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A NOVEL DOUBLE-PETAL LOOP ELEMENT FOR BROADBAND REFLECTARRAY

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Abstract—In this paper, a reflectarray antenna composed of a combination of double-petal loops of variable size is presented. To evaluate the performance of the designed element, a parametric study is carried out using Ansoft HFSS. For the optimal parametrics, the proposed structure shows an almost linear behavior, while the phase range is in excess of 500°. Then, a prime-focus 77-element reflectarray with this type of element has been designed and implemented. The measured results show that the obtained 1-dBi gain bandwidth of the reflectarray with double-petal loop elements can reach as large as 25% and the highest gain is about 19.3 dBi. Compared with the existing single layer elements (cross and rectangle loop, double rings, etc.), microstrip reflectarray with this double-petal loop element can obtain a larger bandwidth.

1. INTRODUCTION

The planar reflectarray has been widely used in both terrestrial and satellite communication systems because of its advantages such as low mass and volume, ease of manufacture, and possibilities offered for beam shaping and electronic beam control [1–5]. The most severe drawback for the reflectarray is its narrowband performance, and intense efforts have been made in recent years to overcome this shortcoming. The bandwidth performance of a microstrip reflectarray is limited primarily by two factors. The first is the inherent narrow bandwidth of microstrip elements themselves. The second is the differential spatial phase delay resulting from the different paths from the feed to each reflectarray element. The bandwidth limitation due to the narrowband nature of the microstrip cell elements is more dominant for moderate size reflectarrays.

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Elements with linear phase response can be used to improve the antenna bandwidth. Linearization of phase response may be done in several ways including using a thick substrate, multiple stacked patches [6], and phase-delay lines [7], etc. However, these designs will lead to other shortcomings such as additional fabrication complexity, increased weight, and higher loss. Any attempt at broadening the bandwidth of the reflectarray should not solely rely on the thick substrate and multiple stacked patches but should also exploit the rich literature on the single-layer structure. In recent years, many single-layer elements have attracted much more attention due to their low-cost manufacturing and other advantages. Many novel designs of the single-layer structure have been proposed for enhancing the reflectarray bandwidth, including the multi cross loop elements [8], microstrip elements composed of rectangular patch and rectangular ring [9].

A novel double-petal loop element is proposed for improving the characteristics of the microstrip reflectarray in this letter. The novel unit cell is capable of offering an almost linear behavior and a phase range that well exceeds 360° for a broadband reflectarray design by inserting empty space of the proper thickness between the substrate and the ground plane.

2. THE PHASE CHARACTERISTICS OF THE PROPOSED ELEMENT

The phasing elements are operating around resonance with grid spacing of the order of 0.5λ. Here, λ stands for the wavelength at the center frequency. Periodic boundary conditions are introduced to take into account interactions with identical neighbor elements. The proposed element is shown in Figure 1. In the figure, the single-layer patch is printed on a substrate A with a relative permittivity of $\varepsilon_r = 2.65$, and B is a substrate of foam as a supporting substrate, $\varepsilon_r = 1.07$. The dielectric property of foam is assumed to be similar to that of air. The elements are all separated with the same spacing of L in x- and y-directions. The relation of L_1, L_2 is assumed as $L_2 = L_1 * K$ $(0 < K < 1)$. To validate the proposed design and evaluate its phase as well as bandwidth performance, a parametric study is carried out for variations of H_1 (thickness of substrate A), H_2 (thickness of substrate B), and parameters K and W. Figures 2 and 3 show the phase of reflected wave versus loop length L_1 for the double-petal loop elements with different thicknesses of substrate A and B. As shown in Figures 2 and 3, when H_1 is equal to 2 mm and H_2 is equal to 3 mm, there is a better linear reflect phase for the proposed structure, with L_1 varying

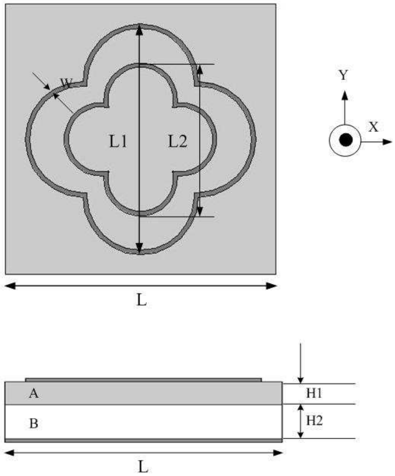

Figure 1. Geometry of the proposed element.

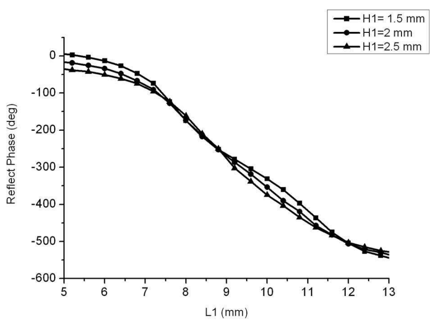

Figure 2. Phase responses of the proposed element for different H_1 at the center frequency of 10 GHz ($H_2 = 3$ mm, $K = 0.66$, and $W = 0.3$ mm).

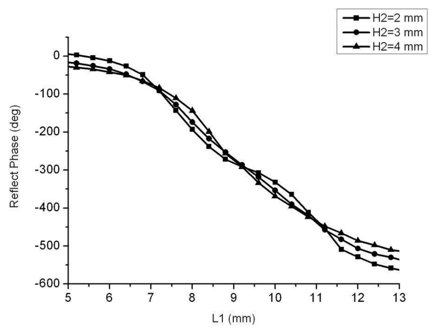

Figure 3. Phase responses of the proposed element for different H_2 at the center frequency of 10 GHz ($H_1 = 2$ mm, $K = 0.66$, and $W = 0.3$ mm).

from 5 to 13 mm. Figures 4 and 5 present the influences of parameters K and W on the reflect phase of the proposed structure at the center frequency of 10 GHz. It can be concluded from Figures 4 and 5 that K has a great influence on the reflect phase. Moreover, a smother phase variation can be achieved, when K is equal to 0.66 and W is equal to 0.3 mm. The final structure parameters are chosen as the following: $H_1 = 2$ mm, $H_2 = 3$ mm, $K = 0.66$, and $W = 0.3$ mm. And then, the

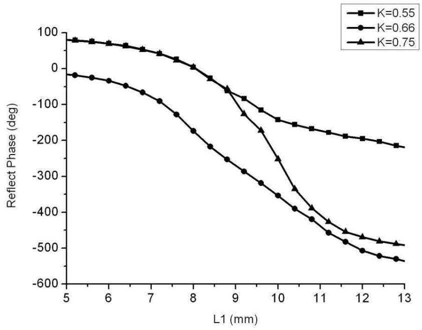

Figure 4. Phase responses of the proposed element for different K at the center frequency of 10 GHz ($H_1 = 2$ mm, $H_2 = 3$ mm, and $W = 0.3$ mm).

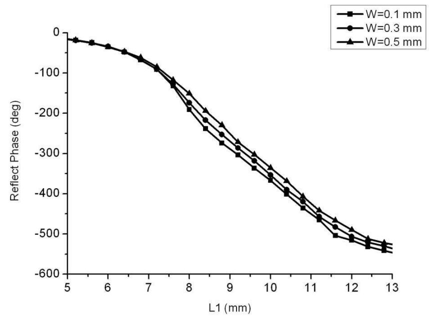

Figure 5. Phase responses of the proposed element for different W at the center frequency of 10 GHz ($H_1 = 2$ mm, $H_2 = 3$ mm, and $K = 0.66$).

proposed structure shows an almost linear behavior, while the phase range is in excess of 500°. Also, the parameters A, B, and W don't have an influence on the reflect phase as great as the parameter K. The phase of reflected wave against loop length L_1 over a frequency range of 8.5, 10, and 11.5 GHz for the reflectarray with the above parameters is shown in Figure 6. As shown in this figure, it can be noticed that the three phase curves are approximately parallel. This property leads to the differential phase shift being approximately constant as a function of frequency in the 8.5–11.5 GHz band. This is the required property for the phase characteristic of reflectarray having wide bandwidth.

3. REFLECTARRAY DESIGN AND PERFORMANCE

In order to validate the phase data of the elements, we designed a prime-focus reflectarray operating at 10 GHz. Figure 7 shows the basic geometry of this reflectarray using 77 double-petal loop elements of variable size.

For those elements located close to the edge of the reflectarray with large incident angles from the feed's incident rays, the reradiated component will be directed toward the main beam, while the reflected component will be directed away from the main beam. It is these edge elements' reflection components that contribute to the side lobes and the inefficiency of the reflectarray. To minimize this inefficiency, one could design the reflectarray with large F/D ratio with elements having minimized reflection component and take into account the oblique incidence. Here, both the size D and focal distance F of the considered array are 140 mm, thus giving a large F/D ratio.

Since the horn will seriously block the reflected wave from the reflectarray, a Vivaldi antenna is chosen as the feed, located 140 mm above the center of the reflectarray. Considering the radiation pattern of the feed and the configuration of the reflectarray, the illumination levels near the centers of four borders are all about -4 dB.

The measured radiation patterns of both copolarization and cross polarization in the E-plane and the H-plane at the centre frequency

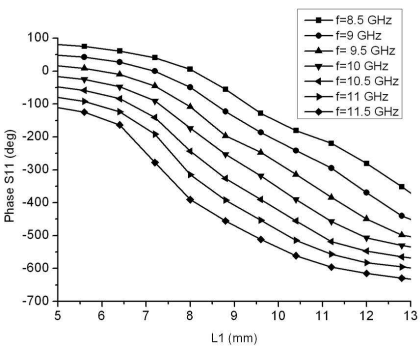

Figure 6. Phase S_{11} versus length for different frequencies (8.5–11.5 GHz) ($H_1 = 2$ mm, $H_2 = 3$ mm, $K = 0.66$, and $W = 0.3$ mm).

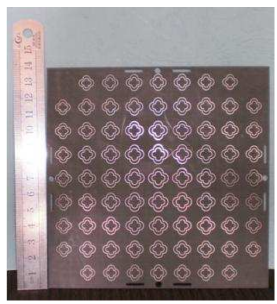

Figure 7. Photograph of the designed 77-element linear reflectarray.

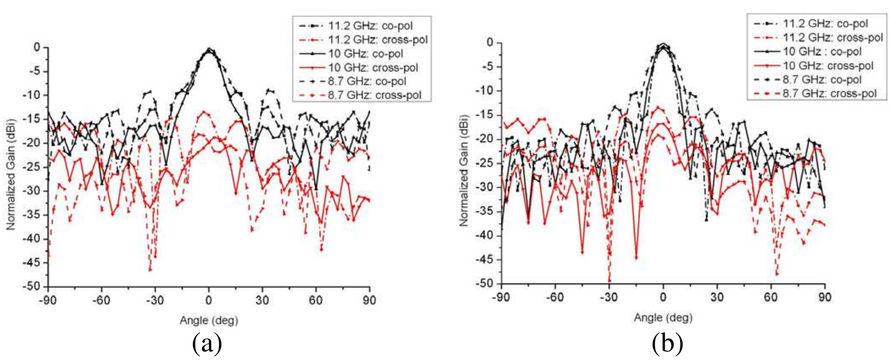

Figure 8. The measured radiation patterns at 8.7, 10, and 11.2 GHz for the designed 77-element linear reflectarray: (a) E-plane, (b) H-plane.

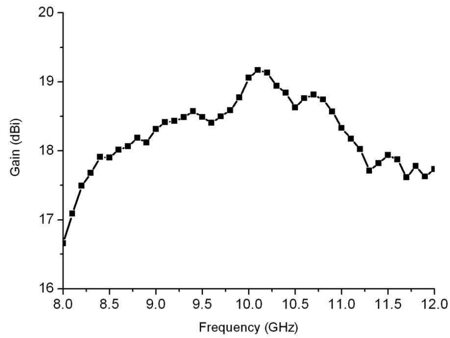

Figure 9. Measured gain of the designed 77-element linear reflectarray with frequency varying from 8 to 12 GHz.

of 10 GHz are shown in Figure 8. The peak gains against frequencies from 8 to 12 GHz of the proposed reflectarray are measured and shown in Figure 9. It can be seen that the bandwidth defined from the 1-dB gain drop is about 25% (from 8.7 to 11.2 GHz). The maximum gain is 19.3 dBi at 10.2 GHz, which shows a small frequency shift from the design frequency of 10 GHz. This frequency shift is attributed to both simulation and fabrication errors and feed location error. The antenna efficiency, calculated by comparing the measured copolarized gain with the directivity based on the physical aperture area, is about 39.8% at 10.2 GHz. The efficiency of the antenna is not very good, which is mainly caused by the illumination levels on the borders of the reflectarray. Also, other factors, such as random phase errors, blockages of the feed, primary feed losses, losses in the substrate, may reduce the antenna efficiency.

4. CONCLUSION

A novel double-petal loop element has been analyzed to design a broadband microstrip reflectarray antenna. Element phase response shows an almost linear behavior within a wide range of frequency band. By using these elements with grid spacing and taking into account the oblique incidence, a prime-focus 77-element reflectarray operating at 10 GHz has achieved a 1-dB gain bandwidth of 25%. Compared with the existing single layer elements (cross loops, double rings, etc.), the reflectarray with this double-petal loop element can obtain a larger bandwidth.

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