

DESIGN OF ARRAY-FED MULTIPLE SHAPED BEAM ANTENNA
THROUGH MAXIMIZING MINIMUM GAIN

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1. Introduction - Large high capacity communication satellites with multiple shaped beam antenna are being developed in Japan, United States and so on. An array-fed reflector system is often used as a multiple shaped beam antenna. In this antenna, the reflector configuration and the excitation distribution of the feed array play important roles in the antenna performance. As the reflector configuration, it was shown that the Front Fed Offset Cassegrain (FFOC) type antenna is very useful⁽¹⁾. Many methods which determine the excitation distribution of the feed array have been reported. One of the well-known methods is a minimax algorithm^{(2),(3)}. In this method, the maximum gain deviation from the required value at each station can be minimized. This method is very useful when the station number is larger than the horn number. But in this method, only the power pattern at each station is considered. So, it's not adequate in the case of covering of isolated stations.

In this paper, a modified minimax method to determine the excitation distribution of the feed array is presented. In this method, both the power and the phase patterns are considered to maximize the power gain at the stations.

A model antenna was designed according to this method, fabricated, and measured. The good coincidence between the measured and designed performance was obtained.

2. Developed method - This method determines the excitation distribution of N horns on condition that the minimum gain of M earth stations becomes maximum.

The main characteristic is as follows. According to this method, the M earth stations are divided into M_A surrounding stations and M_B other stations. The excitation distribution of horns are determined to make the gains at the surrounding stations be equalized and maximized. So, on the gain contour map, the stations with minimum gain exist on one contour curve and other stations exist within it.

At first, on the condition that the M_A surrounding stations are given, the procedure to maximize the equalized received signal level at M_A earth stations illuminated by a beam composed by N primary feeds is investigated. In this procedure, the condition $M_A \leq N$ is necessary. Matrices \mathbf{H} and \mathbf{B} are introduced, each of which has a form of M_A columns x N rows. An element h_{ij} of the matrix \mathbf{H} represents electric field of a j th horn which contributes to

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the i th station. On the other hand, an element b_{kj} of the matrix \mathbf{B} represents a excitation distribution which maximizes the received power at the k th direction. The following relation is obtained⁽⁴⁾.

$$\mathbf{B} = \mathbf{H}^* \quad (1)$$

Using the above matrices, a matrix \mathbf{E} can be obtained as follows:

$$\mathbf{E} = \mathbf{H}\mathbf{B}^T = \mathbf{H}\mathbf{H}^{*T} \quad (2)$$

where an element e_{ij} of the matrix \mathbf{E} represents the received electric field intensity at i th direction by the k th field distribution. Let vector \mathbf{a} and vector \mathbf{d} be introduced.

$$\mathbf{a} = \mathbf{E}\mathbf{x} \quad (3)$$

$$\mathbf{d} = \mathbf{B}^T\mathbf{x} = \mathbf{H}^{*T}\mathbf{x} \quad (4)$$

where \mathbf{x} is a vector, whose component x_k represent the weight of the k th distribution. The component a_i of vector \mathbf{a} denotes the field received at the i th station, and the component d_j of vector \mathbf{d} denotes the excitation distribution of the j th horn.

Now, the condition to equalize the received power for each earth station is $|a_i| = a$, namely

$$a_i = a e^{j\phi_i} = a g_i \quad (5)$$

Then, from Eqs. (2), (3) and (4).

$$\mathbf{x} = \mathbf{E}^{-1}\mathbf{a} \quad (6)$$

and

$$\mathbf{d} = \mathbf{H}^{*T}(\mathbf{E}^{-1}\mathbf{a}) \quad (7)$$

Therefore the sum of power P fed to each horn is written as follows:

$$P = \mathbf{d}^T\mathbf{d}^* = \mathbf{a}^T\mathbf{E}^{*-1}\mathbf{a}^* \quad (8)$$

The power Q received at each earth stations when the input power is normalized to be unity, is written as follows:

$$Q = \frac{a^2}{\mathbf{a}^T\mathbf{E}^{*-1}\mathbf{a}^*} = \frac{1}{\mathbf{g}^T\mathbf{E}^{*-1}\mathbf{g}^*} \quad (9)$$

where \mathbf{g} is a vector whose component is g_i .

Therefore the condition to maximize the received power at each earth station is to minimize the following quantity S :

$$S = \mathbf{g}^T\mathbf{E}^{*-1}\mathbf{g}^* \quad (10)$$

This means that the equalized received levels at the stations depend upon their phase ϕ_i . Let $U_{ij} = |U_{ij}|e^{j\Xi_{ij}}$ be an element of \mathbf{E}^{*-1} , next equation is obtained because of \mathbf{E}^{*-1} being Hermitian.

$$S = \sum_{i=1}^{M_A} U_{ij} + \lambda \sum_{i=1}^{M_A-1} \sum_{j=i+1}^{M_A} |U_{ij}| \cos(\phi_i - \phi_j + \Xi_{ij}) \quad (11)$$

This concludes that the phase at the station ϕ_i shall be determined to minimize the quantity S' below for the given values of $|U_{ij}|$ and Ξ_{ij} .

$$S' = \sum_{i=1}^{M_A-1} \sum_{j=i+1}^{M_A} |U_{ij}| \cos(\phi_i - \phi_j + \Xi_{ij}) \quad (12)$$

Finally the excitation distribution \mathbf{d}_n of the horns can be represented by the normalization by input power as follows.

$$\mathbf{d}_n = \frac{\mathbf{d}}{\sqrt{P}} = \frac{\mathbf{H}^{*T}(\mathbf{E}^{-1}\mathbf{g})}{\sqrt{\mathbf{g}^T\mathbf{E}^{*-1}\mathbf{g}^*}} \quad (13)$$

The method to determine the excitation distribution taking into account of whole earth stations is summarized as follows.

- (1) By making the distribution which maximizes the gain for the corresponding station, the maximum gain for each station can be calculated.
- (2) Let the station whose maximum gain is the minimum be in group A and other stations be in group B. M_A is set to 1.
- (3) Apply the above-mentioned procedure to maximize the equalized gain considering the optimum phase pattern to the stations in group A, and calculate the gain G_A . Using the determined excitation distribution, calculate the gains at stations in group B and let the minimum gain be G_B .
- (4) If $G_A \leq G_B$, then this is the solution. But if $G_A > G_B$, go to the next procedure (5).
- (5) Transfer the station whose gain is minimum in group B to group A and let M_A be M_A+1 . If $M_A > N$, no solution.
- (6) Return to the procedure (3).

3. Design and measurement of a model antenna - To demonstrate the proposed method, Front Fed Offset Cassegrain (FFOC) type multiple shaped beam antenna was designed, fabricated and measured. The configuration of the antenna with 1800 mm diameter is shown in Fig. 1 and its photograph is shown in Fig. 2. A feed array is composed of rectangular horns with 18.75 mm x 18.75 mm aperture. Measured frequency was 20.1 GHz.

Fig. 3 shows the example of the calculated and the measured contours of the beam which contains 3 earth stations with 16 horns. The stations are covered very efficiently and calculated and measured patterns coincide very well. Fig. 4 shows another example of the calculated contours of the beam which has more complicated locations of stations. In this case, the beam splits in two because the phase pattern at the stations are also considered to make the gain higher.

4. Conclusion - A method to determine the excitation distribution of feed array for a multiple shaped beam antenna was proposed, and an experimental model was designed and measured. As the result, this method is verified to be effective for the design of a multiple shaped beam antenna.

Reference

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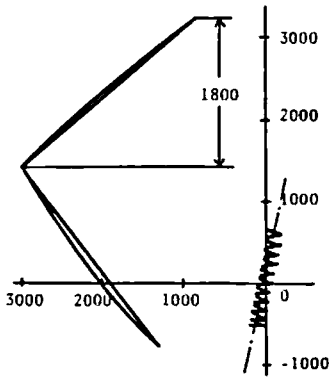


Fig. 1 Configuration of test antenna

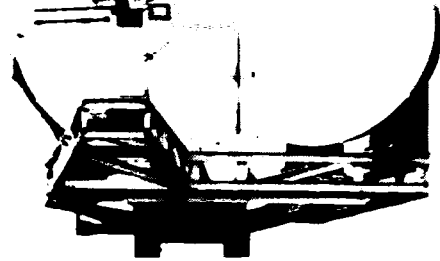


Fig. 2 Photograph of test antenna

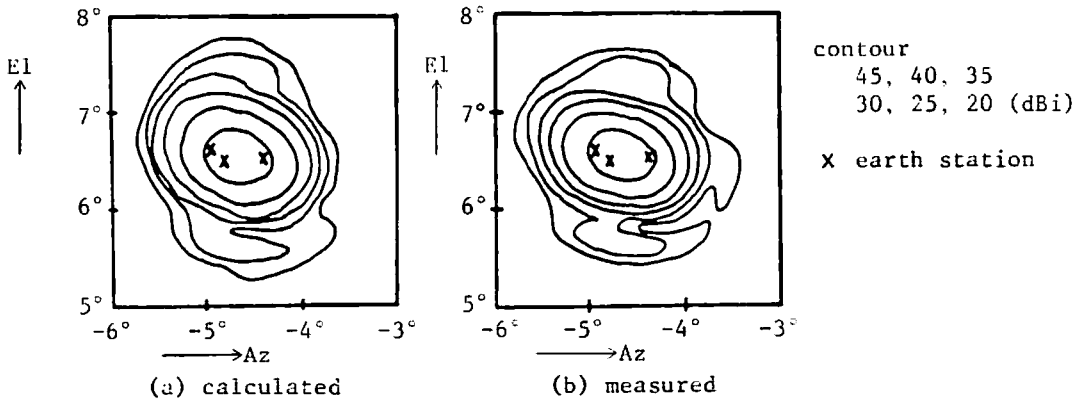


Fig. 3 Radiation pattern of shaped beam $M=3$, $M_A=2$, $N=16$

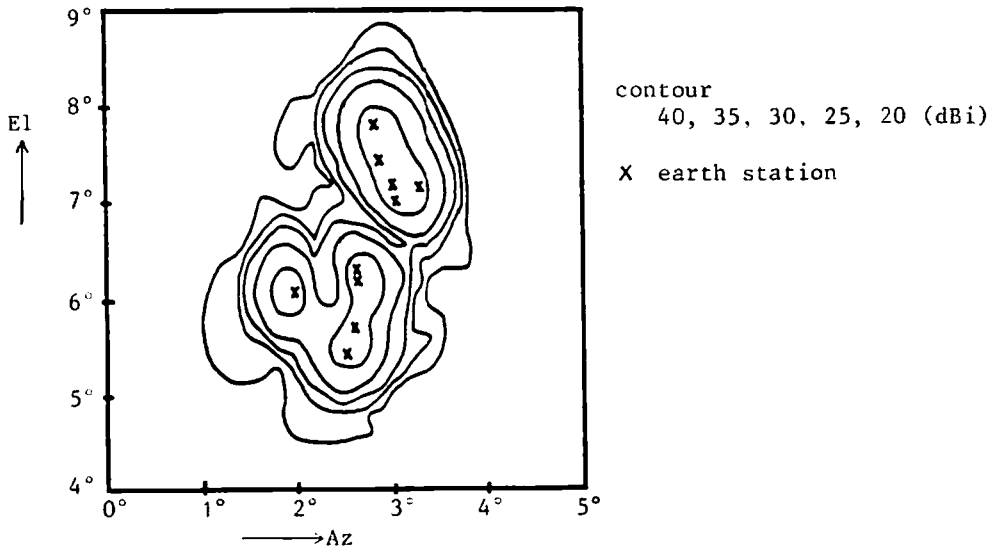


Fig. 4 Radiation pattern of shaped beam $M=10$, $M_A=8$, $N=35$