A High-Efficiency Quarter-Wave Zone Plate Reflector

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Abstract— **A multilayered quarter-wave zone plate reflector antenna operating in the microwave range is presented. The theory for designing the reflector and experimental results are given. An efficiency of 55% was obtained with a prototype reflector antenna.**

I. Introduction

THE FRESNEL ZONE PLATE (FZP) is a planar device that can be used for focusing electromagnetic waves. In its simplest form, it consists of a set of metallic rings printed over a dielectric sheet. The inner and outer radii of the rings are designed to give half wavelength pathlength differences to the chosen focus [1]. This simple structure produces two foci symmetrically located in front and behind the plate and the incident energy is equally divided between them. The phase efficiency of such a plate is only 10%, however [2]. An improved phase efficiency of up to 41% can be achieved by placing a reflector a quarter wavelength behind the zone plate so as to bring the two foci together in front of the plate [1]. An antenna based on this principle which achieved a measured efficiency of 26% was described in [3], and its millimeter-wave integral circuit version was reported in [4]. To increase the efficiency of the FZP antenna further, phase correction techniques must be employed in order to compensate the spherical phase deviation of the aperture field. It has been shown that a quarter-wave zone plate, which employs four stepwise phase shifts within each full-wave zone, has 81% phase efficiency [2], [5].

This letter describes the application of phase correction techniques to the zone plate reflector using a three-layered structure of dielectric sheets with printed metalized rings. An efficiency of 55% was measured for a prototype antenna operating in the 12 GHz band. This is not far short of the performance of dish antenna of comparable size.

II. Reflector Design

To convert a normally incident plane wave into a spherical one converging to the focal point, an ideal symmetric zone plate reflector should provide a gradual phase compensation from 0 to 2π within each full-wave zone [5]. Practically, this can be achieved by dividing each full-wave zone into M subzones and deploying an appropriate constant phase shifter in each subzone to produce a stepwise approximation. The inner and outer radii of the jth subzone in the ith full-wave zone, ρ_{ij} and ρ_{ij+1}, are given by

$$\left(F^2+\rho_{ij}^2\right)^{1/2}=F+(i+j/M)\lambda$$
$$(i=0,1,2,\cdots;\ j=0,1,2,\cdots,(M-1)), \qquad (1)$$

where F is the focal length and λ represents the operating wavelength. The phase difference between adjacent phase shifters is $2\pi/M$. Such a phase correction zone plate is known as the $1/M$-wave zone plate.

The multilayered quarter-wave zone plate reflector and its phase-correcting function is illustrated in Fig. 1. It consists of a metallic ground and three layers of concentric rings separated by three dielectric substrates. The rings are located at different interfaces so that for any full-wave zone with given i, there

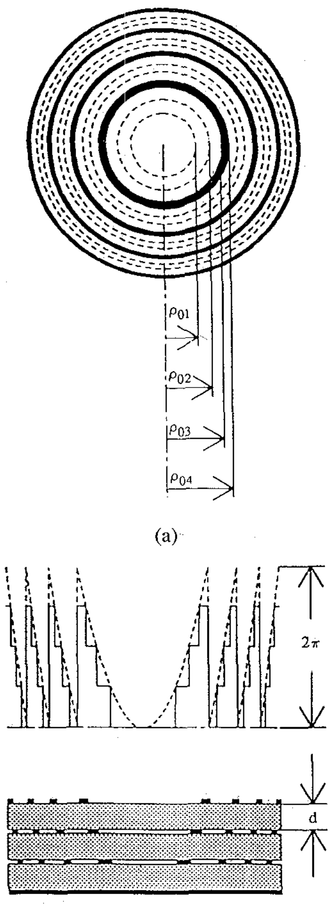

Fig. 1. (a) Front view of the reflector. (b) sectional view and the phase-correcting function.

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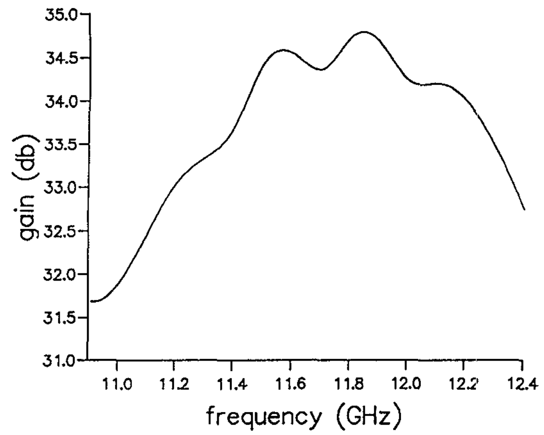

Fig. 2. Measured antenna gain vs. frequency.

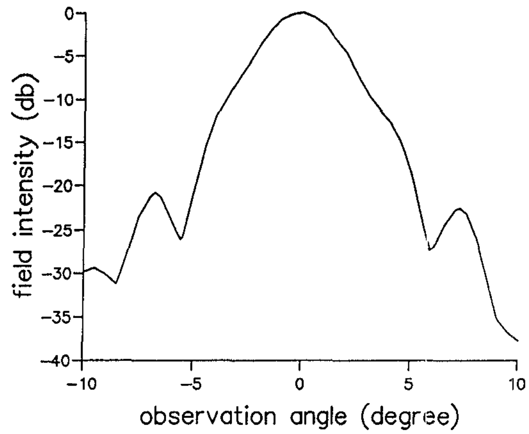

Fig. 3. Typical antenna pattern in the E-plane.

are $(3-j)$ layers of substrates above the conducting ring at the jth subzone ($j = 0, 1, 2, 3$), thus producing a stepwise phase correction to the incoming wave. In fact, this configuration applies to any $1/M$-wave zone plate reflector. The substrate thickness d should be so determined that a normally incident ray experiences $2\pi/M$ phase delay after transmission and reflection in it, and this gives

$$d = \lambda/(2M\sqrt{\varepsilon_r}), \quad (2)$$

where ϵ_r represents the relative dielectric constant of the substrate. With $M = 4$ for the quarter-wave zone plate reflector, (2) leads to four constant phase shifts in each full-wave zone: 0, $\pi/2$, π and $3\pi/2$ (see Fig. 1).

III. Experiment

A quarter-wave zone plate reflector consisting of four full-wave zones was designed at 12 GHz. With a focal length $F = 0.4$ m, (1) yields the reflector diameter $D = 0.6$ m. The dielectric material used for the substrate has a permittivity $\epsilon_r = 2.1$ and loss tangent $\tan\delta = 0.0069$. For convenience, the substrate thickness is chosen as 2 mm instead of 2.15 mm, which is given by (2). This leads to a 83.5° phase shift difference between adjacent subzones. A Marconi polyrod feed with a 43° 3-db beamwidth was used, which yielded a −10.8-db edge illumination level. Fig. 2 shows the measured antenna gain as a function of operating frequency. The maximum measured efficiency was 55% at 11.8 GHz. The 3-db bandwidth was estimated as 13%. Fig. 3 shows a typical E-plane radiation pattern at 11.2 GHz, which was obtained by using the near field measurement technique. The sidelobes are higher than expected. Further investigation has indicated that this can be improved by introducing better phase correction.

IV. Conclusion

The Fresnel zone plate antenna has the advantage of unobtrusiveness and low cost, but its low efficiency is usually unacceptable. Using phase correction techniques, the antenna performance can be greatly improved. In this letter, a multilayered quarter-wave zone plate reflector antenna operating in the microwave range is presented. Theory for the reflector design and experimental results are given. The antenna showed 55% efficiency, which is quite good compared to the conventional dish.

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