B—4—4 Dielectric Lens Antenna with Shaped Surfaces

Yoshihide YAMADA and Tadashi TAKANO

The Yokosuka Electrical Communication Laboratory,

Nippon Telegraph and Telephone Public Corporation

Yokosuka, Kanagawa, Japan

Introduction

On the basis of the increasing demand for an antenna with low sidelobe characteristics, the dielectric lens antenna has attracted special interest recently. The design technique for the surfaces of a dielectric lens antenna to improve the performance was proposed by D.K.Weineo [1], though measured data were not included in ref. [1] .

This paper proposes a design technique to obtain an arbitrary amplitude and phase distribution by controlling inner and outer surface of the lens antenna, which was developed by the authors independently of D.K.Weineo. The usefulness of this technique is verified by experiments. Characteristics are shown superior to that of conventional antennas. Moreover, detailed investigations are made on the analysis of wide angle characteristics of the lens antenna.

Design procedure

In designing the dual reflector antenna, amplitude and phase distribution are controlled, because there are two surfaces to be shaped such as a mainreflector and a subreflector [2]. In case of a dielectric lens antenna, the shaping technique is also thought applicable due to the surfaces of the lens. Fig. 1 illustrates a coordinate system for the dielectric lens antenna. The antenna axis coincide

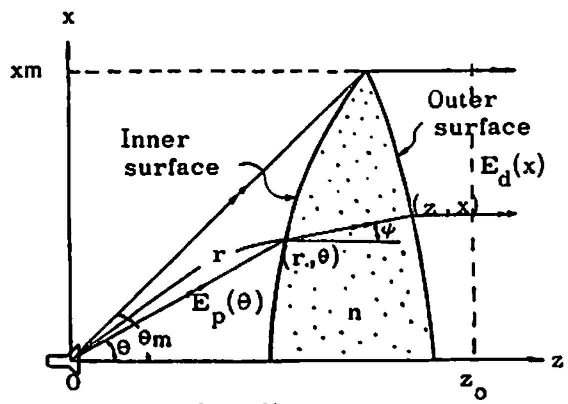

Fig. 1 Coordinate system

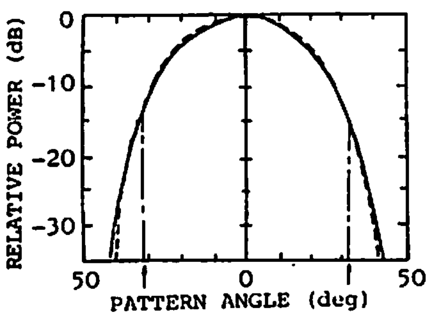

Fig.2 Dielectric focused primary horn radiation pattern
(↑: Dielectric lens edge
—— E-plane
---- H-plane)

with z-axis. X_m is the lens radius and n is the refraction index. The antenna aperture is assumed to be on the $z = z_0$ plane.

In designing the surface curvature, geometrical optic approximation is used. If the ray from the feed horn becomes parallel to the z-axis, after being refracted by the outer surface, the following three conditions are obtained.

(i) Snell's law

$$\frac{dr}{d\theta} = r \cdot \frac{n \cdot \sin(\theta - \psi)}{n \cdot \cos(\theta - \psi) - 1} \quad \text{(for inner surface)} \qquad (1)$$

$$\frac{dz}{d\theta} = \frac{n \cdot \sin\psi}{1 - n \cdot \cos\psi} \cdot \frac{dx}{d\theta} \quad \text{(for outer surface)} \qquad (2)$$

(ii) Path length condition

$$l(x) = r + \frac{n \cdot (x - r\cos\theta)}{\cos\psi} + z_0 - z \qquad (3)$$

where l (x) is path length normalized by wave length from the phase center of the feed horn to the aperture plane.

(iii) Energy condition

According to the power conservation law,

$$\frac{dx}{d\theta} = \frac{E_p^2(\theta) \cdot \sin\theta}{\int_0^{\theta m} E_p^2(\theta) \cdot \sin\theta \cdot d\theta} \cdot \frac{\int_0^{X_m} E_d^2(x) \cdot x \cdot dx}{E_d^2(x) \cdot x} \qquad (4)$$

where $E_p(\theta)$ is feed pattern and $E_d(x)$ is illumination distribution on the aperture.

Equations (1) through (4) form a non-linear differential equation, which is familiar in the design of dual reflector. The values of r, z, x are calculated according to independent variable θ, if functions $E_p(\theta)$, $E_d(x)$ and l (x) are given.

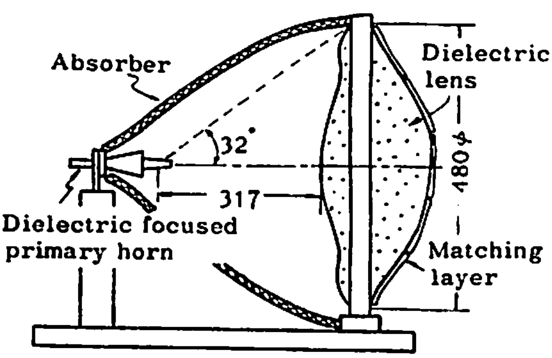

Fig.3 Test antenna configuration

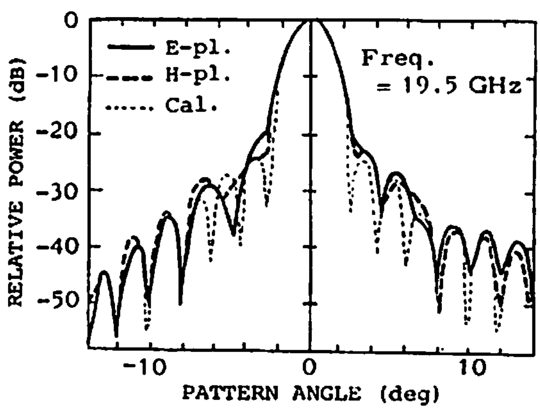

Fig. 4 Near-axis radiation patterns

Design Example

The dielectric focused horn is used as the primary radiator, because this horn has a nealy circular symmetric pattern and law cross-polar characteristics. The radiation pattern is shown in Fig. 2. For aperture distribution, a Taylor amplitude distribution is chosen, which has a -25 dB sidelobe level with $\bar{n} = 3$. The designed antenna configuration is shown in Fig. 3. The surface of the lens is cleary changed from that of a conventional convex lens antenna. The material used is teflon with dielectric constant $\varepsilon = 2.06$. The quarter wave matching layer is a teflon sheet with a dielectric constnat $\varepsilon = 1.41$. The total weight of the lens is about 50 kg.

Experimental study

Near-axis radiation pattern is shown in Fig. 4. E- and H-plane patterns are closely semilar, owing to the symmetry of the primary radiator pattern and the antenna structure. Calculated and measured patterns agree well, except for the angular region from the first to the third sidelobes. The reason is shown by the theoretical investigation that the phase on the aperture is deviated by about 50 degrees at the circumference of the antenna, because the dielectric constant is changed by 5 % due to the temperature shift. The gain was measured to be 38.8 dB at 19.5 GHz, which corresponds to a n 80 % aperture efficiency. This value also agrees well with the theoretical value. The usefulness of the stated design technique is, therfore, confirmed by the experiments.

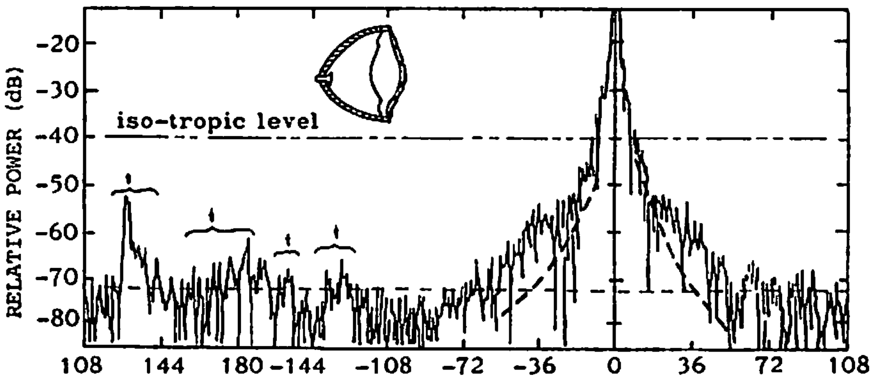

Fig. 5 Wide angle radiation patterns

———— Measured
— — — pattern envelope due to aperture distribution
- - - - - estimated scattered level due to surface roughness
| : reflections from surroundings

The wide angle radiation pattern is shown in Fig. 5. The broken line indicates the pattern envelope calculated from the aperture distribution. In the angular region beyond 70°, the sidelobe level is less than -30 dB_i, which is quite superior to a conventional reflector antenna. The sidelobe level of this region agree well with scattered level, due to surface roughness, which is shown by the dotted line. In the angular region about 20° through 70°, measured level is raised as compared with the calculated level. Levels and shapes of sidelobes in this angular region also agree well with those calculated with the reflected rays between the inner and outer surface of the lens by ray tracing method. If the matching layer is removed, the wide angle sidelobes beyond 20° are increased allmost uniformly by about 10 dB.

Conclusions

It is shown that the prescribed property can be achieved by the proposed design technique of lens surfaces. The aperture efficiency of about 80 % was obtained, and the first sidelobe level was about -25 dB.

With the wide angle characteristics, all lobes beyond 70 became below -30 dB_i when the quarter wave matching layer was attached to the outer surface of the lens. By analysis, those lobes were shown to be determined by the scattering due to surface roughness of the lens. And the usefulness of the matching layer was also shown. In further investigation, a method to reduce lens weight and improve weather durability should be examined.

Acknowledgement

The authors are grateful to Mr. Masaaki Shinji for his continuing guidance and encouragement.

Reference

[1] D.K.Weineo, "Lens Design for Arbitrary Aperture Illumination", 1976 IEEE Ap-S Int'l Symp. pp. 476 - 479.

[2] V.Galindo, "Design of Dual-Reflector Antenna with Arditrary Phase and Amplitude Distributions", IEEE Trans. Ap-12, 4, pp. 403 - 408, July 1964.

[3] T.Takano and Y.Yamada, "A Dielectric Focused Primary Radiator", Trans. of IECE of Jap. Vol. 60, No. 9, Sep. 1977.