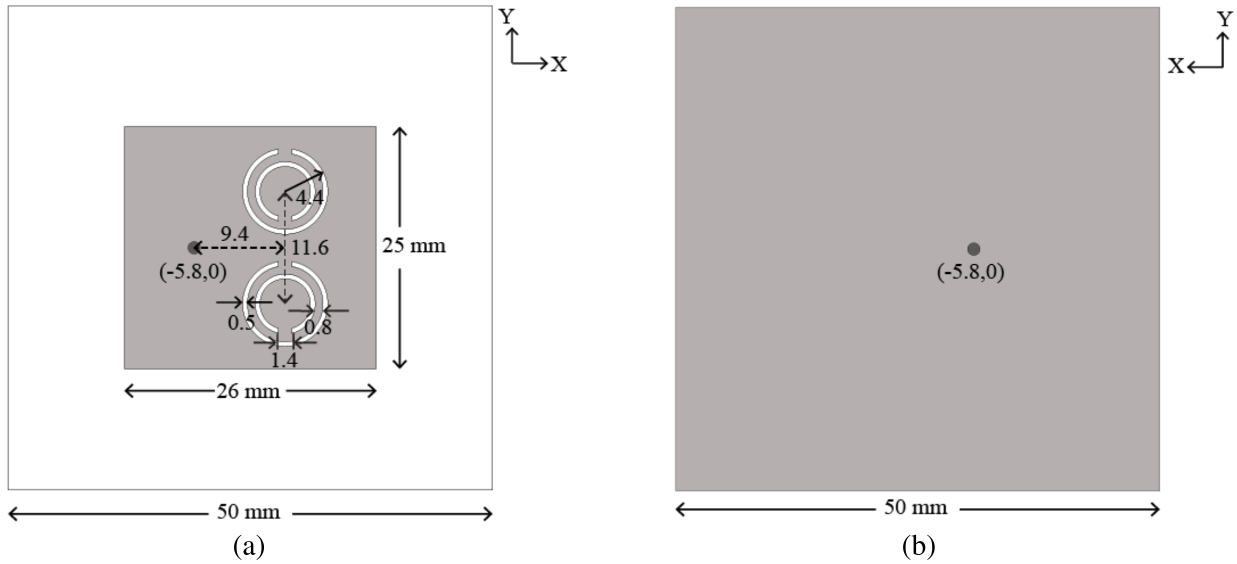

Figure 3. Geometry of the RMSA antenna with CSRRs loaded on patch (a) Top view and (b) Bottom view.

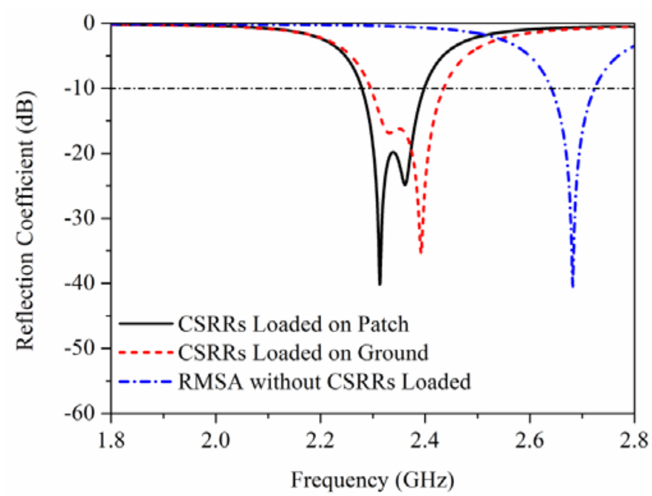

Figure 4. Reflection coefficient characteristics of the antenna without with CSRR load.

Figure 5 presents the surface current distributions over the patch for the two CP antennas. To illustrate the effect of CSRRs loading either on ground or on patch, current distribution of the unloaded RMSA is also shown in the diagram. For an unloaded RMSA currents are directed only along the two non-radiating edges of the patch, but when CSRRs are loaded on RMSAs currents seem to rotate for both CP antennas.

Variations of simulated axial ratio and gain plots of the two antennas are presented in Fig. 6 and Fig. 7, respectively. Minimum axial ratios of the antenna with CSRR loaded on ground and patch are obtained as 1.48 dB at 2.35 GHz and 0.5 dB at 2.34 GHz, respectively. The 3 dB axial ratio bandwidths for CSRR loaded on ground and patch antennas in broadside direction are 1.15% and 1.11%, respectively. Within 3 dB axial ratio bandwidth, the gain variation is below 0.5 dB for both antennas, but the realized gain of CSRRs loaded on patch is low due to high cross polarization value. The plots of total efficiencies of the antenna with CSRRs loaded on patch and ground are shown in Fig. 8. Maximum total efficiencies of the antenna with CSRRs loaded on patch and ground are nearly 29% and 40%, respectively. The

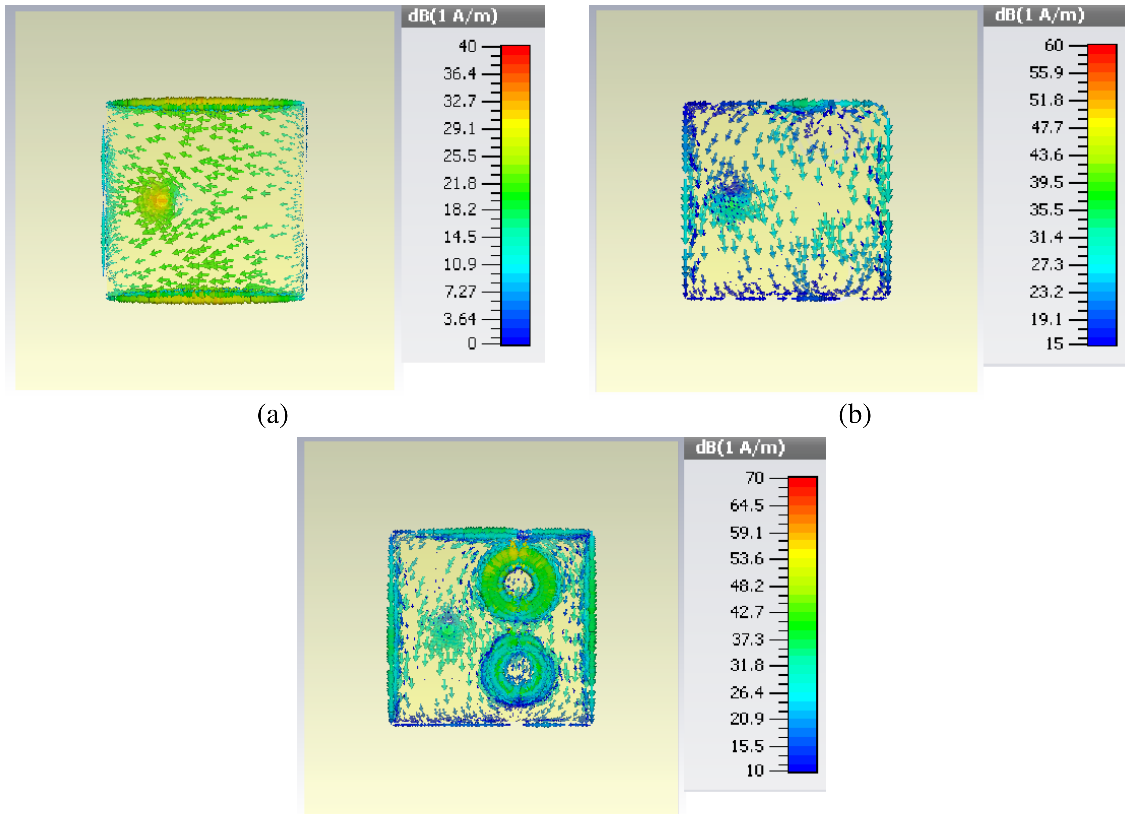

Figure 5. Simulated surface current distribution over radiating patches (a) unloaded RMSA, (b) RMSA with CSRR on ground and (c) RMSA with CSRR on patch.

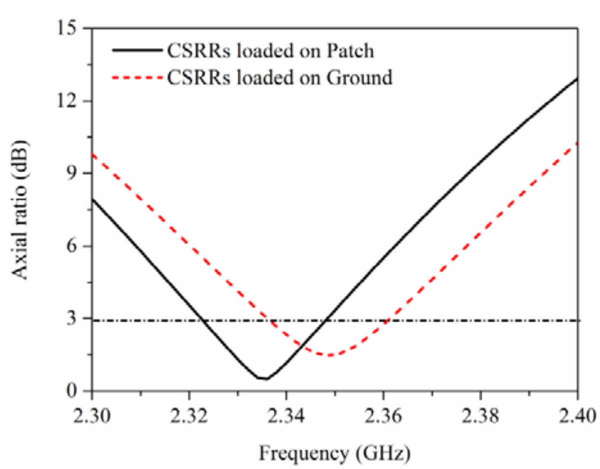

Figure 6. Variation of axial ratio plot of the antenna with CSRRs load.

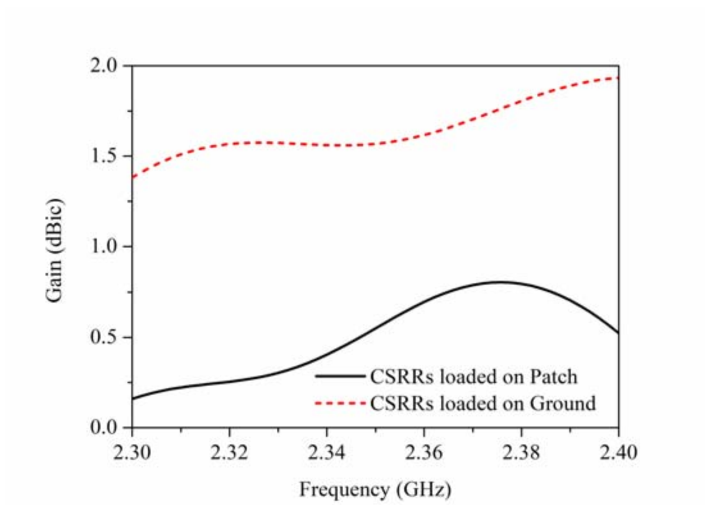

Figure 7. Variation of gain plot of the antenna with CRSSs load.

simulated results of the two CP antennas are listed in Table 1. The quality (Q) factor of an antenna is a measure of bandwidth relative to the centre frequency of the bandwidth, and the values of Q factor for the RMSAs without and with CSRRs are given in Table 1. Higher value of Q represents the narrowband characteristics of the antenna, and vice-versa.

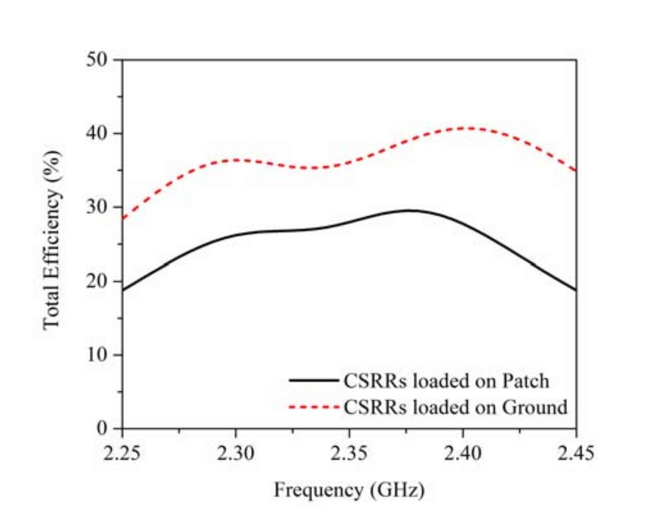

Figure 8. Variation of total efficiency of the antenna with CSRRs load.

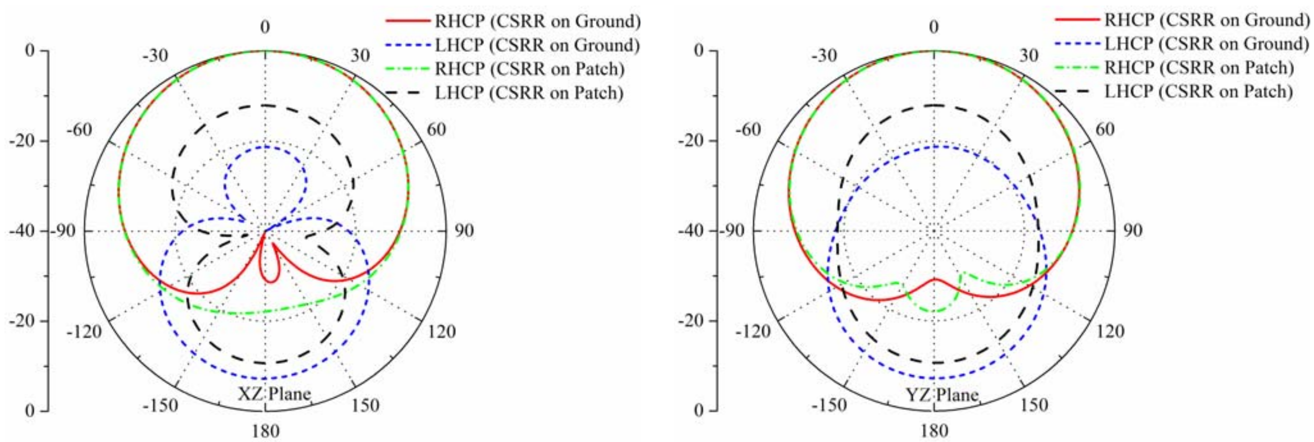

Figure 9. Simulated far field radiation patterns of the antennas with CSRRs loaded on ground and patch at frequency 2.35 GHz in (a) x-z and (b) y-z plane respectively.

Table 1. Comparison of the simulated results of the antennas.

Antenna Structures	10 dB Impedance Bandwidth	3 dB Axial Ratio Bandwidth	Quality Factor	Gain
Unloaded RMSA	(2.641–2.724 GHz) 3.28%	----------	32	3 dBi at 2.68 GHz
RMSA with CSRRs on Ground	(2.296–2.436 GHz) 5.92%	(2.335–2.362 GHz) 1.15%	17	1.57 dBic at 2.35 GHz
RMSA with CSRRs on Patch	(2.275–2.397 GHz) 5.22%	(2.322–2.348 GHz) 1.11%	19	0.62 dBic at 2.35 GHz

The simulated radiation patterns of RMSAs with CSRRs loaded on ground and patch in x-z ($\varphi = 0°$) and y-z plane ($\varphi = 90°$) are shown in Fig. 9 at frequency 2.35 GHz. In both planes, RHCP and LHCP components are discriminated by less than -20 dB for the antenna with CSRRs on ground and less than -12 dB for the antenna with CSRRs on radiating patch.

As the basic principles of achieving circular polarization in the two antennas are same, only the microstrip antenna with CSRRs loaded on patch has been fabricated for experimental verification of the simulated results. The next section presents measured reflection coefficient, gain, and radiation pattern of this antenna.

5. MEASURED RESULTS

A photograph of the proposed CSRR loaded on patch is shown in Fig. 10. Measured reflection coefficient is in good agreement with the simulated result as shown in Fig. 11.

Measured impedance bandwidth of the antenna with $S_{11} < -10\,\text{dB}$ is 110 MHz or 4.8%. Impedance bandwidth obtained in simulation is 119 MHz or 5.12% which is close to the measurement result. Gain and radiation pattern of the fabricated antenna are also measured in an anechoic chamber. The highest gain of this antenna is found at frequency 2.37 GHz, and the value is 1.28 dBic. Fig. 12 shows the simulated and measured gain variations of the antenna from frequency 2.3 GHz to 2.5 GHz.

Measured radiation patterns of the antenna in both principal planes (XZ and YZ planes) at frequency 2.35 GHz are compiled with simulated results in Fig. 13. RHCP patterns in both planes show good degree of correlation. Minor discrepancies in results arise because of fabrication tolerance and error during measurement.

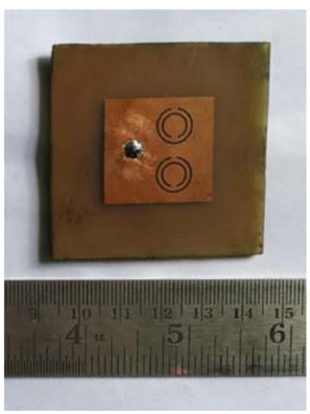

Figure 10. Photograph of the fabricated antenna.

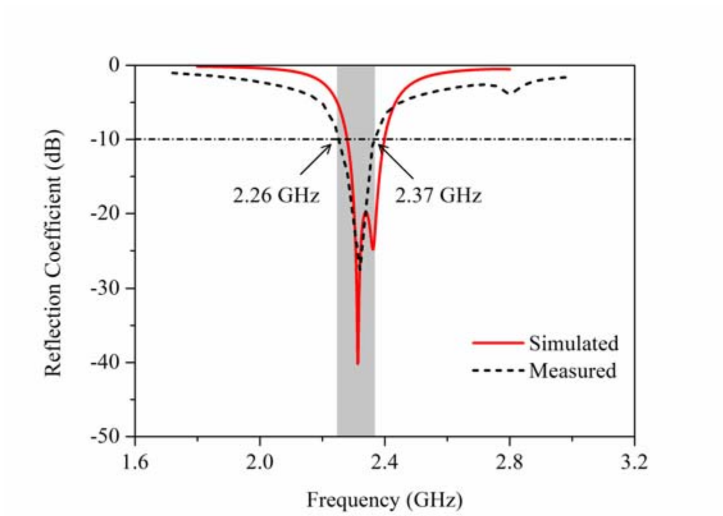

Figure 11. Measured and simulated reflection coefficient characteristics.

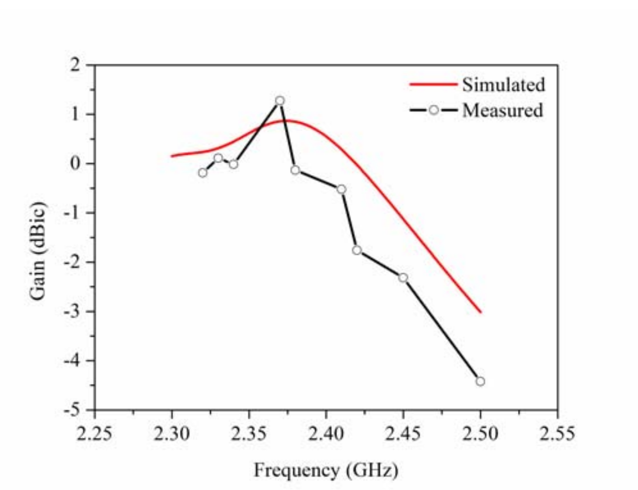

Figure 12. Variation of simulated and measured gain characteristics.

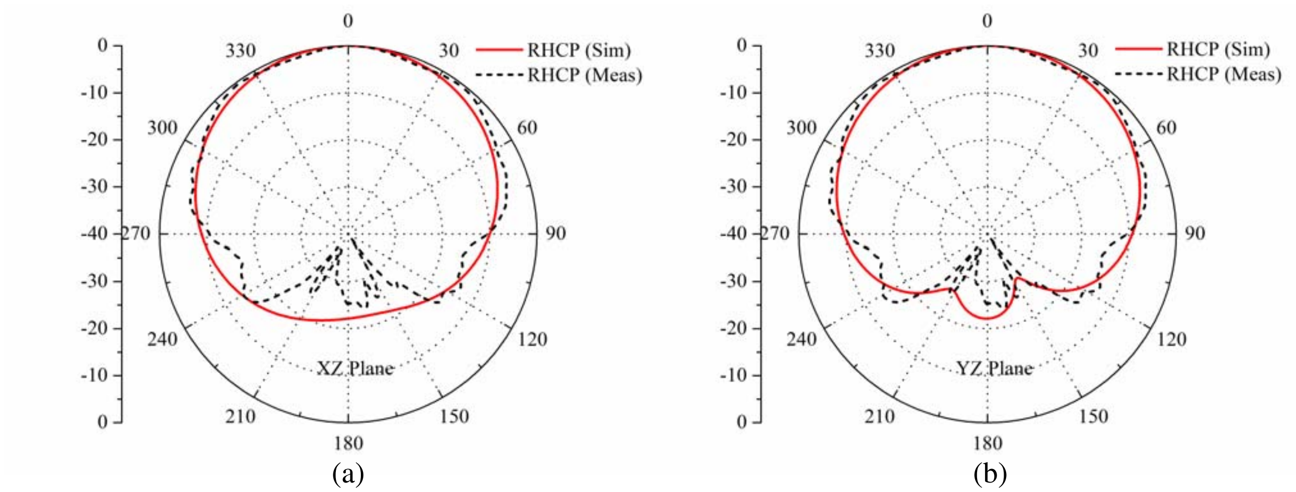

Figure 13. Simulated and measured far field radiation pattern at frequency 2.35 GHz in (a) XZ plane and (b) YZ plane.

6. CONCLUSION

In this paper, a CSRR based rectangular microstrip antenna (RMSA) is designed for circular polarization. In the first antenna design, two circular CSRRs are embedded on the ground plane, and for the second antenna design, CSRRs are loaded on the radiating patch. Introduction of CSRRs on ground and patch is used to reduce the antenna size, and it also increases the impedance bandwidth. The impedance bandwidth of the antennas for $S_{11} < -10$ dB is between 2.3 and 2.4 GHz. Minimum axial ratios of the antenna with CSRR loaded on ground and patch are obtained as 1.48 dB at 2.35 GHz and 0.5 dB at 2.336 GHz, respectively. It is observed that gain variation is below 0.5 dB within the 3 dB axial ratio bandwidth. Higher isolation (> 20 dB) is maintained between co- and cross-polarized components. The quality factor and efficiency characteristics of the antenna are observed.

ACKNOWLEDGMENT

Authors acknowledge Mr. Amitesh Kumar for providing with the measurement facilities in SAMERR Kolkata for measurement of the fabricated antenna.

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