Broadband Design of CP Reflectarray Element with Split-ring-related Structure and Explanation of Its Scattering Mechanism

Fan Wu and Junhong Wang
Institute of Lightwave Technology, Beijing Jiaotong University, Beijing 100044, China
bjtuwf@gmail.com, wangjunh@bjtu.edu.cn

***Abstract* –A new broadband CP reflectarray element based on split-ring-related structure is presented in this paper, which exhibits a bandwidth from 10.1 GHz to 18.3 GHz. In order to see the physical insight behind the multi-band and broadband property of the circular polarized (CP) element, the scattering mechanism of the element is investigated, and intuitive explanations are given. The results in this paper are also helpful to understand the broadband mechanism of the CP relfectarray element proposed in recent literatures.**

***Index Terms* — Broadband, circular polarization, reflectarray antenna, scattering mechanism, split-ring-related element.**

I. Introduction

Circular polarized reflectarray provides attractive features like high gain, spatial feeding configuration and resistance against environment interference. Unfortunately, for most applications, bandwidth of reflectarray is limited by the narrow bandwidth characteristic of its microstrip elements [1, 2]. Previous researches have been succeeded in carrying out some multi-band and broadband CP designs using split-ring-related elements [3, 4]. However, the reason of multi-band or broadband property for CP reflectarray in these studies was explained simply from the view of resonant characteristics of different split-rings involved in the element [4]. In this paper, a new broadband CP element based on split-ring-related structure is proposed, and the scattering mechanism of this CP element is presented by analyzing the scattering property of two orthogonal LP waves involved in the CP wave.

II. Broadband Design of CP Element

In this paper, a modified CP relectarray element of split-ring-related structure for multi-band operation is proposed first, as shown in Fig. 1. The direction of the two inner ring slots (denoted by S_3) is designed 40° clockwise from the direction of the two outer ring slots (denoted by S_1) or 50° counter-clockwise from the connecting strips (denoted by S_2). The element is backed by a grounded substrate with dielectric constant of ε_r = 2.2 and thickness of 1.575 mm. The two short connecting strips play important role in generating new resonant paths of the structure, and make the element exhibit a tri-band CP operating capability corresponding to 9.3 GHz, 9.7 GHz and 15 GHz respectively, as depicts in Fig. 1. Then, an additional foam layer is inserted between the ground plane and substrate, which broadens the three separated operation bands and melts them together, as depicted in Fig. 2. The broadband realization actually benefits from the low Q factor of the foam added structure. It can be found from Fig. 2 that the frequency band of the final element covers a bandwidth from 10.1 GHz to 18.3 GHz.

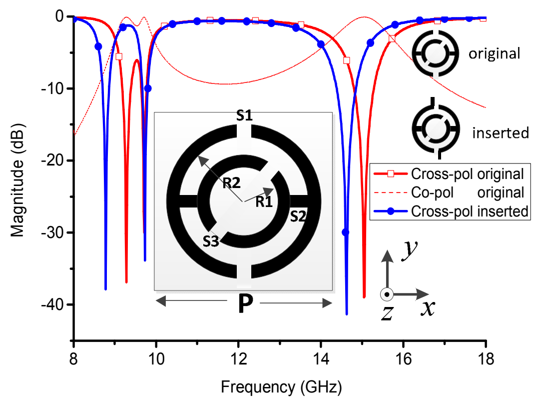

Fig. 1. Top view of the modified split-ring element and the magnitude of back-scattering circularly polarized fields, P = 15 mm, R_1 = 2 mm, R_2 = 3.5 mm, ring widths W = 1 mm, S_1 = S_3 = 0.8 mm, S_2 = 0.6 mm.

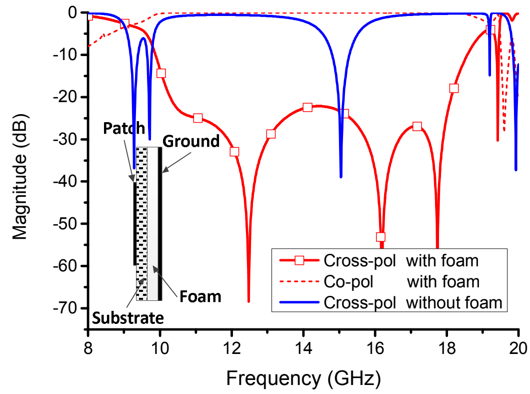

Fig. 2. Cross-section of the proposed broadband CP reflectarray element structure and magnitude of the back-scattering circularly polarized fields.

III. Scattering Mechanism of the Split-ring-related Element

The element rotation technique for designing CP reflectarray was first reported by Huang [5], where the patch element is connected with two orthogonal microstrip delay lines with different lengths. Later, an element of split-ring structure was developed by Han [6] for simplifying the CP element structure. The reversal of polarization due to the ground plane is canceled out by the presence of these CP elements, and an element rotation of $\Delta\varphi$ results in a $2\Delta\varphi$ phase delay of the back-scattering wave.

Fig. 3 shows the basic split-ring element. Using two orthogonal linear polarized incident waves with the same amplitude to excite the element respectively at the operation frequency, we get the corresponding surface current distributions, as shown in Fig. 3. A high level of resonance can be observed when excited by *y*-polarized incident wave, while the element exhibits a relatively low level of resonance when illuminated by *x*-polarized wave. As we know, a CP wave can be seen as a superposition of two orthogonal LP waves, and when the phase delays of these two back-scattering orthogonal LP components caused by unsymmetrical structure of split-ring differ by ±180°, pure back-scattering CP wave can be detected, maintaining the sense of polarization of the incident CP wave.

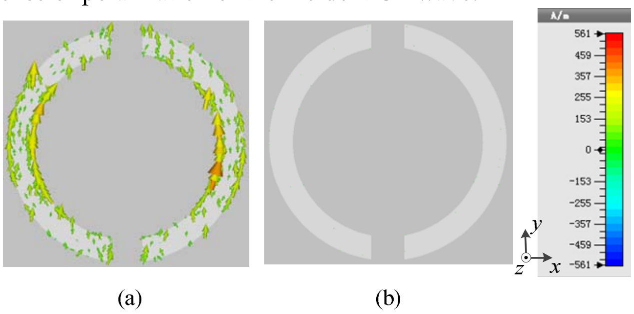

Fig. 3. Surface current distribution of split-ring element excited by: (a) *y*-polarized incident wave and (b) *x*-polarized incident wave.

In order to understand the scattering mechanism of the proposed element shown in Fig. 1, the phase differences of the corresponding two back-scattering waves at three frequencies are shown in Fig. 4. As for the 9.3-GHz curve and 15-GHz curve, phase difference between two orthogonal back-scattering field components closing to -180° is observed when element rotation angle is φ = 0°. So, at frequencies of 9.3 GHz and 15 GHz, capability of the element for regenerating CP wave is realized by two orthogonal resonant paths in the structures along *x*- and *y*-directions. This can also be proved by adding two stubs to the outer split-ring along *y*-direction, as shown in Fig. 1, and then shifting of the resonant frequencies can be observed. For the operation frequency of 9.7 GHz, the two orthogonal directions in which a CP wave can be regenerated are the direction along two inner-ring slots (S_3) and its orthogonal direction, as depicted by Fig. 4.

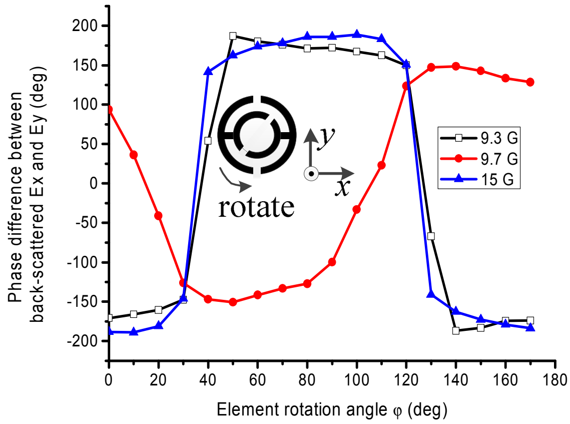

Fig. 4. Phase difference between back-scattering field components *Ex* and *Ey* as function of counter-clockwise rotating angle of the element.

IV. Conclusion

This paper presents the design of a broadband CP reflectarray element, and the multi-band and broadband property of the CP reflectarray element is analyzed. It is shown that the unsymmetrical element structure as a whole exhibits different resonant levels when excited by LP incident wave with different polarization direction. If a pair of orthogonal resonant paths can be found in the structure, and the difference of phase delays of the scattering field components corresponding to the resonant paths is ±180°, then the element will generate the CP scattering wave. Moreover, the bandwidth of the CP reflectarray element is likely depending more on the low Q factor property of structure, rather than the multiple split-ring structure itself.

Acknowledgment

This work was supported in part by NSFC under Grant no. 61331002 and in part by the 973 Program under Grant no. 2013CB328903.

References

[1] D. M. Pozar, "Bandwidth of Reflectarrays", *Electron. Lett.*, vol. 39, pp. 1490-1491, October 2003.

[2] Encinar, J. A. and Zornoza. J. A., "Broadband design of three-layer printed reflectarrays," *IEEE Trans. Antennas Propagat.*, vol. 51, No. 7, pp. 1662-1664, Jul. 1998.

[3] C. Han, J. Huang, and K. Chang, "A high efficiency offset-fed X/Ka-dual-band reflectarray using thin membranes," *IEEE Trans. on Antennas and Propagat.*, vol. 53 no. 9, pp. 2792-2798, Sep. 2005.

[4] M. Zhao, G. Zhang, X. Lei, J. Wu, and J. Shang, "Design of New Single-Layer Multiple-Resonance Broadband Circularly Polarized Reflectarrays," *IEEE Antennas Wireless Propagat. Lett.*, vol, 12, pp. 356-359, 2013.

[5] J. Huang and R. J. Pogorzelski, "A Ka-band microstrip reflectarray with variable rotation angles," *IEEE Trans. Antennas Propagat.*, vol. 46, No. 5, pp. 650-656, May 1998.

[6] C. Han and K. Chang, "Ka-band reflectarray using ring elements," *Electron. Lett.*, vol. 39, March 2003, pp. 491-493.