Fresnel Zone Plate Antenna Designing - A Review

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***Abstract*— The Circular Fresnel zone plate antenna can achieve the same focusing properties of conventional lens or reflectors by controlling the phase shifting property of the aperture rather than its shape. Hence being lighter, easy to design and manufacture at low cost, it may become promising candidate for consumer electronics market. This paper presents two designs of Fresnel zone plate antenna. Here we studied few research papers related to their design and focusing properties. The effect of different design parameters (focal length, diameter, frequency, number of zones) on radiation characteristics are examined.**

***Index Terms*— Fresnel zone plate antenna, Soret zone plate, Phase-correcting (wood) zone plate**

I. INTRODUCTION

Today parabolic reflectors are used in most of the satellite broadcasting applications because of providing high gain pencil beam patterns but it is difficult to make the ideal parabolic surface. Also they are of large volume, weight and need support system that make whole antenna system bulky to transport at some locations like hilly and valley areas. So the overall cost of parabolic reflectors is very high. The growing number of Direct Broadcast Satellites (DBS) asks for simple in fabrication, low cost home receiving systems.

The Fresnel zone plate antenna consist of circular rings which alternate between transparent and opaque(metal), is good alternative of parabolic antennas used in existing home receiving systems because of low profile, low cost and light weight. It is very simple to fabricate and easy to implement, and do not need any support system. It can be placed on ground or terraces. To protect from the unexpected changes of weather, it can be mounted vertically on window panes or building walls where it can like as a decorative piece. There it will not follow the circle but elliptical as per the angle it forms with respect to satellite it sees. Another advantage of FZPA is that it can receive multiple frequencies by the same aperture by changing the feed location. The only drawback of this antenna is with respect to its aperture it gives less gain than an equivalent parabolic reflector. Several methods exist to improve its efficiency.

II. ANTENNA DESIGN

Fresnel zone plate antennas are planner structure having circular rings, when a plane wave incident normally to its surface, it will transformed into a spherical wave focused at some axial point. The feed is placed to collect the focused waves. A circular ring between two adjacent circles is Fresnel zone. The Fresnel zone plate consisting number of circular Fresnel zones that their radii are determined by [2]:

$$r_n = \sqrt{(F + \frac{n\lambda_0}{p})^2 - F^2} \quad n = 1, 2, \ldots, N \tag{1}$$

Where, r_n is the radius of n^{th} zone, F is focal length, λ_0 is free-space wavelength and p represents the number of subzones in each full wave zone. p = 1 represents the full wave zone which contains the phases from 0° to 360° where the phase 0° is arbitrarily set to 0°. Similarly, p = 2 and p = 4 represents the half wave zones (containing phases from 0° to 180°) and the quarter wave zones (containing phases from 0° to 90°) respectively and so on. The basic idea for constructing the Fresnel zone plate antenna is to divide a plane aperture into alternate transparent and opaque circular zones such that they can block the out-of-phase radiation in order to achieve constructive interference at a chosen focal point. The zones are constructed such that a portion of the field contributes for constructive interference which is reflected by the opaque zones of zone plate. A similar constructive interference will occur at focal point behind the zone plate. Hence, due to two focal points associated with this configuration can be categorized either as a Fresnel zone reflector if the feed is on the same side of the aperture as the incident wave or the Fresnel zone lens if the feed is located on the opposite side of the zone plate. The opaque zones may be constructed by any reflective materials e.g. metal rings. Also this design can be fabricated from any materials which allow to propagate the electromagnetic waves.

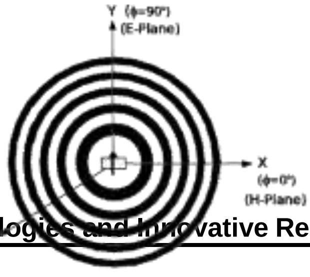


Fig.1 Front view of Circular Fresnel zone Plate

The simplest structure is the Soret zone plate which is half wave zone plate having very less efficiency. In order to increase the efficiency, phase correcting zone plates can be obtained by making the blocking zones into phase reversal so that they also can contribute into constructive interface at a focal point. The front view of both structures are shown in Fig.1.

(a) Soret zone plates

The classical microwave Soret zone plate structure is a half wave zone plate consist of transparent & opaque zones. The opaque zones can be made by using the metal rings. For lens structures, if the transparent zone focuses the waves with positive phase then it is called positive Soret zone plate else it is called as negative Soret zone plate. Same classification can be applied in reflector structures for opaque zones. Depending upon the type (lens/reflector) and phase (positive/negative) of FZP, the material (metal/dielectric) for the first ring is chosen accordingly. The cross-sections of different Soret zone plates are shown in fig. 2.

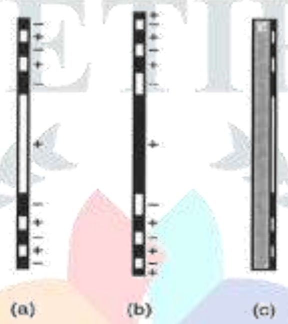


Fig. 2: Cross-sectional view of Soret zone plate (a) Positive Soret zone lens / negative Soret zone reflector (b) Negative Soret zone lens / Positive Soret zone reflector (c) Soret zone plate with metal rings fixed on thin dielectric plate

The fabrication of Soret zone plate is possible by printed microstrip technology. In this technology, the metal elements are usually fixed on a thin substrate. Reflection from surface of such metallic Fresnel zones or transmission through a transparent dielectric Fresnel zones will result in amplitude amplification [2]. Soret zone plates of this type are less efficient because half of the electromagnetic energy is focused to each of its two focal points. One solution is to obtain folded zone plate by placing the perfect conductor disc at a distance λ/4 behind the zone plate. The field reflected by the disc add constructively with the field reflected by the opaque zones at a focal point, it will increase the efficiency compared to classical Soret zone plate.

(b) Phase-correcting Zone plates

Soret zone plates require large area for achieving high gain. If the diameter, D of the zone plate is chosen such that D = $2r_n$, then the number of zones can be calculated by equation (2)

$$N = \frac{2D}{\lambda_0}\left[\sqrt{\left(\frac{F}{D}\right)^2 + \frac{1}{4}} - \left(\frac{F}{D}\right)\right] \qquad (2)$$

From above equation, it is observed that for constant (F/D), number of zones, N will increase directly with D/λ_0. At optical wavelengths it is possible to achieve high gain due to large number of zones but for larger wavelengths such as millimeter and centimeter wavelengths, it will require large apertures to increase the gain at sufficient level.

The solution to increase the gain without expanding the diameter, is to construct the phase correcting zone plate by replacing the opaque/transparent zones into lens/reflector with phase correcting zones. In order to achieve the phase correction, the single dielectric phase correcting zone plate in which phase correcting is done by cutting the grooves on dielectric plate with permittivity ε_r which allows microwaves. The groove depth d, for phase correcting plate, cut into the dielectric plate is calculated as [3]

$$d = \frac{\lambda_0}{p\sqrt{\varepsilon_r}-1} \qquad (3)$$

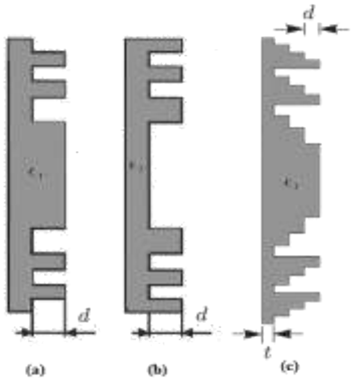


Fig. 3: Cross-sectional view of grooved dielectric phase correcting zone plate (a) negative phase reversing zone plate (b) positive phase reversing zone plate (c) quarter wave phase correcting zone plate

As shown in fig. 3, the phase reversing (half-wave) zone plate need only one groove depth but for quarter wave correction, there is successive groove depths of 0, 2d and 3d cut in repetitive order. This design give higher efficiency than simple Soret zone plate antenna.

III. LITERATURE REVIEW

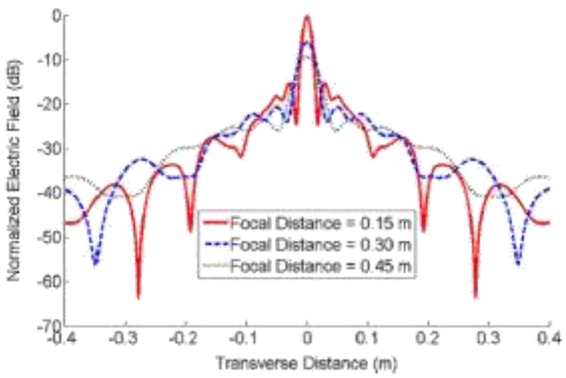
A. Design parameters and focusing properties of Fresnel zone plate antenna [4]

In this paper, some focusing characteristics of Soret FZP antenna are examined. The effects of various design parameters (focal length F, diameter D, number of zones N and frequency f) on focusing properties are investigated. FZP antennas with diameter of 0.16 m and various focal lengths are designed to analyze the characteristics for the operating frequency of 32 GHz.to compare the simulation results, two FZP antennas with focal lengths of 0.15m and 0.45 m are fabricated by etching process on 0.508 mm thin RT/duroid 5880 substrate.

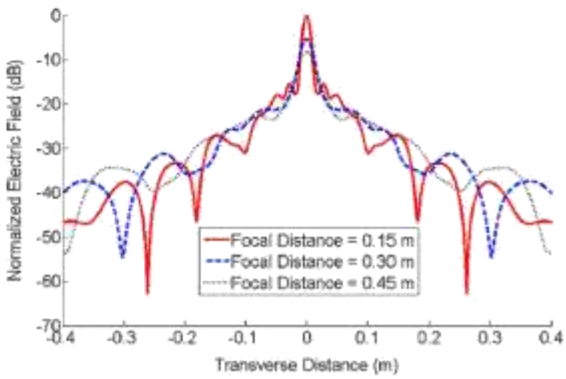
Table I: The Number of Zones and Diameter of Each Zone Plate

Focal length (m)	Number of Zones, N	Diameter (m)
0.05	16	0.168
0.075	14	0.158
0.15	10	0.156
0.3	8	0.155
0.45	8	0.163
0.6	8	0.167
0.75	6	0.171
0.9	6	0.171

Simulated results shows that the maximum intensity of electric field occurred at z = 0.137 m and z = 0.343 m for FZP with the focal length, F of 0.15 m and 0.45 m respectively. This shows the displacement of maximum intensity of electric field. The narrower beam is obtained at maximum intensity plane compared to focal plane. The normalized electric field distributions for different focal lengths at the focal planes and intensity planes are shown in fig. 3(a) and fig.3 (b) respectively.



(a)



(b)

Fig. 3: Normalized electric field distribution of the FZP for different focal lengths at (a) focal plane (b) maximum intensity plane [4]

The focal point moves away from the aperture the focal distance moves away from the antenna aperture the focal displacement increases and maximum intensity decreases [4].

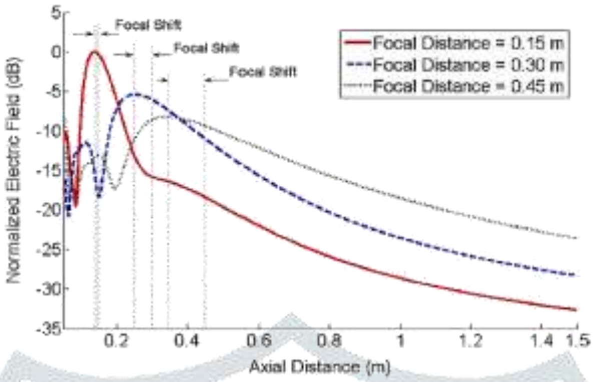


Fig. 4: Normalized electric field intensity of the FZP antenna versus the axial direction for different focal lengths [4]

(a) (b)

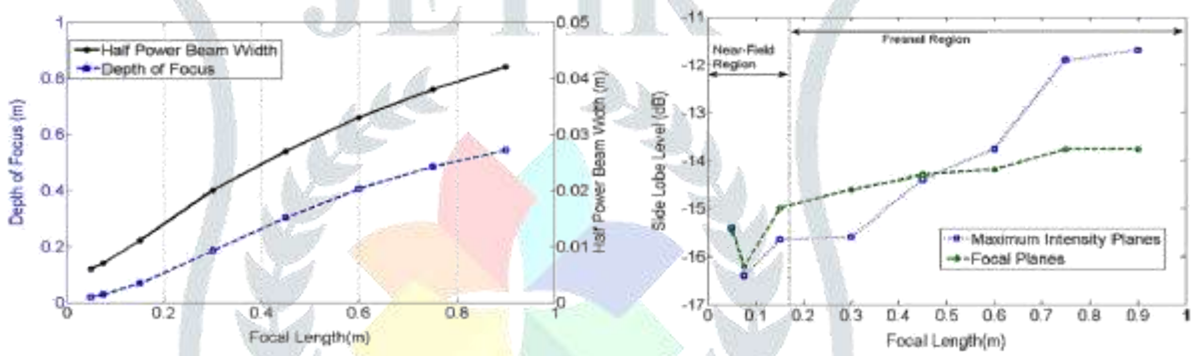
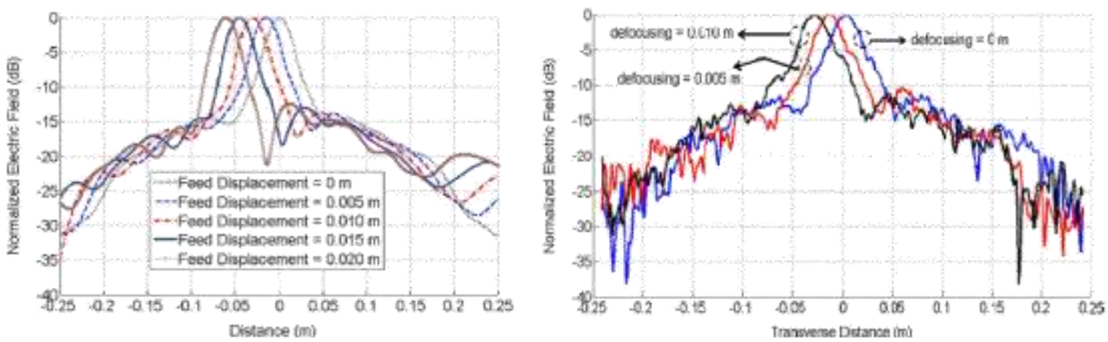


Fig. 5: (a) Variations of depth of focus and half power beamwidth of the electric field pattern at maximum intensity plane versus the focal length of the FZP antenna (b) Variations of side lobe level of electric field pattern at maximum intensity planes andfocal planes versus focal length of the FZP antenna [4]

It is observed that the HPBW, depth of focus at maximum intensity planes increases with increasing focal length as shown in fig.5 (a). In Fresnel region, side lobe levels of the electric field patterns increases in both planes as the focal length increases and hence it causes wider focusing gain.

Beam scanning is done by displacing the horn antenna along transverse axis. The beam is steered by approximately 0.015 m for each 0.005 feed displacement. Simulated and measured results in fig.6 shows that the steered beams have approximately same parameters as the original FZP antenna. Hence, if the feed is displaced from the focal point, the scanned beam degradations are negligible.



(a) (b)

Fig. 6: (a) simulated and (b) measured steered focused beam of the FZP antenna with the focal length of 0.45 m at the maximum intensity plane for various feed displacements [4]

B. *Design of phase-correcting zone plate antenna for microwave and millimeter-wave applications using a full electromagnetic analysis* [5]

In this paper various characteristics for phase-correcting FZPA is analyzed and compared with hyperbolic lens having same design parameters. The FZPA is fabricated using dielectric Rexolite ($\varepsilon_r = 2.53$) having thickness of 0.1λ. the number of subzones are 4. Both devices focus energy to the desired focal point but for FZPA, there is additional focal point at F/3.it is also observed that the reduction in volume can be achieved by replacing the lens with FZPA and weight of the device can be reduced by a factor of about six. For the analysis of FZPA, design parameters are presented in terms of free space wavelength λ i.e. F/λ and D/λ in which F/λ is varied from 1 to 50, D/λ is varied from 3.5 to 75 and N ranges from 1 to 37. It was observed that D/λ while keeping F/λ constant, focusing gain increases and also by increasing D/ λ and F/λ while holding N constant, focusing gain increases.

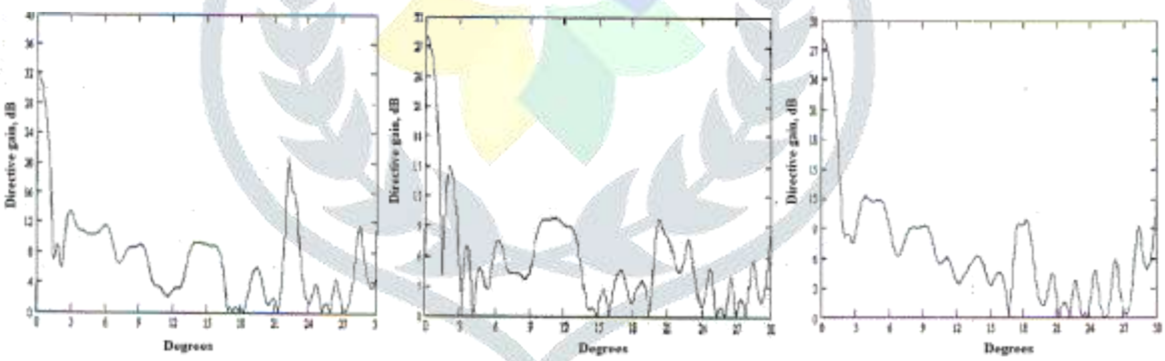
C. *Analysis and Evaluation of Fresnel Zone Antenna Designs* [6]

This paper include design and radiation characteristics of Soret and Wood (phase-correcting) types of FZPs. The effects of various design parameters like number of zones and aperture diameter on the radiation characteristics are analyzed. Table II summarizes some results for both type of FZPs.

TABLE II: Summary of the obtained results for Soret and Phase-correcting zone plate [6]

N	D (m)	Soret type				Phase-correcting type			
		HPBW (degree)	SLL (dB)	Directive gain (dB)	Efficiency (%)	HPBW (degree)	SLL (dB)	Directive gain (dB)	Efficiency (%)
5	1.14	1.5	-15.7	28.2	8.84	1.5	-14.7	34.2	35.38
6	1.15	1.5	-13.2	27.9	6.90	1.5	-12.8	33.8	27.12
7	1.24	1.3	-17.9	30.4	10.48	1.3	-18.4	36.4	42.88
9	1.41	1.2	-19.6	32.1	11.86	1.2	-20.2	38.2	46.60

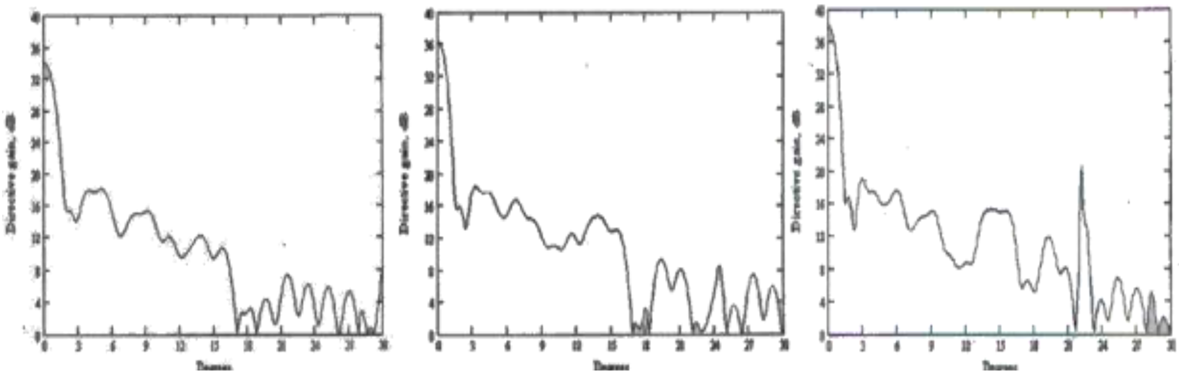
The Soret type FZPA is designed for operating frequency 11.1 GHz, focal length 2 m with different number of zones (N = 5, 6, 7, 9). It was observed that the gain, directivity and efficiency increase with increasing the number of zones. The directivities achieved by the Soret zone plate having different number of zones are shown in Fig. 7



(a) (b) (c)

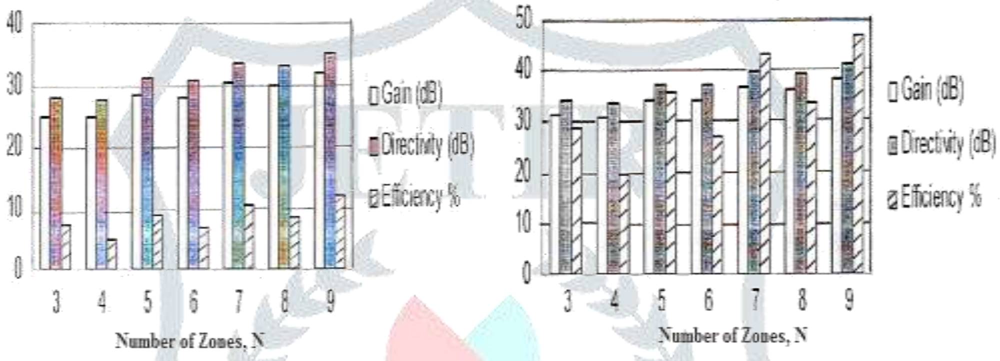
Fig. 7: Directive gain of Soret type with (a) 5 zones (3 transparent/ 2 absorbing) (b) 6 zones (3 transparent/ 3 absorbing) (c) 9 zones (5 transparent/ 4 absorbing) [6]

The Wood type FZP is designed for $\varepsilon_{r1} = 1$ and $\varepsilon_{r2} = 4$ and other design parameters were same as the Soret FZP. From the Fig. 8, it can be observed that the directivity achieved by the Wood zone plate is higher than the Soret type.



(a) (b) (c)

Fig. 8: Directive gain of phase-correcting (Wood) type with (a) 5 zones (3 transparent/ 2 absorbing) (b) 6 zones (3 transparent/ 3 absorbing) (c) 9 zones (5 transparent/ 4 absorbing) [6]



(a) (b)

Fig. 9: Change in gain, directivity and efficiency with respect to the number of zones for (a) Soret type and (b) phase-correcting type [6]

From Fig. 9, we can see that the FZP with odd zones is better in radiation characteristics than that with even zones and the aperture efficiency is four times higher than the Soret type.

IV. SUMMARY AND FUTURE WORK PLAN

Both designs studied in this literature are very useful to achieve radiation characteristics of reflectors or lens with flat aperture. The main advantage of these antennas is that they can focus multiple frequencies by changing the feed location. Though the Soret zone plates are less efficient, they can be used for many low cost applications. Phase-correcting zone plates can replace the parabolic reflectors as they have approximately same radiation characteristics. By selecting the appropriate design parameters we can achieve better radiation characteristics.

Our work involves the design and fabrication of both Soret and phase-correcting zone plates and make them capable of replacing the parabolic reflectors used in existing Direct broadcast systems. Though antenna is a reciprocal device, FZPA is not suitable to use as transmitter antenna because of having less efficiency but it is promising candidate to use as a receiver antenna. In future broadcast satellites are going to use 20 GHz (downlink) / 30 GHz (uplink) frequencies for DTH services. Fresnel zone plate antenna for these frequencies will have reduced size of aperture and higher efficiency.

We will design the Fresnel zone plate antenna for Ku band using printed technology in High Frequency Structure Simulator (HFSS) software. The material chosen is RT/Duroid 5880. The receiving horn will be designed using HFSS. After testing the whole device we will make suitable modifications in order to connect DBS set top box.

V. Acknowledgment

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