A Study of the Broadband Characteristic of Reflectarray Antennas Using Aberration Theory

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***Abstract* – In this paper, the broadband conditions of a reflectarray antenna will be shown using aberration theory. By using aberration theory, the mechanism of the frequency characteristics of the beam shift and gain reduction will be clarified. Further, a method for the mirror surface is described to become wide band. The validity is verified by an analysis and a theoretical formula.**

***Index Terms* — Reflectarray, Aberration, Beam shit, Gain reduction.**

1. Introduction

A reflectarray antenna is obtained by applying the reflection phase control function of a metal plate loaded FSR (Frequency Selective Reflector) to the reflecting mirror [1]. The antenna is structured by a plane mirror and primary radiator. A plane wave is formed by controlling the reflection phase of the spherical waves fed by the primary radiator. In this paper, the beam shift and gain reduction caused by the residual aberration will be clarified using aberration theory.

2. Residual aberration

Assuming that the resonance elements have no frequency characteristics of the reflection phase, the residual aberration is obtained as

$$d\Delta_0 = \frac{\lambda_0 - \lambda}{\lambda_0}\Delta \tag{1}$$

Where Δ is the optical path difference to be compensated, λ_0 is the design frequency, and λ is a frequency other than the design frequency. In (1), residual aberration does not occur in the case of $\lambda = \lambda_0$. However, in the case of $\lambda \neq \lambda_0$, residual aberration will be generated according to the wavelength ratio. F’ in Fig. 1 represents the position of the image of the primary radiator at F. There for, the image of the primary radiator radiates a spherical wave. The optical path difference between the spherical wave and the desired plane wave is the aberration Δ to be compensated. The aberration Δ can be divided into the first-order aberration Δ_1 and second-order aberration Δ_2. At $\lambda = \lambda_0$, the aberration Δ can be compensated however, at $\lambda \neq \lambda_0$, the residual aberration $d\Delta_0$ will still remain, as in (1). The beam shift is caused by the first-order residual aberration, whereas the gain reduction is caused by the second-order residual aberration.

3. First order aberrations

A first-order aberration is geometrically determined from three parameters the distance R from the primary radiator to the center of the reflectarray, the aperture diameter D, and the inclination angle θ of the image of the primary radiator with respect to the beam direction. The first-order residual aberration ΔL is determined by replacing Δ in (1) with L in Fig. 1. The wavefront slope θ_s can be obtained as follows:

$$\theta_s = \tan^{-1}\frac{\Delta L}{D} \tag{2}$$

The analysis parameters are as follows.

- R = 500 mm
- D = 500 mm
- f = 12 GHz
- X_1 = 200 mm
- θ = -20,0,20 deg

The beam shifts with respect to frequency are shown in Fig. 2. The dashed line represents the results calculated with (2), and the solid line represents the analytical results of the designed reflectarray. From Fig. 2, the analytical and calculation results are observed to be in good agreement. When θ = 0[deg], the image of the primary radiator is at the center of the aperture, and a beam shift does not nearly occur. In each case, the radii of the ring elements change almost concentrically, and the center of the concentric circles coincides with the position of the image of the primary radiator. Therefore, in the case of θ = 0[deg], where no beam shift occurs, the center of the concentric circle coincides with the center of the aperture.

4. Second order aberrations

The gain reduction will be examined by the second-order residual aberration. The gain reduction due to the second-order residual aberration can be calculated by the fundamental beam mode [2]. The magnitude of the gain reduction G_d can be calculated as

$$G_d = 20\log\frac{\omega_0}{\omega} \tag{3}$$

where ω is the beam radius on the aperture plane, and ω_0 is the beam radius at the beam waist considering the radius of curvature of the second-order residual aberration at the aperture. The radius of curvature can be geometrically determined by Fig. 1 and (1). In the analysis, θ is fixed at 0[deg] to avoid the beam shift discussed in Section 3. Fig. 4

shows the frequency characteristics of the gain for D = 150,300, and 450 mm. In these cases, the shapes of the reflector systems are similar, as R/D = 1. As shown in the figure, the results are consistent when the aperture diameter is small. On the other hand, a difference occurs as the aperture diameter increases. Fig. 5 shows the frequency characteristics of the gain for R = 150,300, and 450 mm with a fixed aperture diameter D =150 mm. As shown in the figure, a lower gain reduction is achieved when R is higher. This means that a reflectarray antenna system with a large R/D has wideband characteristics.

5. Conclusion

In this paper, the mechanism of the frequency characteristics of the beam shift and gain reduction was clarified by using aberration theory. A simple formula was derived to evaluate the magnitudes of the beam shift and gain reduction. Two important points were clarified to design a more broadband antenna. First, it is necessary for the image of the primary radiator to be at the aperture. Second, R/D needs to be larger.

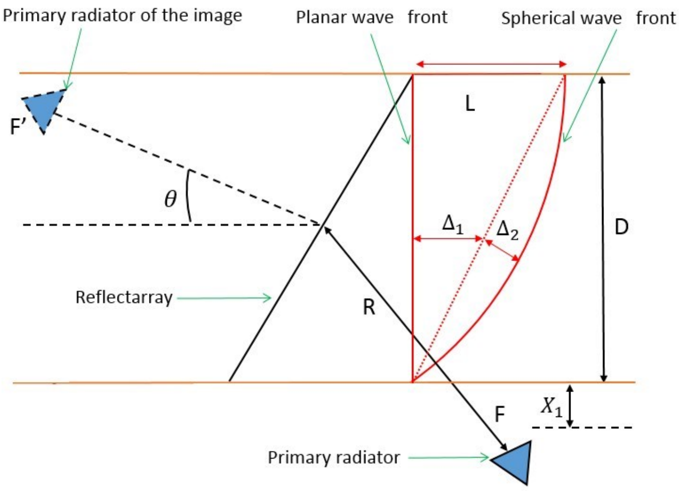

Fig. 1. Analysis model parameters

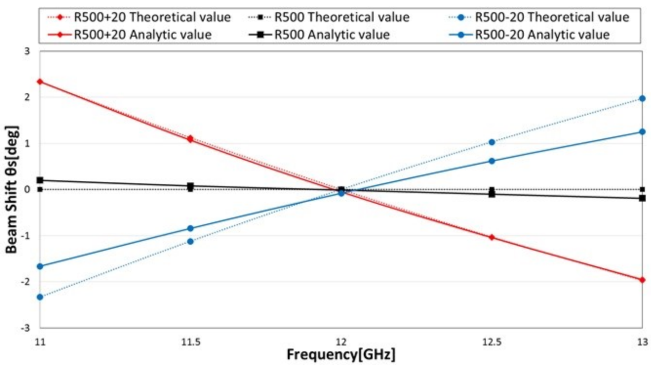

Fig. 2. The beam shift with respect to the frequency

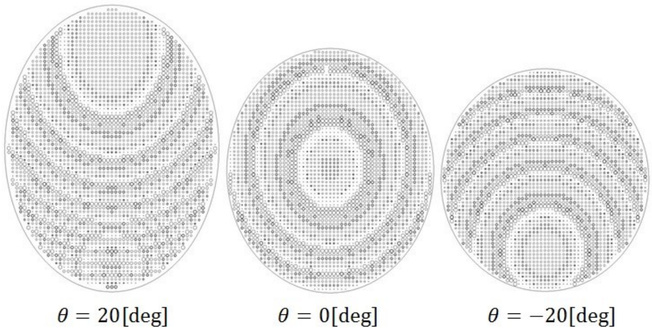

Fig. 3. Arrays of resonant elements

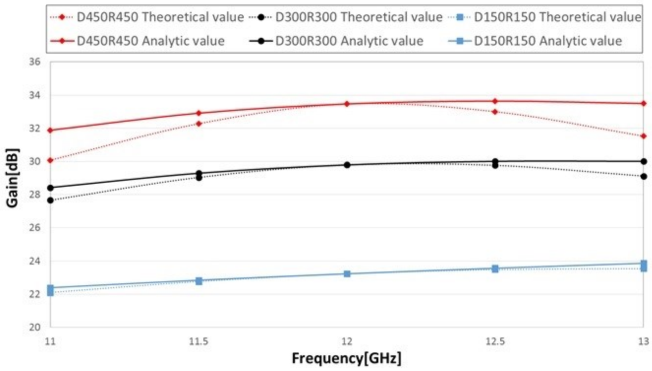

Fig. 4. Gain-frequency characteristics (for R/D =1)

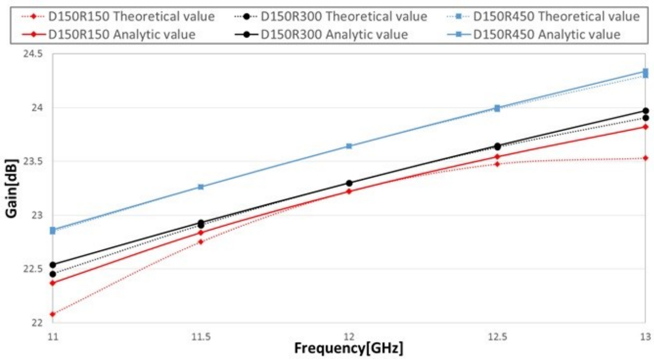

Fig. 5. Gain-frequency characteristics
(for varius values of R)

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