

# Low RCS Microstrip Patch Antenna Using Complementary Split-Ring Resonators

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**ABSTRACT:** Amicrostrip antenna with low RCS is proposed in this paper. RCS reduction is accomplished by employing complementary split ring resonator in the ground plane of the proposed antenna. A conventional antenna is designed and simulated for a frequency of 11.5GHz.As compared to the conventional microstrip antenna, the monostatic RCS can be reduced as much as 15dBwhile preserving almost the same radiation characteristics. Measured results acceptably agree with the simulated results.

**KEYWORDS:** Complementary split-ring resonator (CSRR), microstrip patch antenna, radar cross section (RCS) reduction.

## I. INTRODUCTION

The radar cross-section (RCS) is an important constraint for the design of modern aircrafts, missiles, helicopters, ground military vehicles, launchers, and other important strategic installations. The accomplishment with which a radar system can detect a target depends primarily on how much of electromagnetic energy illuminating a target is reflected back to the radar [1]. In strategic applications it is crucial to reduce the RCS of air targets to preserve the low observable nature. Meanwhile the onboard antennas cause a substantial contribution to the overall RCS of airborne vehicle, the designing of antennas have to be done judiciously to meet low RCS requirement. The study of techniques allow reducing the RCS of antenna is therefore of great practical interest.

The RCS reduction technique for antenna system proposed in this paper is based on the loading of Complementary split-ring resonator (CSRR)to the antenna. The idea which is trying to implement here, is to replace the ground plane of antenna with suitable CSRR element. The complementary split-ring resonators are spatial filters of electromagnetic waves, which can be used to improve the antenna performance and reduce the RCS effectively. Thus, it is possible to make the antenna operational for a particular resonant frequency and remains inactive for all other frequencies.

Different types of RCS reduction techniques exist at present.RCS reduction by shaping is one of the methods that has been using from the beginning of stealth technology. Since the metallic parts of aircraft are reflecting in nature, by coating those with radar absorbing material [2] RCS can be reduced. Different radar absorbing coatings are available for applying on the outer metallic parts of the aircraft. Active cancellation techniques are also employed in which train of coherent waves are generated to cancel the scattering echo signals. Practically, generating cancellation signal having same amplitude, frequency and phase of that of the echo is a difficult task. All these methods reduce the overall RCS of the aircraft system. The main contributor of RCS is planar antennas used in the aircraft. This paper focuses on the RCS reduction of planar antenna.

Using frequency selective surfaces (FSS) for RCS reduction came into the world of science after 2000.Dependent on structure, FSS can act as band pass or band stop which will transmit or reflect the EM wave at their resonance frequency [3].Furthermore, electromagnetic band gap (EBG) structures are widely employed to reduce RCS.

Mushroom-like electromagnetic band gap (EBG) structures are incorporated to attain out-of-band RCS reduction [4], [5]. Even though the backward RCS of the patch array antenna with EBG can be reduced, its directivity is 2 dB inferior. Besides, using fractal structure [6], modifying the antenna structure [7, 8], and using bionics principle [9] the RCS of antennas can be reduced.

Using the SRR and CSRR structure low pass filter [10], high pass filter [11], and so on can be implemented. In this paper, the in-band RCS reduction of micro stripe antenna is realized by the use of a new compact CSRR structure.

## II. COMPLEMENTARY SPLIT-RING RESONATOR

In modern years CSRR metamaterial element along with patch antenna is used for antenna miniaturization, RCS reduction and much more. Complementary split rings resonators (CSRRs) are proposed by Pendry [12]. Negative-effective permittivity can be anticipated for any CSRR-based medium. By etching the rings or loops in the ground plane, just beneath the conductor strip CSRR can be realized. It is equivalent to a parallel LC resonant tank circuit with a resonant frequency given by

$$f = 1 / (2\pi L_{eq} C_{eq})$$

where  $L_{eq}$  and  $C_{eq}$  are the equivalent inductance and capacitance of the CSRR.

In order to realize the effect of RCS reduction, the traditional CSRR needs to be minimized. For a resonant frequency of 11GHz, the compact CSRR is designed and simulated.

Table 1. The parameters of the CSRR unit cell.

|            |      |     |      |      |     |      |
|------------|------|-----|------|------|-----|------|
| Parameters | D1   | D2  | D3   | D4   | D5  | D6   |
| Value (mm) | 5.95 | 7   | 3.25 | 1    | 1.1 | 2.15 |
| Parameters | D7   | D8  | D9   | D10  | D11 |      |
| Value (mm) | .7   | 1.3 | .3   | 3.15 | .7  |      |

The incident wave within the CSRR's stop-band will be reflected while the incident wave outside of the CSRR's stop-band will transmit through the CSRR without any hindrance. This can be useful for RCS reduction. The geometry of CSRR unit cell is shown in Fig.1. In Fig.2, it is clearly found that CSRR presents a stop-band characteristic of in the vicinity of 10.8GHz. To validate the performance of the proposed stop band characteristic, a four-period prototype device has been designed, simulated and measured.

In order to investigate the influence of CSRR on radiation characteristics and RCS of microstrip antenna, a variety of simulations have done. As the CSRR has an opening end, the structure is asymmetric. Depending upon the orientation of the opening end, the antenna performance is possibly affected, that can be verified by simulations.

Fig. 3 shows the reference antenna with a central frequency of 11.5 GHz. The proposed antenna is designed on an inexpensive FR4 dielectric substrate with permittivity of 4.4, a loss tangent of 0.024 and is fed by coaxial probe. The structure has been simulated using the time domain solver based Computer Simulation Technology microwave studio (CST MWS). The proposed antenna has the parameters of  $L_p = 5.1$  mm,  $W_p = 4.9$  mm,  $L_s = 19.2$  mm,  $W_s = 20.5$  mm and feed is located at  $W_p/4.36$  as shown in Fig.3(a). On the ground plane, a CSRR structure is etched. The dimensions of the patch have a significant effect on the resonance frequency and the radiation patterns.

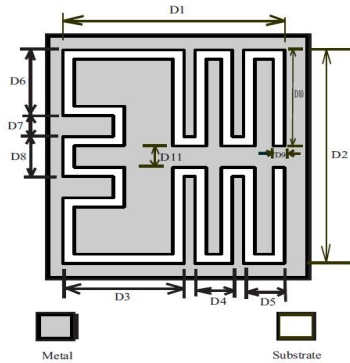


Fig 1. Geometry of each CSRR unit cell.

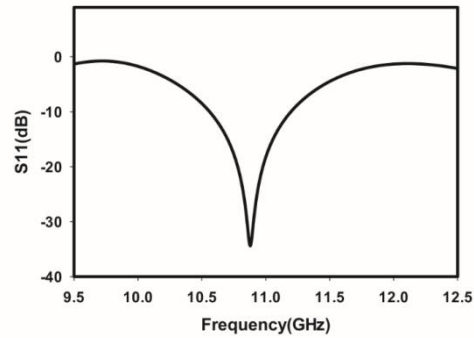


Fig 2. S-parameters of the CSRR cell.

In Fig. 3, on both sides of the line AB and CD two CSRRs are etched. In Figs. 3(b), (c), the orientation of the opening end is along x axis and y axis, respectively. In Fig. 4 and Fig. 5, the simulated S11 and radiation patterns are shown respectively under three different conditions. From the current distribution as shown in Fig.6, it is definite that the orientation of the opening end should be parallel to the y axis.

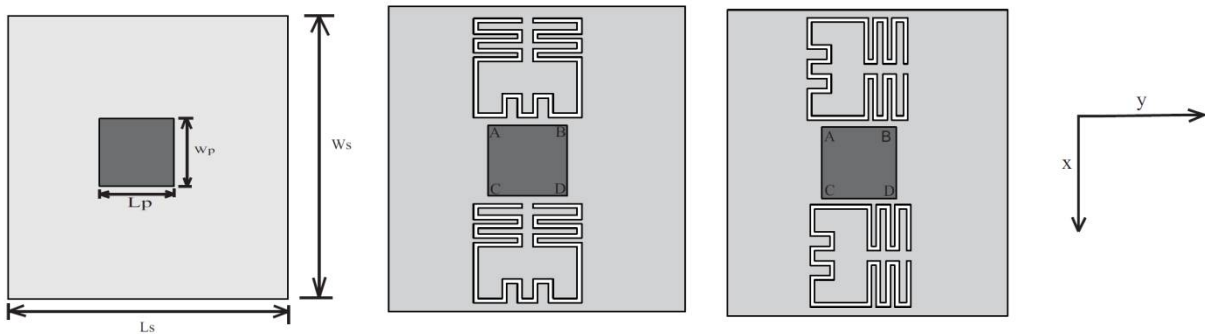


Fig3. (a) Geometry of the microstrip antenna. (b) The orientation of the opening end along x-axis. (c) The orientation of the opening end along y-axis.

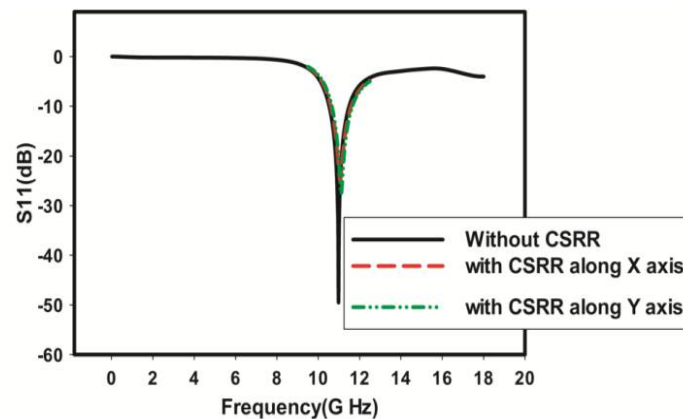


Fig 4. Comparisons of the simulated S11 of antennas with CSRRs with different orientations of the opening end.

Fig. 6 shows the current distribution of the antenna with and without CSRR. From Fig. 6, it is seen that CSRRs have nearly no effect on current distribution when the orientation of the opening end is parallel to the x-axis.

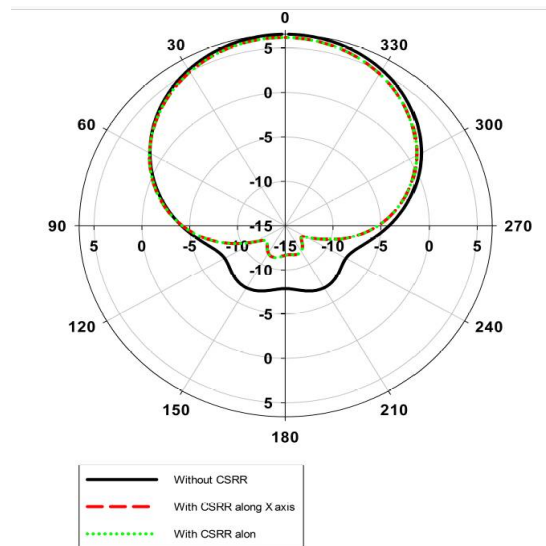


Fig 5. Comparisons of the simulated radiation patterns of antennas with CSRRs with different orientations of the opening end.

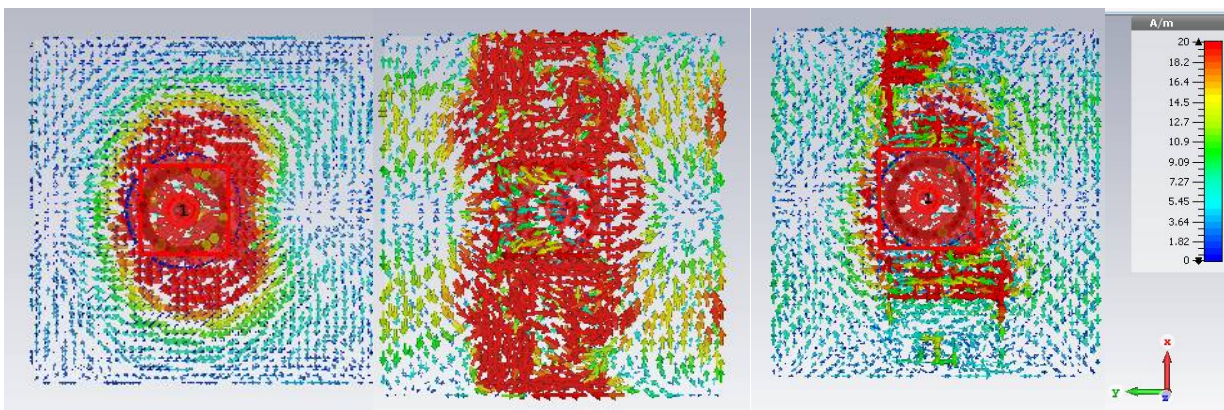


Fig6. Current distribution on the ground of the antenna at 5 GHz, (a) without CSRRs, (b) the orientation of the opening end along y-axis, (c) the orientation of the opening end along x-axis

An external electric field can excite the CSRR. As shown in Fig.6 the electric field is parallel to y-axis. CSRR can radiate when it is excited by electric field. The radiation principle of CSRR is identical to the slot antenna radiation principle. Besides, it holds its own resonance frequency and radiation patterns. The antenna's resonance frequency and radiation patterns are affected by excited CSRR.

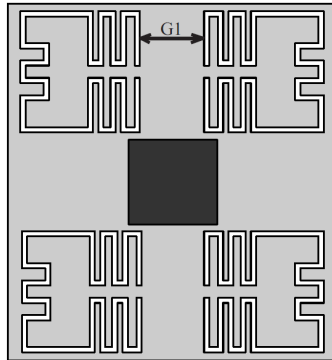


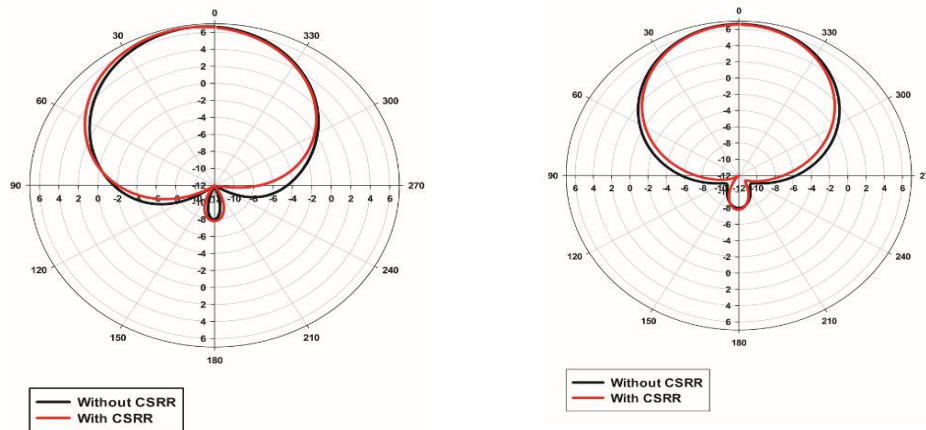
Fig 7. Geometry of microstrip antenna with CSRRs etched on the ground.

With a center frequency of 11.5 GHz, a low RCS microstrip antenna with CSRRs is shown in Fig. 7. The parameter  $G1=3.9\text{mm}$ . In order to simulate the unit cell the boundary conditions are set as follows.

$X_{\min}, X_{\max}$ =electric

$Y_{\min}, Y_{\max}$ =magnetic

$Z_{\min}, Z_{\max}$ =open (add space)



(a) xoz plane

(b) yoz plane

Fig 8. Comparisons of the simulated radiation patterns of antennas with and CSRR

The gain of the antenna with and without CSRRs in the normal direction (z-axis) is 4.85 dB and 5.54 dB, respectively. The gain loss is 0.69 dB at 11.5 GHz, which is less than 1 dB. The gain loss is due to the energy leakage occurs while changing the ground with the CSRR structure. Fig. 8 gives the radiation patterns of two antennas. From the Fig. 8 it is concluded that the main lobes of two radiation patterns are in fine agreement both in xoz-plane and yoz-plane.

### III. FABRICATION OF THE ANTENNA AND RESULT USING VECTOR NETWORK ANALYZER

In order to confirm the design strategies above, the prototypes of the reference and proposed antennas are manufactured and tested. Figure 9 shows photographs of the proposed antenna.



(a) Top View

(b) Bottom View

Fig 9. Photograph of the microstrip antennas with CSRRs etched on the ground.

The simulated and measured radiation characteristics are compared in this section. Figure 10 shows the S11 parameters of the reference and proposed antennas. It is observed that the measured results are agreed with the simulated results.

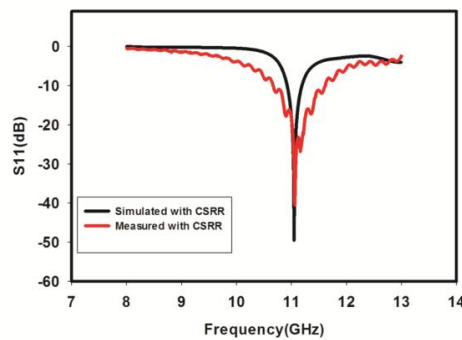
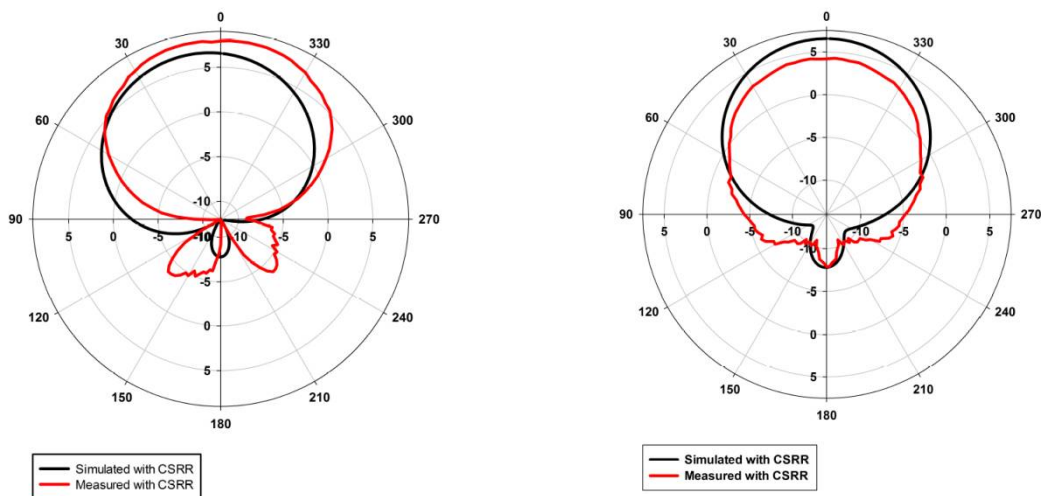


Fig 10. Comparison of simulated and measured S11 of antennas with CSRR.

The resonant frequency of the patch antenna without CSRRs is 11.2 GHz. Fig.9 shows the measured reflection coefficient and radiation characteristics of the patch antenna. It is seen from Fig. 10, that the measured reflection coefficient is  $-40\text{dB}$ . The measured radiation patterns are shown in Fig. 11. Once more, a better agreement between the simulated and measured results is obtained. Alike, the minor difference between them is caused due to its fabrication tolerance and measurement error.



(a) xoz plane

(b) yoz plane

Fig 11. Comparison of simulated and measured S11 of antennas with and without CSRRs.

To illustrate the variation of in-band RCS versus the theta angle, the low, central and high frequency points are chosen, respectively. Figure 12(a) shows that in the normal direction the in-band RCS can be reduced as much as 15 dB at 11.5 GHz in the xoz plane. It is also shown that the RCSs have efficiently reduced within the angular ranges  $[-25^\circ, 25^\circ]$ . Moreover, due to the excitation of the slots, the in-band RCS of the proposed antenna increases within the angular ranges  $[50^\circ, 100^\circ]$  and  $[-100^\circ, -50^\circ]$ .

Figure 11(b) shows the in-band RCS for yoz plane. It is seen that in yoz plane also RCS gets reduced considerably as 15 dB at 11.5 GHz. It is also shown that the RCSs have efficiently reduced within the angular ranges  $[-25^\circ, 25^\circ]$ . Moreover, Figure 12 shows that due to the excitation of the slots the in-band RCS of the proposed antenna increases within the angular ranges  $[40^\circ, 100^\circ]$  and  $[-100^\circ, 40^\circ]$ .

The CSRRs are resonating at the resonance frequency of patch antenna, which leads to the current to be rearranged. But due to the larger current on the ground plane, the antenna has larger back lobes. The RCS of the antenna greatly depend on the numbers of the CSRRs unit cells and the distance between the antenna and the CSRR unit cells.

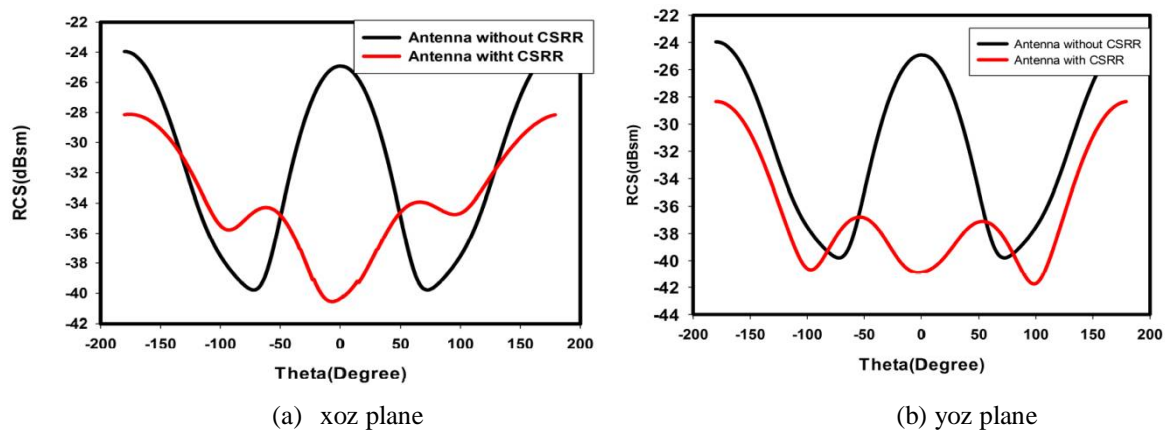


Fig 12. Comparisons of monostatic RCS between the reference antenna and the proposed antenna

The reason for two large RCS peaks is the discontinuous structure. So when the theta angle exceeds a specific value, the slots cannot work and will result in two large RCS peaks.

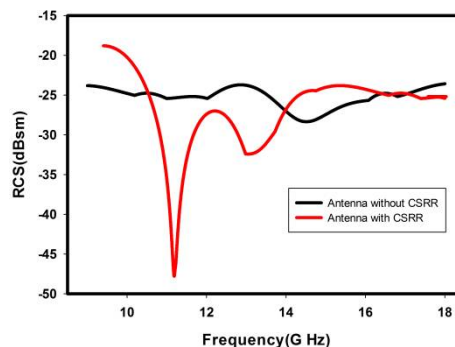


Fig 13. Comparison of monostatic RCS between the reference antenna and the proposed antenna

Fig. 13 is the graph plotted between the RCS versus the frequency for a normal incident plane wave. There is a significant RCS reduction for the frequency 11.5GHz. Because of these outstanding features, the proposed antenna

can be employed in low-RCS platforms.

#### IV. CONCLUSION

A novel microstrip patch antenna is considered as the test case to confirm the strategy for RCS reduction. A microstrip antenna with four CSRR's etched on the ground plane is presented. Antenna with and without CSRR is simulated and fabricated. The results show that it is promising to attain RCS reduction at the resonant frequency of the reference antenna.

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