# Fresnel Zone Plate Reflector Incorporating Rings

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***Abstract*—A novel high-efficiency Fresnel zone plate reflector antenna is presented. The reflector consists of an inhomogeneous array of circular conducting rings printed on a grounded substrate. By adjusting the geometrical parameters of the rings and the distances between them, the reflector provides a space-varying phase correction required for focusing an incoming plane wave. Compared with a phase reversal zone plate, an average of 3-dB gain improvement and significant sidelobe reduction have been obtained.**

## I. Introduction

CONFORMAL flat antennas are desirable in many applications such as DBS reception and receive-only VSAT. The Fresnel zone plate (FZP) reflector serves as an attractive candidate for this purpose, especially when high gain, low cost, light weight, etc., are concerned. The simplest FZP reflector is the so-called phase reversal FZP, which consists of a set of concentric conducting loops printed on a grounded dielectric substrate [1], [2]. This reflector is easy to manufacture, but its aperture phase efficiency is only 41%. It has been shown that by employing phase-correction techniques, the aperture phase efficiency of the FZP reflector can be significantly improved [3]. In [4], the authors reported a multi-layer quarter-wave FZP reflector with 55% antenna efficiency. Compared with the phase-reversal FZP reflector, however, the multi-layer configuration increases manufacturing complexity and cost. In this paper, a novel FZP reflector which consists of an array of conducting rings printed on a grounded substrate is presented. The reflector functions as an inhomogeneous reflective phase shifter. By adjusting the geometrical parameters of the rings and the distances between them, the reflector provides a space-varying phase correction required for focusing an incoming plane wave. As an experimental prototype, a quarter-wave FZP reflector was fabricated to operate at 10.39 GHz. Compared with a reference phase-reversal FZP, the new reflector showed significant sidelobe reduction, much narrower main beam and an average of 3-dB gain increase, which agrees with the predicted 81% aperture phase efficiency. The two reflectors had the same 12% 3-dB bandwidth.

## II. Reflective Phase Shifter

The design of the new reflector is based on the concept of the reflective phase shifter [5]. It consists of an array of periodically distributed conducting elements printed on a grounded low-loss substrate. Using a transmission line model, the phase delay of the phase shifter to an incoming plane wave is derived as

$$\Phi = \pi - 2\tan^{-1}\{BZ_1\tan(k_1t)/[Z(Z_1\tan(kt)+B)]\} \quad (1)$$

where $Z$ and $k$ represent the wave impedance and wave number of free space, $Z_1$ and $k_1$ represent those of the dielectric, $B$ represents the equivalent reactance of the array, and $t$ is the substrate thickness. It can be proved with (1) that for a fixed operating frequency and substrate thickness, a $2\pi$ dynamic range of the phase shift can be obtained by changing B from $-\infty$ to $+\infty$.

With conducting rings as elements, the performance of the reflective phase shifter can be directly analyzed by using the spectral domain integral equation method [6], [7]. Fig. 1 gives the performance of a reflective phase shifter as a function of the median ring radius $r$ for different distances between ring centers $d$, where an equilateral triangular grid is employed and the operating frequency is 10.39 GHz. The substrate thickness is 5 mm, the dielectric permittivity is 2.08, and the ring width is fixed at 0.4 mm. It is observed that the phase shift is mainly determined by the ring dimension. Small rings are capacitive and large rings are inductive. For a given phase shift, the closer the separation between adjacent rings, the smaller the median ring radius. With 16-mm separation, a phase shift in the range of 0 to $3\pi/2$ can be obtained simply by adjusting the ring radius. In practice, the widths of the full wave zones of a FZP reflector are limited, so a smaller $d$ should always be used whenever possible. However, it is seen from Fig. 1 that for any given phase shift, there is a minimum separation $d$. The smaller the phase shift, the greater the minimum. This means that the minimum dimension of the rings is limited by the required phase shift. An approach to reducing ring dimensions is to use substrates with high permittivities.

## III. FZP Reflector Design and Performance

A uniform reflective phase shifter provides a specific phase shift at a given frequency. To obtain a space-varying phase correction required for focusing an incoming plane wave, the conducting rings must be inhomogeneously distributed. This can be done by dividing the reflector into subzones and covering different subzones with different size rings. The ring parameters and their separations are chosen according to the requirements for the homogeneous reflective phase shifters.

As an experimental prototype, a quarter-wave FZP reflector incorporating conducting rings was fabricated to operate at 10.39 GHz. The reflector covers only one full wave zone and its front view is given in Fig. 2, where three different rings are used in the three inner quarter-wave zones and the fourth one is left blank. The outmost smallest rings are used

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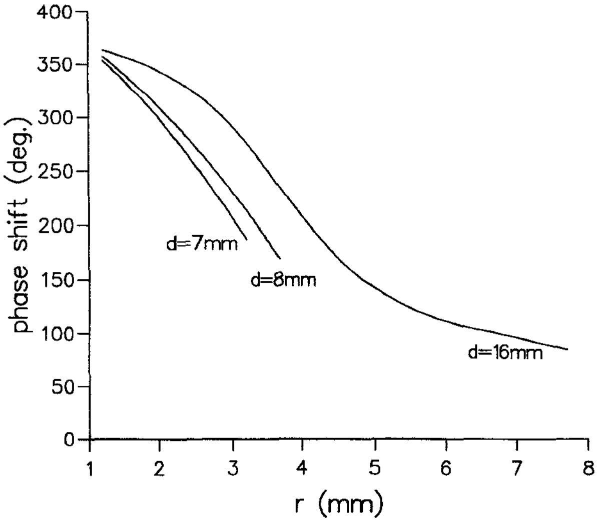


Fig. 1. Phase shifting performance of a reflective phase shifter with rings. $r$ is the median ring radius and $d$ is the distance between adjacent ring centers.

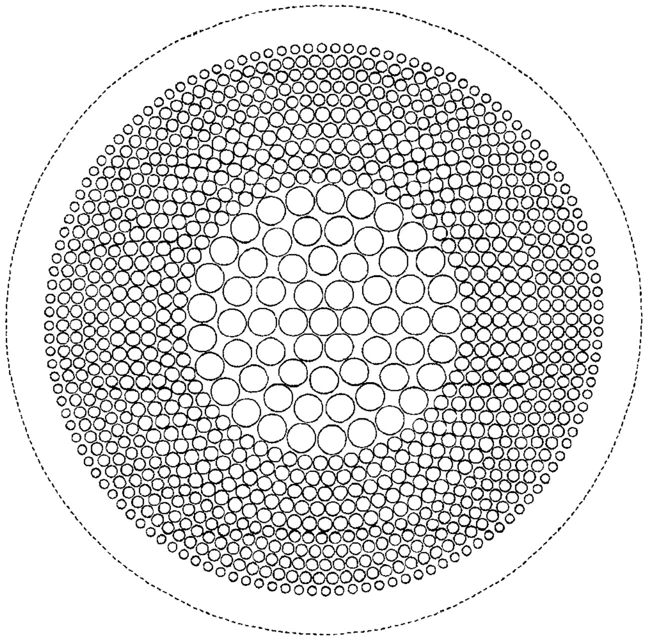

Fig. 2. Ring arrangement of the quarter-wave FZP reflector.

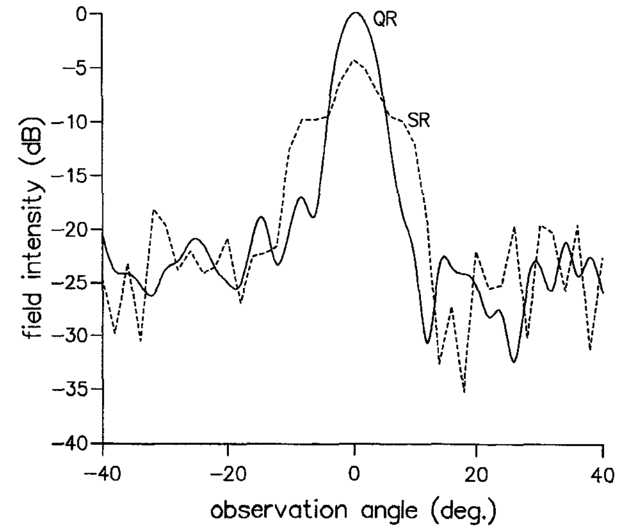


Fig. 3. Radiation patterns of the quarter-wave and the phase-reversal FZP reflectors.

for smoothing the boundary transition. The substrate is of 5-mm thickness and has the permittivity of 2.08. The reflector has a 33.2-cm diameter and a 46.24-cm focal length. To demonstrate the phase-correcting mechanism, a simple phase-reversal FZP of the same size was used as a reference. A helical antenna was employed as the feed in order to reduce the aperture blockage. The helix has a 39° 3-dB beamwidth, which is about the same as the angle spanned by the reflector. It does not give the optimum edge illumination level but is acceptable for comparison between the two reflectors [3]. Fig. 3 shows a set of typical radiation patterns of the two reflectors at 10.1 GHz, where QR stands for the new reflector and SR the phase reversal FZP. It is seen that the new reflector has a much narrower main beam. Because of the phase correction, the radiation energy initially distributed in the skirt of the main beam is transferred to the boresight direction, thus leading to significant efficiency increase and sidelobe reduction. Experiments showed that the 3-dB bandwidth of the new reflector is about 12%, which is about the same as that of the phase-reversal FZP. In the operating band, the new reflector has an average of 3-dB gain increase over the phase-reversal FZP. Taking the phase efficiency of the phase-reversal FZP as 41%, this gives the predicted 81% phase efficiency for the quarter-wave FZP [3], [8]. Since the two reflectors comprise only one full wave zone, however, it was noted that their resolutions were worse than the theoretical predictions.

## IV. Conclusion

A novel quarter-wave FZP reflector with an array of conducting rings printed on a grounded substrate is presented. By using different rings within different subzones, the new reflector antenna achieved 3 dB higher gain than the conventional phase-reversal FZP, which confirms the expected improvement in aperture phase efficiency from 41% to 81%. This gain is obtained by redirecting the energy normally wasted in close-in sidelobes and in the skirts of the main lobe. The bandwidth of the new and the conventional reflectors were comparable at 12%.


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