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Broadband Reflectarray with Convex Strip Elements for Dual-Polarization Use

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Abstract— **This paper proposes new reflectarray elements for dual-polarization and wideband use. These elements provide liner phase property with the same slope characteristics for dual polarization, thereby achieving the desirable reflection phase over wide frequency range. The usefulness of the proposed elements is verified by comparing between the calculated reflection phase for periodic reflectarray and the measured one. Finally we present an offset reflectarray designed by using the proposed elements, and also confirm wideband frequency characteristics numerically and experimentally.**

I. INTRODUCTION

Microstrip reflectarrays are very attractive aperture antennas because of their planar structure and a simple feed system [1]. However, the bandwidth is usually limited, because the reflection phase of each element greatly depends on the frequency. To overcome its drawback, the authors have developed single-layer reflectarrays with microstrip elements arranged densely [2]. We have reported a wideband reflectarray based on two-resonant [3] or three-resonant behavior [4]. Then, similar approach has been reported in [5], [6] to improve the bandwidth in the single-layer reflectarray. We have also proposed a reflectarray based on two resonant elements for dual-polarization use, by using the four elements bent convexly [7]. However, it is difficult to obtain the good performance in the low-frequency side for wideband use, because the lengths of these elements are limited for extending them in a unit cell. For realizing a wideband dual-polarization operation, this paper proposes new reflectarray elements modified from previous ones. A design example of the reflectarray constructed by these elements is demonstrated and its effectiveness is verified by comparing of the reflection phase characteristics and the radiation patterns between the calculated results and the measured ones in the Ku band.

II. PRINCIPLE

A. *Reflectarray Antenna*

Figure 1 shows basic geometry of microstrip reflectarrays consisting of a planar strip array of dipoles with variable length printed on a grounded single-layer substrate. The design of a reflectarray makes use of the reflection-phase shift due to the resonant phenomenon of the element. To achieve the desired phase over wide-frequency range in dual-polarization use, we consider four elements based on convex ones as a unit cell as shown in Fig. 2.

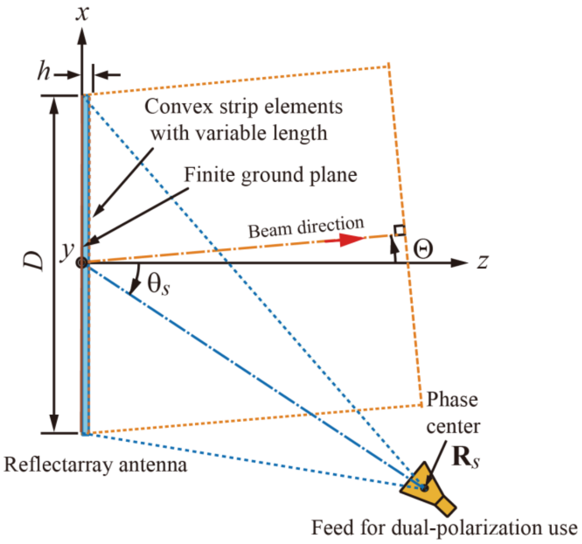


Fig. 1. Microstrip reflectarray antenna with offset feed.

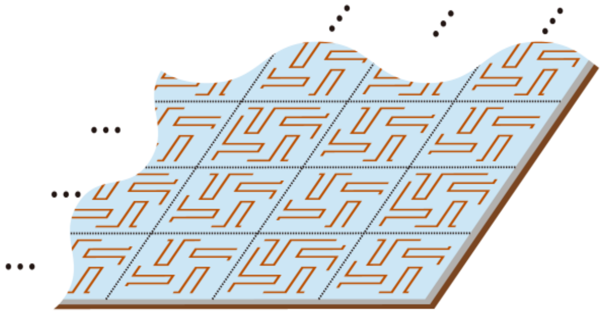


Fig. 2. Proposed reflectarray elements.

B. *Reflection Phase of Previous Elements*

Figure 3 shows the phase characteristics for the previous elements [3]. It is necessary to arrange additional two resonant elements perpendicular to the previous ones, to achieve the dual-polarization use. However, if the element length becomes long, the adjacent contact each other. Therefore, in this paper the four resonant elements of each cell are bent convexly and each of them is arranged as shown in the inset of Fig. 4. Their reflection phase characteristics for the TE-wave and the TM-wave incidence are shown in Fig. 4. The reflection-phase properties are analyzed by the method of moments based on the spectral domain Green function with the periodical boundary condition [8]. It is obvious from Fig. 4 that its combination of the short elements cannot be used, around 10 GHz because the reflection phase-shift range is less than 360°. As a result, the combination of the longer elements of which the first resonant point is set at the lower frequency is required for wideband use. However the length of these elements limited for extending them in a unit cell.

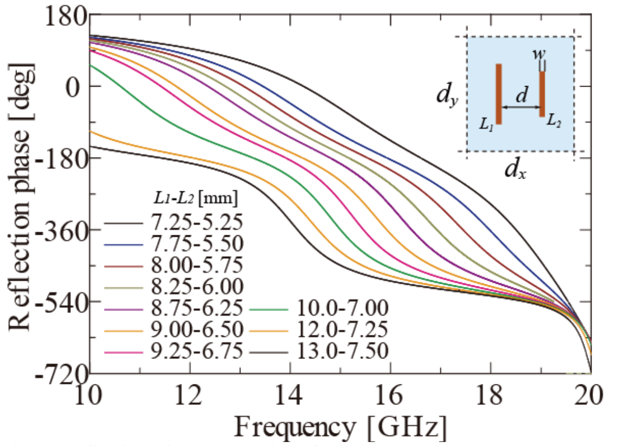


Fig. 3. Reflection phase properties of previous two-resonance elements.

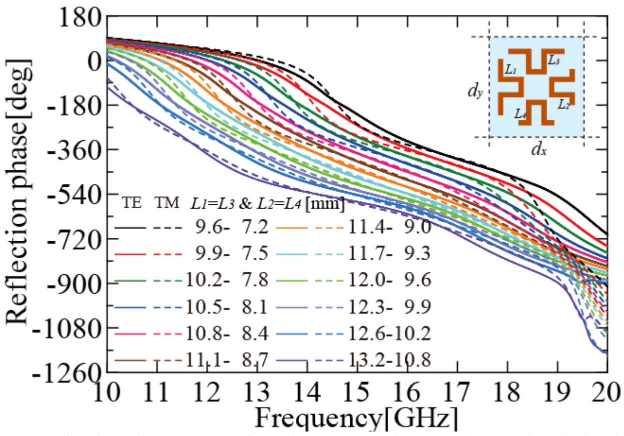


Fig. 4. Reflection phase properties of previous elements for dual-polarization use.

C. *Reflection Phase of Proposed Elements*

To make the strip length long, in this paper, a convex part of the proposal elements are shifted from the center of the element, and each of them is arranged as shown in Fig. 5. Their reflection phase characteristics for the TE-wave and the TM-wave incidence are shown in Fig. 6. The calculation is performed as the unit cell dimension $d_x = d_y = 9.6$ mm, the incident angle $\theta_s = 30°$, the thickness $h = 3.0$ mm between the film and the ground plane, and the strip width $w = 0.3$ mm of the element. It is clear that the elements achieve good phase properties with similar curves for both incidence while providing phase-shift range of 360° enough to realize the desired phase over the aperture.

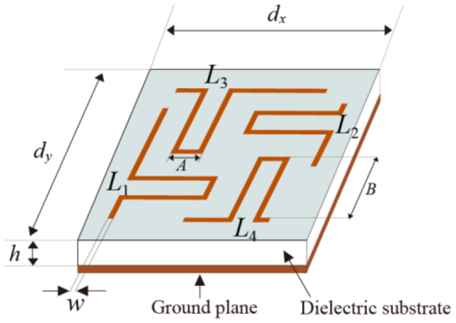
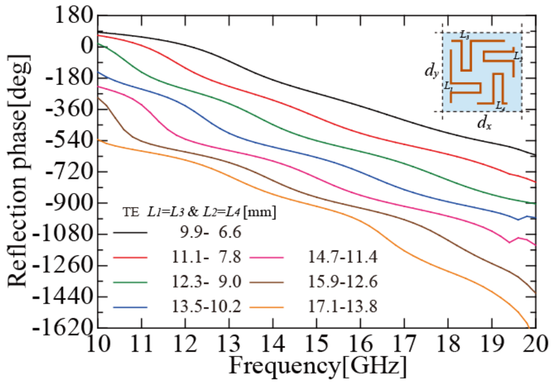
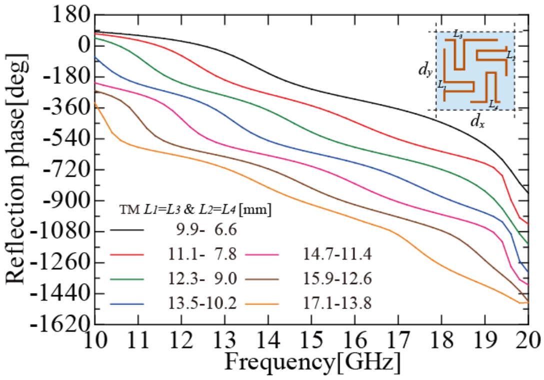


Fig. 5. Basic geometry of proposed elements.



(a) TE-wave.



(b) TM-wave.

Fig. 6. Reflection phase properties of proposed elements.

III. DESIGN EXAMPLES

We now design a reflectarray with a square aperture of dimension 144 × 144 mm^2 (15 × 15 cells). Figure 7 illustrates the designed antenna configuration. The standard gain horn in the Ku band is used as a primary radiator, and R_s is chosen to be 400 mm to obtain the edge level of the aperture, -13 dB. In this case, the main-beam direction is $\Theta = 0°$ perpendicular to the flat surface of the reflectarray. It is different from the specular-reflection direction of the incident angle $\theta_s = 30°$. Figure 8 shows contour map of the desired reflection phase at the centre frequency $f_0 = 15$ GHz. The lengths L_1, L_2, L_3 and L_4 of the proposed elements are determined from the design charts for each illumination angle which is determined by the element position on the array. Figure 9 shows the top view of the designed reflectarray.

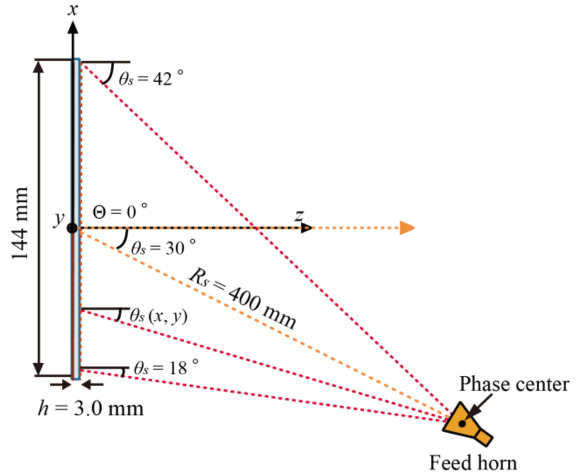


Fig. 7. Design example (x-z plane).

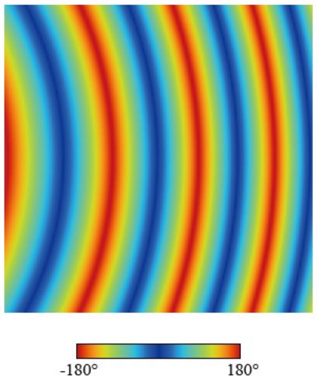


Fig. 8. Desired reflection phase distribution on aperture.

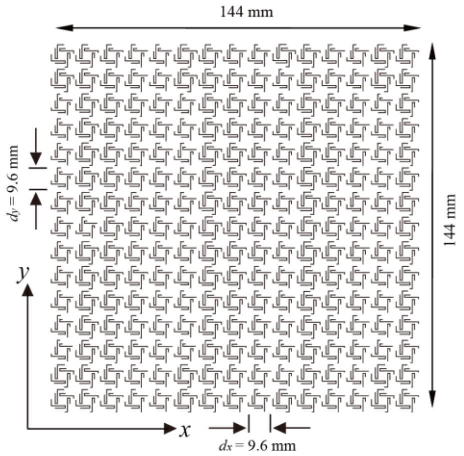
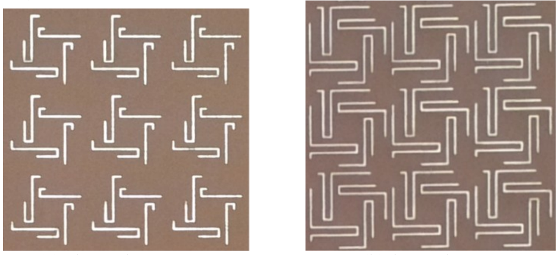


Fig. 9. Designed reflectarray.

IV. EXPERIMENTS

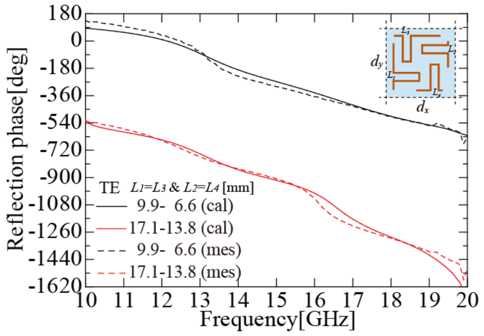
A. *Frequency Characteristics of Reflection Phase*

To measure reflection phase characteristics, two kinds of the reflectarrays are fabricated. Figure 10(a) and (b) show their photographs for the short elements ($L_1 = L_3 = 9.9$ mm, $L_2 = L_4 = 6.6$ mm) and the long one ($L_1 = L_3 = 17.1$ mm, $L_2 = L_4 = 13.8$ mm), respectively. The conductor strips are the copper with thickness 18 μm printed on a thin dielectric film (Polyimide) with thickness 125 μm and also the interval between the film and ground plane is kept by a polyfoam (dielectric constant $\varepsilon_r = 1.68$) with thickness $h = 3.0$ mm. Figure 11 shows the comparison of calculated results with measured one of reflection phase properties for (a) the TE-wave and (b) the TM-wave incidence. The measured results agree with the calculated ones for both incident waves each other very well.

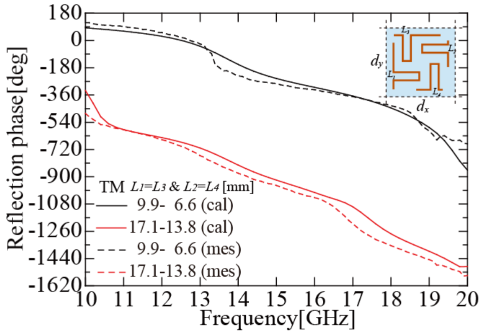


(a) short elements. (b) long elements.

Fig. 10. Part of fabricated periodic reflectarray.



(a) TE-wave.

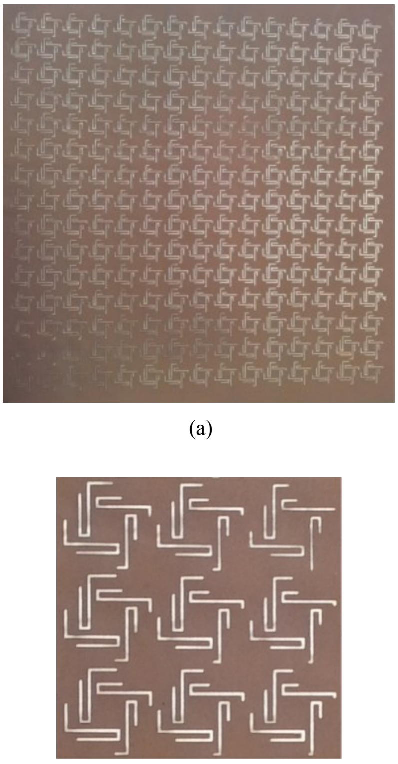


(b) TM-wave.

Fig. 11. Comparison of calculated results with measured one of reflection phase properties.

B. *Radiation Patterns of Proposed Reflectarray*

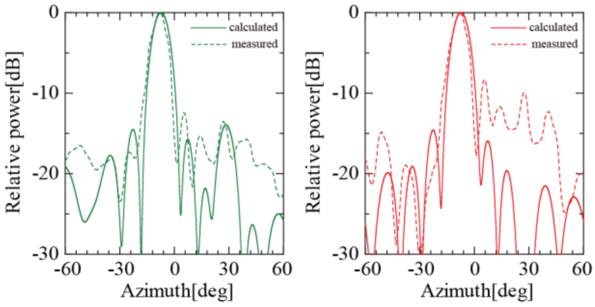
Figure 12(a) is the photograph of the fabricated reflectarray, and (b) is the close-up one. The far-field measurements are performed at 12, 15 and 19 GHz. Figure 13 shows the comparison of the calculated results with the experimental ones of the radiation patterns for the TE-wave and the TM-wave incidences. It is confirmed that the sidelobe level is about -10 dB and the specular reflection level is suppressed less than -10dB over 12-19 GHz. The main-beam patterns for both incident waves agree with each other. It is clarified from this experimental verification that the proposed reflectarray elements works well for the dual-polarization use over wide frequency range.



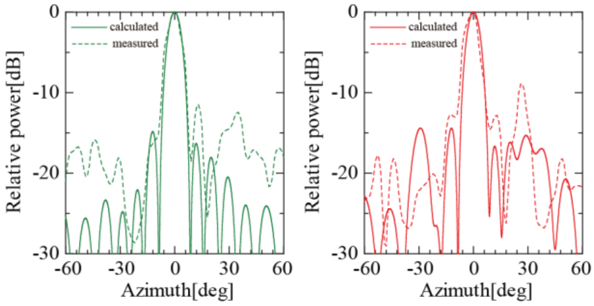
(a)

(b)

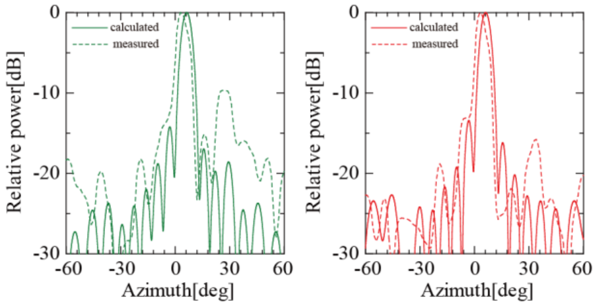
Fig. 12. (a) Photograph of fabricated reflectarray and (b) close-up view in middle of fabricated reflectarray.



(a) TE-wave (12 GHz). (b) TM-wave (12 GHz).



(c) TE-wave (15 GHz). (d) TM-wave (15 GHz).



(e) TE-wave (19 GHz). (f) TM-wave (19 GHz).

Fig. 13. Comparison of calculated results with measured one of radiation pattern.

V. CONCLUSION

We have presented the single-layer wideband reflectarray for dual-polarization use. The experimental investigation about reflection phase of the proposed element has been performed for the fabricated periodic reflectarray in the Ku band. The performance of the proposed reflectarray has been verified by the numerical evaluation and the experiment for the designed reflectarray antenna.

ACKNOWLEDGMENT

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