A Single-Layered Reflectarray Antenna with Split Rectangular Loop Elements

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***Abstract*— A metal plate loaded frequency selective reflector (FSR) was applied to a reflectarray antenna. Various beam shapes can be obtained by appropriately selecting the arrangement and dimensions of the FSR resonant elements. Previous research has shown that the attenuation of electromagnetic waves caused by double-layer structures results in low aperture efficiency, and although research has been conducted on single-layer structures, 360 [deg] phase region coverage has not been possible. This study investigates the use of a resonant element shape with polarization-dependent beam orientation to cover a phase range of 360 [deg] with a single-layer antenna. The results show that a split-type rectangular loop element is able to cover the target phase range.**

I. INTRODUCTION

Reflectarray antennas (hereinafter referred to as "reflectarray") have been studied as a low-cost and reliable deployment antenna for satellites. A method has been proposed to change the beam direction depending on polarization by appropriately selecting the array and dimensions of the resonating elements [1]. In this paper, we propose a single-layer resonant element geometry that enables independent phase control and covers a reflection phase area of 360 [deg], using a resonant element spacing able to inhibit propagation of grating lobes through a dielectric.

II. ELEMENT REQUIREMENTS

Two properties are required for devices that exhibit polarization-dependent beam orientations:

(A) Independent phase control depending on polarization

(B) Phase coverage range of 360 [deg] for each polarization

In addition, when designing the resonant element, it is important to determine the element spacing d to achieve high-efficiency and low side-lobe characteristics. In a previous study [2], a double-layer structure model was adopted in which the layers of the element were divided by polarization. When determining the element spacing, the following condition was used to prevent the propagation of grating lobes in free space [3]:

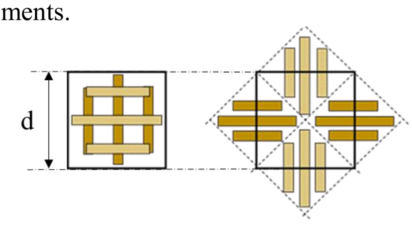
$$\frac{d}{\lambda} \leq \frac{1}{1+\sin\theta} \tag{1}$$

where d is the resonant element spacing and θ is the maximum incident angle. However, this condition (1) did not sufficiently suppress the side lobes. Conversely, the condition for which the grating lobes do not propagate in the dielectric:

$$\frac{d}{\lambda} \leq \frac{1}{\sqrt{\varepsilon_r} + \sin\theta} \tag{2}$$

where ε_r is the dielectric constant, is shown to sufficiently suppress unwanted radiation, resulting in high efficiency and low side-lobe characteristics [4]. Based on the aforementioned discussion, in this study, the element spacing d was determined using (2), while the dielectric constant $\varepsilon_r = 2.59$ was used.

The conventional double-layer and single-layer models are shown in Fig. 1(a) and Fig. 1(b) respectively [5] [6]. In the double-layer model, three-line elements are placed in each layer and the reflection phase is controlled by varying the element length. Using (2), we were able to satisfy element requirements, but the lattice area was reduced to approximately 58.0% of that in the previous study [2]. For the conventional single-layer model, the element shape is the same as that of the double-layer model. In addition, the single-layer elements are arranged such that the elements of each polarization do not overlap. The design area of each polarization is limited by the diagonal lines of the lattice, as indicated by the dotted lines in Fig. 1(b). As a result, the area available for each polarization element in a single lattice is half that for a double-layer structure, and the lattice area is reduced to approximately 29.0% of that in the previous study [2]. Consequently, as the available design area was greatly reduced and the element length could not be secured to the same level as before, the conventional single-layer model could satisfy only requirement (A) for the elements. Therefore, this paper proposes the use of split rectangular loop elements to assemble a single-layer element shape that satisfies both requirements.



(a) Double layer (b) Single layer

Fig. 1. Conventional model

III. ELEMENT DESIGN

The altered element shape is shown in Fig. 2, and the model of the resonant element is shown in Fig. 3. The design parameters of the elements are listed in Table I. To cover a phase region of 360 [deg] for both polarizations, the length of each element must be longer than that of the conventional element. Therefore, the side elements were folded back and extended from the conventional element shape, as shown in Fig. 2 (steps 3 and 4).

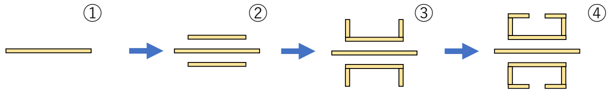


Fig. 2. Variation of element shape

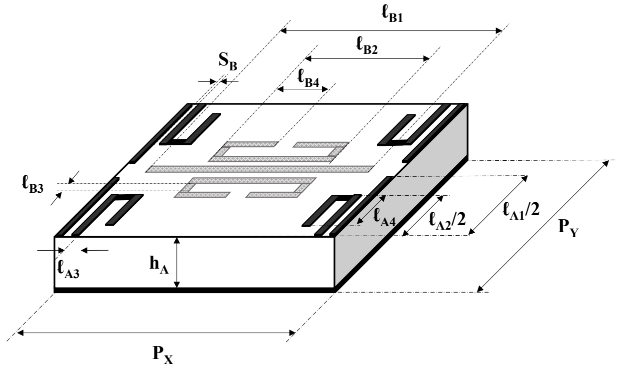


Fig. 3. Model of resonant element

Table I. Design parameters of element

Band	***Ku***	**Line width w**	**0.004λ**
Thickness h_A	**0.127λ**	**Interval of line S_b**	**0.020λ**
Dielectric constant ε_r	**2.59**	**Element length ℓ_{A1}, ℓ_{B1}**	**0.004λ ~ 0.354λ**
tanδ	**0.0028**	**Element length ℓ_{A2}, ℓ_{B2}**	**0 ~ 0.235λ**
Angle of incidence	**25 [deg]**	**Element length ℓ_{A3}, ℓ_{B3}**	**0 ~ 0.020λ**
Element spacing P_X, P_Y	**0.394λ**	**Element length ℓ_{A4}, ℓ_{B4}**	**0 ~ 0.107λ**

IV. ANALYSIS RESULT

For each of the vertical and horizontal polarizations (V and H respectively), the total element length for the polarization orthogonal to the main polarization (hereinafter referred to as the orthogonal polarization) was fixed at the maximum value of $\ell = 1.33\lambda$, and the total element length for the main polarization ℓ varied between 0.004λ and 1.33λ. The reflection phase characteristics of the V and H polarization elements are shown in Figs. 4 and 5 respectively. These results confirm that the elements were able to cover the 360 [deg] phase range for both polarizations. Additionally, when the total element length of the orthogonal polarization was fixed at the maximum value, the phase change of the orthogonal polarization was less than 22 [deg] in both cases.

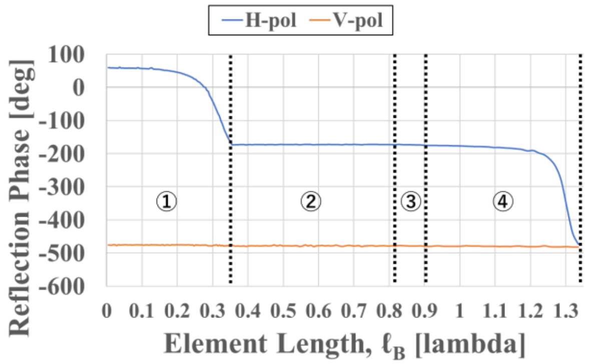


Fig. 4. Reflection phase characteristic of H-polarization

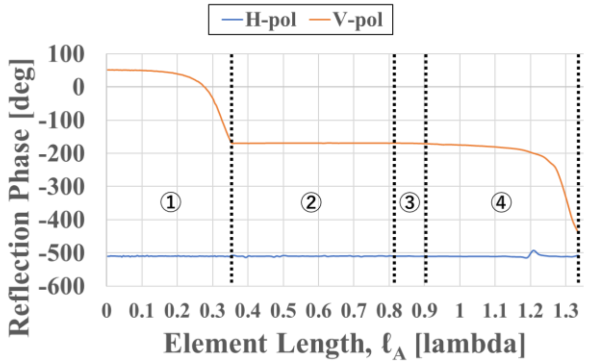


Fig. 5. Reflection phase characteristic of V-polarization

V. CONCLUSION

This study demonstrated independent phase control and a 360 [deg] phase region coverage for both polarizations, by arrangement of the split rectangular loop elements to eliminate element overlap. We plan to next use these proposed elements to build a prototype reflectarray and undertake measurements to verify the array utility.

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