Analysis and Design of Beam-scanning Reflectarray with Circular Polarization

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Abstract— The design of a beam-scanning reflectarray with circular polarization is presented. The element allows tuning of the reflected signal's phase over a 360 range, and the spiral antenna is adopted as the feed of the reflectarray. By full-wave commercial simulation software HFSS, the model of the antenna is simulated and optimized. Two reflectarray prototypes with different compensate methods for phase delays are designed and proceed, of which one is with different length of stubs, the other is with different rotated angle.

1. INTRODUCTION

A microstrip reflectarray antenna [1, 2], being the mixture of a reflector antenna and a planar phased array antenna, uses a suitable phasing scheme for its elements to convert a spherical wave produced by its feed into a plane wave.

Printed reflectarrays consist of an array of microstrip elements illuminated by a primary radiator, typically represented by a horn antenna. The printed elements, giving a flat reflecting surface, are designed to reradiate the incident field with a planar phase front in a prescribed direction. The use of microstrip technology gives significant improvements, in terms of low-cost, less-weight, and easy installation, with respect to standard parabolic reflectors. On the other hand, the feeding mechanism inherited from reflector antennas avoids the disadvantages, in terms of complexity and losses, due to the feeding networks usually adopted in phased arrays.

Various configurations of passive printed reflectarrays, adopting different tuning mechanisms, have been introduced in literature [3]. Dynamic phase control techniques have been also investigated for the design of active reflectarrays [4], and significant achievements have been obtained in the improvement of bandwidth performances [5]. Analysis methods based on different approaches, such as that assuming an infinite array model [6] or that considering each radiator as an isolated element on a grounded dielectric substrate [7], have been considered in literature, and various numerical methods have been implemented for both single-layer and multilayer reflectarrays. A very efficient synthesis technique based on the intersection approach [8] and properly taking into account both the amplitude and the phase of the field reflected by the reflectarray unit cell, has

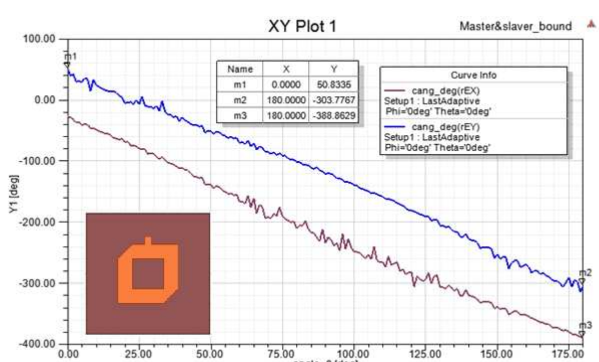

Figure 1: Top view of reflectarray element configuration and simulation reflection phase with different rotate angle.

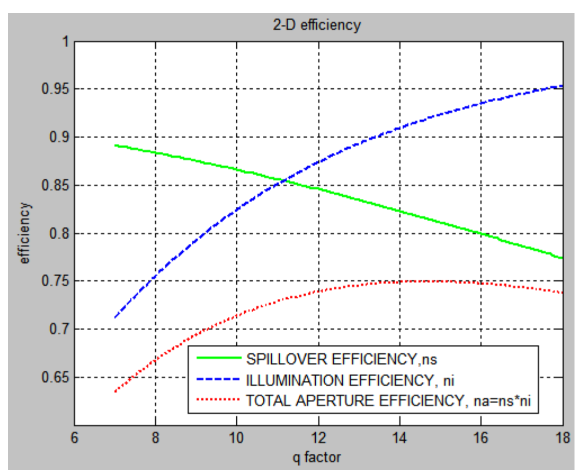

Figure 2: Microstrip reflectarray spillover and illumination efficiencies versus feed pattern shape.

been developed and applied in [9]. Experimental methods alternative to the standard waveguide simulator approach [10] have been developed, with the adoption of open resonator [11] and near field [12] techniques for the characterization of both passive and active reflectarray unit cell.

In this paper, the design of beam-scanning reflectarray with circular polarization is presented. A quadrilateral ring microstrip patch is chosen as reconfigurable reflectarray element, which allows tuning of the reflected signal's phase over a 360 range, and the spiral antenna is adopted as the feed of the reflectarray. Three fixed-beam reflectarray prototypes with different rotated angle for compensate phase delays is designed and proceed.

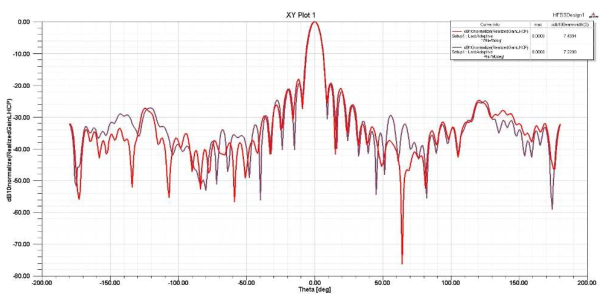

Figure 3: Simulation plane pattern of reflectarray at $\theta = 0°$ and $\theta = 90°$.

Figure 4: Photograph of the reflectarray prototype into the anechoic chamber.

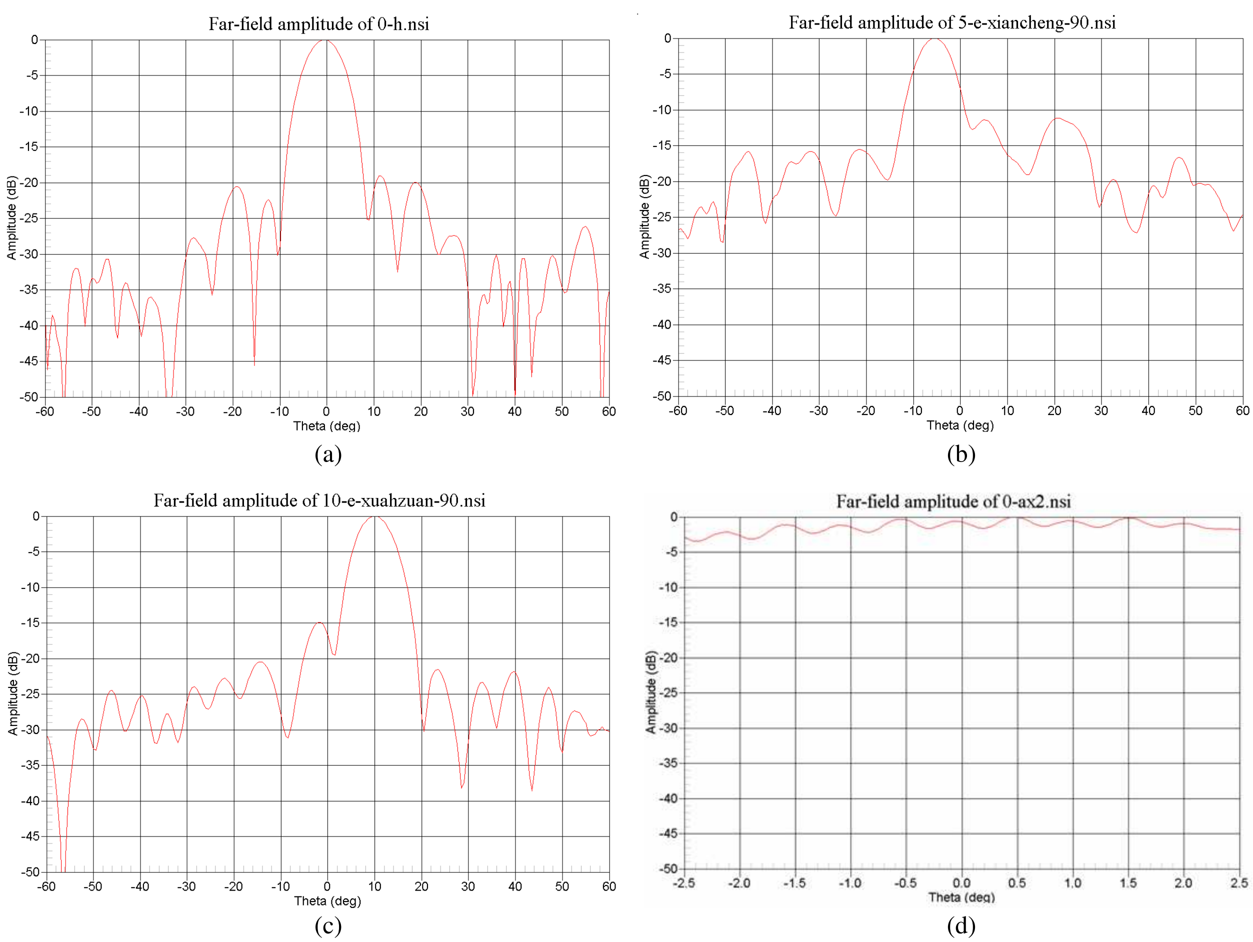

Figure 5: Measured radiation patterns for various beam direction, (a) 0°, (b) 5°, (c) 10°, (d) axial ratio.

2. ANALYSIS AND SIMULATION

In a circularly polarized microstrip reflectarray, the circular polarization can be achieved by many types. Considering connecting with the phase shifts, we chose the quadrilateral ring microstrip patch with short stub which is shown in Fig. 1. By the software HFSS, the performance of circular polarization and impedance matching can be optimized.

To each patch element is rotated its angle in Z axis to compensate for the phase delay over the path from the illuminating feed. In theory, the reflection phase is 36 degree when the element is rotated by 180 degree from its initial position; the phase curve of the X component of E field is parallel to that of Y component and the difference of each other is 90 degree or 270 degree. The simulation results in general accord with above conclusions, which are shown in Fig. 1.

The two primary factors that govern the efficiency of the microstrip reflectarray are very similar to those for the parabolic reflector. These are the aperture illumination efficiency and the feed spillover efficiency [13]. The efficiencies are plotted against the feed pattern shapes in Fig. 2 with a given reflectarray diameter of 130 mm at 21 GHz and an f/D ratio of 0.85.

The model of reflectarray antenna with phase-delay compensation by rotation of identical elements and a spiral antenna as feed is shown in the upper left corner of the Fig. 3. Simulation plane pattern of reflectarray at $\theta = 0°$ and $\theta = 90°$ are also shown in Fig. 3. The gain 3 dB beam width and axial ratio are 25.3 dB, 7.3° and 0.9 dB respectively.

3. REFLECTARRAY PROTOTYPE AND MEASUREMENT

Photograph of the reflectarray prototype into the anechoic chamber is shown in Fig. 4. Three microstrip reflectarray prototypes by rotated angle for compensate phase delays form the feed is proceed and measured, of which with different beam directivity (0° 5° 10°). Two methods are adopted to achieve beam deviation, one is changing the length of stub and the other is rotation of identical elements. For the approximate simulation of two bits phase shifts, the phase difference between elements is set to 0° 90° 180° and 270°. So the first sidelobe of scanning antenna is relative high.

Measured radiation patterns for three reflectarray antennas are shown in Fig. 5. Relative good agreement are found between simulation and measured results.

4. CONCLUSION

The design of circular polarization reflectarray consists of an quadrilateral ring microstrip patch, printed on the TLY-5 substrate is analysis, simulated and measured. For the approximate simulation of two bits phase shifts, two reflectarray prototypes with different compensate methods for beam-scanning are proceed, of which one is with different length of stubs, the other is with different rotated angle. Due to the four states of the switch phase shifter, the first sidelobe of antenna is high, up to -11.5 dB when beam scanning to 5°.

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REFERENCES

1. Malagasi, C. S., "Microstrip disc element reflectarray," *Electron. Aerospace Syst. Conv.*, Sep. 1978.
2. Kelkar, A., "FLAPS: Conformal phased reflecting surfaces," *Proc. IEEE National Radar Conf.*, 58–62, Los Angeles, CA, Mar. 1991.
3. Pozar, D. M. and T. A. Metzler, "Analysis of a reflectarray antenna using microstrip patches of variable size," *Electronics Letters*, Vol. 29, No. 8, 657–658, 1993.
4. Hum, S. V., M. Okoniewski, and R. J. Davies, "Realizing an electronically tunable reflectarray using varactor diode-tuned elements," *IEEE Microwave and Wireless Components Letters*, Vol. 15, No. 6, 422–424, 2005.
5. Encinar, J. A., "Design of two-layer printed reflectarrays using patches of variable size," *IEEE Transactions on Antennas and Propagation*, Vol. 49, No. 10, 1403–1410, 2001.
6. Pozar, D. M., "Microstrip reflectarrays: Myths and realities," *Proceedings of the International Symposium on Antennas (JINA'04)*, 175–179, Nice, France, 2004.

7. Venneri, F., G. Angiulli, and G. Di Massa, "Design of microstrip reflectarray using data from isolated patch analysis," *Microwave and Optical Technology Letters*, Vol. 34, No. 6, 411–414, 2002.
8. Bucci, O. M., G. Franceschetti, G. Mazzarella, and G. Panariello, "Intersection approach to array pattern synthesis," *IEE Proceedings H*, Vol. 137, No. 6, 349–357, 1990.
9. Costanzo, S., F. Venneri, G. Di Massa, and G. Angiulli, "Synthesis of microstrip reflectarrays as planar scatterers for SAR interferometry," *Electronics Letters*, Vol. 39, No. 3, 266–267, 2003.
10. Tsai, F. C. E. and M. E. Bialkowski, "An equivalent waveguide approach to designing of reflect arrays with the use of variablesize microstrip patches," *Microwave and Optical Technology Letters*, Vol. 34, No. 3, 172–175, 2002.
11. Costanzo, S., G. DiMassa, and O. H. Moreno, "Improved open resonator technique for dielectric characterization," *Proceedings of the 6th European Conference on Antennas and Propagation (EuCAP'12)*, 2127–2129, 2012.
12. Costanzo, S. and G. Di Massa, "Far-field reconstruction from phaseless near-field data on a cylindrical helix," *Journal of Electromagnetic Waves and Applications*, Vol. 18, No. 8, 1057–1071, 2004.
13. Rudge, A. W., K. Milne, A. D. Olver, and P. Knight, *The Handbook of Antenna Design*, Vol. 1, 169–172, London, England, Peter Peregrinus Ltd., 1982.