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Citation for published version (APA):

Hristov, H. D., & Herben, M. H. A. J. (1995). Quarter-wave Fresnel zone plate lens and antenna. *IEEE Microwave and Guided Wave Letters*, 5, 249-251. <https://doi.org/10.1109/75.401077>

DOI:

[10.1109/75.401077](https://doi.org/10.1109/75.401077)

Document status and date:

Published: 01/01/1995

Document Version:

Publisher's PDF, also known as Version of Record (includes final page, issue and volume numbers)

Please check the document version of this publication:

- A submitted manuscript is the version of the article upon submission and before peer-review. There can be important differences between the submitted version and the official published version of record. People interested in the research are advised to contact the author for the final version of the publication, or visit the DOI to the publisher's website.
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Quarter-Wave Fresnel Zone Planar Lens and Antenna

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Abstract—A new variety of the Fresnel zone planar lens with enhanced focusing quality is proposed. Each full-wave zone is divided into four quarter-wave subzones, which are covered by dielectric rings having equal thickness but different permittivities. Based on this planar lens configuration, a transmissive-type Fresnel-zone antenna for DBS-reception with more than 50% aperture efficiency is developed and examined theoretically.

I. INTRODUCTION

THE Fresnel zone lens is a focusing and imaging device invented and studied by A. Fresnel more than one hundred and fifty years ago. For a long time its applications have been mainly restricted to optical systems. Since the Fresnel-zone principle works at any frequency, the corresponding lens can also be used as focusing element for microwaves.

For many applications the simplest (low-cost) Fresnel zone lens with alternate transparent and reflecting (or absorbing) rings has inadequate focusing properties and the aperture efficiency of the corresponding lens antenna is less than 15%. To increase the lens focusing quality and to utilize the opaque zone apertures, Wiltse replaced the reflecting (or absorbing) rings by phase-reversing dielectric ones, and thus a planar dielectric lens was introduced [1]. Based on this lens, various transmissive-type antennas have been developed and examined [2], [3], [5]–[7], and [11]–[13]. A typical range for the aperture efficiency of these antennas is about 25–30%. From a commercial point of view, however, the antenna efficiency of microwave aperture antennas has to be at least 50%.

In this letter, a new variety of transmissive quarter-wave Fresnel zone planar lens with increased focusing quality is proposed. Each full-wave zone is divided into four quarter-wave subzones, which are covered by dielectric rings having equal thickness but different permittivities. This lens configuration has better focusing properties and compared to the grooved Fresnel lens [5] it has the advantage that the front and back surfaces are flat, i.e. this planar lens has better aerodynamical properties and does not accumulate dust, rain and snow. It will be demonstrated in this letter that the aperture efficiency of the corresponding quarter-wave Fresnel zone antenna is about 50–55%.

The idea behind the multi-dielectric transmissive-type Fresnel zone plate is not a new one [5], [6], but to the authors' knowledge there are no publications on the specific lens design and its electromagnetic analysis. In principle, the working

Manuscript received January 20, 1995.

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IEEE Log Number 9412817.

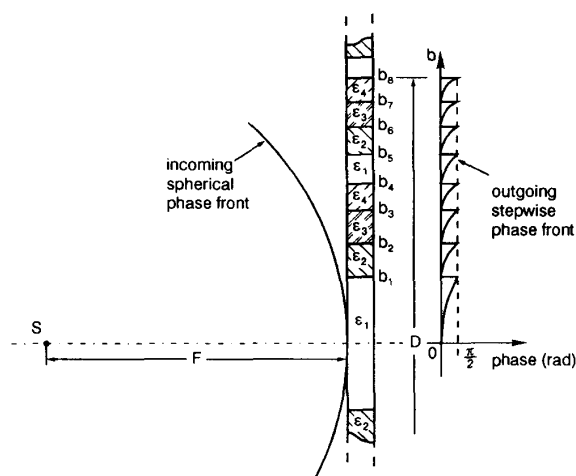


Fig. 1. Planar quarter-wave Fresnel-zone dielectric lens as a discrete phase transformer.

mechanism of our lens and antenna is similar to that used in some reflector-type Fresnel zone plates and antennas, proposed and examined recently by Guo and Barton [9], [10]. For an X -band multi-layer quarter-wave Fresnel reflector antenna, they reported a measured aperture efficiency of 55%.

II. LENS CONFIGURATION

In principle, the Fresnel zone lens does not transform smoothly the incoming spherical phase front into an outgoing plane one. It is a stepwise phase-transformer and in the case of the quarter-wave Fresnel lens the maximum phase deviation (aperture phase error) equals $\pi/2$.

Fig. 1 shows a sketch of the proposed quarter-wave Fresnel lens. Each full-wave Fresnel zone is divided into four quarter-wave subzones. The central subzone is open and the next three subzones are covered by dielectric rings with different, properly chosen permittivities. All other full-wave zones have similar arrangements.

To accomplish a quarter-wave stepwise phase-correction, the relative permittivities have to obey the following sequence: $\epsilon_1 = 1$, $\epsilon_2 = 6.25$, $\epsilon_3 = 4$, and $\epsilon_4 = 2.25$. This follows from the computed "infinite" transmission phase-shift characteristics [12], [13] of dielectric plates with the above sequence of permittivity values and with the thickness of the ideal dielectric phase-shifter, i.e. $\lambda/2$ for $\epsilon = 4$.

It is expected that by using printed-type (microstrip) technology instead of solid dielectric rings, lighter and cheaper phase-shifting structures and quarter-wave Fresnel lenses can be fabricated.

TABLE I
RADIATION CHARACTERISTICS OF THREE FRESNEL ZONE ANTENNAS

Fresnel zone antenna type	Directive gain (dBi)	Sidelobe level (dB)	Aperture efficiency (%)
(1) Quarter-wave FZA	34.7	-30.5	50.7
(2) Half-wave FZA	32.3	-22.0	29.3
(3) Classical FZA	28.1	-16.0	11.4

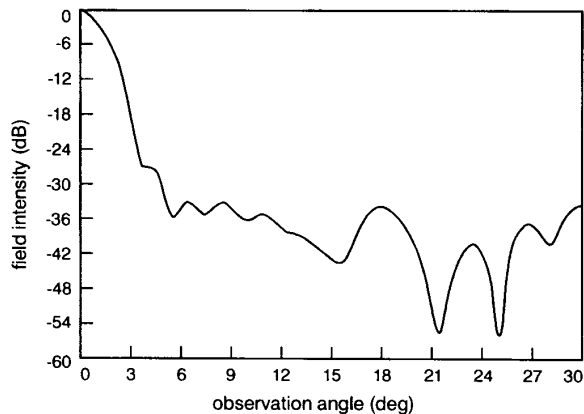


Fig. 2. Copolar radiation pattern of quarter-wave FZA.

III. FRESNEL ZONE LENS ANTENNA FOR DBS-RECEPTION

The described quarter-wave Fresnel zone lens was used to design a transmissive-type Fresnel zone antenna (FZA) for DBS-reception. The far-field radiation characteristics of the planar lens illuminated by a scalar feed were calculated by the use of multiple reflection and transmission coefficients for real dielectric plates ($\tan \delta = 0.001$), and vectorial Kirchhoff diffraction theory [12], [13]. In these far-field calculations, the internal reflections at the edges of the rings were neglected.

Fig. 2 shows the copolar radiation pattern of a quarter-wave FZA with an aperture diameter $D = 600$ mm, a focal length $F = 400$ mm, a lens thickness $d = 12.9$ mm and an edge illumination of -12 dB, at the design frequency of 12.1 GHz. In Table I the main radiation characteristics of the quarter-wave FZA 1) are compared with those of a FZA consisting of phase-reversing dielectric rings 2), and with those of the classical FZA having alternate transparent and opaque zones 3).

It appears that for the same antenna dimensions and design parameters, the quarter-wave FZA with a directive gain of 34.7 dBi and aperture efficiency of 50.7% surpasses 2.4 dB in gain and 1.7 times in efficiency the half-wave FZA, and 6.6 dB in gain and 4.4 times in efficiency the classical FZA. The calculated gain versus frequency characteristics of the three FZA designs, shown in Fig. 3, demonstrate that the gain bandwidths of all three designs are large enough to include the whole DBS frequency band. It was also found that quarter-wave FZA's with smaller apertures have an even higher efficiency. For example, if $D = 250$ mm, $F = 400$ mm, and $d = 12.4$ mm the antenna has a directive gain of

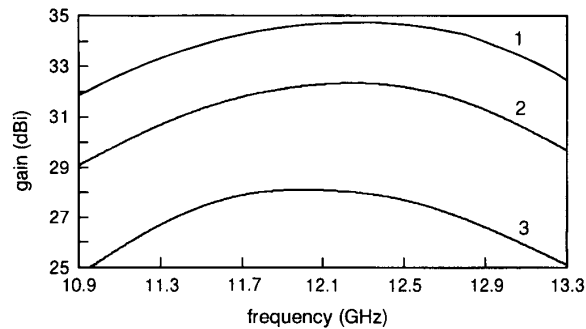


Fig. 3. Directive gain versus frequency for: (1) quarter-wave FZA, (2) half-wave FZA, and (3) classical FZA.

27.6 dBi and an aperture efficiency of 56.7%, for the optimum frequency of 13.7 GHz.

IV. CONCLUSION

A new variety of planar Fresnel zone lens with enhanced focusing quality was proposed. This planar lens transforms a spherical wave into a quasi-plane one with a maximum phase error of $\pi/2$.

Based on this lens configuration, a transmissive-type antenna for DBS-reception was developed, and the basic results of its theoretical study were presented. This quarter-wave FZA has an aperture efficiency of 50.7%, and a gain bandwidth which includes the whole DBS frequency band.

ACKNOWLEDGMENT

The European COST Telecommunications Secretariat (Commission of the European Communities, Brussels) is gratefully acknowledged for granting the first author Research Contract CIPA 3510 CT926503/1993 on the analysis and design of transmissive Fresnel-zone antennas at Eindhoven University of Technology.

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