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Analysis Results of Single-Layered Reflectarray Antenna with Split Rectangular Loop Elements

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Abstract—The reflectarray antenna (hereinafter referred to as "reflectarray") applies the reflection phase control function of frequency selective reflector to a plane reflector. Various beam shapes can be formed by appropriately selecting the mirror surface configuration and the shape of the resonance elements. In this study, a reflectarray that changes the beam direction depending on the polarization is investigated.

Keywords—reflectarray antenna, polarization, grating lobe, element spacing, single layer antenna

I. INTRODUCTION

The reflectarray antenna [1] (hereinafter referred to as "reflectarray") has a plane reflector with resonant elements periodically arranged at spacing *d*. It has been shown that a reflectarray with low-side-lobe and high-efficiency characteristics can be designed using (1) for resonant element spacing *d*, where the grating lobe does not propagate in the dielectric material [2]:

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

Here, λ is the wavelength corresponding to the maximum frequency in the frequency band, ε_r is the dielectric constant, and θ is the maximum incident angle. Using resonant element spacing that satisfies (1), a reflectarray that changes the beam direction according to the polarization was studied [3]. However, in the study of the two-layer model [3], the gain was reduced owing to the reflection loss caused by the multi-layer structure. To improve this, a single-layer model study [4] was conducted. A reduction in the number of layers reduced the reflection loss and improved the aperture efficiency. However, the 360 [deg] reflection phase region could not be satisfied because the designable area for each polarization was reduced by approximately half for each layer. Therefore, in our previous report [5], we proposed a split rectangular loop element that can cover the reflection phase region by extending the element length by bending it.

In this study, we present the analytical results of a reflective array designed using this split rectangular loop element.

II. ELEMENT DESIGN

A. Element Requirements

In designing the elements, the frequency band was set to the Ku band, as in a previous study [4]. Similarly, for the resonant element spacing *d*, (1) was used to prevent the propagation of the grating lobes within the dielectric.

The requirements for the resonant elements to change the beam direction according to the polarization are as follows:

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(a) Phase-coverage range of 360 [deg] for each polarization.

(b) Independent phase control depending on polarization.

Therefore, we investigated a single-layer element that satisfies all of the above conditions.

B. Model Design

The design model is illustrated in Fig. 1. The design parameters of the elements are listed in Table Ⅰ, where λ_0 is the wavelength corresponding to the design frequency f_0. Furthermore, the thickness of the dielectric substrate was h_A. Fig. 2 shows the order of changes in the element shapes using the element for H-polarization as an example. The same is true for the element for V-polarization if the entire element is rotated by 90 [deg].

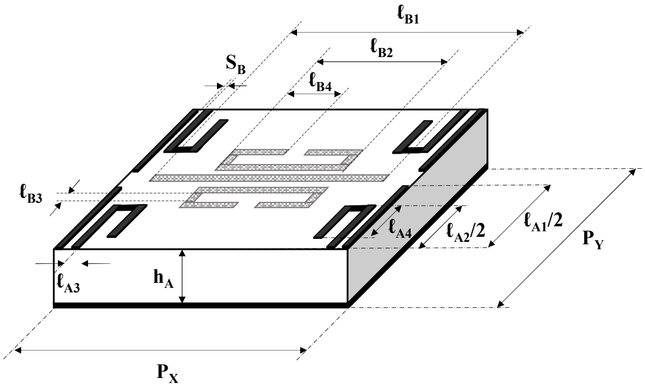

Fig. 1. Element Model

TABLE I. DESIGN PARAMETERS OF ELEMENT

Band	Ku	Line width w	$0.004\ \lambda_0$
Thickness h_A	$0.127\lambda_0$	Interval of line S_B	$0.020\ \lambda_0$
Dielectric constant ε_r	2.59	Element length l_{A1}, l_{B1}	$0.004\ \lambda_0$～$0.354\ \lambda_0$
tanδ	0.0028	Element length l_{A2}, l_{B2}	0～$0.235\ \lambda_0$
Angle of incidence [deg]	25	Element length l_{A3}, l_{B3}	0～$0.020\ \lambda_0$
Element spacing P_X, P_Y	$0.394\ \lambda_0$	Element length l_{A4}, l_{B4}	0～$0.107\ \lambda_0$

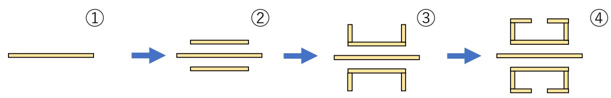

Fig. 2. Variation of element shape

C. Reflection Phase Characteristic

The total elements ℓ_A and ℓ_B are defined as $\ell_A=\ell_{A1}+2\ell_{A2}+4\ell_{A3}+4\ell_{A4}$, and $\ell_B=\ell_{B1}+2\ell_{B2}+4\ell_{B3}+4\ell_{B4}$, respectively, where the total element length for the polarization orthogonal to the co-polarization is fixed at a maximum value $\ell=1.33\lambda_0$ and the total element length for the main polarization ℓ was varied in the interval from $0.004\lambda_0$ to $1.33\lambda_0$. The angle of incidence in the element analysis is 25 [deg]. The reflection phase characteristics of the H-and V-polarized elements are shown in Fig. 3 and 4, respectively. Areas ①–④, which are divided by dotted lines in the graphs, correspond to the changes in the element shape shown in Fig. 2. According to Fig. 3 and 4, the phase changed significantly owing to the folded element. Here, the phase change of the co-polarization was 360 [deg] or more in both cases, thus covering the phase region when each polarization was the co-polarization. Furthermore, the phase change of the polarization orthogonal to the co-polarization is sufficiently small, less than 22 [deg] for each polarization, and it was confirmed that independent phase control is possible for each polarization.

Therefore, it can be said that the proposed element shape satisfies both conditions (a) and (b) for changing the beam direction depending on the polarization.

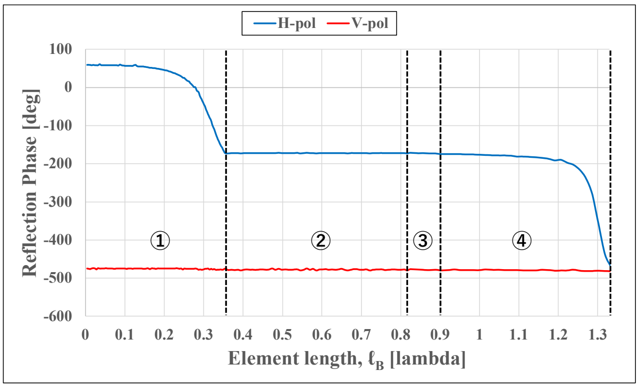

Fig. 3. Reflection phase characteristic of H-polarization

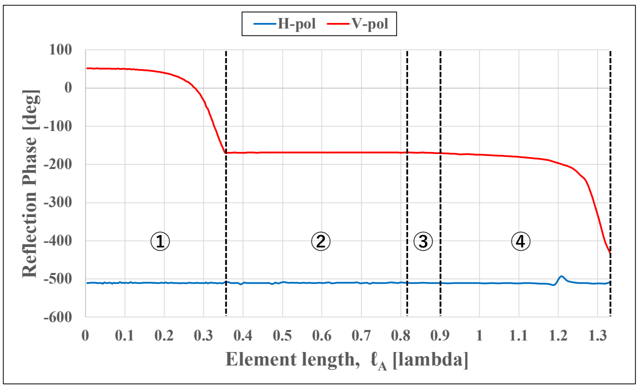

Fig. 4. Reflection phase characteristic of V-polarization

III. Analysis Result

A. Reflector Design

The reflectarray was designed based on the reflection phase characteristics, as shown in Fig. 3 and 4. The design parameters of the reflectarray are listed in Table II. Here, the position of the primary radiator is *F* and the center of the mirror surface is *O*. The beam directions were designed to be separated from each other by one beam width (=3.04 [deg]).

TABLE II. Reflectarray Design Parameters

Tilt angle [deg]	**25**
Beam direction [deg]	**±1.52**
Diameter of opening surface *D*	**$19.92\lambda_0$**
Distance from F to *O*	**$17.93\lambda_0$**
Clearrance *c*	**$3.77\lambda_0$**

B. Radiation Pattern

A full-wave analysis using the finite element method was performed on the mirror surface designed with the proposed split rectangular loop elements. ANSYS HFSS was used for the analysis. Fig. 3 shows a comparison between the calculated values of the radiation patterns for the H and V polarizations at the center frequency of f_0. Table III lists the beam direction, gain, and aperture efficiency for each polarization. According to Fig. 5, the side lobe of the co-polarization component is sufficiently suppressed, and the beams swing in different directions for each polarization. Furthermore, Table III shows that the analyzed values of the beam direction agree with the design values.

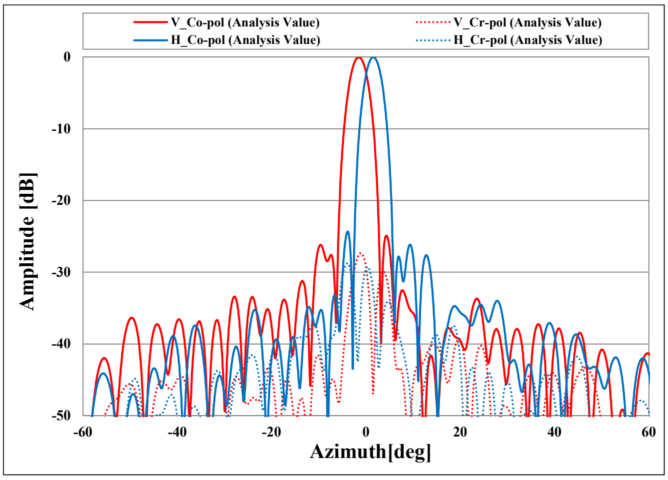

Fig. 5. Radiation pattern of V-pol and H-pol

TABLE III. Beam Direction and Gain Analysis Results

Fre.	Pol.	Beam direction [deg]	Gain [dBi]	Efficiency [%]
f_0	H	+1.555	33.63	59
	V	-1.534	33.44	56

IV. Conclusions

By using a split rectangular loop element, the amount of reflection phase change was improved. As a result, we met all requirements of the element. In addition, by using this element shape to design the mirror surface of the reflectarray, we changed the beam direction for each polarization.

In the future, we plan to fabricate a prototype of the designed reflectarray and confirm its performance by performing measurements.

References

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