B—5—4 A DESIGN THEORY OF DOUBLY CURVED REFLECTORS

Shin-ichi Itoh
Nippon Electric Co., Ltd., Tokyo, Japan

1. INTRODUCTION

Recent surveillance radar systems have required some improved radiation patterns of doubly curved reflector antennas. They are primarily sharp cut-off elevation patterns on the ground-side and high beams with moderate underside broadness to reduce the multi-path effect and clutter contamination. Although the sharp cut-off patterns may be formed by simply enlarging the reflector aperture, this method narrows the beam width at the same time and causes inefficient energy radiation compared with the required radar system coverage.

This paper deals with methods to obtain more desirable elevation patterns rationally. First, the power conservation equation is reexamined considering the power on the whole reflector aperture. Next, a design condition between the aperture dimensions and secondary pattern design functions is derived in an attempt to synthesize the secondary pattern with minimum reflector dimensions. A main beam design function consisting of a Delta and a sector functions is then proposed to form a sharp cut-off pattern while maintaining a wider main beam width. These theoretical considerations are numerically evaluated and shown effective.

2. REFLECTOR DESIGN THEORY

2.1 Reflector Design Equations

A doubly curved reflector antenna used in a surveillance radar is designed to form a pattern which is shaped in the elevation plane and has a narrow beam width in the azimuth plane. The reflector transverse surface is composed of strips of paraboloids which may be computed after the central vertical curve is determined [1].

Figure 1 shows the coordinate system used in reflector design. The reflector central vertical curve is determined by solving simultaneous differential equations. The first equation expresses geometrical optics reflection [1]. The second one, expressing power conservation relation between the primary feeder and the desired secondary pattern, is given by Eq. (1), generally considering the power distribution on the whole reflector surface:

$$\frac{d\theta}{d\phi}=K\cdot\frac{Q(\phi)}{P(\theta)},\quad K=\int_{\theta_1}^{\theta_2}P(\theta)d\theta\Big/\int_{\phi_1}^{\phi_2}Q(\phi)d\phi \qquad (1)$$

where

$P(\theta)$ = Secondary pattern design function

$$Q(\phi)=\int_{y_1(\phi)}^{y_2(\phi)}I(\phi,y)\left(1+\frac{y^2}{4\rho_c^2\cos^2\left(\frac{\theta-\phi}{2}\right)}\right)\left(1-\frac{y^2}{4\rho_c^2\cos^2\left(\frac{\theta-\phi}{2}\right)}\frac{d\theta}{d\phi}\right)\frac{\rho_c^2}{\rho^2}dy. \qquad (2)$$

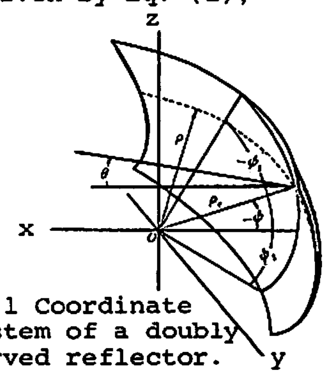

Fig.1 Coordinate system of a doubly curved reflector.

The integration in Eq.(2) is carried out along the transverse strips for each ϕ, and $I(\phi,y)$ is the primary feeder power function. Taking the limit of integration width as zero, Eqs.(1) and (2) reduce to the conventional equation.

In the formation of the secondary pattern, the power radiated from the feeder and scattered by the reflector is distributed in the elevation plane to conform to the given secondary pattern design function. Utilization of Eqs.(1) and (2) improves the power conservation relation in a geometrical optics sense, because the power distributed on the whole reflector aperture is considered instead of considering only the central vertical strip as usual. This fact was confirmed by numerical computation, but the effect is not large.

2.2 An Approach to the Optimum Aperture Design

The above method assures power scattering in a geometrical optics sense, but the actual pattern formation obeys the wave phenomenon. This difference has necessarily required deliberate selection of the secondary pattern design function and some trial and error computation. To reduce these efforts and to design the reflector optimally, the relationship between the aperture dimensions and the design functions is examined in the following.

The reflector vertical aperture is divided into two sections as shown in Fig.2. The upper section contributes to forming the main beam region of the secondary pattern as a wave phenomenon. The lower section contributes to forming the higher-elevation region in a geometrical optics manner. The gain function $G(\theta)$ of the secondary pattern is expressed by

$$G(\theta)=\begin{cases} G_1(\theta)P_{w_1}/P_t & \text{for main beam region,} \quad (3)\\ G_2(\theta)P_{w_2}/P_t & \text{for high elevation region,} \quad (4)\end{cases}$$

where $P_{w_1}=\int_{\theta'_1}^{\theta_1} P_1(\theta)d\theta,\quad P_{w_2}=\int_{\theta_1}^{\theta_2} P_2(\theta)d\theta,\quad P_t=P_{w_1}+P_{w_2}.$

$P_1(\theta)$ and $P_2(\theta)$ are the main beam design function and the higher-elevation design function, respectively.

In order to obtain more definite form, it is assumed that the power distribution is uniform on the reflector vertical aperture, aperture sizes a_1 and a_2 are simply propor-

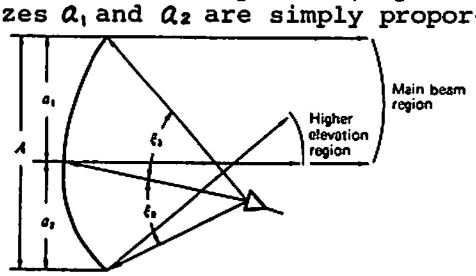

Fig.2 Beam formation by a doubly curved reflector.

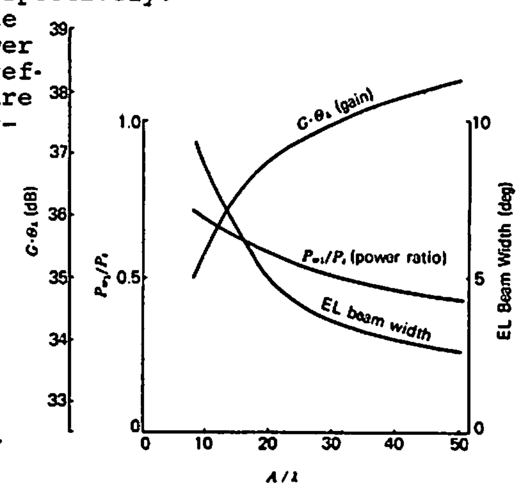

Fig.3 Power ratio, gain and beam width vs. full aperture size.

tional to secondary pattern integrated powers P_{w1} and P_{w2}, the reflector upper section is a part of a paraboloid, and the lower section shapes the beam in a completely geometrical optics manner. Equations (3) and (4) reduce to

$$G(\theta)\Theta_{\perp} = \begin{cases} (4\pi/\lambda)(a_1^2/A) \text{ for main beam region,} & (5) \\ \dfrac{4\pi P_2(\theta)}{\int_{\theta_1}^{\theta_2} P_2(\theta)d\theta} \cdot \left(1-\dfrac{a_1}{A}\right) \text{ for higher elevation region,} & (6) \end{cases}$$

where $\Theta_{\perp}$ is the azimuth beam width of the secondary pattern. The power ratio of the main beam design function can be determined depending on the gain difference between the above two regions. Figure 3 shows the design function power ratio vs. the total aperture size A, in the case that the gain difference between the beam nose and θ_1 direction is taken 3 dB for a typical design function $P_2(\theta)$ of the higher-elevation region. The figure also shows the expected directivity and the beam width when the indicated power ratio is used.

Through various numerical evaluation of the graphs, it was found that the graphs have to be modified depending on the type of the main beam design functions. That is, gain for the Delta function case (refer to the next section) is larger than values of the graph, gain for a narrow Gaussian function case agrees with the graph, and gain and beam width for a broader function are smaller and broader than the graphs, respectively. The graphs are effective in determining the aperture size to realize the specified sharpness of the ground-side pattern.

2.3 Design Functions for Main Beam Region

The same magnitude of the power ratio P_{w1}/P_t may be obtained by infinite kinds of main beam design functions $P_1(\theta)$, if a higher-elevation design function is kept unchanged. In Fig.4, representative main beam design functions are tabulated. The Delta function composes a paraboloid and the narrowest main beam may be obtained. The Gaussian function was proposed by [2] to realize the specified main beam shape exactly and is effective in designing a sharp cut-off reflector [3]. A sector function and a Delta-sector function are hereby proposed as means to realize sharp cut-off patterns on the ground-side while maintaining broader beam width.

MAIN BEAM DESIGN FUNCTION $P_1(\theta)$		POWER P_{w1}
DELTA (Paraboloid)	$P_\delta\delta(\theta-\theta_1)$, θ_1	P_δ
GAUSSIAN	θ_i θ_1	$\int_{\theta_i}^{\theta_1} P_1(\theta)d\theta$
SECTOR	a, θ_i θ_1	$a(\theta_1-\theta_i)$
DELTA-SECTOR	$P_\delta\delta(\theta-\theta_i)$, a, θ_i θ_1	$P_\delta+a(\theta_1-\theta_i)$

Fig.4 Table of main beam design functions.

3. NUMERICAL EVALUATION

A universal computer programs were developed containing the design theories in the previous section and the pattern computation equations [3], and the theories were evaluated numerically. Reflectors were first designed by using sector functions as main beam design functions and the power ratios were taken around the values in Fig.3, considering the broadness of the design functions.

The sharpness of the elevation pattern may be expressed by gain reduction at each underside angle from the beam nose. Figure 5 shows the degree of sharpness of ground-side patterns for the beam width of the sector design functions. The figure also shows improvement of sharpness by application of the Delta-sector functions. Cases for sector beam width of six degrees are shown and we can observe that the degree of underside cut-off is drastically improved by increasing the percentage of the Delta function part. Figure 6 is a comparison example of secondary pattern main beams, in which it is notable that the shape near the beam nose is almost unchanged and only the underside is sharpened as expected.

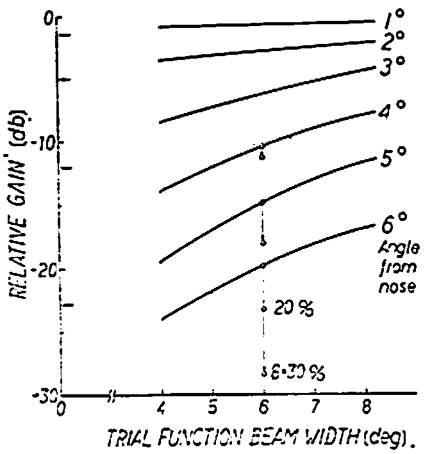

Fig.5 Degree of pattern sharpness vs. design function beam width.

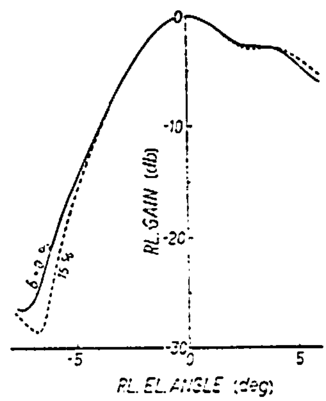

Fig.6 Improved design sharp cut-off pattern.

4. CONCLUSION

Theories on doubly curved reflector antennas were treated to synthesize desirable elevation patterns through rational aperture design procedures.

The power conservation equation was extended by considering the feeder power on the whole reflector aperture. A method for choosing the reflector aperture dimensions and the power ratio of the main beam region was discussed. It resulted in graphs giving expected directivity and beam width vs. vertical aperture size. These graphs may be used to synthesize the secondary pattern with minimum reflector dimensions. Then, a main beam design function consisting of a Delta and sector function was newly proposed, and the effectiveness was substaintiated by numerical computation.

REFERENCES

[1] S.Silver, Microwave Antenna Theory and Design,McGraw-Hill.
[2] A.S.Dunbar, Proc. of IRE, Vol.36, No.10,pp.1289-1296.
[3] S.Itoh & H.Yokoyama,NEC R&D, No.47,pp.47-54, Oct.1977.