Progress In Electromagnetics Research, Vol. 146, 125–132, 2014

A Low RCS Dual-Frequency Microstrip Antenna with Complementary Split-Ring Resonators

Ying Liu*, **Yuwen Hao, Yongtao Jia, and Shuxi Gong**

Abstract—A novel dual frequency microstrip antenna with low radar cross section (RCS) is proposed in this paper. Compared with the traditional microstrip antenna, the novel microstrip antenna loaded complementary split-ring resonators (CSRRs) has a low RCS. The novel and traditional dual-frequency microstrip antennas with the center frequency of 3.4 GHz and 5 GHz are designed and fabricated. The results demonstrate that the monostatic RCS of the proposed antenna has been well reduced. The RCS reduction at 5 GHz is as much as 17 dB. Besides, in the case of the φ-polarized incident wave, the RCS reduction can be achieved in the angular ranges of $-90^\circ \leq \theta \leq +90^\circ$ in xoz-plane and yoz-plane. At the same time, the CSRRs cause no obvious deterioration in radiation performance.

1. INTRODUCTION

Stealth technique is very indispensable in 21st modern Electronic War. For low observable platform, antennas contribute most to the total radar cross section (RCS), which in turn makes the consideration of antenna scattering more important [1]. To reduce the RCS of the microstrip antenna, some methods have been proposed, such as changing the shape of the antenna and attaching radar absorbing materials on the surface of the antenna. Nevertheless, these methods may cause detrimental effects on the antenna's radiation characters.

Microstrip antennas have been widely used. To achieve the RCS reduction of the microstrip antenna, a variety of effective techniques are presented, such as structural modification [2, 3], and the use of frequency selective surface (FSS). The FSS is able to realize the out-band RCS reduction, but it can hardly modify the in-band RCS reduction. Loading electromagnetic band-gap (EBG) structure is also an available approach to reduce the in-band RCS [4]. Unfortunately, the RCS reduction can be achieved only in the angular ranges of $-45^\circ \leq \theta \leq +45^\circ$. Although the microstrip antenna loading distributed resistance has low RCS, radiation efficiency of the antenna is sacrificed. Besides, slots on the antenna can achieve RCS reduction at the expense of gain loss [5]. Significant RCS reduction effect can be obtained by loading absorbing material but the antenna has a high cost and poor radiation performance [6].

CSRR is the complementary structure of split rings resonators (SRRs) proposed by Pendry [7]. Over the past years, much attention has been paid to CSRR structure, such as size reduction of microstrip antenna [8], band-notched function [9], filter design [10] and so on. Nevertheless, almost no research about loading CSRRs to accomplish RCS reduction has been done. In this paper, a novel compact CSRRs structure is etched on the ground of the dual-frequency microstrip antenna to fulfill RCS reduction. The dimensions of antennas are designed and optimized by using Ansoft's High Frequency Solution Solver (HFSS) software. At 5 GHz, the RCS can be reduced in the angular ranges of $-90^\circ \leq \theta \leq +90^\circ$ both in the xoz-plane and yoz-plane. And at 3.4 GHz, the RCS reduction can be achieved in the angular ranges of $-40^\circ \leq \theta \leq +40^\circ$ both in the xoz-plane and yoz-plane.

Received 17 March 2014, Accepted 16 April 2014, Scheduled 13 May 2014
* Corresponding author: Ying Liu (liuying@mail.xidian.edu.cn).
The authors are with the National Laboratory of Science and Technology on Antennas and Microwaves, Xidian University, Xi'an, Shaanxi 710071, China.

2. COMPLEMENTARY SPLIT-RING RESONATOR

In order to etch more CSRRs on the ground of the antenna, the traditional CSRRs need to be minimized. So a compact CSRR is designed and simulated with the resonant frequency at 3.4 GHz and 5 GHz. After miniaturization, more CSRRs can be etched on the ground of the antenna to realize better effect of RCS reduction.

Table 1. The parameters of the CSRR.

L_1	L_2	L_3	L_4	L_5	L_6	L_7
2 mm	0.9 mm	0.7 mm	0.9 mm	0.9 mm	0.9 mm	0.9 mm
L_8	L_9	L	D	G	g	l
0.9 mm	0.9 mm	11 mm	1 mm	0.2 mm	0.7 mm	6.6 mm
l_1	l_2	l_3	l_4	l_5	l_6	l_7
0.7 mm	0.8 mm	0.8 mm	0.8 mm	0.8 mm	0.8 mm	0.7 mm

The CSRR is printed on a 1 mm thick FR4 (substrate with the relative permittivity of 4.4). The geometry of the proposed compact CSRR is shown in Fig. 1. Table 1 shows the parameters of the CSRR. In Fig. 2, we can clearly observe that the resonance frequency is 3.4 GHz and 5 GHz. The simulation results demonstrate that the distance D between the CSRR's inner ring and the CSRR's outer ring has a remarkable effect on the resonance character. When the value of distance D is increased, the resonance character of the CSRR at low frequency can be better. However, the above method will increase the dimension. Therefore, the value of the distance D of the proposed CSRR has been optimized.

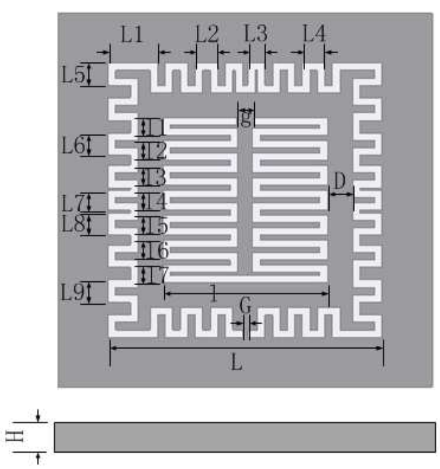


Figure 1. Simulative demonstration and geometry of the compact CSRR.

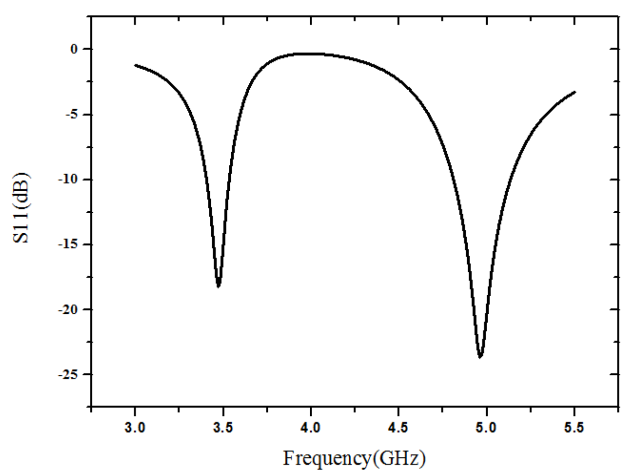


Figure 2. Simulated S_{11} of compact CSRR under periodic boundary conditions.

At first, a variety of simulations have been done to explore the influence of the CSRRs on radiation characters of the dual-frequency microstrip antenna. Because of the opening end, the CSRR is an asymmetric structure. Therefore, the antenna performance is possibly affected by different orientations of the opening end, which can be verified by the following simulations. As shown in Fig. 3, a dual-frequency microstrip antenna working at 3.4 GHz and 5 GHz is presented, with the parameters of $L_1 = 13.6$ mm, $W_1 = 20.8$ mm, $L_2 = 43.6$ mm, $W_2 = 50.8$ mm. In Fig. 3, two CSRRs are etched on both sides of the line AB and CD. In Figs. 3(b), (c), the orientation of the opening end is parallel with the line AB and the line AC, respectively. Under three different conditions, the simulated S_{11} and radiation patterns are given in Fig. 4 and Fig. 5, respectively. According to Fig. 4 and Fig. 5, it can be

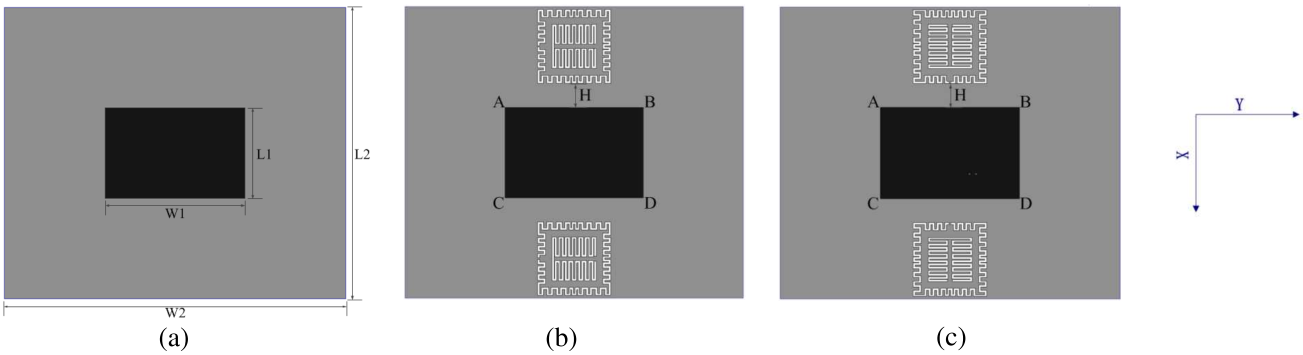


Figure 3. (a) Geometry of the microstrip antenna. (b) The orientation of the opening end along y-axis. (c) The orientation of the opening end along x-axis.

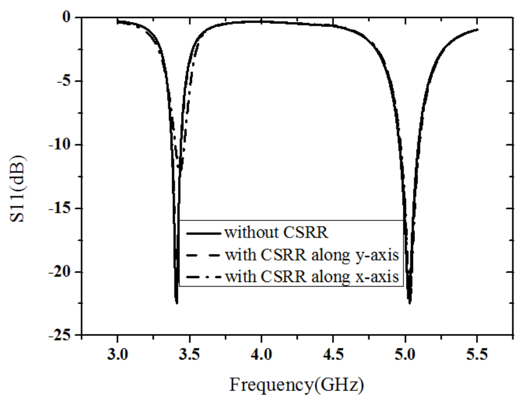


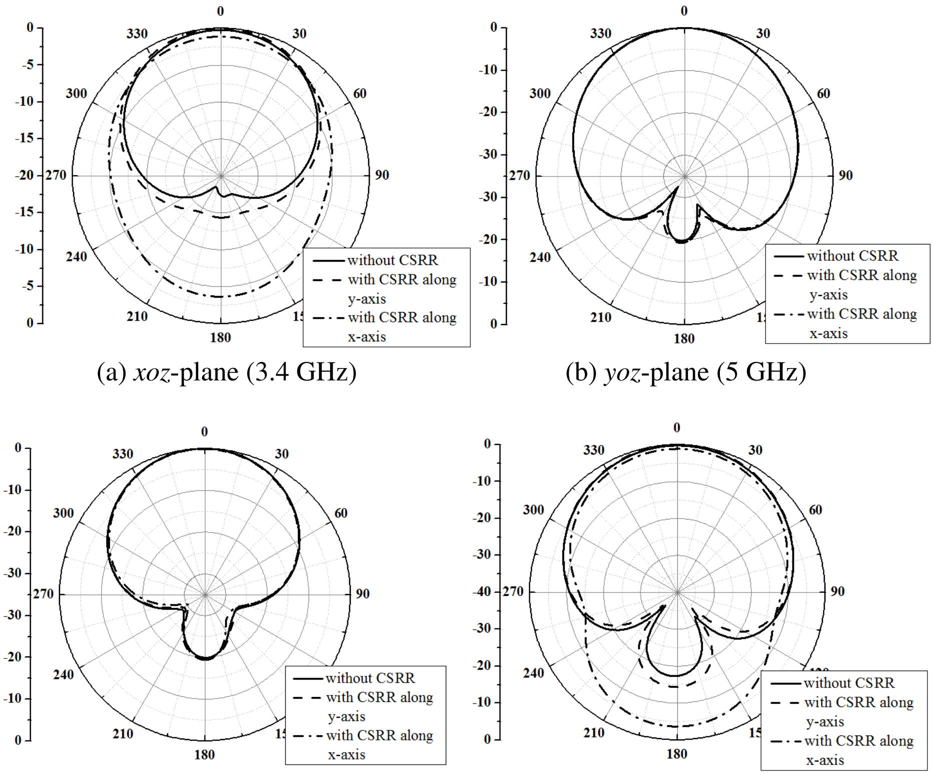
Figure 4. Comparisons of the simulated S_{11} of antennas with CSRRs with different orientations of the opening end.

concluded that the orientation of the CSRR's opening end should be parallel with the line AB. If the orientation of the opening end is normal to the line, the antenna can not operate. If CSRRs are etched on both sides of the line AC and BD, similar conclusions can be summed up.

Based on the current distribution of the antenna with and without CSRRs, the above analysis can be also verified. The dimensions of the patch have a significant effect on the resonance frequency and the radiation patterns. The CSRR can be excited by external electric field [11]. And the direction of the external electric field is parallel to y-axis in Fig. 3. When the CSRR is excited, it can radiate. The CSRR's radiation principle is similar to the slot antenna's radiation principle. Furthermore, it has its own resonance frequency and radiation patterns [12]. The excited CSRR is able to affect the antenna's radiation performance including resonance frequency and radiation patterns. That conclusion can be verified by the current distribution. The current distribution of the antenna with and without CSRRs at 3.4 GHz is given in Fig. 6. Moreover, the current distribution of the antenna with and without CSRRs at 5 GHz is given in Fig. 7. From Fig. 6, we can find that CSRRs have almost no effect on current distribution at 3.4 GHz when the orientation of the opening end is parallel to the y-axis. However, CSRRs with different orientation of the opening end have almost no effect on current distribution at 5 GHz. In addition, we can draw the similar conclusion when CSRRs are etched on both sides of the line AC and BD. Based on the above analysis, the proposed antenna is designed and shown in Fig. 8.

3. LOW RCS DUAL-FREQUENCY MICROSTRIP ANTENNA

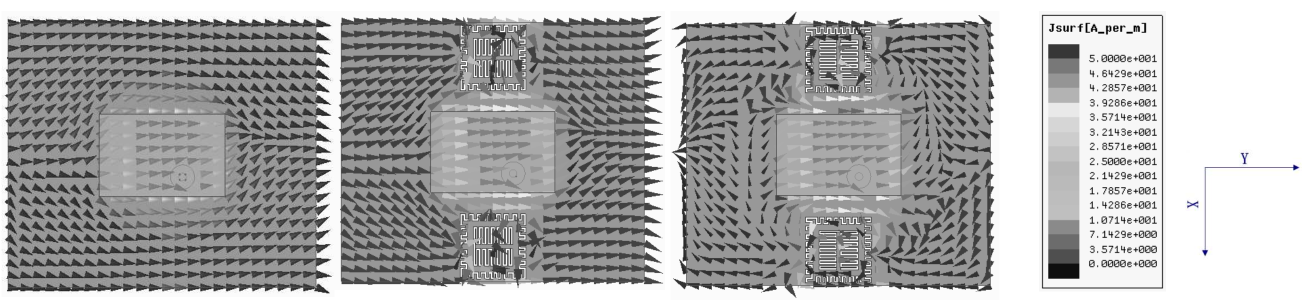
Based on the above analysis, a dual-frequency microstrip antenna with CSRRs is shown in Fig. 8, with a center frequency of 3.4 GHz and 5 GHz. The dimension of the patch and ground is same as



(a) *xoz*-plane (3.4 GHz) (b) *yoz*-plane (5 GHz)

(c) *xoz*-plane (3.4 GHz) (d) *yoz*-plane (5 GHz)

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



(a) (b) (c)

Figure 6. Current distribution on the ground of the antenna at 3.4 GHz, (a) without CSRRs, (b) the orientation of the opening end along y-axis, (c) the orientation of the opening end along x-axis.

the antenna designed in Section 2. Furthermore, the loaded CSRR has the identical parameters with the simulated one in Section 2. The other parameters are as following: $G_1 = 1$ mm, $G_2 = 2.1$ mm, $G_3 = 2.1$ mm. Besides, the relative permittivity of the substrate is 4.4, with thickness of 1 mm. The fabricated antennas are shown in Fig. 9.

4. NUMERICAL AND EXPERIMENTAL RESULTS

In Fig. 10, the simulated and measured S_{11} of two microstrip antennas with and without CSRRs are given. At the same time, the VSWR of antennas operating at 3.4 GHz and 5 GHz CSRRs are given in Fig. 11(a) and Fig. 11(b), respectively. From the results of Fig. 10, we can obviously find that two

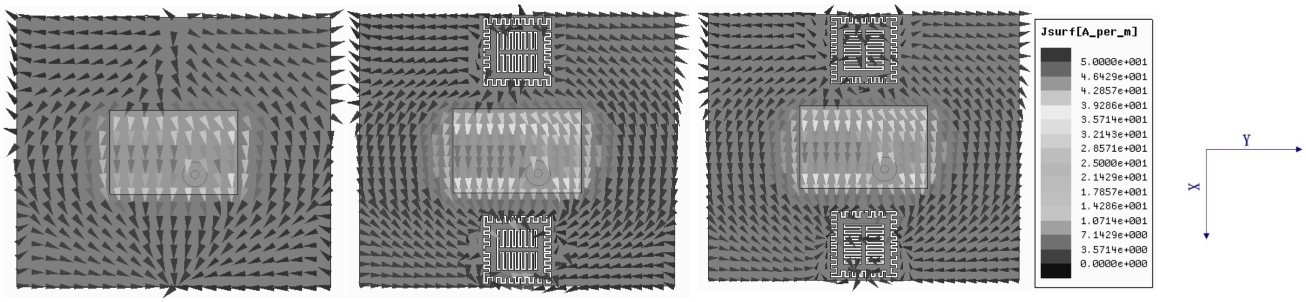


Figure 7. Current distribution on the ground of the antenna at 5 GHz, (a) without CSRRs, (b) the orientation of the opening end along y-axis, (c) the orientation of the opening end along x-axis.

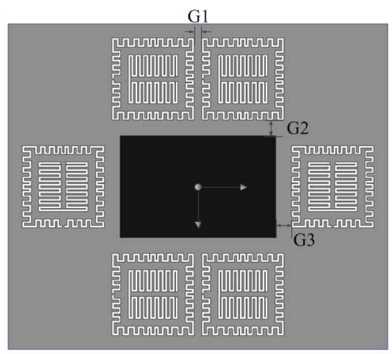


Figure 8. Geometry of microstrip antenna with CSRRs etched on the ground.

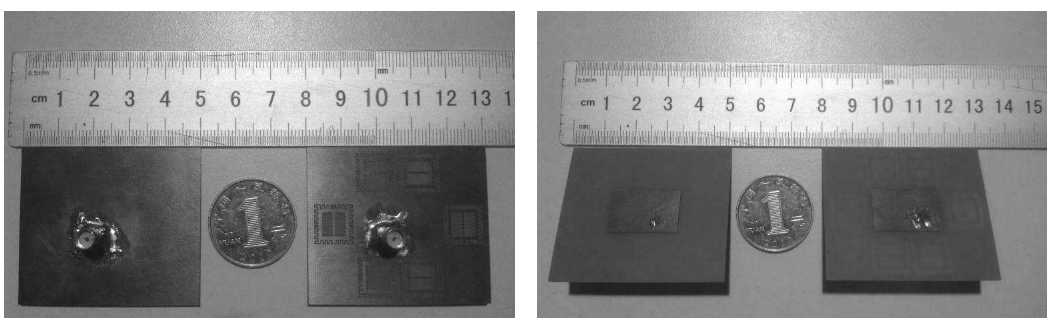


Figure 9. Photograph of the microstrip antennas with and without CSRRs etched on the ground.

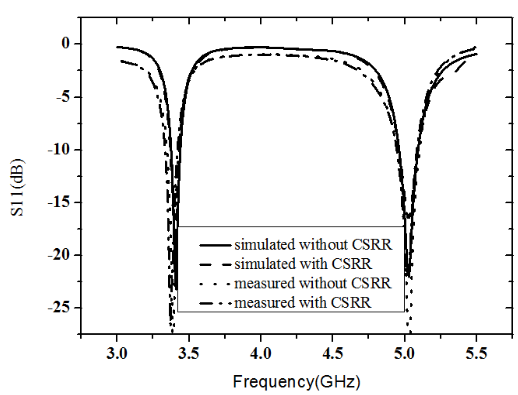


Figure 10. Comparison of simulated and measured S_{11} of antennas with and without CSRRs.

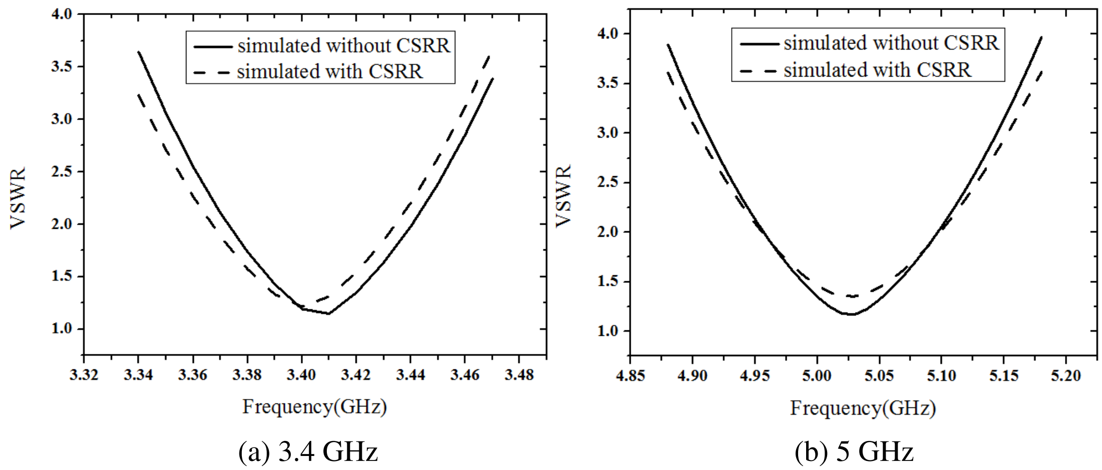


Figure 11. Comparisons of the simulated VSWR of antennas with and without CSRRs.

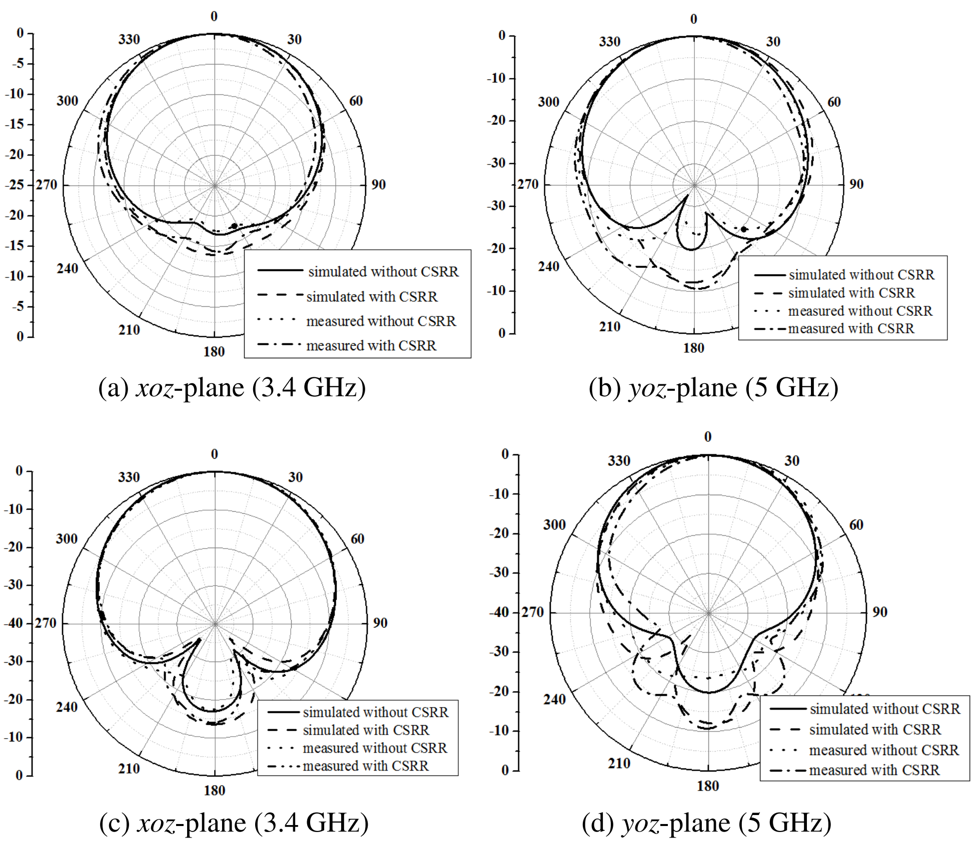


Figure 12. Comparisons of simulated and measured radiation patterns of antennas with and without CSRRs.

antennas work at same frequency and the simulation results are in agreement with the experimental ones. At 3.4 GHz and 5 GHz, the gain of the antenna without CSRRs in the normal direction (z-axis) is 2.13 dB and 5.07 dB, respectively. And at 3.4 GHz and 5 GHz, the gain of the antenna with CSRRs is 2.39 dB and 4.35 dB, respectively. At 3.4 GHz, there is no gain loss. The gain loss is 0.66 dB at 5 GHz, which is less than 1 dB. The Fig. 12 gives the radiation patterns of two antennas. We can draw the conclusion from Fig. 12 that the main lobes of two radiation patterns are in good agreement both in

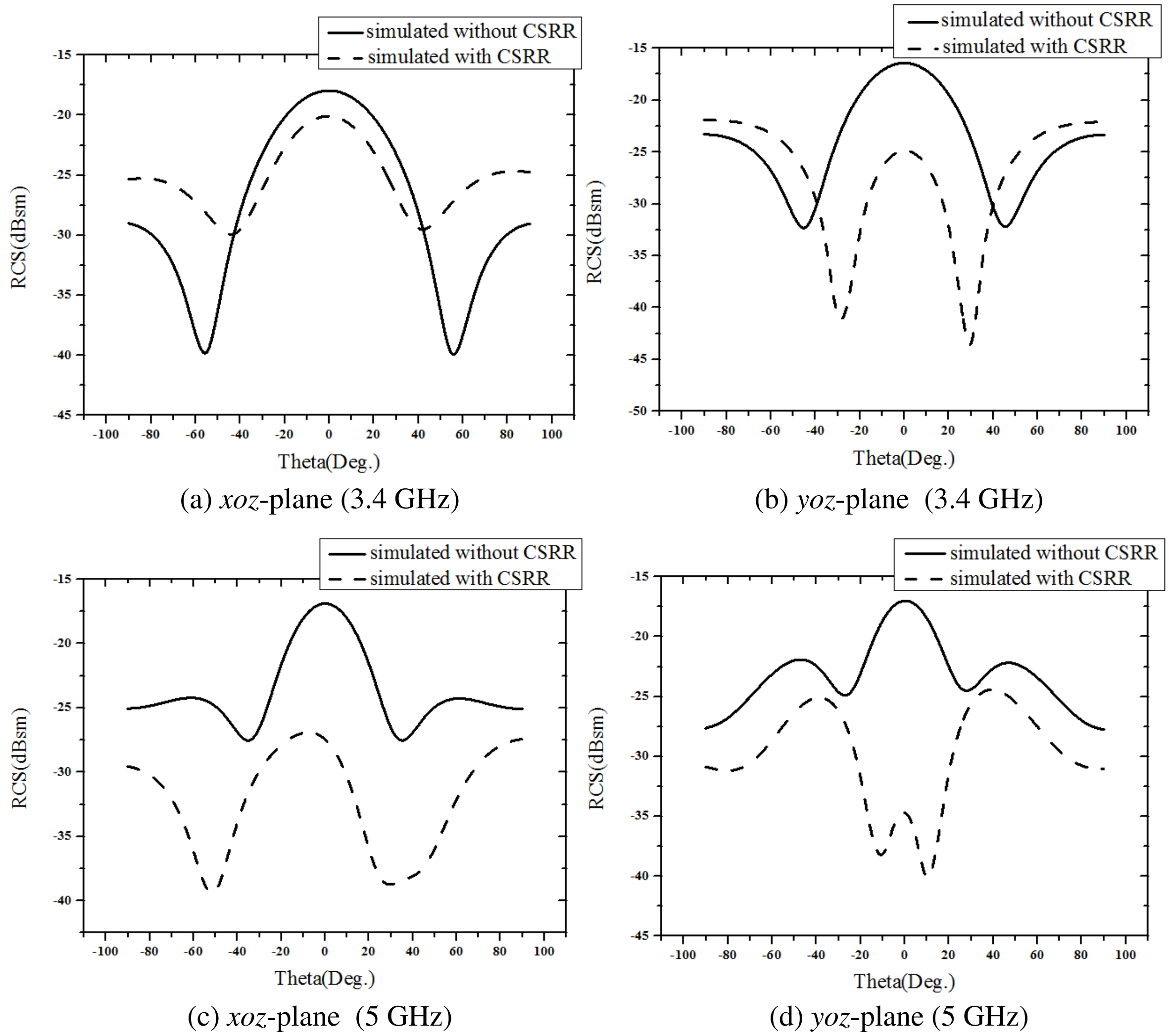


Figure 13. Comparisons of monostatic RCS of two antennas with φ-polarized incident wave at different frequency.

xoz-plane and yoz-plane.

The monostatic RCS of two microstrip antennas irradiated with φ-polarized incident in xoz-plane and yoz-plane is given in Fig. 13. At 3.4 GHz, monostatic RCS is reduced in angular ranges of $-40° \leq \theta \leq +40°$ both in xoz-plane and in yoz-plane. In the xoz-plane and yoz-plane, RCS reduction in the normal direction of the antennas is 2.1 dB and 8.4 dB, respectively. For the case of 5 GHz, monostatic RCS is reduced in angular ranges of $-90° \leq \theta \leq +90°$ both in xoz-plane and in yoz-plane. In the xoz-plane and yoz-plane, RCS reduction in the normal direction of the antennas is 10.6 dB and 17.3 dB, respectively. As shown in Fig. 8, we can find that the number of CSRRs whose opening end is parallel with y-axis is more than the number of CSRRs whose opening end is parallel with x-axis. The effect of RCS reduction in yoz-plane is better than that in xoz-plane. Moreover, the antenna operating at 5 GHz has more significant RCS reduction than that at 3.4 GHz. The reason is that S_{11} of CSRRs at 5 GHz is lower than that at 3.4 GHz in Fig. 2. Therefore, more transmitted waves are generated at 5 GHz than 3 GHz when the antenna is irradiated with φ-polarized incident. Because the CSRR has a narrow band, only in-band RCS reduction can be achieved.

When the angle of the incident wave increases, the direction of electric field is still parallel to x-axis or y-axis. So CSRRs can be excited by an external electric field all the time. In other word, it is possible to reduce RCS from wide range of angles.

5. CONCLUSION

A novel compact CSRR structure is designed and applied to RCS reduction of dual-frequency microstrip antenna. Two antennas with and without CSRRs are simulated and measured. Results indicate that the RCS can be significantly reduced when CSRRs have the same resonance frequency with the antenna. And we can achieve the in-band RCS reduction in wide angular ranges without degrading antenna's radiation performance.

ACKNOWLEDGMENT

The work is supported by the National Natural Science Foundation of China (No. 61372001) and by the Program for New Century Excellent Talents in University of China (NCET-11-0690).

REFERENCES

1. Liu, Y., S. Gong, and H. Zhang, "A novel fractal slot microstrip antenna with low RCS," *IEEE Antennas and Propagation Society International Symposium*, 2603–2606, 2006.
2. Jia, Y., Y. Liu, S. Gong, T. Hong, and D. Yu, "Printed UWB end-fire Vivaldi antenna with low RCS," *Progress In Electromagnetics Research Letters*, Vol. 37, 11–20, 2013.
3. Li, R., Z. Niu, and R. Lin, "A novel method for the RCS reduction of conformal microstrip antenna," *Cross Strait Quad-regional Radio Science and Wireless Technology Conference (CSQRWC), 2011*, Vol. 1, 516–519, IEEE, 2011.
4. Zhang, J., J. Wang, M. Chen, and Z. Zhang, "RCS reduction of patch array antenna by electromagnetic band-gap structure," *IEEE Antennas and Wireless Propagation Letters*, Vol. 11, 1048–1051, 2010.
5. Ding, J., C. Cheng, and C. Guo, "A method for microstrip antenna RCS reduction," *Computer Simulation*, Vol. 25, No. 9, 130–133, 2008.
6. Li, Y., H. Zhang, Y. Fu, and N. Yuan, "RCS reduction of ridged waveguide slot antenna array using EBG radar absorbing material," *IEEE Antennas Wireless Propag. Lett.*, Vol. 7, 473–476, 2008.
7. Pendry, J., "Magnetism from conductors and enhanced nonlinear phenomena," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 47, No. 11, 2075–2084, 1999.
8. Baee, R., G. Dadashzadeh, and F. Kharakhili, "Using of CSRR and its equivalent circuit model in size reduction of microstrip antenna," *Asia-Pacific Microwave Conference*, 1–4, 2007.
9. Jiang, D., "Compact dual-band-notched UWB planar monopole antenna with modified CSRR," *Electronics Letters*, Vol. 48, No. 20, 1250–1252, 2012.
10. Liu, J., "An improved equivalent circuit model for CSRR-based bandpass filter design with even and odd modes," *IEEE Microwave and Wireless Components Letters*, Vol. 20, No. 4, 193–195, 2010.
11. Baena, J., "Equivalent-circuit models for split-ring resonators and complementary split-ring resonators coupled to planar transmission lines," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 53, No. 4, 1451–1461, 2005.
12. Kumar, G. and K. Ray, *Broadband MSA*, Artech House, 2003.