Shaped-Beam Reflectarray Antenna Optimized at Multiple Frequency

Sanshiro Shigemitsu /Syota Takino/Shigeru Makino
Kanazawa Institute of Technology
7-1 Ohgigaoka, Nonoichi, Ishikawa, Japan.
Mail:b1600502@planet.kanazawa-it.ac.jp

Hiromasa Nakajima/Michio Takikawa
Mitsubishi Electric Corporation
5-1-1 Ofuna, Kamakura, Kanagawa, Japan.

***Abstract*— In previous research, only the center frequency was optimized when designing a reflectarray antenna that radiates a shaped beam. In this study, we designed a shaped beam reflectarray antenna by optimizing the center frequency as well as multiple frequencies, in addition to using the conventional design method.**

Keywords—reflectarray antenna; shaped-beam antenna; simple evaluation method; multi-frequency optimization

I. INTRODUCTION

In shaped-beam antennas, it is difficult to geometrically obtain the reflection phase because the shaped beam is radiated in various directions. Therefore, the reflection phase of all resonant elements should be determined using a nonlinear optimization technique such that the required gain in the beam's radiation direction can be satisfied. In previous studies [1], aberration theory was used to reflectarray antenna design using a simple evaluation method that can evaluate the ideal reflection phase. This technique applies the desired reflection phase at the center frequency to other frequencies and can be evaluated without any device design or frequency-response analysis of the reflection phase. The conventional shaped-beam design is created by applying conditions where the reflection phase of the resonant elements is frequency-independent without phase error. However, the conventional shaped-beam reflectarray antenna is optimized only at the center frequency and has a drawback in that the frequency characteristics deteriorate unless a good evaluation point is selected. In this study, we improve the formula of the conventional evaluation function to be optimized at other frequencies. Furthermore, we design the shaped-beam reflectarray antenna optimized at three frequencies and demonstrate its validity.

II. EVALUATION FUNCTION

In the past, the shaped beam was designed to be optimal at the center frequency f_0; thus, frequencies other than the center frequency f_0 were not guaranteed. Let Φ(f) be the frequency characteristic of the reflection phase, and Φ_0 be the reflection phase at the design frequency f_0. The conditional expression that the reflection phase of the resonant element does not cause a phase error regardless of the frequency is as given in (1):

$$\Phi(f) = \Phi_0 \qquad (1)$$

By applying (1), if the desired reflection phase is obtained, it can be evaluated without frequency characteristic analysis of the reflection phase or device design within a short calculation time. Further, by using this condition, optimization, including an arbitrary number of frequencies becomes possible.

The formula of the evaluation function for optimizing an arbitrary number of frequencies is expressed by (2):

$$\mathrm{F} = \sum_{i=1}^{n}\sum_{p=1}^{P} W_{ip}\left(G_{ip} - G_{0p}\right)^2 \qquad (2)$$

where n is the number of frequencies to be optimized, P is the number of evaluation points, and Wp is the weight of the gain at the frequency of i. Where I represents the frequency at which optimization is performed. G_{ip} is the gain function at the direction point, and G_{0p} is the required gain. The reflection phase is determined using the steepest descent method in order to minimize the evaluation function F.

III. SHAPED-BEAM DESIGN AND MEASUREMENT RESULTS

The design parameters used in this study are listed in Table 1. Fig. 1 shows the design parameters used to design the mirror surface. Figs. 2, 3, and 4 show the analysis results obtained by optimizing only the conventional center frequency f_0 and the analysis results when optimized at three points: $0.957f_0$, center frequency f_0, and $1.043f_0$. Moreover, they show the conventional analysis results and the analysis results optimized for three frequencies of the radiation pattern in the reflectarray antenna with the ring design. Fig. 5 shows the locations of the evaluation points where differences in gain are observed between the conventional and new designs. Fig. 6 shows the corresponding gain frequency characteristics of each evaluation point. In the designed reflectarray antenna, 11 evaluation points were set using the analysis method [2]. From the analysis results of the radiation pattern, no significant difference at $f=f_0$ was observed; however, at $f=0.957f_0$ and $1.043f_0$, there were differences near Hokkaido, Okinawa, and the Ogasawara Islands. Fig. 6 shows that at points far from the mainland, such as for Hokkaido and Okinawa, the low and high frequency side gains are more than 0.8 dB, which is higher than the value for the conventional design.

IV. CONCLUSION

In this study, a shaped-beam reflectarray antenna was designed and optimized at three frequencies. The analysis results revealed that the shaped-beam reflectarray antenna optimized at three frequencies showed frequency characteristics and higher gain, compared to those optimized at one frequency. The analysis of the radiation patterns at the low and high-frequency sides shows that the radiation patterns are not disturbed, and it can be observed that a wider bandwidth can be achieved compared to the conventional design. Therefore, an evaluation method that optimizes at frequencies other than the center one is appropriate. In future, we will prototype and evaluate a multi-frequency-optimized reflectarray antenna. This work was supported by JSPS20K04491.

REFERENCES

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[2] Y.Sunaga, "Simple Frequency Characteristic Evaluation of Shaped-Beam Design for Reflectarray Antenna"IEEE APS.Boston.USA.July.2018

TABLE 1. Desired reflection phase design parameters

Design Frequency band: f_0	Ka
Element shape	Ring
Dielectric substrate thickness: t	0.15λ
Dielectric constant of dielectric: ε_r	2.56
Mirror angle: θd[deg]	25
Center of opening surface: O(x,y,z)	344.72, 0.0, −289.26
Ring width: w	0.096λ
Ring radius: r	0.14λ-1.77λ
Opening surface size: D	47.92λ
Distance from primary radiator to center of aperture: R	43.13λ
Resonant element spacing: d	0.383λ
Clearance: c	9.077λ

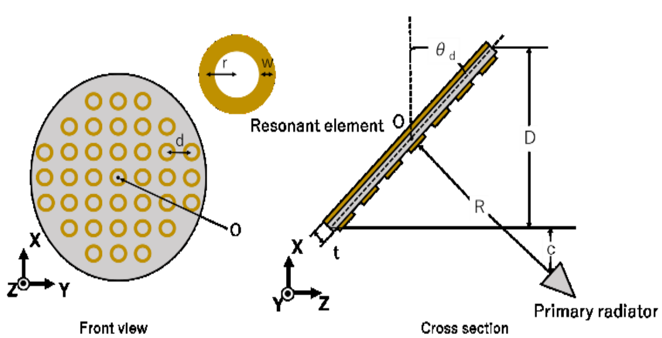

Fig. 1 Design parameters for specular system

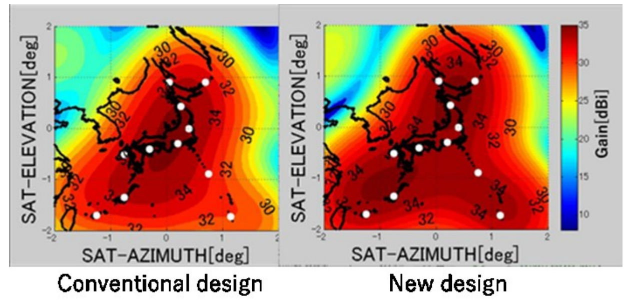

Fig. 2 Radiation pattern ($f=0.957f_0$)

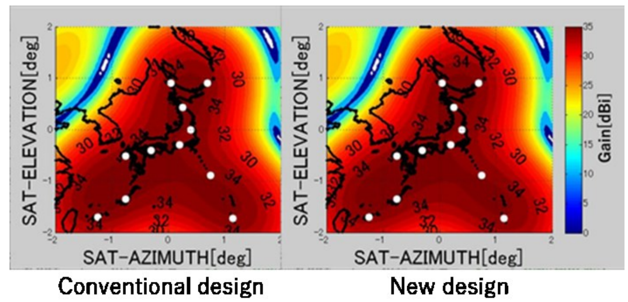

Fig. 3 Radiation pattern ($f=f_0$)

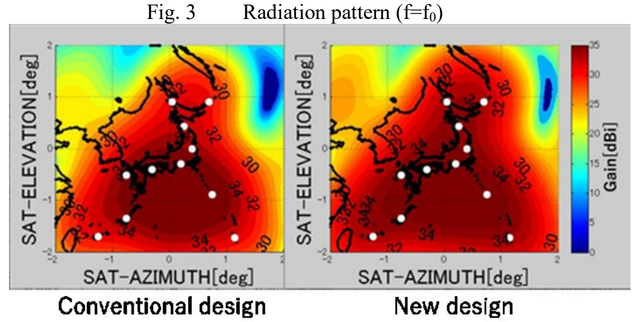

Fig. 4 Radiation pattern ($f=1.043f_0$)

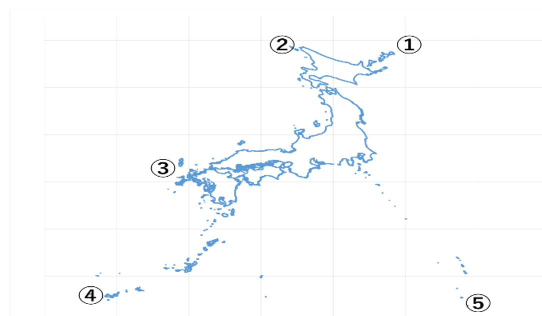
Fig. 5 Location of the evaluation point away from the mainland

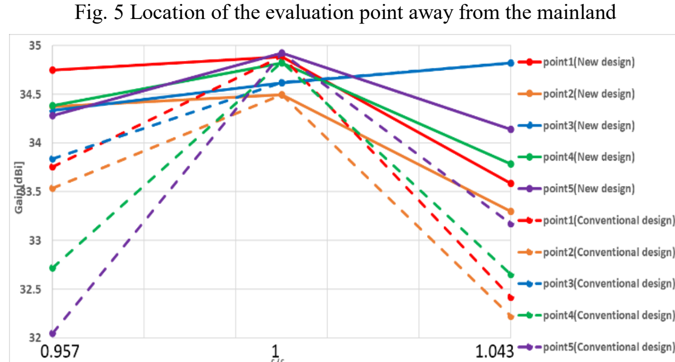

Fig. 6 Gain frequency characteristics at the evaluation points