E-shaped Element Design for Linearly Polarized Transmitarray Antennas

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Abstract **– This paper proposes a novel transmitarray element consisting of 3-layer identical E-shaped metal patch. Several transmitarray elements of different shapes are analyzed. The E-shaped unit is developed to alleviate the cross polarization level in this linear-polarized transmitarray design, and a smooth phase curve is obtained. Through simulation, the proposed 3-layer E-shaped unit reaches a phase range of 270 degrees above −1dB transmission magnitude, and an average 50dB cross polarization discrimination.**

Index Terms **— E-shaped, lens array, linear-polarized, low cross-polarization, transmitarray.**

I. INTRODUCTION

High gain antennas are required in modern communication systems, such as satellite communications and point-to-point data relay, etc. The transmitarray antenna, also known as lens array or discrete lenses, is a potential candidate for these applications. Combined with the features of planar arrays and space feeding, it can avoid the complexity of fabrication and the power dissipation of feeding network [1]. Furthermore, the feed blockage effect, which is a critical issue in reflectarray designs, is eliminated as the feed is placed at the opposite side of the radiation direction. Nevertheless, it is a major challenge to get sufficient phase range above satisfying transmission magnitude in a transmitarray unit design, as the illuminating wave would be almost totally reflected in some specific frequencies or configurations.

The basic concept of a high gain transmitarray antenna is to apply the proper phase shift to each unit on the array individually and to get a constant phase front in the desired radiation direction. A unit embedded with transmission line, which connects two patches on the opposite sides of substrate, was proposed when the printed circuit technology was getting popular [2]. The transmission line conveys energy and also controls the phase of the transmitting wave. Several ways of wave coupling are developed in the following years, such as aperture coupling [3] and coplanar waveguide slot coupling [4]. However, demanding precision is required in the fabrication and calibration of the receive-transmit type unit. Another type of transmitarray unit was recently introduced from the optics theory, namely gradient-index flat lens [5]. By altering the equivalent permittivity of the dielectric, the transmission phase of each unit is set respectively to form an equiphase front, but it is with relatively high profile and weight. The third type of transmitarray unit is realized in the way of aperiodic frequency selective surfaces (FSS) [6]. Several identical (or similar) layers are cascaded with specified layer spacing. The geometry of this unit is concise and convenient to fabricate.

In this paper, several FSS-type elements for linearly polarized transmitarrays are investigated to complement the phase vacancy of a dipole element. By comparing the cross polarization level, the E-shaped element shows a better performance. A 3-layer E-shaped element design is simulated to verify its phase range and cross polarization discrimination.

II. EVOLUTION OF THE E-SHAPED ELEMENT

The transmission coefficient of a multilayer transmitarray element is determined only by the response of one-layer unit, if the configuration of each layer is identical [7]. Hence, the one-layer unit is analyzed, and the performance of a 3-layer unit can be calculated via a cascade model using S-parameter. All the following unit cells are of the same periodicity 9 mm ($0.6\lambda_0$ at 20 GHz) to avoid the onset of grating lobes. For the time being an air substrate is used in simulations.

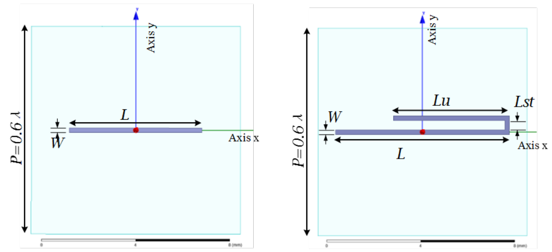
In the derivations in [7], the transmission coefficient (S_{21}) of a lossless, reciprocal single-layer transmitarray unit obeys:

$$S_{21} = (\cos\theta)\cdot e^{j\theta} \tag{1}$$

where θ is the transmission phase, and $\cos\theta$ is the transmission magnitude. Consequently, the full phase range of a one-layer unit is $-90°$ to $90°$.

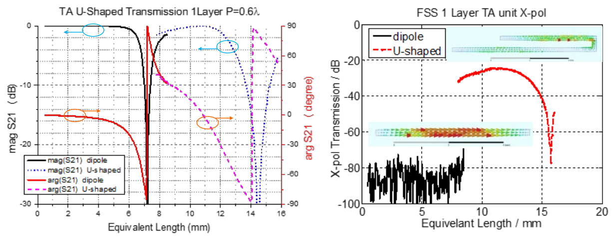
A dipole element, as shown in Fig. 1(a), is the simplest structure to get a linearly polarized resonance. The defect is obvious: it is unable to cover full phase range, as shown in Fig. 2(a). In order to increase the phase coverage under the periodicity limit, it is an instinctive idea to further extend and bend the dipole to form a U-shaped element, as shown in Fig. 1(b). The length variation introduces an additional resonance; therefore, the phase coverage is completed for a full 360° range. A smooth phase curve is also realized in the U-shaped unit, owing to the linear relationship between the equivalent inductance and the length of the U-shaped arm, which alleviates the requirement of fabrication accuracy.

The cross polarization level of a dipole unit is as low as −80 dB, but that of a U-shaped unit reaches −25dB, as Fig. 2(b) shows. Strong surface currents are induced at the turning of the U-shaped unit, which are orthogonal to the E field polarized direction and consequently reinforce the cross polarized wave.



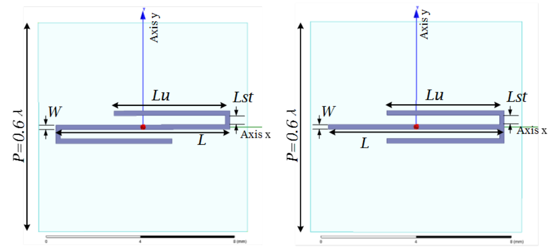
(*a*) (*b*)

Fig. 1. The dipole-type transmitarray element: (*a*) a simple dipole element; (*b*) an asymmetrical U-shaped element. W = 0.2mm, Lst = 0.4mm, and L is fixed at 7.5mm in (*b*).



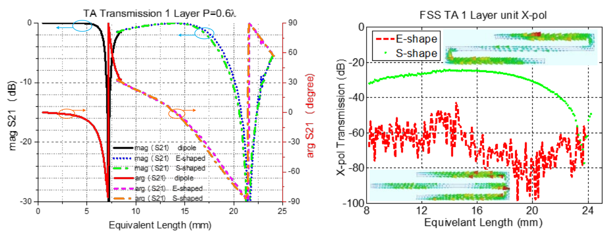
(*a*) (*b*)

Fig. 2. Simulation results: (*a*) the transmission response and (*b*) the cross polarization levels and surface currents of a dipole element and an extended U-shaped element. Equivalent length is L+Lu for the U-shaped element.



(*a*) (*b*)

Fig. 3. (*a*) An S-shaped element. (*b*) An E-shaped element. L is fixed at 7.5mm.



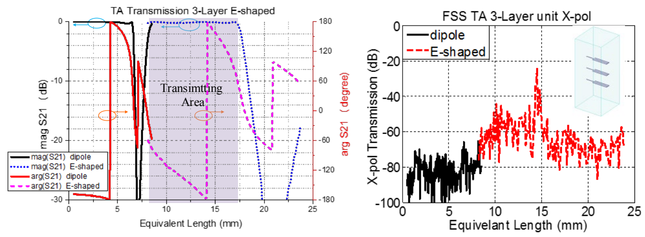
(*a*) (*b*)

Fig. 4. Simulations results: (*a*) the transmission response and (*b*) the cross polarization levels and surface currents of an S-shaped element and an E-shaped element. Equivalent length is $L+2Lst+2Ls$ ($L+2Lst+2Le$).

Considering symmetrical shape is potential to cancel the orthogonal current and to get a lower cross polarization level, an S-shaped unit and an E-shaped unit are investigated, whose geometries are illustrated in Fig. 3.

Both of the S-shaped and E-shaped elements are able to cover full phase range, as shown in Fig. 4. Although the S-shaped element is central symmetrical, the currents at both turnings are in the same orientation, so the cross polarization level is as high as that of the U-shaped element. In contrast, the E-shaped element directs the orthogonal currents into different directions. The cross polarization level is reduced significantly to −50 dB in average, thanks to the mutual cancellation of the orthogonal currents.

Based on the single-layer analysis, a 3-layer E-shaped element is analyzed for practical designs, whose simulation results are shown in Fig. 5. The spacing between each layer is $\lambda_0 / 4$ taking advantage of anti-reflection. The transmitting phase range (with magnitude above −1 dB) is extended to be about 270° by cascading the 3 E-shaped layers. An average −50 dB cross polarization level is achieved in the transmitting area except for a few spikes.



(*a*) (*b*)

Fig. 5. (*a*) The transmission response and (*b*) the cross polarization level of a 3-layer E-shaped element

III. Conclusion

This paper demonstrates the sufficient phase coverage and good cross polarization discrimination of the E-shaped element, in comparison of the traditional dipole, U-shaped, and S-shaped elements. A 3-layer E-shaped element is simulated for transmitarray designs, with the capability of approximate 270° smooth phase range and an average 50 dB cross polarization discrimination.

References

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

[2] D. T. McGrath, "Planar three-dimensional constrained lenses," *IEEE Trans. Antennas Propazg.*, vol. 34, no. 1, pp. 46-50, Jun. 1986.

[3] D. M. Pozar, "Flat lens antenna concept using aperture coupled microstrip patches," *Electronics Letters*, vol. 32, no. 23, pp. 2109-2111, Nov. 1996.

[4] A. Abbaspour-Tamijani, K. Sarabandi, and G. M. Rebeiz, “Antenna-filter-antenna arrays as a class of bandpass frequency-selective surfaces,” *IEEE Trans. Microw. Theory Tech.*, vol. 52, no. 8, pp.1781-1789, 2004.

[5] Y. Zhang, R. Mittra, and W. Hong, “On the synthesis of a flat lens using a wideband low-refraction gradient-index metamaterial,” *Journal of Electromagnetic Waves and Applications*, vol. 25, no. 16, 2178-2187, 2011.

[6] C. G. M. Ryan, M. R. Chaharmir, J. Shaker, J. R. Bray, Y. M. M. Antar, and A Ittipiboon, "A wideband transmitarray using dual-resonant double square rings," *IEEE Trans. Antennas Propagat.*, vol. 58, no. 5, pp .1486-1493, May. 2010.

[7] A. H. Abdelrahman, A. Z. Elsherbeni, and F. Yang, “Transmission phase limit of multilayer frequency selective surfaces for transmitarray designs,” *IEEE Trans. Antennas Propag.*, vol. 62, no. 2, pp. 690-697, Feb. 2014.