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Simple Frequency Characteristic Evaluation of Shaped-Beam Design for Reflectarray Antenna

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***Abstract*— The analysis of the reflectarray antenna's frequency characteristics is a time consuming task. This is owing to the design of the size of the phasing elements, and the analysis of the reflection phase of the phasing elements. We propose a method for estimating the frequency characteristics of a reflectarray antenna by introducing aberration theory. The frequency characteristics can be estimated without the design consideration to phasing element size, and by the analysis of the reflection phase of phasing elements by the conditions of aberration theory. Therefore, in this paper, we propose a simple method to estimate the frequency characteristics of the reflectarray antenna that does not require element design estimates the frequency characteristics by using the desired reflection phase of our proposed design frequency.**

Keywords— Reflectarray antenna, aberration theory, shaped beam design

I. INTRODUCTION

The procedure for evaluating the frequency characteristics of the reflectarray antenna is as follows. First, the reflection phase of each phasing element is analyzed, and the size of phasing elements is determined to realize the desired reflection phase. Next, the radiation characteristics of the reflectarray antenna are determined by analyzing the reflection phase frequency characteristics of the element. Since the reflectarray antenna has a very large number of elements, it takes a very long time to design the size of phasing elements, and to analyze the frequency characteristics of the reflection phase. Consequently, a large amount of time required to design a shaped beam for a desired service area. We propose a simple method to evaluate the frequency characteristics of a reflectarray antenna with a pencil beam design by using aberration theory [1]. In this paper, we present this simple method to estimate the frequency characteristics of the reflectarray antenna of shaped beam design by using the desired reflection phase of our proposed design frequency.

II. EVALUATION OF FREQUENCY CHARACTERISTICS BY APPLYING ABERRATION THEORY

The frequency characteristics of the reflection phase were assumed to be $\Phi(f)$ and the reflection phase at the design frequency f_0 was defined as $\Phi_0 = \Phi(f_0)$. The conditions under which the phase error of the reflectarray antenna does not occur are as follows.

$$\Phi(f) = \frac{f}{f_0}\Phi_0 \qquad (1)$$

In this case, since the frequency characterisitic of the element's reflection phase is always negative, Φ_0 must also be negative to satisfy Eq.1. Generally, in the case of a single layer reflectarray antenna, the range of the achievable reflection phase Φ_0 is limited to about 360° and the reflection phase Φ0 includes a positive value such as, $-\pi \leq \Phi_0 \leq \pi$. Therefore, the realizable ideal frequency characteristics $\Phi(f)$ is constant with respect to frequency, as follows:

$$\Phi(f) = \Phi_0 \qquad (2)$$

The realizable wavefront can be estimated by using the desired reflection phase Φ_0 at the design frequency for the analysis of other frequencies. Therefore, the frequency characteristics of the wavefront can be estimated without designing the phasing element size. Figure 1 shows the frequency characteristics of the phase error on the aperture (XZ plane). The broken line indicates the phase error on the aperture that was calculated by using Eq. 2 (hereinafter, simple design), the solid line shows the phase error calculated by a was performed with a reflectarray antenna with pencil beam design, a design frequency of 12.0 GHz, and aperture diameter of 1,000 mm. Figure 1 shows that the phase error on the aperture in the detailed design and simple design are generally in agreement. Therefore, it was concluded that the simple design could estimate the frequency characteristics of the reflectarray antenna.

III. SHAPED BEAM DESIGN

Figure 2 shows the geometrical configuration of the reflectarray antenna. A primary radiator was located at F. The aperture diameter D = 2,000 mm. O was the center point of the reflectarray antenna with diameter D, and the distance from point F to point O was R = 2,000 mm. The clearance to avoid the blocking of a primary radiator was c = 300 mm. The inclination angle of the reflectarray antenna's mirror surface was θ_d = 20.27°. The design frequency was 12.5 GHz. Figure 3 shows the radiation pattern that used the evaluation function of 5 blue points determined such that the coverage area becomes the shape of the Japanese archipelago, where (a) is the analysis result of detailed design; (b) is the analysis result of the simple design. The detailed design is the analysis result of design the size of phasing element to realize the desired reflection phase Φ_0, and calculate the frequency characteristic of the phasing element. The simple design is the analysis result applying desired reflection phase Φ_0 at design frequency to each frequency. Detailed design values and simple design values generally agree, and it became clear that the radiation pattern not much difference between the detailed design and the simple design at design frequency. To optimize the phase distribution on the aperture, we optimized the defined evaluation function by using the steepest descent method.

IV. Analysis Result

Table 1 lists the analysis time of the detailed design and simple design. Figure 4 and 5 show the analysis results of the radiation pattern the outside design frequency of the detailed design (a) and simple design (b), where Figure 4 shows the results in the case of 12.1 GHz, while Figure 5 shows the results in the case of 12.9 GHz. Table 2 shows the gain differences radiated to the three cities under normal design shorter analysis time was entailed in the simple design, in comparison to the detailed design. Figures 4 and 5 show that the radiation pattern of the detailed design is roughly in agreement with that of the simple design. Table 2 shows that only a small gain difference existed between the radiation pattern of the normal design and that of the simple design.

V. Conclusion

In this paper, the simple frequency characteristic evaluation method of shaped-beam design for reflectarray antenna was proposed. The validity of the simple design was verified based on the fact that the difference between gain value of detailed design, and gain value of simple design is very small. It was shown that the simple design is more efficient than detailed design. It was shown that the simple evaluation method is effective for judging the adequacy of the frequency characteristics of shaped beam design for the reflectarray antenna.

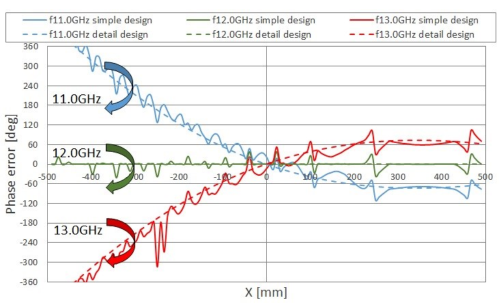


Fig. 1. Phase error on aperture (XZ plane).

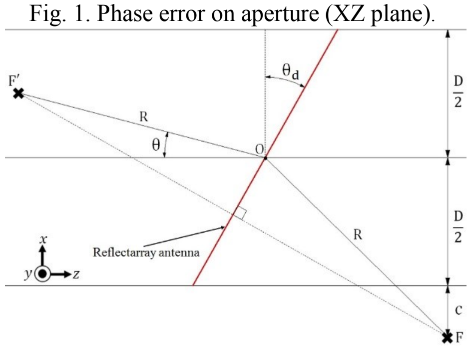
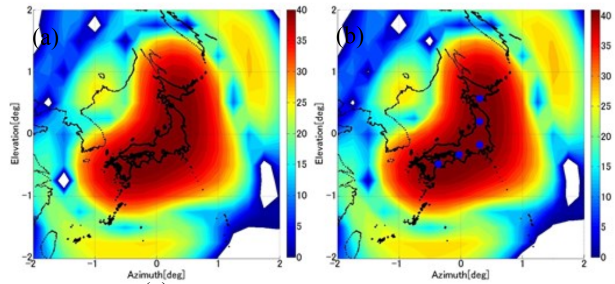
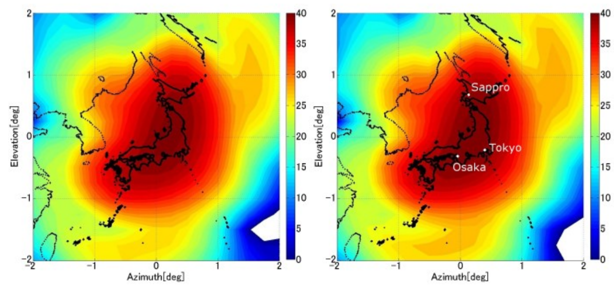


Fig. 2. Geometrical configuration of reflectarray antenna.



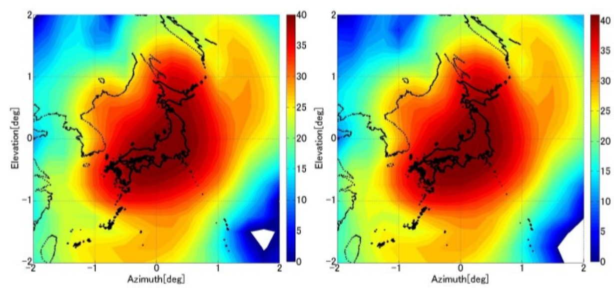
(a) (b)

Fig. 3. Radiation pattern of 12.5 GHz.



(a) (b)

Fig. 4. Radiation pattern of 12.1 GHz.



(a) (b)

Fig. 5. Radiation pattern of 12.9 GHz.

Table 1. Review time

	RingDesign	FrequencyCharacteristics	Total
detailed	15 h	10 h	25 h
simple	0 h	5 min	5 min

Table 2. City gains

	12.1 GHz	12.5 GHz	12.9 GHz
Tokyo	0.20 dB	0.15 dB	0.13 dB
Osaka	0.12 dB	0.05 dB	0.01 dB
Sappro	0.40 dB	0.32 dB	0.24 dB

References

[1] S. Makino, "Estimation of Frequency Characteristics of Reflectarray by Introducing Aberration Theory" EUCAP. Paris. France. March 2017