A MULTI-FOCAL REFLECTOR ANTENNA FOR MULTI-BEAM APPLICATION

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1. Introduction

To make more effective use of the limited frequency spectrum, extensive studies on satellite-borne multi-beam antennas (MBA) have been conducted(1).

In the past the authors developed an offset bifocal dual-reflector antenna which has no aberration at all, and an almost circular symmetric aperture distribution in spite of its offset configuration(2). The experiment showed that this antenna was most suitable for scanning a spot beam over a one dimensional wide angular region. Furthermore, we have devised a multi-focal dual-reflector antenna capable of performing two dimensional beam scanning, for more advanced multi-beam applications.

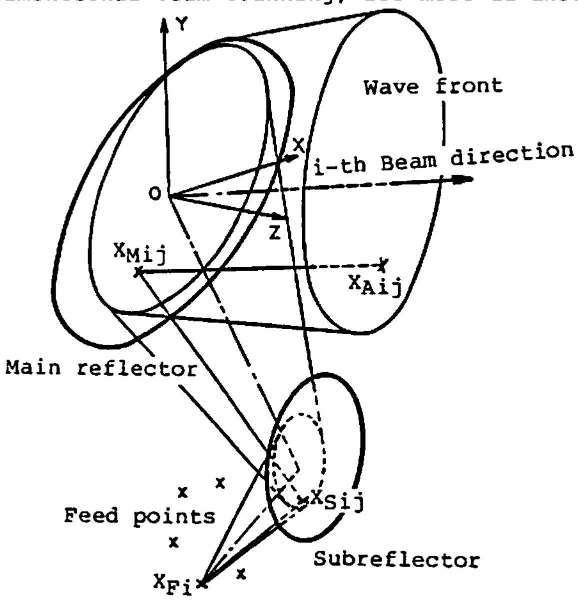


Fig.1 Ray tracing in dual reflector system

In this paper, we present a design concept of the multi-focal antenna, and demonstrate the theoretical beam scanning characteristics.

2. Design procecdure

Among antennas with more than three foci, there seems to be no aberration-free dual-reflector antenna. Therefore, it has been necessary to design a dual-reflector antenna with multiple quasi-foci, with an aberration which is small enough to permit practical use. Hereafter, it is refered to as a multi-focal antenna. The multi-focal antenna can be designed by minimizing the aberration over the antenna aperture using geometrical optics. Details of the design procedure are as follows.

We assume the surface of the main reflector $Z_p(\rho,\psi)$ and that of sub-reflector $Z_q(\rho,\psi)$ to be expressed with cylindrical coordinate as follows:

$$Z_{p,q}(\rho,\psi)=Zo_{p,q}(\rho,\psi)+\sum_m\sum_n Cmn_{p,q}\,\rho^{n+1}\begin{cases}\cos(m-1)\psi & m\ ;\ odd\\ \sin(m-1)\psi & m\ ;\ even\end{cases} \quad (1)$$

, where $Cmn_{p,q}$ is a coefficient to be optimized by the use of mathematical programming, and $Zo_{p,q}(\rho,\psi)$ is given as an initial surface.

For a given beam direction, the j-th ray from the i-th feed point X_{Fi} is traced to the aperture point X_{Aij}, via the subreflector point X_{Sij} and the main reflector point X_{Mij}, as shown in Fig. 1.

Next, we define a desired aperture distribution X_{Dij}, which offers a satisfactory radiation pattern, on the aperture plane perpendicular to the

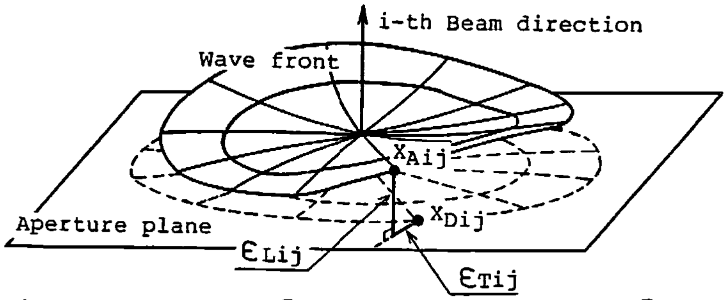


Fig.2 Phase error ϵ_{Lij} and amplitude error ϵ_{Tij}

beam direction as shown in Fig. 2. There is a difference between X_{Aij} (solid line) obtained by ray tracing and X_{Dij} (dotted line). The longitudinal component of the difference corresponds to "phase error" ϵ_{Lij}. On the other hand, the transverse one corresponds to "amplitude error" ϵ_{Tij}.

Now we can evaluate the total error ϵ as follows:

$$\epsilon^2 = \epsilon_L^2 + W \times \epsilon_T^2 \tag{2}$$

, where $\epsilon_L = \max_i \left\{ \text{r.m.s.}_j (\epsilon_{Lij}) \right\}$

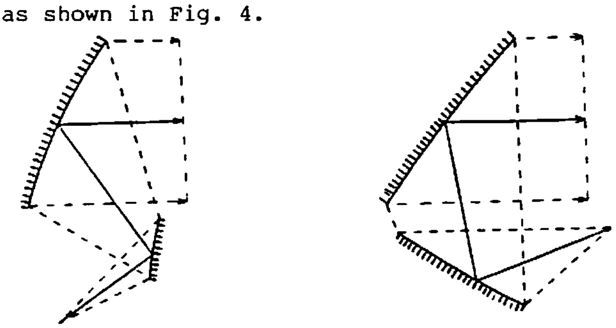
$\epsilon_T = \max_i \left\{ \text{r.m.s.}_j (\epsilon_{Tij}) \right\}$.

The weighting factor W in the above equation has to take such a value that the contriubtion of ϵ_L^2 and $W \times \epsilon_T^2$ to the radiation characteristics becomes the same. The value W depends on the ratio of the aperture diameter to wavelength (D/λ).

From the above discussions it becomes clear that the shapes of two reflectors, and the feed positions, can be determined by minimizing the objective function in Eq. (2) with respect to such parameters as $Cmn_{p,q}$, X_{Fi} ,···,etc.

3. Calculation of results

For calculating the multi-beam radiation characteristics by multi-focal antenna, two types of reflector configuration shown in Fig. 3 are employed ; one is a rear-fed type, and another is a front-fed type. These antennas are designed to have six quasi-foci associated with six beams which are set at the same interval near the edge of the Earth when viewed from the geo-stationary orbit as shown in Fig. 4.



(a) Rear-fed type (b) Front-fed type

Fig.3 Two types of reflector configuration

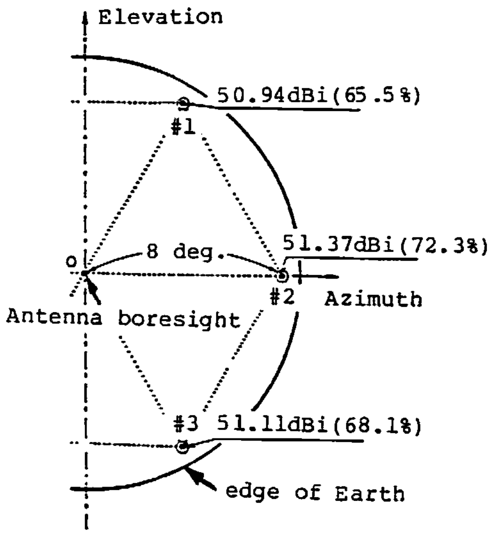


Fig.4 Diagram of 6 beams directions with their gains (and efficiencies)

We choose the value of D/λ to be 138 (beam width = 0.5°) and use a scalar feed of the illumination function $\cos^{20}\theta$, while the edge level of the subreflector is about -10dB.

Table 1 shows the results of ϵ_L and ϵ_T by optiminzation. We can see that the front-fed type(3),(4) has intrinsically superior scanning characteristics to the rear-fed one. In Table 1 it should be mentioned that especially ϵ_L are reduced successfully in both types.

The absolute gains of the front-fed type multi-focal antenna in the direction of #1, #2 and #3 are shown in Fig. 4. High aperture efficiency greater than 65% is achieved for each beam in spite of largely separated beam directions. Therefore the antenna can effectively cover the whole area of Earth by multiple spot beams.

In Figs. 5 and 6, the calculated results of azimuth patterns scanned to the azimuth direction, and contour maps of radiation intensity are illustrated, respectively. As is clearly seen from these figures, the multi-focal antenna offers excellent scanning performance.

4. Conclusion

This paper has described the design concept of MBA by a multi-focal dual refector antenna and has shown some excellent radiation characteristics. It can be concluded that this multi-focal antenna seems to be quite effective as a future satellite-borne MBA.

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Table 1 Results of optimization with $W=10^{-4}$

Type	Beam	ϵ_L ($\times 10^{-3}$D)	ϵ_T (×D)
		A → B	A → B
Rear-fed	#1	4.13 → 1.60	0.239 → 0.201
	#2	3.55 → 1.60	0.230 → 0.208
	#3	4.13 → 1.60	0.195 → 0.208
Front-fed	#1	1.56 → 0.385	0.066 → 0.066
	#2	1.56 → 0.383	0.090 → 0.061
	#3	1.56 → 0.385	0.096 → 0.070

A ; before optimization
B ; after optimization

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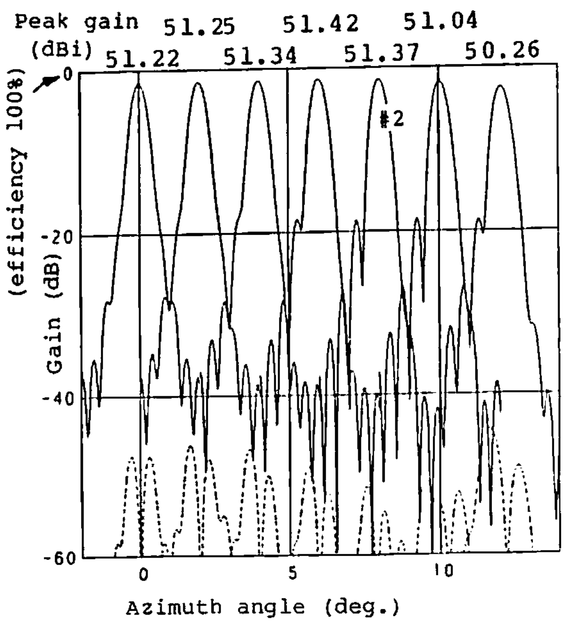

solid line : co-polarization
dotted line : cross-polarization

Fig.5 Calculated azimuth patterns scanned to the azimuth direction (Elevation = 0°)

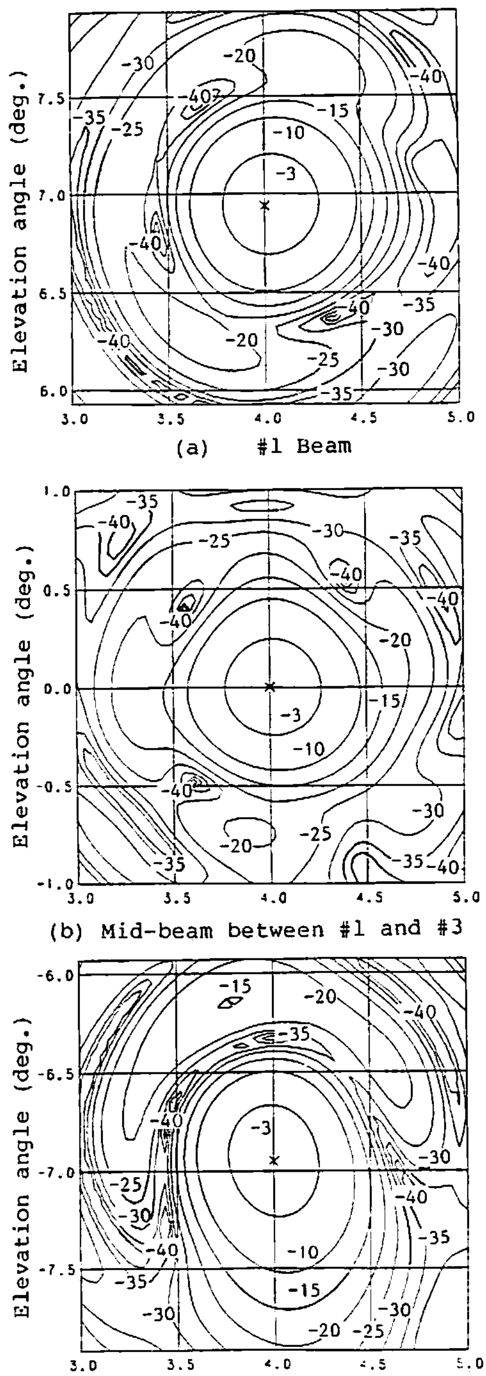

Fig.6 Calculated contor maps of radiation intensiy