Reflectarray Antenna with High Efficiency and Low Side Lobe

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***Abstract*—The design of a reflectarray antenna(hereinafter referred to as a reflectarray), is generally based on the resonant element spacing to suppress the grating lobes in free space. However, considering that this condition is not sufficient, we designed a resonant element spacing to suppress the grating lobe in the dielectric. This paper compares the radiation pattern and gain designed with the resonant element spacing obtained under these two conditions, and evaluates the efficiency and side-lobe characteristics.**

***Index Terms*—frequency selective reflector(FSR), side lobe, grating lobe, efficiency**

I. Introduction

In a metal-plate-loaded FSR, wherein the metal plate is loaded into an FSR via a dielectric, the reflection phase of an incident electromagnetic wave can be controlled by appropriately selecting the radius and shape of the resonant element. A reflectarray applies the reflection phase control function of the metal-plate-loaded FSR to the reflector. It consists of a flat mirror surface and a primary radiator, and it can form a plane wave by controlling the reflection phase of a spherical wave fed from the primary radiator - [1]. In the conventional design of the reflectarray, the propagation of the grating lobe, generated from the resonant element, into the dielectric body causes a low efficiency and a high side lobe. In contrast, in the proposed design, the grating lobe does not propagate into the dielectric body or free space. The resonant element spacing conditions in existing prototype reflectarrays, wherein grating lobes do not propagate in the dielectric, have achieved efficiencies of over 60% and low side lobe characteristics with side lobe levels of 30 dB or less in a certain frequency band f_L-f_H in the Ku band [2]. In this study, we analyzed reflectarrays designed with six patterns wherein the resonant element spacing was 0.9, 1, and 1.1 times the resonant element spacing obtained by the conditional equation for the dielectric substrate and for free space. We then determined the allowable resonant element spacing for fabricating the actual reflectarray. These analyses only consider the center frequency f_0.

II. Design of Reflectarrays with High Efficiency and Low Sidelobe

First, the conditions under which the grating lobes do not propagate in free space are shown in (1).

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

The conventional reflectarray exhibits a low efficiency and high side-lobe characteristics at the resonant element spacing d obtained using (1). This is because (1) does not consider the generation of the grating lobe in the dielectric body, although the grating lobe is generated with a low efficiency and high side-lobe characteristics. Fig. 1 shows a detailed diagram of the grating lobe generation in the dielectric. The incident

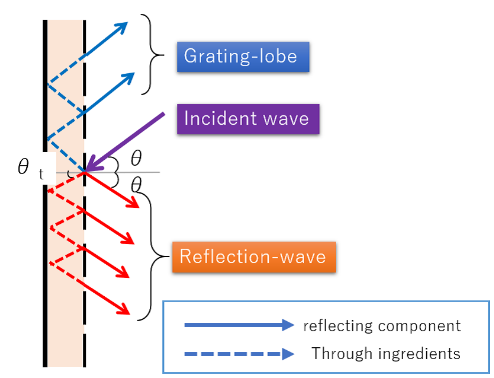


Fig. 1. Detailed diagram of grating lobe generation

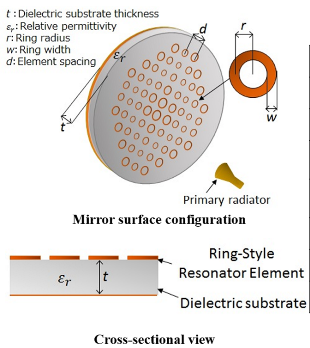
radio waves are divided into components that are reflected by the resonant element and the transmitted component. The reflected component is reflected at the same angle as the angle of incidence. In contrast, the transmitted component propagates between the metal plate and the dielectric, and is finally reflected at the same angle as the incident angle. Herein, when the grating lobe component propagates in the transmitting component, it radiates in an unintended direction. Accordingly, we proposed a design that considers the grating lobe in the dielectric [3]. Each resonant element controls the reflection and transmission; thus, the spacing between the resonant elements is considered. Equation (2) shows the element spacing conditions for preventing the grating lobes from propagating into the dielectric.

$$\frac{d}{\lambda_0} < \frac{1}{\sqrt{\epsilon_r}+\sin\theta_0} \tag{2}$$

Here, we use a dielectric with relative permittivity ϵ_r=2.59 and the wavelength condition λ can be determined at a certain frequency f_0 in the Ku band. In addition, θ is set to 25°. Using (1) and (2), the resonant element spacing d is calculated for 0.9times, 1 time, and 1.1times the element spacing. The six patterns considered are 0.4392λ, 0.4961λ, 0.5409λ, 0.6303λ, 0.6995λ, and 0.7727λ. The radiation patterns and the efficiencies of these six patterns were compared to determine the optimum resonant element spacing of the actual reflectarray and to confirm the validity of (2).

III. RESULT AND COMPARISON

The parameters of the reflectarray designed in this study are shown in Fig.2. Five design parameters are considered: dielectric substrate thickness t, relative permittivity ϵ_r, resonant element spacing d, ring width w, and ring radius r. Results of



Design frequency f_0	Ku
Relative permittivity ε_r	2.59
Dielectric substrate thickness t	0.1301λ
Element spacing d	0.4392λ,0.4961λ,0.5409λ 0.6303λ,0.6995λ,0.7727λ
Coordinates of the mirror origin (x,y)	(344.72,-289.26)
Mirror angle θ_d[deg]	25
Ring width w	0.0081λ
Ring radius r	0.0122λ~0.1749λ

Fig. 2. Design parameters

the full-wave analysis of the high frequency structure simulator using ANSYS are depicted in Fig.3, and those of the H and V-polarization radiation patterns for 0.9, 1, and 1.1 times the resonant element spacing using (1) and (2) are depicted in Fig. 4. These radiation patterns are obtained at a certain frequency f_0 in the Ku band. From Figs. 3 and 4, it can be observed that the sidelobes in the radiation pattern at 0.9times and 1 time the resonant element spacing of (2) are low sidelobes at approximately 30 dB for both H- and V-polarization. Consequently, the optimum resonator spacing in the radiation pattern is determined using (2). Fig. 5 depicts the

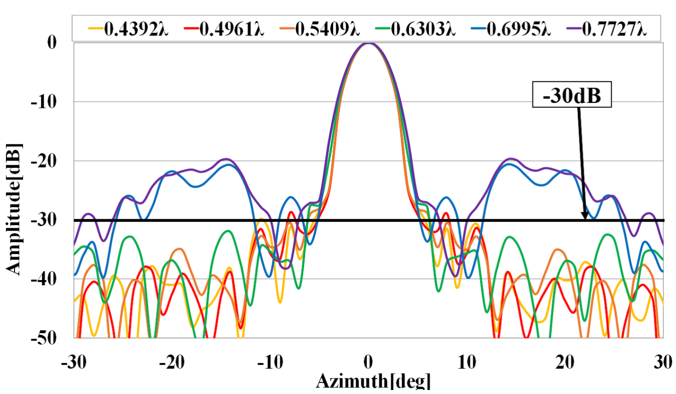


Fig. 3. Radiation pattern of H-polarization at an interval of six resonant elements

graphs of the efficiency and gain of the H- and V-polarizations. From Fig. 5, it can be seen that the efficiency of the H- and V-polarizations at 0.9 times and 1 time the intervals of the

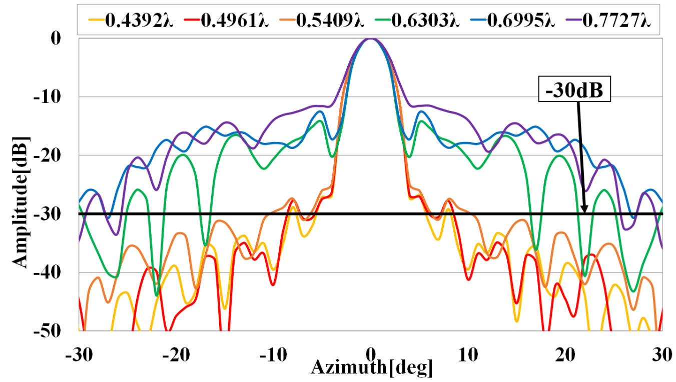


Fig. 4. Radiation pattern of V-polarization at an interval of six resonant elements

resonator in (2) exceed 60%, which is the optimum interval for the resonators. Therefore, it can be concluded that the optimum element spacing is obtained by (2).

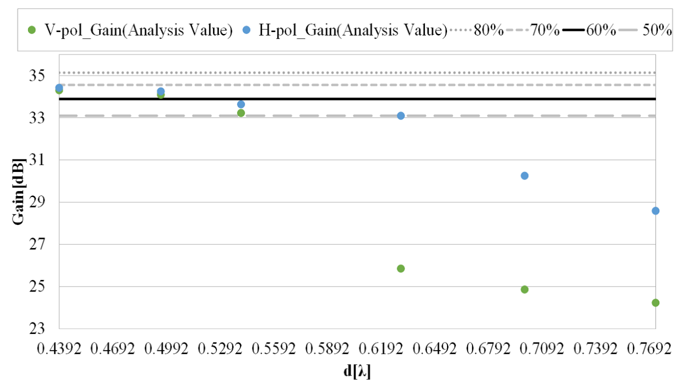


Fig. 5. Efficiency/gain of H- and V-polarization

IV. CONCLUSION

In this study, the antenna efficiency and radiation patterns of a reflectarray were compared using resonant element encoding in six cases. Consequently, the resonant element spacing determined by (2) was considered to be optimum for designing the elements of the reflectarray antenna. This report was supported by JSPS (20K04491).

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