A High-Efficiency Single-Layer Dual-Band Circularly Polarized Reflectarray Antenna

Ruyuan Deng, Shenheng Xu, and Fan Yang
State Key Laboratory on Microwave and Digital Communications
Tsinghua National Laboratory for Information Science and Technology
Department of Electronic Engineering, Tsinghua University, Beijing, China, 100084
dengruyuan@126.com, shxu@tsinghua.edu.cn, fan_yang@tsinghua.edu.cn

***Abstract* – A single-layer dual-band circularly polarized reflectarray antenna is presented for satellite communications. This reflectarray antenna element is composed of a concentric split-ring combination with a modified Malta Cross, where variable rotation angle and variable element size techniques are utilized to compensate the phase delay, respectively. A reflectarray with a circular aperture of 420 mm in diameter is designed and analyzed. The numerical results demonstrate that this reflectarray can achieve aperture efficiency of 66% at 20 GHz and 55% at 30 GHz, respectively.**

***Index Terms* — Circular polarization, dual-band, satellite communications, reflectarray**

I. INTRODUCTION

Printed reflectarray antennas possess the desirable features of reflectors and phased-arrays and have emerged as a new generation of high-gain antennas due to the high radiation efficiency, low profile, significant simplification of the feeding system, and low cost, as described in [1]. They generally consist of an array of radiating elements that are illuminated by a primary source to produce a collimated or shaped beam. The phase compensation can be achieved by tuning the reflection phase of each reflectarray element independently. However, the main limitation to printed reflectarray antenna performance is the narrow bandwidth, as demonstrated in [2]. Bandwidth limitation is an inherent characteristic of printed reflectarrays and much effort has been made to overcome this restriction, such as stacked patches of variable size [3], true-time delay [4], and sub-wavelength techniques [5].

In this paper, a circularly polarized reflectarray antenna is designed for the increasing demands of Ka-band direct broadcast satellite (DBS) services. A novel combination phasing element is proposed, namely, the concentric split-ring combination with modified Malta Cross element [6]. The phase compensation is accomplished by using variable rotation technique [7] at 20 GHz, and variable element size [8] at 30 GHz, respectively. This reflectarray is designed to achieve a left-handed circularly polarized (LHCP) pencil beam at 20 GHz, and a right-handed circularly polarized (RHCP) pencil beam at 30 GHz, respectively. After introducing the element structure and its optimization procedure in Section II, a reflectarray is designed and analyzed in Section III. Finally, some concluding remarks are given in Section VI.

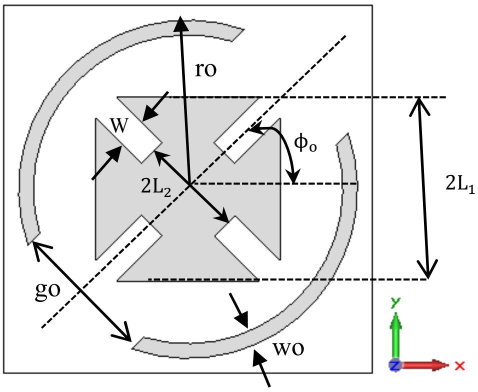

Fig. 1 Geometry of the proposed reflectarray element.

II. REFLECTARRAY ELEMENT ANALYSIS AND OPTIMIZATION

The proposed phasing element geometry is depicted in Fig. 1, which is printed on a 0.762 mm Arlon Di880 grounded substrate with $\epsilon_r = 2.2$ and $\tan\delta = 0.0009$. This novel element is composed of two parts. The outer one is a concentric split-ring, which is characterized by its radius r_o, gap width g_o, line width w_o and rotation angle ϕ_o. The inner one is the modified Malta Cross, which was first introduced in [6] to design a single-frequency broadband reflectarray antenna, and its geometrical parameters are the element size L_1, the slots length L_2, and the slots width W.

The commercial software CST microwave studio suite is utilized for the element analysis and optimization procedure. Periodic boundary conditions (PBC) are placed around a single unit cell to model a two dimensional infinite array environment while a plane wave is launched to illuminate upon the unit cell with an incidence angle of 25°. For the purpose of avoiding grating lobes, the periodicity is set to be 5 mm, which is equal to half wavelength in free space at 30 GHz. In order to utilize the rotation angle technique, gaps must be introduced in the concentric-ring element structure so that the incoming single-sensed circular polarization (CP) signal could recognize the rotation direction and re-radiate with the same-sensed CP signal. In other words, by adding gaps to the ring structure and thus adding capacitance, the ring elements are transformed from a none-polarization-sensed element to a single-sensed CP element. However, for each value of ϕ_o, g_o must be optimized to obtain a minimum cross-polarization reflection. As for the modified Malta Cross element, it is a none-polarization-sensed element, thus the variable element size technique can be used to obtain the required reflection phase.

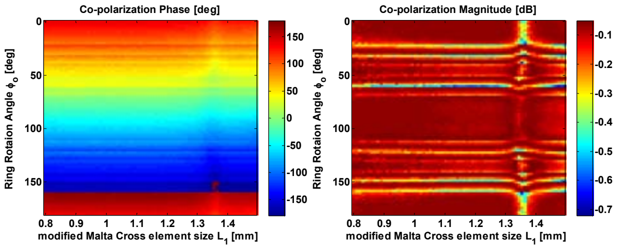

Fig. 2 Co-polarization reflection coefficient at 20 GHz: phase (left) and magnitude (right).

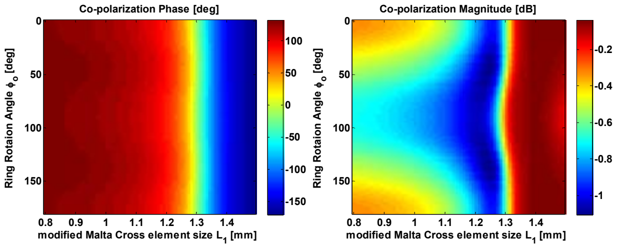

Fig. 3 Co-polarization reflection coefficient at 30 GHz: phase (left) and magnitude (right).

The simulated reflection coefficients of the proposed element at 20 GHz and 30 GHz are presented in Figs. 2 and 3, respectively. The phase responses at two bands are well isolated after the optimization, which are primarily determined by the rotation angle ϕ_o at 20GHz and by the element size L_1 at 30GHz, respectively. Moreover, the element loss at 20 GHz has been considerably reduced, which is approximately −0.15 dB.

III. REFLECTARRAY DESIGN

Using this proposed phasing element with optimized reflection coefficients, an offset reflectarray antenna is designed. The reflectarray aperture is circular with diameter of 420 mm. It is illuminated by a CP feed antenna located at an offset angle of 25° and the *f*/*D* ratio is 0.618, providing a proper illumination with –10 dB taper. The designed main beam is also tilted 25° away from the boresight of the reflectarray aperture.

A numerical code has been implemented to design and analyze reflectarray antennas, which calculates the radiated far field by the equivalent currents technique [9]. The required compensation phase for each element is calculated as [8]

$$\varphi_{\rm mn} = k\times\left(r_{\rm fmn} - \hat{u}_0\cdot\vec{r}_{\rm mn}\right) + 2\pi N,\ \ N = 0, \pm1, \pm2, \cdots$$

where k is the free space wavenumber, r_{fmn} is the spatial distance between the feed and the mnth element, $\hat{u}_0$ is the unit vector in the main beam direction, $\vec{r}_{mn}$ is the position vector of the mnth element. The compensation phase distribution and the element configurations can thus be determined. Finally, the simulated radiation patterns are plotted in Fig. 4. At the center frequencies of interest, the computed gains are 36.56 dBi at 20 GHz and 39.35 dBi at 30 GHz, which are equivalent to aperture efficiency of 66% and 55%, respectively. It proves that by carefully tuning the element parameters and isolating the mutual interference, high radiation efficiency at both frequencies can be achieved in a single-layer dual-band reflectarray antenna. It is also observed that the radiation patterns are well-defined with sidelobe levels below −22 dB and the cross polarization levels below −25 dB, which further validates the effectiveness of the proposed design.

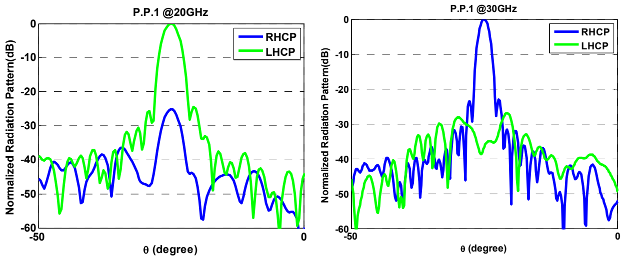

Fig. 4 Computed far-field radiation pattern in the offset plane: 20 GHz (left) and 30 GHz (right).

IV. CONCLUSION

In this paper, a high efficiency single-layer dual-band circularly polarized reflectarray antenna has been designed and analyzed. A novel phasing element, namely, the concentric split-ring combination with modified Malta Cross is introduced and optimized to achieve a LHCP pencil beam at 20 GHz and a RHCP pencil beam at 30 GHz, respectively. The computed gains are 36.56 dBi and 39.35 dBi, which are equivalent to aperture efficiency of 66% and 55%, respectively.

REFERENCES

[1] J. Huang and J. A. Encinar, *Reflectarray Antennas*: Wiley Online Library, 2008.

[2] D. M. Pozar, "Bandwidth of reflectarrays," *Electronics Letters,* vol. 39, pp. 1490-1491, 2003.

[3] J. A. Encinar, "Design of two-layer printed reflectarrays using patches of variable size," *IEEE Trans. Antennas Propag.,* vol. 49, pp. 1403-1410, 2001.

[4] E. Carrasco, J. A. Encinar, and M. Barba, "Bandwidth Improvement in Large Reflectarrays by Using True-Time Delay," *IEEE Trans. Antennas Propag.,* vol. 56, pp. 2496-2503, 2008.

[5] P. Nayeri, F. Yang, and A. Z. Elsherbeni, "Broadband Reflectarray Antennas Using Double-Layer Subwavelength Patch Elements," *IEEE Antennas and Wireless Propagation Letters,* vol. 9, pp. 1139-1142, 2010.

[6] P. De Vita, A. Freni, G. L. Dassano, P. Pirinoli, and R. E. Zich, "Broadband element for high-gain single-layer printed reflectarray antenna," *Electronics Letters,* vol. 43, 2007.

[7] J. Huang and R. J. Pogorzelski, "A Ka-band microstrip reflectarray with elements having variable rotation angles," *IEEE Trans. Antennas Propag.,* vol. 46, pp. 650-656, May 1998.

[8] D. M. Pozar, S. D. Targonski, and H. D. Syrigos, "Design of millimeter wave microstrip reflectarrays," *Antennas and Propagation, IEEE Transactions on,* vol. 45, pp. 287-296, 1997.

[9] P. Nayeri, A. Z. Elsherbeni, and F. Yang, "Radiation Analysis Approaches for Reflectarray Antennas [Antenna Designer's Notebook]," *Antennas and Propagation Magazine, IEEE,* vol. 55, pp. 127-134, 2013.