Progress In Electromagnetics Research Letters, Vol. 25, 117–126, 2011

A NOVEL DUAL-BAND PATCH ANTENNA WITH COMPLEMENTARY SPLIT RING RESONATORS EMBEDDED IN THE GROUND PLANE

Y. Xie*, L. Li, C. Zhu, and C. Liang

Science and Technology on Antenna and Microwave Laboratory, School of Electronic Engineering, Xidian University, Xi'an, Shaanxi 710071, China

Abstract—In this paper, a novel design of dual-band microstrip antenna with complementary split ring resonators (CSRRs) is presented. A simple and successful dual-band antenna can be realized by etching three CSRRs in the ground plane of a conventional patch antenna. The proposed antenna shows good performances at both resonant frequencies. The CSRRs embedded in the ground plane make a major contribution to the first operating band, but has minor effect on the second operating band. It is beneficial for designing a dual-band antenna as well as a miniaturized antenna flexibly. The simulation results are analyzed and compared with measured results in a good agreement.

1. INTRODUCTION

The concept of left-handed material (LHM) was first proposed by Veselago in 1968 [1], and negative permeability medium was first developed by Pendry in 1999, which consist of an array of split ring resonators (SRRs) [2]. It was not until 2000 that the first artificial LHM was implemented by Smith in a two dimensional periodic array of SRRs and long wire strips [3].

As a basic particle for design of artificial media, SRRs have been applied in many applications. The most attractive feature of this structure is its ability to exhibit a quasi-static resonant frequency at wavelengths that are much smaller than its own size. Therefore, the application of SRRs for designing small antennas is of great interest. By considering the concepts of duality, the negative permittivity nature

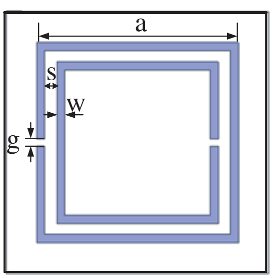
Received 28 June 2011, Accepted 28 July 2011, Scheduled 5 August 2011
* Corresponding author: Yihong Xie (yhxie0118@126.com).

of CSRR can be derived from the negative permeability nature of SRR in a straightforward way, which has strong potential applications in designing simple planar filters [4–6], compact antennas [7–9], circularly polarized antennas [10, 11] and dual-band antennas [12–14].

In [12, 13], dual-band antennas are presented by loading a CSRR unit in the patch of conventional microstrip antenna, but they still suffer from low gain at the resonant frequency stimulated by the CSRR. In [14], a dual-band antenna is presented realized by loading two CSRR units and two CELC (complement electric-LC resonators) units in the ground plane of a microstrip antenna. In this paper, a novel dual-band patch antenna is simply realized by etching three CSRRs in the ground plane of a conventional patch antenna, not only simple in structure but also achieving higher gain at both working frequencies.

2. ANTENNA DESIGN

According to the Babinet principle, the complementary of a planar metallic structure is obtained by replacing the metal parts of the original structure with apertures, and the apertures with metal plates. As shown in Fig. 1, the original split-ring resonator is the dual of its complementary one. Hence, due to the duality theorem, these two structures have approximately the same resonant frequency. The main difference between SRR and CSRR is that SRR has negative permeability characteristics, while CSRR has negative permittivity characteristics. Figs. 2(a) and (b) show the S-parameter characteristics of CSRR and its negative permittivity characteristics when the physical dimensions of the CSRR are set to be: $a = 5.2$ mm, $w = 0.2$ mm, $g = 0.2$ mm and the relative permittivity of the substrate is $\varepsilon_r = 2.45$ with a thickness of 1.5 mm. It can be seen from Fig. 2 that CSRR



(a) SRR

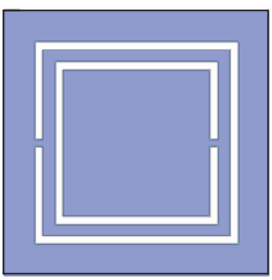

(b) CSRR

Figure 1. Geometry of (a) SRR and (b) CSRR.

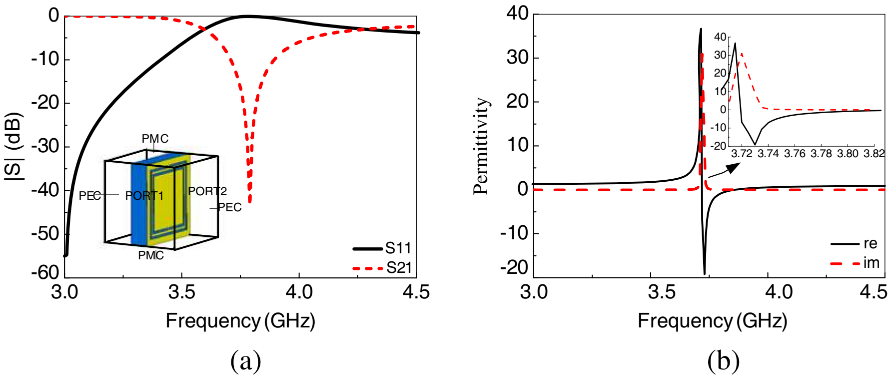


Figure 2. (a) S-parameter and (b) extracted effective permittivity of CSRR.

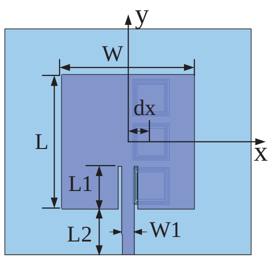
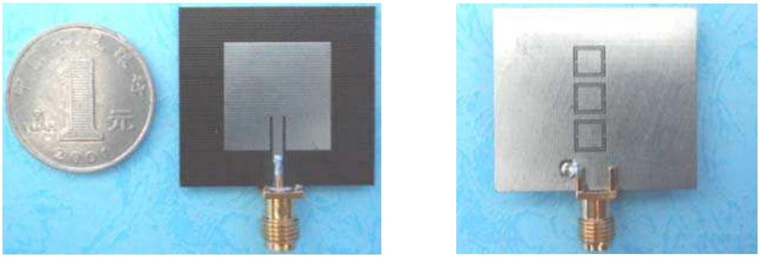


Figure 3. Configuration of dual band antenna with three CSRRs etched in the ground plane.

resonates at 3.80 GHz and its equivalent relative permittivity is truly negative from 3.72 GHz to 3.82 GHz.

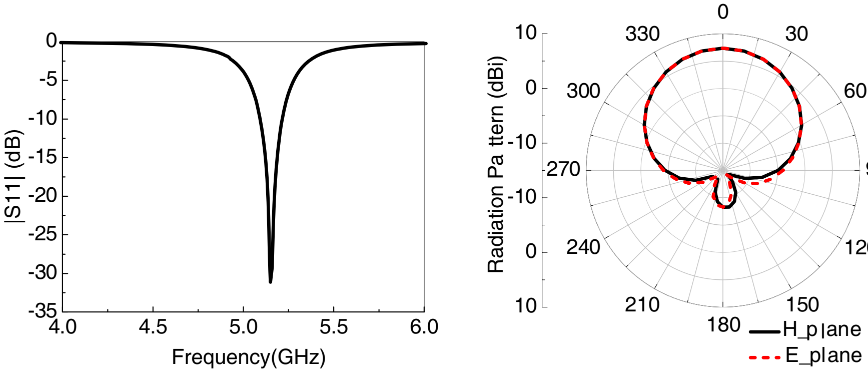
The configuration of the proposed dual-band antenna is shown in Fig. 3 [a prototype is shown in Fig. 4]. A substrate with thickness (h) of 1.5 mm and relative dielectric constant (ε_r) of 2.45 is used. The square has the dimensions of 17.7 mm $\times$ 17.5 mm and it is fed by a 50 Ω microstrip transmission line. Three CSRRs are etched in the ground plane at the position with a distance of dx away from the central line to produce a dual-band antenna. The parameters of the CSRRs are: $a = 5.2$ mm, $s = 0.2$ mm, $g = 0.2$ mm, $dx = 1.0$ mm and the separation distance between the CSRR unit-cell is 1 mm.

Compared to the dual-band antennas presented in [13, 14], the dual-band antenna proposed in this paper is designed with the CSRRs etched in the ground plane instead of in the patch, which not only keeps the patch radiating almost the same as the conventional patch



(a) (b)

Figure 4. Photograph of the fabricated antenna (a) front view, (b) back view.



(a) (b)

Figure 5. (a) Simulated reflection coefficient and (b) radiation patterns of the designed conventional patch antenna.

antenna at the frequency stimulated by the CSRRs but also has minor effect on the frequency produced by the patch. Thus, the antenna proposed has higher gain at both working bands.

3. RESULTS AND DISCUSSIONS

The antenna is simulated by using finite-element analysis based on Ansys HFSS. The resonant frequency of the patch antenna without CSRRs is 5.15 GHz. The simulated reflection coefficient and radiation characteristics of the patch antenna are shown in Fig. 5. As can be seen from Fig. 5, the patch antenna resonates at 5.15 GHz with the reflection coefficient of −31.1 dB, and the simulated radiation gain is 7.35 dBi.

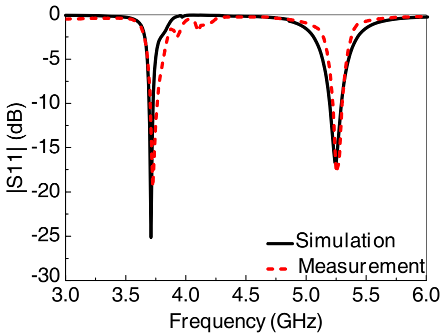
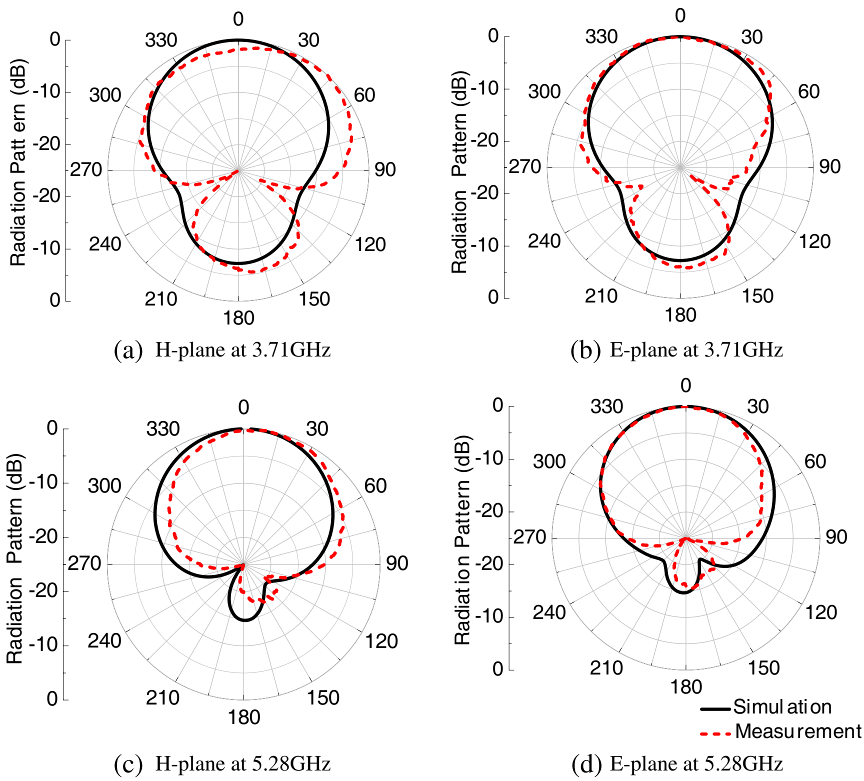


Figure 6. Simulated and measured S_{11} for the proposed dual-band antenna.



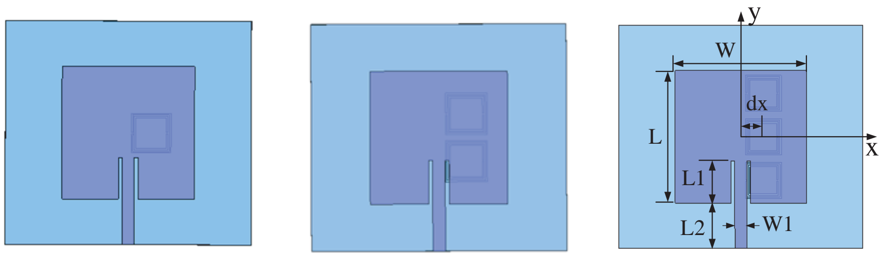
(a) H-plane at 3.71GHz

(b) E-plane at 3.71GHz

(c) H-plane at 5.28GHz

(d) E-plane at 5.28GHz

Figure 7. Normalized simulated and measured radiation patterns for the proposed antenna.



(a) With one CSRR (b) with two CSRRs (c) with three CSRRs

Figure 8. Structures of antennas with different numbers of CSRRs.

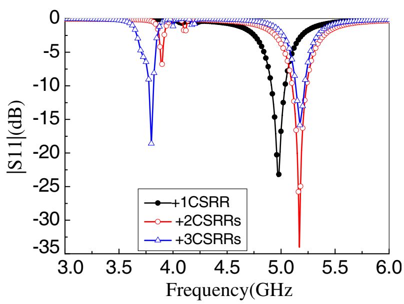


Figure 9. Simulated reflection coefficient of the antennas with different number of CSRRs.

The reflection coefficient of the fabricated antenna is measured using the vector network analyzer Agilent 8719ES. The simulated and measurement S-parameters of the proposed dual-band antenna are shown in Fig. 6, which are in good agreement. The measured reflection coefficient is -19.4 dB at 3.73 GHz and -17.8 dB at 5.25 GHz, and the fractional bandwidth for the lower band and the higher band are 1.2% and 1.5%, respectively. The simulated and measured radiation patterns are normalized and compared in Fig. 7. Again, a good agreement between the simulated and measured results is obtained. Similarly, the minor difference between them may be caused by its fabrication tolerance and measurement error.

Here the number of the CSRRs is choose to be three because when the number of CSRRs decreases it fails to stimulate a new working band. Fig. 8 shows the structures of antennas with different number of CSRRs and Fig. 9 shows the reflection coefficient of each antenna. It can be seen that the antenna with one CSRR has only one working band, which is a little lower than that of the antenna without CSRR.

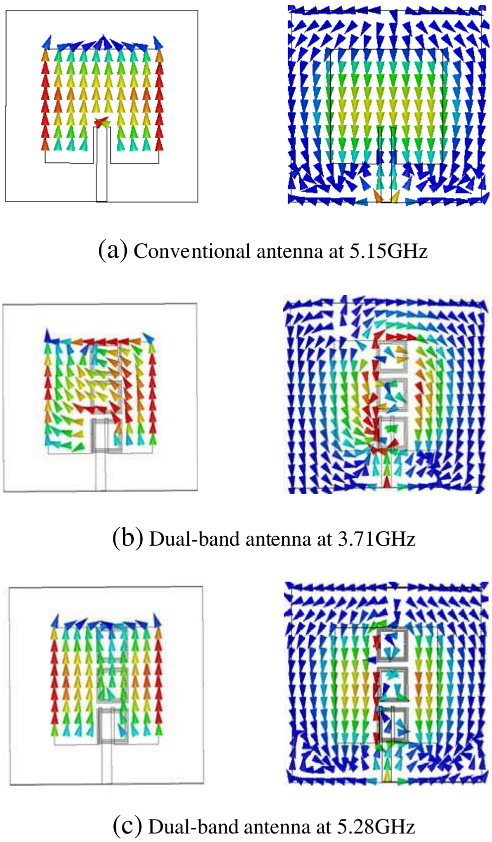


Figure 10. Current distributions on the patch (left) and ground plane (right). (a) Conventional antenna at 5.15 GHz. (b) Dual-band antenna at 3.71 GHz. (c) Dual-band antenna at 5.28 GHz.

When two CSRRs are loaded, it does show two resonant frequencies but it is very hard to make the antenna matched at the resonant frequency stimulated by CSRRs.

Figure 10 shows the current distributions on the patch and the ground plane of the conventional patch antenna at its fundamental working frequency and the CSRRs-etched dual-band antenna at two working frequencies. It can be seen that at the lower frequency, the current distributions of the proposed dual-band antenna on both patch and ground plane are similar with but somewhat different from that of the conventional patch antenna. The CSRRs are resonating at this frequency, which leads to the current to be rearranged. But due to the larger current on the ground plane, the antenna has larger back

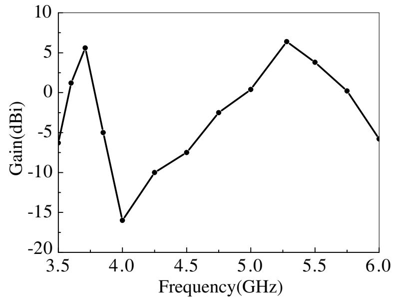


Figure 11. Peak gain versus frequency of the proposed dual-band antenna.

lobes at this frequency. By contrast, at the higher frequency the current distributions on both the patch and the ground plane are much more similar with those of the conventional patch antenna, which can be explained by the fact that the CSRRs are not resonating at this frequency and have weaker effect on the patch.

Based on the above analyses, it can be concluded that the first band is mainly inspired by the CSRRs in the ground and its resonant frequency is similar to that of CSRRs which can be mainly determined by the dimensions of the CSRRs. If the first band is the desired working band, a size reduction of antenna can be achieved. The second band is produced by the patch itself. But due to the coupling between the CSRRs and the patch, there is a small frequency shift to higher frequencies. Besides, the lower the resonant frequency of the CSRRs is, the smaller the shift is. Therefore, two resonant bands of the antenna can be fixed by adjusting the parameters of the CSRRs, which made the design of the dual-band antenna flexibly.

Figure 11 shows the gain of the proposed dual-band antenna in the broadside direction against the frequency. The maximum gains within dual-band are 5.2 dBi at 3.71 GHz and 6.4 dBi at 5.28 GHz, respectively, which are larger than those of the antenna proposed in [13].

4. CONCLUSION

In this paper, a new dual-band microstrip patch antenna with three CSRRs etched in the ground plane is presented. Due to the inclusion of CSRRs, the conventional microstrip antenna only resonating at one frequency produces two working frequencies. At each working frequency, good matching and radiation characteristics are obtained. A good agreement between simulated and measured results validates our design. The proposed CSRRs antenna provides us a new way to design dual-band antennas achieving considerable gain at both working bands. Besides, thanks to the presence of the CSRRs a size reduction of microstrip antenna can be achieved.

ACKNOWLEDGMENT

This work is supported partly by the Program for New Century Excellent Talents in University of China, and partly supported by the National Natural Science Foundation of China under Contract No. 61072017 and No. 60801040, Natural Science Basic Research Plan in Shaanxi Province of China (No. 2010JQ8013), the Fundamental Research Funds for the Central Universities, and Foundation for the Returned Overseas Chinese Scholars, State Education Ministry.

REFERENCES

1. Veselago, V. G., "Electrodynamics of substrates with simultaneously negative values of ε and μ," *Sov. Phys. Usp.*, Vol. 10, 509–514, Apr. 1968.
2. Pendry, J. B., A. J. Holden, D. J. Robbins, and W. J. Stewart, "Magnetism from conductors and enhanced nonlinear phenomena," *IEEE Trans. on MTT*, Vol. 47, 2075–2084, 1999.
3. Smith, D. R., W. J. Padilla, D. C. Wier, S. C. Nemat-Nasser, and S. Schultz, "Composite medium with simultaneously negative permeability and permittivity," *Phys. Rev. Lett.*, Vol. 84, 4184–4187, May 2000.
4. Martin, F., F. Falcone, J. Bonache, T. Lopetegi, R. Marques, and M. Sorolla, "Miniaturized coplanar waveguide stopband filters based on multiple tuned split ring resonators," *IEEE Microw. Wireless Compon. Lett.,* Vol. 13, No. 12, 511–513, Dec. 2003.
5. Karthikeyan, S. S. and R. S. Kshetrimayum, "Harmonic suppression of parallel coupled microsrip line bandpass filter using CSRR," *Progress In ELectromagnetics Research Letters*, Vol. 7, 193–201, 2009.
6. Keshvari, M. and M. Tayarani, "A novel miniaturized bandpass filter based on complementary split resonators (CSRRs) and open-loop resonators," *Progress In Electromagnetics Research Letters*, Vol. 23, 165–172, 2011.
7. Ma, J. J., X. Y. Cao, and T. Liu, "Design the size reduction patch antenna based on complementary split ring resonators,"

Proceedings of International Conference on Microwave and Millimeter Wave Technology (ICMMT), 401–402, May 2010.

8. Lee, Y., S. Tse, Y. Hao, and C. G. Parini, "A compact microstrip antenna with improved bandwidth using complementary split-ring resonant (CSRR) Loading," *IEEE Antennas and Propagtion Society Intenational Symposiun*, 5431–5434, 2007.
9. karimzadeh Baee, R., G. Dadashzadeh, and F. Geran Kharakhili, "Using of CSRR and its equivalent circuit model in size reduction of microstrip antenna," *Proceeding of Asia-Pacific Microwave Conference (APMC)*, 1–4, 2007.
10. Ke, L., G.-M. Wang, T. Xu, and H.-X. Xu, "A novle circularly polarilized antenna based on the single complementary split ring resonator," *Proceeding of Intenational Symposium on Signal Systems and Electronics (ISSSE)*, Vol. 2, 1–4, 2010.
11. Zhang, H., Y.-Q. Li, X. Chen, Y.-Q. Fu, and N.-C. Yuan, "Design of circular polarization microstrip patch antennas with complementary split ring resonator," *IET Microw. Antennas Propag.*, Vol. 3, No. 8, 1186–1190, Feb. 2009.
12. Ortiz, N., F. Falcone, and M. Sorolla, "Dual band patch antenna based on complementary rectangular split ring resonators," *Proceeding of Asia-Pacific Microwave Conference (APMC)*, 2762–2765, 2009.
13. Zhang, H., Y.-Q. Li, X. Chen, Y.-Q. Fu, and N.-C. Yuan, "Design of circular/dual-frequency linear polarization antennas based on the anisotropic complementary split ring resonator," *IEEE Trans. Antennas Propagat.*, Vol. 57, 3352–3355, 2009.
14. Li, M., M. Lu, and T. J. Cui, "Novel miniaturized dual band antenna design using complementary metamaterial," *Proceeding of Intenational Workshop on Metamaterials*, 374–376, 2008.