A New Fresnel Zone Antenna with beam Focused in the Fresnel Region

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Abstract

A new Fresnel Zone (FZ) Antenna to focus the microwave power in the radiation near field region is presented. FZ Antennas, in comparison with array antennas or reflector antennas, conventional focused antennas, take the advantages of design simplicity as well as lower sidelobe levels (SLL) in both axial and transverse directions. Simulation results and comparisons made between the new structure and aperture antennas based on the quadratic phase distribution show a reduction of sidelobe levels in both axial and transverse directions.

1. Introduction

Antennas are commonly characterized in terms of their far field radiation patterns. However, in some applications, antennas are specified to focus microwave power in their radiating near field regions. These antennas, called Focused Antennas, are of interest in medical, Microwave power transition and some other applications [1-3].

It was proved theoretically that in the focal plane of a focused aperture, near the axis, the electric field will have all the properties of the far field radiation pattern if a quadratic phase distribution is adjusted on the aperture of the antenna [4, 5]. Some attempts have been made using array antennas or conventional reflector antennas to generate quadratic phase distributions and focus power at nearby points [6-9]. However, the main problems arising in focused antennas with this kind of aperture distribution are high lobes in both axial (forlobes and aftlobes) and transverse (sidelobes) directions. Direct amplitude tapering on the aperture gives low sidelobes but high forelobes and aftlobes. On the other hand, inverse tapering (high at edge, low in center) gives low forlobes and aftlobes but high sidelobes [10]. In addition, a precise generating of a quadratic phase distribution using array antennas is complex, costly and limited due to the difficulties of implementing of beam forming networks.
On the other hand, conventional reflector antennas can be used to generate a quadratic aperture distribution. However, the ability to represent a desired aperture distribution using a conventional reflector like parabolic reflector antenna is limited. Although the problem can be solved using shaped reflectors, their implementation is very costly. In addition, since usually a large aperture antenna is desired for this application, implementations will be more difficult and costly.

In this paper, a new focused antenna using FZ concept is proposed. This antenna takes the advantages of low sidelobes, forelobes and aftlobes as well as design simplicity. In fact, the flatness aspect of the Fresnel zone antenna is its benefit in the manufacturing process.

2. Design Procedure

A Fresnel zone consists of a set of radial concentric strips, arranged on a flat surface, which alternate between reflective and non-reflective surfaces (Fig. 1). If the zones be spaced so that radiating waves from all the zones arrive in phase at the desired focus point, there will be constructive inference. When these zone arrangements are illuminated by a source, like a horn antenna located at the focal point of the geometry and a $\lambda/4$ back plate is placed behind the FZ plate, all of the rays impinging on the reflector surface will add up in phase at the focus point after reflecting by the strip rings and the back plate [11, 12].

The geometrical optic (GO) method is used in the design in order to get constructive interference at the focus point. The design is performed in the plane (2 dim.) and then the shape is completed by revolving it around the axis of symmetry.

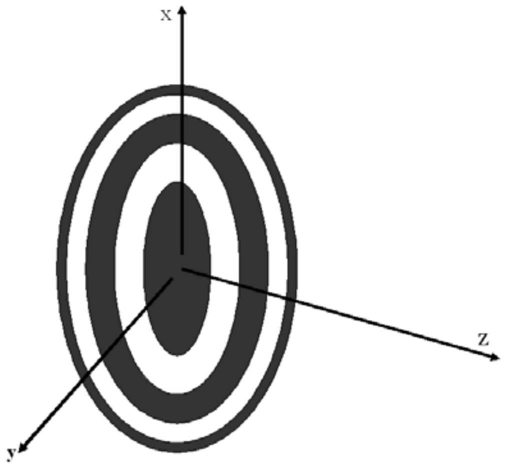


Fig. 1: 3D view of a Fresnel antenna

The design parameters as shown in Fig. 2 are D_m, diameter of the fresnel zone plate, F_1, the distance from the feed antenna to the center of the zone plate, F_2, the distance from the focused point to the center of the zone plate, and r_m which is the radius of the *m*th ring

The values of r_m must be determined such that the rays emanating from the source, impinging the FZ surface, and reflected by it satisfy the following equations:

$$L_1 + L_2 - (F_1 + F_2) = \frac{m\lambda}{2} \tag{1}$$

and

$$\sqrt{F_1^2 + r_m^{\ 2}} + \sqrt{F_1^2 + r_m^{\ 2}} = \frac{m\lambda}{2} + F_1 + F_2 \tag{2}$$

, where *m* is an integer and λ is the wavelength.

3. Design Examples

Now, we compare two antenna designs, a circular aperture antenna based on the quadratic phase distribution for different amplitude tapering and a design based on the FZ antenna. The diameter of the aperture is equal to 56.4λ for both cases. F_1 and F_2 are equal to 50λ and 300λ, respectively. The feed is assumed to have a cosine-on-pedestal-field distribution on the FZ plate. The edge taper value is equal to -10dB for this case.

Axial field distributions for the Fresnel zone antenna and the aperture antenna with a quadratic phase distribution with a uniform and a cosine-on-pedestal tapering amplitude distribution are depicted in Figs. 3a and 3b, respectively. Electrical field distributions along the transversal direction at the focal point ($z = 260\lambda$) are also shown in Figs. 4a and 4b. It should be noticed that the maximum of the field along the axis does not occur at $z = F_2$ since the field is multiplied by the inverse of the distance, to account for the spherical spreading of wave front away from the aperture.

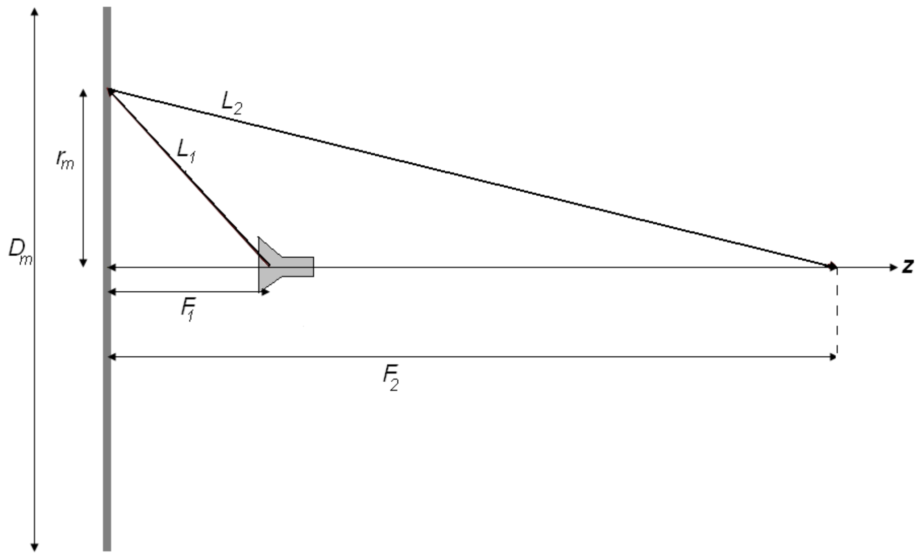
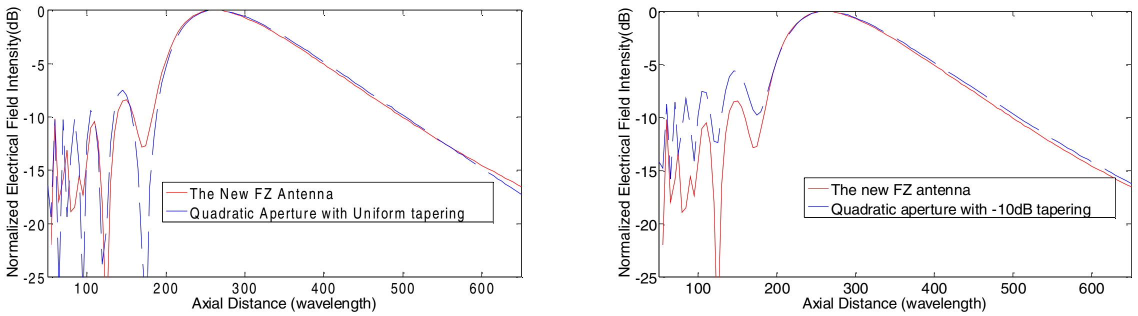
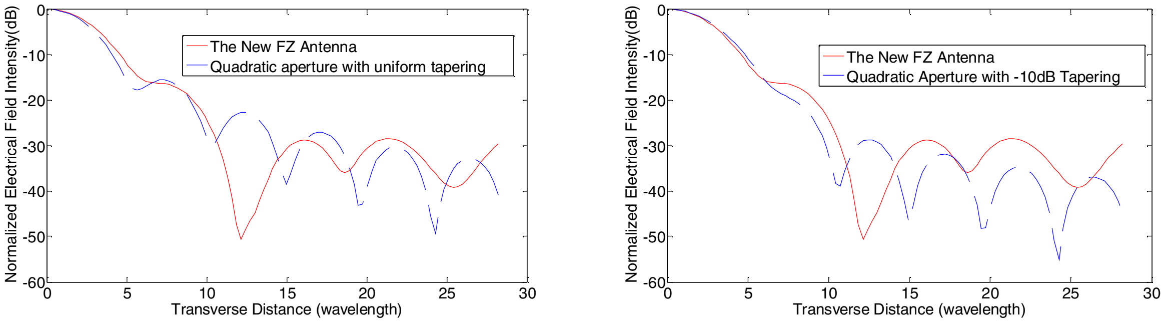


Fig. 2: Fresnel Zone configuration



(a) (b)

Figure 3: Axial field distribution for the proposed FZ antenna and an aperture antenna with the quadratic phase and a) uniform Amplitude distribution b) direct tapering Amplitude distribution



(a) (b)

Figure 4: Transverse field distribution at the focal point for the proposed FZ antenna and an aperture antenna with the quadratic phase and a) uniform Amplitude distribution b) direct tapering Amplitude distribution

Sidelobe levels, forelobe levels and depth of focus values for these configurations have been recorded in table I.

Table I: A comparison between two antenna designs

	Sidelobe level(dB)	Forelobe level(dB)	Depth of Focus(λ)
The New FZ Antenna	-28.8	-8.41	148
Quadratic Phase aperture with uniform tapering	-15.58	-7.53	150
Quadratic Phase aperture with -10dB tapering	-28.73	-5.62	152

The results given in Figs 3-4 and Table I show that Forelobe level and SLL of the proposed FZ antenna is less than that of the quadratic aperture distribution for both cases. Besides depth of focus of the new structure is a slightly less than the others. The depth of focus is defined as the distance between the axial -3dB points about the focal plane [4].

4. Conclusion

A new method in designing FZ antennas to produce a beam focused in the near field region of the antenna was presented. Unlike array antennas or parabolic reflectors, which are conventional choices for the beam focusing purpose, the new configuration took the benefits of simplicity in design and manufacturing process. In addition, simulation results verified achieving the lower sidelobes and forelobes for this FZ antenna in comparison to an aperture antenna with the ideal quadratic phase.

5. References

1. J. O. McSpaddan, and J. C. Mankins, "Space Solar Power Programs and Microwave Wireless Power Transmission Technology," *IEEE Microwave Magazine*, vol. 3, no. 4, Dec. 2002, pp. 46-57.
2. W. Gee, S. W. Lee, N. K. Bong, C. A. Cain, R. Mittra, and R. L. Magin, "Focused Array Hyperthermia Applicator: Theory and Experiment," *IEEE Trans. Biomedical Eng.*, vol. BME-31, no. 1, Jan. 1984, pp. 38-46.
3. J. T. Loane III, and Shung-Wu Lee, "Gain Optimization of a Near-Field Focusing Array for Hyperthermia Applications," *IEEE Trans. Microwave Theory and Tech.*, vol. 37, no. 10, Oct. 1989, pp. 1629-1635.
4. J. W. Sherman, "Properties of Focused Aperture in the Fresnel Region," *IRE Trans. Antennas Propagat.,* vol. AP-10, no. 4, July 1962, pp. 399-408.
5. W. J. Graham, "Analysis and Synthesis of Axial Field Patterns of Focused Apertures," *IEEE Trans. Antennas Propagat.*, vol. AP-31, no. 4, July 1993, pp. 665-668.
6. M. Bogosanovic, and A. G. Williamson, "Antenna Array with Beam Focused in Near-Field Zone," *Electronic Letters*, vol. 39, no. 9, May 2003, pp. 704-705.
7. A. J. Fenn, "On the Radial Component of the Electric Field for a Monopole Phase Array Antenna Focused in the Near Zone*," IEEE Trans. Antennas Propagat.*, vol. 40, no. 6, June 1992, pp. 723-727.
8. P. S. Kildal, and M. M. Davis, "Characterization of Near-Field Focusing with Application to Low Altitude Beam Focusing of the Arecibo Tri-Reflector System," *IEE Proceedings*, vol. 143, no. 4, Aug. 1996, pp. 284 – 292.
9. L. Shafai, A. A. Kishk, and Sebak, "Near Field Focusing of Apertures and Reflector Antennas," *IEEE communications, power and computing conference*, 22-23 May 1997, pp. 246 – 251.
10. R. C. Hanson, "Focal Region Characteristics of Focused Array Antennas," *IEEE Trans. Antennas Propagat.*, vol. AP-33, no. 6, Dec. 1985, pp. 1328-1337.
11. B. Khayatian, and Y. Rahmat-Samii, "A Novel Antenna Concept for Future Solar Sails: Application of Fresnel Antenna," *IEEE Antennas Propagat. Magazine*, vol. 46, no. 2, April 2004, pp. 50-63.
12. L. F. Van Buskirk, and C. E. Hendrix, "The Zone Plate as a Radio-Frequency Focusing Element," *IRE Trans. Antennas propagat.*, vol. AP-9, May 1961, pp. 319-320.