Multilayer Offset Fresnel Zone Plate Reflector

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***Abstract*—An offset phase-correcting Fresnel zone plate (FZP) reflector antenna based on the multilayer configuration is presented. The reflector consists of a conducting ground and four layers of conducting patterns separated by four dielectric substrates. An experimental prototype designed at 10.39 GHz was fabricated and tested. With a 0.32 m by 0.34 m elliptical reflector aperture and a pyramidal feedhorn, the antenna achieved −20-dB sidelobe level and 61% maximum efficiency. Compared with a phase reversal FZP of the same size, a 3.3-dB gain improvement and significant sidelobe reduction were obtained.**

I. Introduction

Owing to the advantages of conformability and low-cost etc., the Fresnel zone plate (FZP) antenna has raised considerable interest in recent years [1]–[7]. In previous papers, the authors described a symmetrical phase-correcting FZP reflector based on the multilayer configuration [2], [3]. Although the symmetric FZP antenna can be employed in many applications, the offset FZP must be developed to take advantage of its conformability fully and to avoid feed blockage. In this letter, the multilayer phase correction technique is applied to the offset FZP reflector. A 1/5-wave zone reflector of 20° offset angle and operating at 10.39 GHz was fabricated and tested. With a 0.32 m by 0.34 m aperture and a pyramidal feedhorn, the reflector achieved −20-dB sidelobe level and 61% maximum efficiency. Compared with a phase reversal FZP of the same size, a 3.3-dB gain improvement and significant sidelobe reduction were obtained in the operation band.

II. Configuration Description

The symmetrical FZP has concentric circular zone boundaries and the direction of the maximum radiation is normal to the plate surface. For the offset FZP, however, the direction of the maximum radiation forms an angle with the plate normal. Defining this angle as the offset angle α and choosing the plate surface as the xy plane of a Cartesian co-ordinate system, the outer boundary of the m'th subzone in the n'th full wave zone is given by

$$x^2/b^2 + (y-c)^2/a^2 = 1 \quad (1)$$

where

$$a = \{2[(n-1)+m/M]f\lambda + [(n-1)+m/M]^2\lambda^2(1+\tan^2\alpha)\}^{1/2}/\cos\alpha \quad (2.a)$$

$$b = a\cos\alpha \quad (2.b)$$

$$c = [(n-1)+m/M]\lambda\tan\alpha/\cos\alpha \quad (2.c)$$

$$(m = 1,2,\ldots,M; n = 1,2,\ldots)$$

with λ as the operating wavelength, f as the focal length and M as the number of subzones in each full-wave zone. Equation (1) describes a set of eccentric ellipses with eccentricity $\sin\alpha$. When a feedhorn is placed at the focal point, $(0,\ -f\sin\alpha,\ f\cos\alpha)$, it must be pointed at the origin of the co-ordinates.

In [2] and [3], the authors reported a multilayer phase-correcting configuration to realize high-efficiency symmetrical FZP reflectors, where the subzone phase correction is obtained by changing the position of the conducting rings. Replacing circular subzones with elliptical ones described by (1), this configuration can be employed to produce an offset FZP reflector. For illustration, an offset multilayer 1/5-wave zone reflector is shown in Fig. 1. It consists of a metallic ground and four layers of different metallic patterns separated by four dielectric substrates. The top conducting layer covers the fifth subzones, the second one covers the fourth and the fifth subzones, the third one covers the third and the fourth subzones, and the fourth one covers the second and the third subzones. As an improvement to the configuration used for the circular FZP reflector, an overlapping area of one subzone is introduced here to reduce the scattering effect from the outer edges of the elliptical conducting rings. In fact, a few reflectors with different overlapping area have been fabricated and tested. It appeared that extending the overlapping area further does not make noticeable difference. The four dielectric substrates shown in Fig. 1 serve as spacers and the substrate thickness, d, provides the path length difference required to produce a stepwise subzone phase correction function. A simple geometrical optics analysis gives

$$d = (1-\sin^2\alpha/\varepsilon_r)^{1/2}\lambda/(2M\sqrt{\varepsilon_r}) \quad (3)$$

where ε_r is the relative dielectric constant of the substrate [4]. For the present 1/5-wave zone FZP, this configuration produces five phase shifts in each subzone: 0, $2\pi/5$, $4\pi/5$, $6\pi/5$ and $8\pi/5$.

III. Experimental Results

As an experimental prototype, an offset 1/5-wave zone reflector comprising two full wave zones was designed and fabricated to operate at 10.39 GHz. The reflector has a 0.32 m by 0.34 m elliptical aperture, a 20° offset angle, and a 0.19-m focal length. The dielectric material used for the substrate has a permittivity $\varepsilon_r = 2.1$ and loss tangent $\tan\delta = 0.0069$. For convenience, the substrate thickness was chosen as 2 mm,

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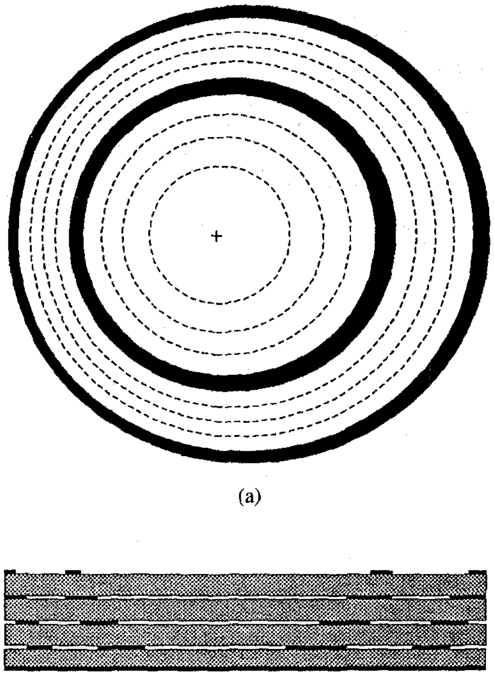

(a)

(b)

Fig. 1. Illustration of the multilayer offset FZP reflector. (a) Front view. (b) Sectional view.

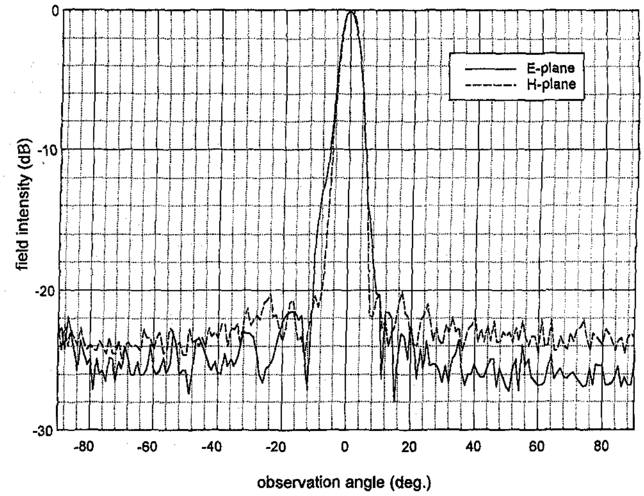

Fig. 2. E-plane and H-plane patterns of the multilayer FZP reflector at 10.39 GHz.

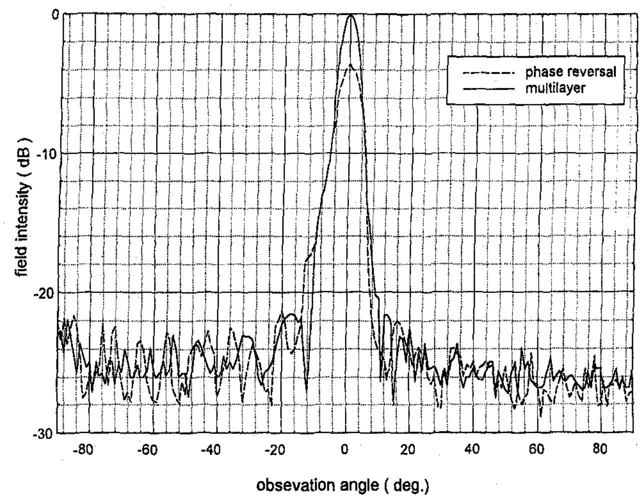

Fig. 3. Comparison of the E-plane patterns of the multilayer and the phase reversal FZP reflectors.

which is 3 % greater than that given by (3). A pyramidal horn with aperture dimension 4.1 cm by 2.8 cm was used as the feed. This design was not aimed to obtain the optimum antenna performance, but to demonstrate the feasibility of the configuration. The maximum efficiency of the antenna was measured as 61%. Fig. 2 shows the measured E-plane and H-plane patterns of the antenna at the design frequency. The two patterns have almost the same 3-dB beamwidth and the sidelobe level is below -20 dB. Owing to the configuration asymmetry in the E-plane, however, it is observed that the main beam of the E-plane pattern becomes broadened from the shoulders. For comparison, an offset phase reversal FZP was also fabricated. Experimental results showed that the two reflectors have an average gain difference of 3.3 dB in a 10.3% 3-"20°(20°)"dB bandwidth. Taking the phase efficiency of the phase reversal FZP as 41%, this gives the predicted 87.5% phase efficiency for the 1/5-wave zone FZP [4]. For illustration, the measured E-plane patterns of the two reflectors are shown in Fig. 3. Significant reduction of the sidelobe level relative to the main lobe, which is due to the increase in antenna gain, has been achieved by the multilayer FZP reflector.

It should be pointed out that for an offset FZP reflector, the feed and its supporting structure need not protrude into the optical path of the incident (outgoing) wave, so the spurious scattering and associated gain loss due to the blockage can be avoided. In fact, it can be proved from (1) and (2) that the projection of the elliptical contour of the offset FZP reflector in the direction of the maximum radiation is a circle whose diameter is equal to the minor axis of the ellipse. Compared with the symmetrical FZP reflector with such a circular aperture, lower sidelobes and higher efficiency can be obtained with the offset configuration.

IV. Conclusion

The subzone phase correction technique is an effective approach to producing high-efficiency and low sidelobe FZP antennas [1]–[4]. In this paper, a 1/5-wave zone offset FZP reflector based on the multilayer configuration is presented. A sidelobe level below -20 dB and 61% maximum efficiency was measured. Experiments showed that the E-plane and H-plane patterns have the same 3-dB beamwidth. Owing to the asymmetry of the configuration in the E-pane, however, the E-plane main beam was slightly broadened from the shoulders. Compared with a phase reversal FZP reflector of the same size, a 3.3-dB average gain increase and significant sidelobe reduction were obtained.

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