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A Dual-Band High Gain Antenna Based on Split Ring Resonators and Corrugated Plate

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Abstract—In this paper, a dual-band high-gain antenna based on the split ring resonators (SRRs) and corrugated plate is presented. By combining the SRRs and corrugated plate, the presented antenna resonating at different frequencies with high performance is easily achieved based on the superposition of the electric fields radiated by the SRRs and the grooves. Both the simulated and measured results show that the gain is improved by 6 dB at 12.7 GHz and 6.5 dB at 14.2 GHz respectively compared with the conventional flat antenna without grooves. Moreover, half-power beam width (HPBW) of E-plane is reduced by more than 100 degrees at 12.7 GHz and 14.2 GHz.

1. INTRODUCTION

In the last few years, the wireless communication system has been improved rapidly, and multi-frequency antennas with high-performance are needed to meet the requirement [1, 2]. Great attention has been paid to the metamaterials, especially split ring resonators (SRRs), because of their specific properties which have not been discovered in nature [3, 4]. The SRRs, proposed by Pendry et al., have been widely employed in the designs of the filters and antennas [3–7]. Different resonant frequencies of the SRR can be obtained by changing the dimension of the ring's radius, width, etc., respectively. However, the dual-band antennas loaded with the SRRs usually exhibit low gain at the resonant frequency [8, 9].

The conventional metal flat antenna is always designed without grooves. According to the experiments, the application of the surface corrugated structure can enhance the gain and narrow the beam width in microwave region [10]. Based on the above two specific properties, the surface corrugated structures have been used in the designs of antennas to improve their radiation performance [11–13].

The designs of filters and multi-band antennas based on SRRs have been reported [6–8]. However, the design based on the combination of the SRRs and corrugated plate has not been reported before. In this paper, the combination of the SRRs and corrugated plate not only enhances the gain of the antenna but also makes the designs of the flat antennas with different frequencies much easier. The dual-frequency behavior of the proposed antenna is realized by using the SRRs with different sizes. The grooves can be regarded as the secondary sources, which increase the gain of the proposed antenna efficiently. Additionally, an annular aperture is employed in the design of the presented corrugated plate, which can restrain side lobe efficiently.

2. ANTENNA STRUCTURE

The structure of the proposed antenna is shown in Fig. 1. The proposed antenna consists of an aluminum corrugated plate with an annular aperture and a pair of SRRs etched on a dielectric substrate (FR4, $\varepsilon_r = 4.4$, $\tan\delta$=0.02). The resonant frequency of the SRRs $f = 1/\sqrt{LC}$ can be obtained by reference to [15, 16], where $L = \mu_0 r(\log 32r/b - 2)$ is the effective inductance from the metal rings and

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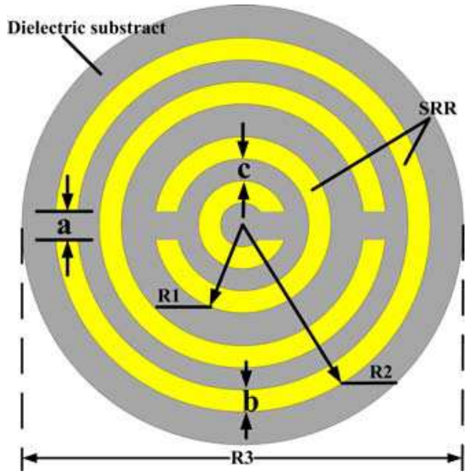
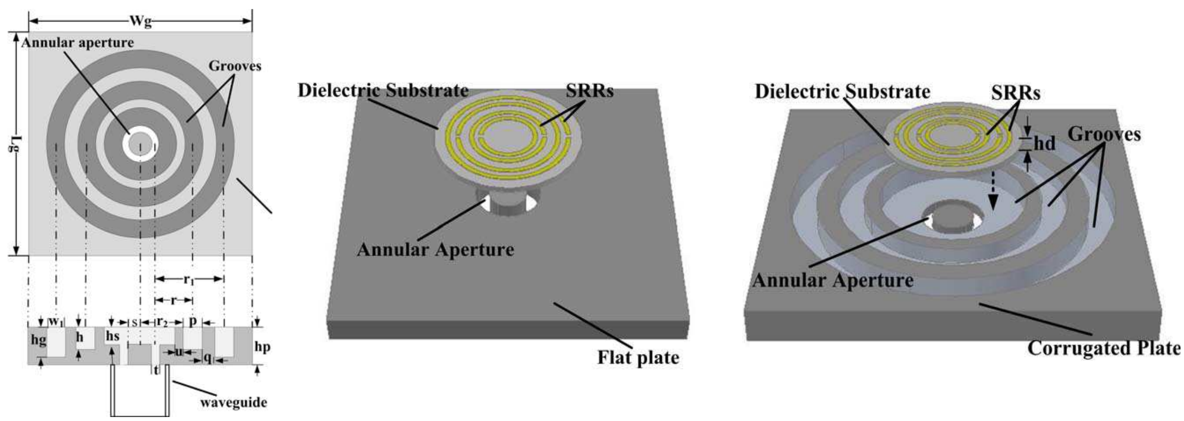


Figure 1. The SRRs etched on a dielectric substrate.



(a) (b) (c)

Figure 2. (a) Top view and cross sectional view of the aluminum corrugated plate. (b) The conventional antenna without grooves. (c) The proposed antenna.

$C = (\pi C_p + C_s)/2 - (\pi - \beta)^2 C_p^2/4C_0$ is the effective capacitance of the metal rings. Here, C_p is the capacitance between the two rings, C_s the capacitance through the split, r the radius of inner ring, and $\beta = \pi$ the angle between the two splits. The proposed antenna is fed by a regular waveguide and its size is $23 \times 10 \times 25\,\mathrm{mm}^3$. The power fed by the waveguide is coupled to the SRRs fabricated on the dielectric substrate through the central annular slot. Fig. 1 shows the dielectric substrate and SRRs which make the antenna resonate at 12.7 GHz and 14.2 GHz. The optimum dimensions of the SRRs etched on the dielectric substrate are listed as follows: $a = b = c = 0.5\,\mathrm{mm}$, $R1 = 2.6\,\mathrm{mm}$, $R2 = 7.9\,\mathrm{mm}$ and $R3 = 9\,\mathrm{mm}$. The SRR with a low physical size resonates at a high frequency.

The corrugated plate depicted in Fig. 2(a) consists of a subwavelength annular aperture surrounded by two grooves. As shown in Fig. 2(b), a conventional flat antenna without grooves has been designed to demonstrate the superiority of the proposed antenna. The dielectric substrate is placed in the center of the corrugated plate as shown in Fig. 2(c).

The groove in the center is used to place the dielectric substrate which can lower the profile of antenna to some extent. Compared with the conventional flat antenna, grooves are notched in the flat plate to generate superposition of radiated electric fields and the dielectric substrate loaded with SRRs is added in the center of the plate to realize the dual-frequency behavior of the proposed antenna. In [11, 14], in order to obtain an optimum transmission, the structure parameters can be achieved approximately as follows:

$$\begin{cases} t \ll \lambda_0/\sqrt{\varepsilon_r} \\ r \approx \lambda_0/\sqrt{\varepsilon_r} \\ r_1 \approx \lambda_0/\sqrt{(\varepsilon_r+1)/2} \\ p, w_1 \approx \lambda_0/4\sqrt{\varepsilon_r} \end{cases}, \tag{1}$$

where λ_0 is the wavelength in free space and ε_γ the relative dielectric constant of the FR4 dielectric substrate. The grooves are employed to enhance the performance of the proposed antenna. The width and depth of grooves affect the performance of the proposed antenna significantly. The distances between grooves and the center slit are close to the working wavelength which may result in the multiple source coherent superpositions. And the superposition determines the beaming effect. The proposed antenna is analyzed by the full-wave electromagnetic solver HFSS and the optimum dimensions of the corrugated plate are listed in Table 1.

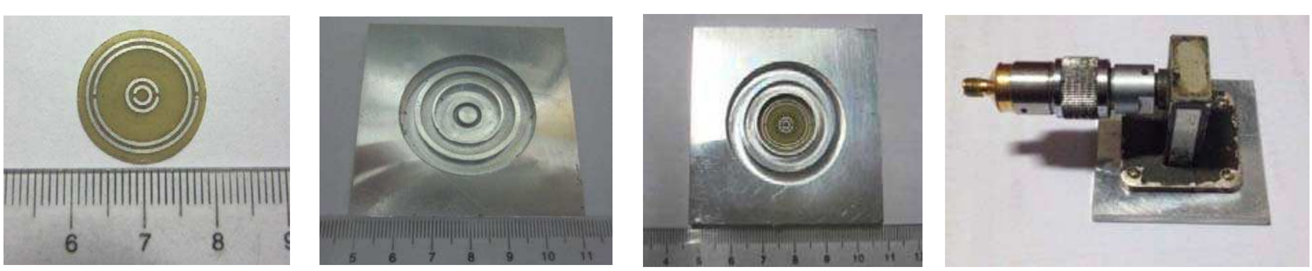
Table 1. Dimensions of the corrugated plate.

Parameter	Value/mm	Parameter	Value/mm
h	2.2	w_1	4
h_g	4.1	s	2.8
h_s	3	r	9.1
h_p	5	p	3
u	1	q	1.8
t	1.2	h_d	0.3
L_g	60	W_g	60
r_1	14.4	r_2	10

3. RESULTS AND DISCUSSION

The proposed antenna has been fabricated and measured (Fig. 3). The surface of the SRRs is tinplated to resist oxidization. The measured and simulated reflection coefficients (S_{11}) of the proposed antenna are given in Fig. 4. The measured result is obtained by Vector Network Analyzer (HP8722ET, 50 MHz–40 GHz). A good agreement has been achieved between the measured and simulated results. As shown in Fig. 4, a little frequency shift may be caused by the fabrication error.

The radiation patterns of the antennas with and without grooves are shown in Fig. 5. The measured radiation patterns of the proposed antenna are in good agreement with the simulated results. The dual-band operation of the proposed antenna is realized by the SRRs. It can be seen from Section 2 that



(a) (b) (c) (d)

Figure 3. (a) The SRRs of the fabricated antenna. (b) Aluminum corrugated plate. (c) Top view of the fabricated antenna. (d) Bottom view of the proposed antenna.

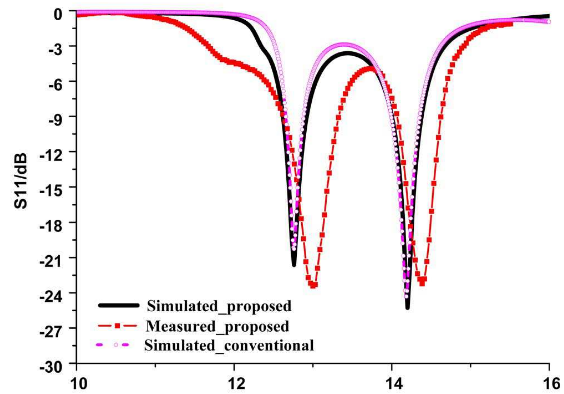


Figure 4. Simulated and measured reflection coefficient of the proposed antenna and simulated reflection coefficient of conventional antenna.

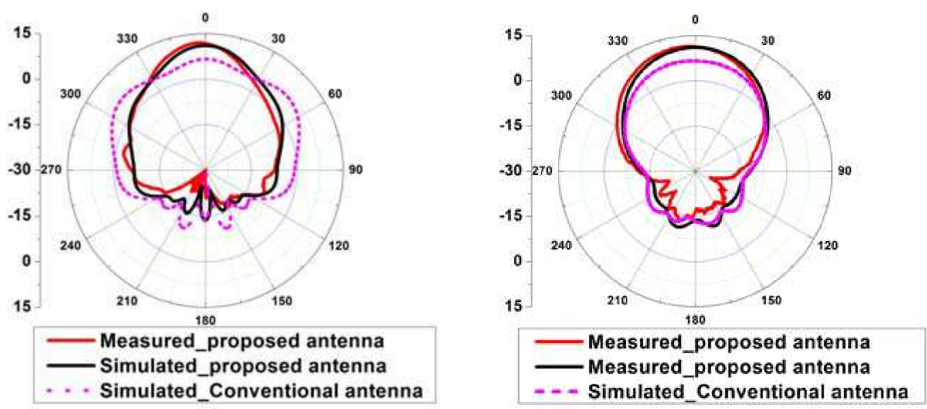
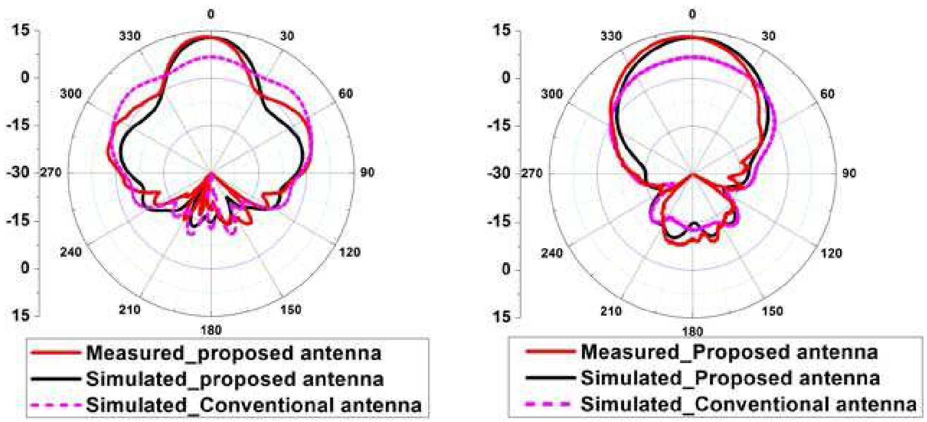


Figure 5. The radiation patterns of the conventional flat antenna without grooves and proposed antenna. (a) E-plane and (b) H-plane at 12.7 GHz.

the equivalent inductance "L" from the metal rings will be affected significantly with variable b or variable r changing. The width between the two rings and the width of split are the main factors which affect the equivalent capacitance of rings much. Moreover, variables b and r have certain effect on the capacitance "C", but the effect is relatively small. Different resonant frequencies of the proposed antenna are achieved by two sets of SRRs with different radii. The corrugated plate works at dual-band due to these two grooves which are independent of each other. The distances between the grooves and the center are different which means that the corresponding wavelengths of them are different from each other.

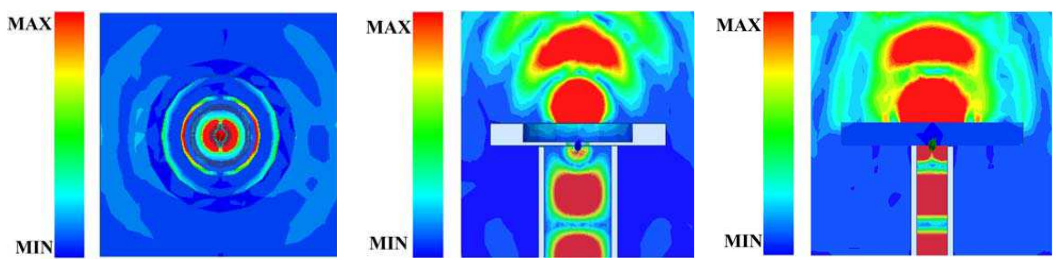
In Fig. 5, the forward gain of the conventional flat antenna is 6.1 dB. However, the grooves make the forward gain significantly increased by 6 dB at 12.7 GHz in comparison to the conventional flat antenna without grooves. The HPBW of E-plane is reduced by 102 degrees as shown in Fig. 5(a). Fig. 6 shows that the gain of the proposed antenna is 12.9 dB which is increased by 6.5 dB and the HPBW of E-plane is reduced by 124 degrees compared with the conventional flat antenna at 14.2 GHz. The results indicate that antenna's directionality is optimized. The beaming angle where coherent interference takes place is affected by the depth and width of the grooves [10]. The final dimensions of the grooves are optimized by HFSS. Due to the employment of corrugated structure, the sidelobe level is reduced, and HPBW is observably narrowed. The performance of the antenna is significantly improved.

The surface electric field distribution on the SRRs and corrugated plate is shown in Fig. 7(a). The corrugated structure results in the redistribution of the surface electromagnetic wave. The enhanced performance of the proposed antenna can be explained as the superposition of the electric fields radiated by the SRRs and the grooves. The SRRs are excited by the annular aperture. The power is mainly



(a) (b)

Figure 6. The radiation patterns of the conventional flat antenna without grooves and proposed antenna. (a) E-plane and (b) H-plane at 14.2 GHz.



(a) (b) (c)

Figure 7. (a) Surface electric field distribution of the proposed antenna. (b) Instantaneous electric field strength distribution of H-plane. (c) Instantaneous electric field strength distribution of E-plane.

radiated through the SRRs and the rest propagates along the metal-medium interface and metal-air interface. When the surface wave propagates to the edge of the grooves, it reradiates into free space. It can be seen that most surface EM waves are affected by the grooves and high field strength exists in the groove regions of the output surface which radiates the power into free space as a secondary source. Moreover, a weak electric field is generated at the edge of the plate. However, it has little effect on the performance of the antenna because of the propagation loss. The SRRs are the primary sources and the grooves can be regarded as the secondary sources. These secondary sources may lead to the coherent superposition in the far field for both frequencies by working with the primary source as shown in Figs. 7(b) and 7(c). The instantaneous electric field strength distributions of E-plane and H-plane are depicted in Figs. 7(b) and 7(c). It can be seen that the instantaneous electric field of E-plane has been modulated with the help of the grooves and the surface energy radiated into free space makes a positive contribution to the performance of the proposed antenna. The enhanced gain and reduced HPBW result from the coherent superposition of the radiated electric fields. In addition, the radiation characteristic can be improved greatly with increasing the number of grooves within limits [11].

4. CONCLUSION

In conclusion, a dual-band high-gain antenna based on the combination of SRRs and Corrugated Plate is presented. Both the simulated and measured results show that the performance of the proposed antenna has been significantly improved compared to the conventional flat antenna without grooves. The size of the SRRs is a main parameter that affects the resonant frequency of the proposed antenna. As a result, antennas radiating at different frequencies can be designed easily by changing the parameters of the SRRs.

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REFERENCES

1. Islam, M. T., M. N. Shakib, and N. Misran, "Design analysis of high gain wideband L-probe fed microstrip patch antenna," *Progress In Electromagnetics Research*, Vol. 95, 397–407, 2009.
2. Sun, X. L., S. W. Cheung, and T. I. Yuk, "Dual-band monopole antenna with compact radiator for 2.4/3.5 GHz WiMAX applications," *Microwave and Optical Technology Letters*, Vol. 55, 1765–1770, 2013.
3. Pendry, J. B., A. J. Holden, D. J. Robebins, and W. J. Stewart, "Magnetism from conductors and enhanced nonlinear phenomena," *IEEE Trans. on Microwave Theory and Tech.*, Vol. 47, 2075–2084, 1999.
4. Herraiz-Martínez, F. J., L. E. García-Muñoz, D. González-Ovejero, V. González-Posadas, and D. Segovia-Vargas, "Dual-frequency printed dipole loaded with split ring resonators," *IEEE Antennas and Wireless Propag. Lett.*, Vol. 8, 137–140, 2009.
5. Liu, Y., X. Tang, Z. X. Zhang, and X. L. Huang, "Novel nested split-ring-resonator (SRR) for compact filter application," *Progress In Electromagnetics Research*, Vol. 136, 765–773, 2013.
6. Kim, D.-O., N.-I. Jo, H.-A. Jang, and C.-Y. Kim, "Design of the ultrawideband antenna with a quadruple-band rejection characteristics using a combination of the complementary split ring resonator," *Progress In Electromagnetics Research*, Vol. 112, 93–107, 2011.
7. Bait-Suwailam, M. M., O. F. Siddiqui, and O. M. Ramahi, "Mutual coupling reduction between microstrip patch antennas using slotted-complementary split-ring resonators," *IEEE Antennas and Wireless Propag. Lett.*, Vol. 9, 876–879, 2010.
8. 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 Transaction on Antennas and Propagation*, Vol. 57, 3352–3355, 2009.
9. Xie, Y. H., C. Zhu, L. Li, and C. H. Liang, "A novel dual-band metamaterials antenna based on complementary split ring resonators," *Microwave and Optical Technology Letters*, Vol. 54, 1007–1009, 2012.
10. Huang, C., Z. Zhao, Q. Feng, and X. Luo, "A high-gain antenna consisting of two slot elements with a space larger than a wavelength," *IEEE Antennas and Wireless Propag. Lett.*, Vol. 9, 159–161, 2010.
11. Beruete, M., I. Campillo, J. S. Dolado, and J. E. Rodriguez-Seco, "Enhanced microwave transmission and beaming using a subwavelength slot in corrugated plate," *IEEE Antennas and Wireless Propag. Lett.*, Vol. 3, 328–330, 2004.
12. Beruete, M., I. Campillo, J. S. Dolado, J. E. Rodríguez-Seco, E. Perea, F. Falcone, and M. Sorolla, "Dual-band low-profile corrugated feeder antenna," *IEEE Antennas Wireless Propag. Lett.*, Vol. 54, 340–350, 2006.
13. Huang, C., Z. Zhao, Q. Feng, C. Wang, and X. Luo, "Grooves-assisted surface wave modulation in two-slot array for mutual coupling reduction and gain enhancement," *IEEE Antennas and Wireless Propag. Lett.*, Vol. 8, 912–915, 2009.
14. García-Vidal, F. J. and L. Martín-Moreno, "Transmission and focusing of light in one-dimensional periodically nanostructured metals," *Physical Review B*, Vol. 66, 155412-1–155412-10, 2002.
15. Simovski, C. R., P. A. Belov, and S. He, "Backward wave region and negative material parameters of a structure formed by lattices of wires and split-ring resonators," *IEEE Transaction on Antennas and Propagation*, Vol. 51, 2582–2591, 2003.
16. Chen, J.-Y., W.-L. Chen, J.-Y. Yeh, L.-W. Chen, and C.-C. Wang, "Comparative analysis of split-ring resonators for tunable negative permeability metamaterials based on anisotropic dielectric substrates," *Progress In Electromagnetics Research M*, Vol. 10, 25–38, 2009.