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Single-Layered Reflectarray Antenna with Branch Elements

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***Abstract*—A 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 shape of the resonant elements. In this study, the shape of the resonant elements of the reflectarray, which changes the beam direction depending on the polarization, is investigated.**

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

I. Introduction

A reflectarray antenna [1] (hereinafter referred to as "reflectarray") has a plane reflector with resonant elements periodically arranged at spacing *d*. It has been demonstrated 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].

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

where 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 a resonant element spacing that satisfies condition (1), a reflectarray that changes the beam direction depending on the polarization was investigated [3]. Consequently, it satisfied all the requirements of the element; however, it led to the issue of gain reduction owing to the multilayer structure. Therefore, a single-layer element was considered to solve this problem [4]. The design difficulty of the element increased significantly because the designable area of the polarization was reduced by approximately half by the single-layered structure. Although independent phase control was achieved for each polarization by changing the length of each of the three line elements for one polarization, the phase change for each polarization was approximately 270°, which could not cover the phase range of 360°.

In this study, we examined the resonant element shape of a single layer. We demonstrated that by modifying the shape of the resonance element, we can achieve independent phase control for each polarization while satisfying the 360° reflection phase range for each polarization.

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 employed to prevent 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.

(a) Phase-coverage range of 360° for each polarization.

(b) Independent phase control depending on polarization.

Therefore, we investigated a single-layer element that satisfies both of these above-mentioned conditions.

B. Model Design

The design model is illustrated in Fig. 1. The design parameters of these 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. The element spacing *d* is denoted as P_X and P_Y in the model diagram for easy distinction of the directions. Essentially, $d = P_X = P_Y$. Fig. 1 shows a top view of one of the cells in the element model. The model consists of a dielectric layer, represented in green, on top of a metal plate, and a resonance element on top of the dielectric layer.

The order of change in the element shape is shown in Fig. 2, using the element for H-polarization as an example. The element length is extended, and the reflection phase is changed in the order of ①–③ in Fig. 2. The same applies to the element for V-polarization by replacing the element length ℓ_B with ℓ_A for each step and rotating the entire element by 90°. The resonance elements were designed to vary symmetrically with respect to one cell to suppress the generation of cross-polarization components.

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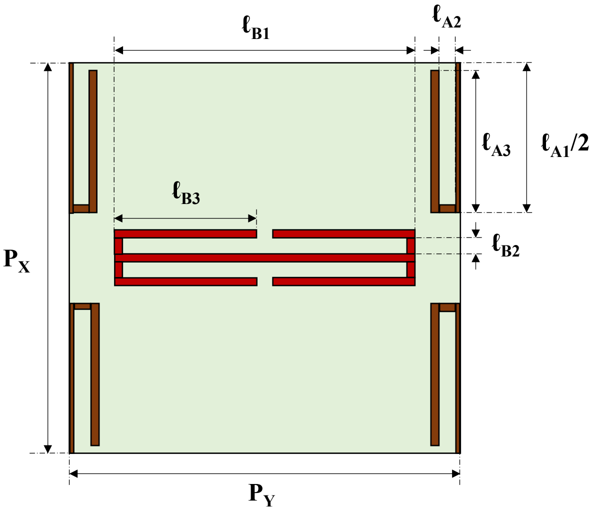

Fig. 1. Element model

TABLE I. DESIGN PARAMETERS OF ELEMENT

Band	Ku
Thickness h_A	$0.127\lambda_0$
Dielectric constant ε_r	2.59
tanδ	0.0028
Angle of incidence [deg]	25
Element spacing P_X, P_Y	$0.394\ \lambda_0$
Line width w	$0.004\ \lambda_0$
Element length ℓ_{A1}, ℓ_{B1}	$0.004\ \lambda_0$~$0.354\ \lambda_0$
Element length ℓ_{A2}, ℓ_{B2}	0~$0.007\ \lambda_0$
Element length ℓ_{A3}, ℓ_{B3}	0~$0.173\ \lambda_0$

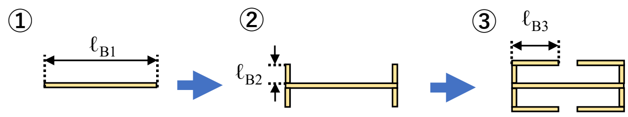

Fig. 2. Variation of element shape

III. ANALYSIS RESULT

Electromagnetic field analysis was performed for the proposed element geometry using ANSYS HFSS. We defined $\ell_A = \ell_{A1} + 4\ell_{A2} + 4\ell_{A3}$ and $\ell_B = \ell_{B1} + 4\ell_{B2} + 4\ell_{B3}$ for the total element length ℓ_A and ℓ_B. For each of the V- and H-polarizations, the total element length of the polarization orthogonal to the main polarization (hereinafter referred to as orthogonal polarization) was fixed at the maximum value $\ell = 1.08\lambda_0$, and the total element length of the co-polarization ℓ was varied in the range $0.004\lambda_0$ to $1.08\lambda_0$. The reflection phase characteristics of the H-polarization and V-polarization are shown in Figs. 3 and 4, respectively. Areas ①–③, which are divided by dotted lines in the graphs, correspond to the changes in the element shape shown in Fig. 2. The blue areas in the graphs indicate the areas where the phase of the main polarization changes by 360°. Fig. 3 shows that when the H-polarization is co-polarized, the phase change of the H-polarization is 411°. The phase shift of the V-polarization was 10.2° when the H-polarization was changed by 360°. Similarly, Fig. 4 shows that the phase change of the V-polarization was 396° when the V-polarization was co-polarized. In this case, the phase change of the H-polarization was 8.51° when the V-polarization changed by 360°.

As shown above, a phase range of 360° was covered for each polarization. The phase change of the orthogonal polarization to the co-polarization was sufficiently small (less than 11°) to enable independent phase control for each polarization. Therefore, the proposed element shape satisfies both conditions (a) and (b) for changing the beam direction depending on the polarization.

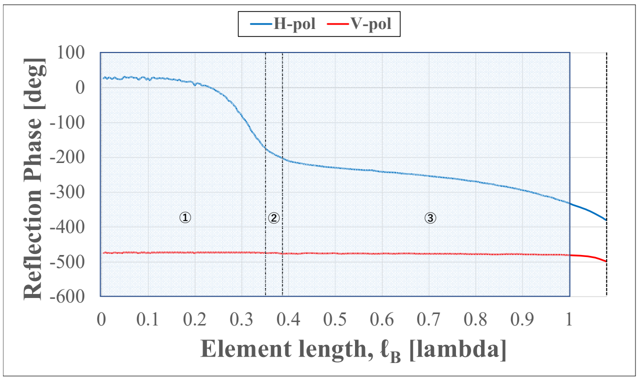

Fig. 3. Reflection phase characteristic of H-polarization

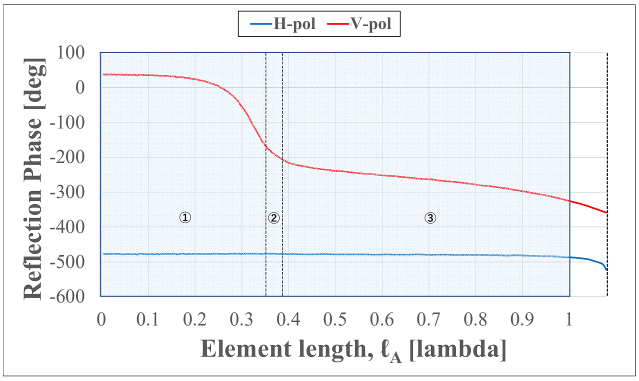

Fig. 4. Reflection phase characteristic of V-polarization

IV. CONCLUSION

This study demonstrated independent phase control and 360° phase region coverage for both polarizations by the arrangement of the branch elements. We plan to employ these proposed elements to build a prototype reflectarray and perform measurements to verify the array utility.

REFERENCES

[1] J. Huang, J.A.Encinar, “Reflectarray Antennas,” Wiley, New Jersey, 2007.

[2] Y. Fuji, et al., “High-efficiency and Low-side-lobe Reflectarray Antenna,” ISAP, December, 2014.

[3] M. Fukaya, R. Obata, S. Makino, H. Nakajima, M. Takikawa, “A Dual-polarized Stacked Reflectarray Antenna with Changing Beam-direction,” AP-S, July, 2020.

[4] S. Takino, S. Shigemitsu, Y. Kaimori, S. Makino, “A Dual-polarized Single Layer Reflectarray Antenna with changing beam-direction,” IEICE Technical Report A･P2021-138, January, 2022 (in Japanese).