Proceedings of ISAP2007, Niigata, Japan

A Short Backfire Antenna with Fresnel Zone Plates

Junji YAMAUCHI, Osamu FUKUSHIMA, and Hisamatsu NAKANO
Faculty of Engineering, Hosei University
3-7-2 Kajino-cho Koganei-shi, Tokyo, 184-8584 Japan,
E-mail: osamu.fukusima.bf@gs-eng.hosei.ac.jp

1. Introduction

The short backfire antenna (SBA) developed by Ehrenspeck [1] has received much interest for its advantages, such as low cost, compactness, simplicity of construction, and high gain. The conventional SBA is composed of two parallel reflectors (main and sub reflectors) and a feed, which commonly includes a dipole placed between the reflectors, or an open-ended waveguide [2]. The SBA has successfully been used as either a single antenna or a primary feed in reflector antennas.

On the other hand, we have recently proposed an antenna system in which a short cylindrical dielectric rod is mounted on a launcher composed of Fresnel zone plates (FZPs) [3], [4] and a circular ground plane [5]. The FZPs have an advantage over a conventional dielectric lens in that its structure is planar.

In this paper, we develop a new SBA, in which FZPs are applied to a subreflector. We numerically demonstrate that high gain characteristics can be obtained with a simple configuration using the body-of-revolution finite-difference time-domain (BOR-FDTD) method [6].

2. Configuration and Numerical Method

Fig. 1 shows the configuration of an SBA with FZPs fed by a metallic waveguide (WCI-120). A launcher is composed of FZPs and a circular ground plane whose radius is r_{GP}. A rim whose height is L_{rim} is placed at the edge of the ground plane. It is assumed that the ground plane, FZPs and rim are perfectly conducting.

The original structure of the FZPs whose even zones are transparent is shown in the inset of Fig. 1. When the focal length and the free-space wavelength are, respectively, designated as F and λ_0, the radius R_n (n = 1, 2, 3, …) of the each zone is given by

$$R_n = \sqrt{nF\lambda_0 + (n\lambda_0/2)^2}\ . \qquad (1)$$

The focal length and the design frequency are, respectively, chosen to be $F = 0.7\lambda_0$ and 11 GHz ($\lambda_0 \cong 27.3$ mm), so that the radii of the edges of each zone are $R_1 = 0.97\lambda_0$, $R_2 = 1.54\lambda_0$, and $R_3 = 2.08\lambda_0$, The present configuration may also be considered to be an application of partially reflecting sheet arrays [7]. Note that the original structure defined by Eq. (1) is somewhat modified after the basic investigation.

To obtain the impedance matching between the air and waveguide regions, we insert a tapered dielectric rod into the metallic waveguide. The relative permittivity of the rod is chosen to be $\varepsilon_r = 2.0$ (Teflon). The waveguide is excited with the TE_{11} mode.

The BOR-FDTD method is used to evaluate the radiation characteristics. The excitation scheme of a +*z*-propagation incident waveform is used for continuous wave simulation of the TE_{11} mode. The directivity is calculated from the fields on a virtual closed surface regarded as a Huygens plane which encloses the antenna structure in the computational region. The grid widths are fixed to be $\Delta r \cong 0.29$ mm and $\Delta z \cong 0.27$ mm. As an absorbing boundary condition, the second-order Higdon operator is placed at the edge of the computational region.

ISBN: 978-4-88552-223-9 C3055©IEICE

3. Discussion

We first investigate the dependence of the gain on the ground plane r_{GP} and the rim length L_{rim}. Fig. 2 shows the contour plots of the gain. It is found that the gain reaches a maximum value of 19.4 dBi, when r_{GP} and L_{rim} are taken to be $2.7\lambda_0$ and $0.5\lambda_0$, respectively. Using these parameters, we study the basic characteristics of this antenna.

Figs. 3(a) and (b) present the radiation patterns in the E- and H-planes, respectively. The data presented by a dotted line is the calculated value for the antenna without the FZPs, while broken and solid lines show those with one FZP and two FZPs, respectively. As can be seen, the addition of the FZPs contributes to a sharper beam. The half-power beamwidths of the antenna with two FZPs are calculated to be ±6 degrees in both E- and H-planes.

Frequency responses of the gain and the return loss are shown in Fig. 4. It is found that a gain of greater than 19 dBi is obtained over a frequency range of 10.7 to 12.7 GHz, while a return loss of greater than 15 dB is maintained over a frequency range of 11 to 13 GHz. It is noted that the maximum gain is rather obtained at frequencies higher than the design frequency. This is partly due to the fact that Eq. (1) assumes a point source at the origin of the co-ordinate system.

To obtain the maximum gain at a design frequency of 11 GHz, we next investigate the modification of the FZPs. Preliminary calculation shows that a higher gain can be obtained at 11 GHz when the radii of the edges of each zone are somewhat changed. As a result, the optimum radii are found to be $R_1 = 0.96\lambda_0$, $R_2 = 1.61\lambda_0$, and $R_3 = 2.51\lambda_0$, when r_{GP} and L_{rim} are fixed to be $2.7\lambda_0$ and $0.5\lambda_0$, respectively. We choose these radii in the following analysis. We refer FZPs with the modified radii to modified FZPs.

In order to determine the optimum values of r_{GP} and L_{rim}, we calculate the gain as a joint function of the ground plane r_{GP} and the rim length L_{rim}. The results are shown in Fig. 5. It is observed that the rim length L_{rim} is insensitive to the gain. A maximum gain of 21.6 dBi is obtained when r_{GP} and L_{rim} are chosen to be $3.1\lambda_0$ and $0.7\lambda_0$, respectively.

The radiation patterns in the E- and H-planes for the maximum gain are shown in Figs. 6(a) and (b), respectively. For comparison, the results for the SBA with the original FZPs are also presented. It can be seen that the patterns for the SBA with the modified FZPs have a sharper beam than that with the original FZPs. The half-power beamwidths of the SBA with the modified FZPs are calculated to be ±5 degrees and ±4.5 degrees in the E- and H-planes, respectively.

Fig. 7 shows the gain and the return loss as a function of frequency. It is confirmed that a maximum gain of 21.6 dBi is obtained at a frequency of 11 GHz at the expense of a narrower bandwidth than the SBA with the original FZPs shown in Fig. 4. A return loss of greater than 15 dB is obtained over a wide frequency range of 11 to 13 GHz.

4. Conclusion

We have numerically analyzed a short backfire antenna with FZPs using the BOR-FDTD method. The use of the FZPs contributes to forming a sharper beam. By choosing the optimum values of the rim height and the radius of the ground plane, a gain of greater than 19 dBi is obtained over a wide frequency range of 10.7 to 12.7 GHz, while a return loss of greater than 15 dB is maintained over a frequency range of 11 to 13 GHz. To increase the gain at a design frequency of 11 GHz, we have modified the parameters of the FZPs. As a result, a maximum gain of 21.6 dBi is obtained at the design frequency.

Acknowledgments

The authors would like to thank Mr. Shin’ichi Nakano for his basic study of the short backfire antenna with FZPs.

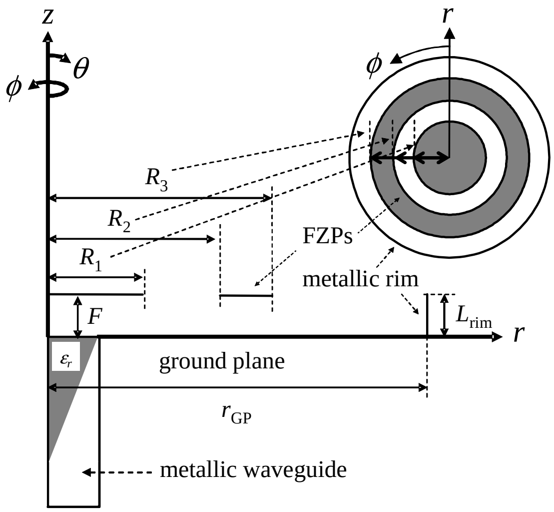


Fig. 1: Configuration

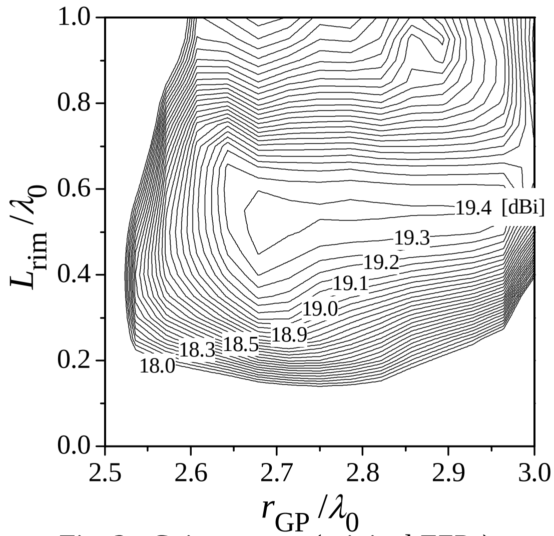
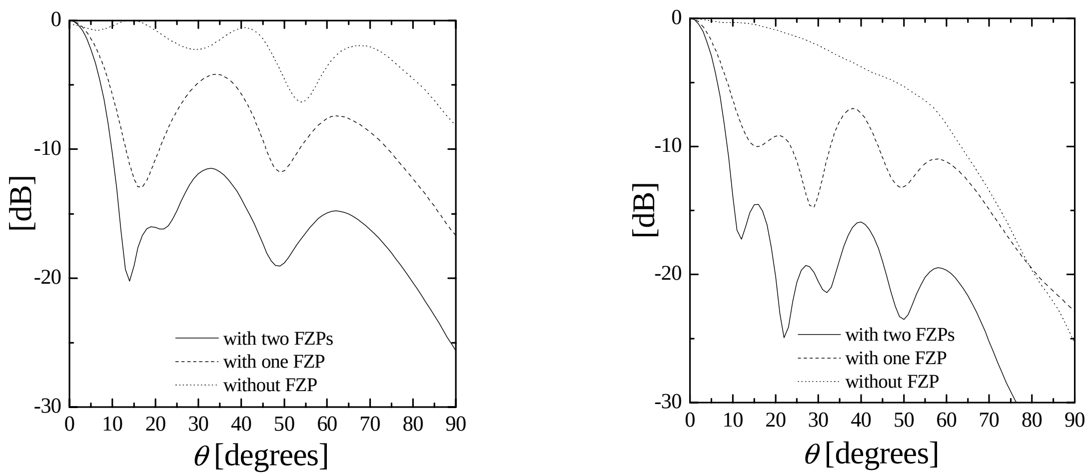


Fig. 2: Gain contour (original FZPs)



(a) E-plane

(b) H-plane

Fig. 3: Radiation patterns ($r_{GP} = 2.7\lambda_0$, $L_{rim} = 0.5\lambda_0$)

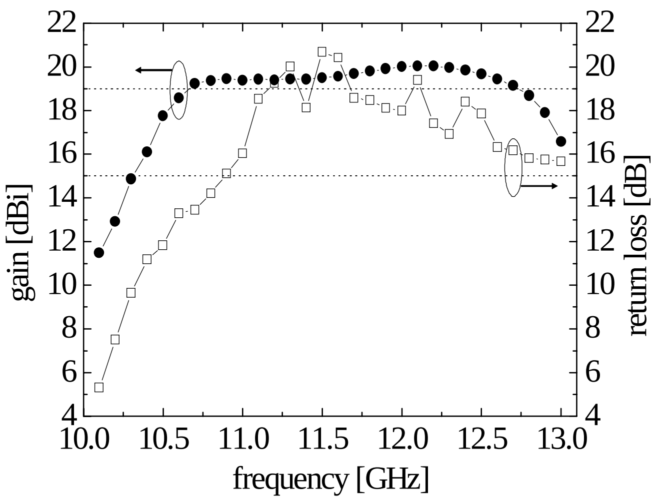


Fig. 4: Frequency responses of the gain and the return loss (original FZPs)

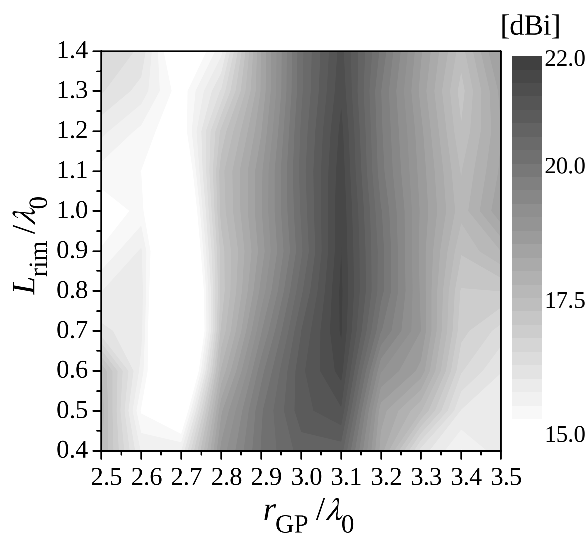
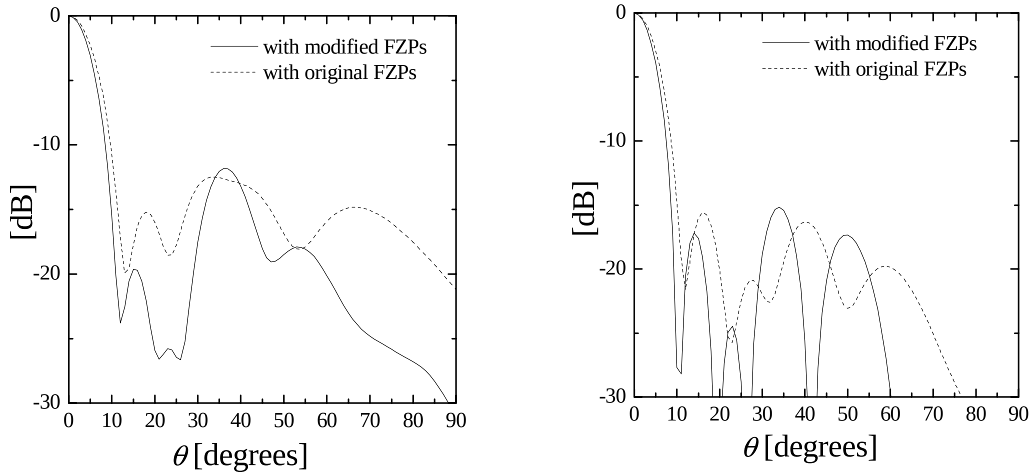


Fig. 5: Gain contour (modified FZPs)



(a) E-plane

(b) H-plane

Fig. 6: Radiation patterns (r_{GP} = 3.1λ_0, L_{rim} = 0.7λ_0)

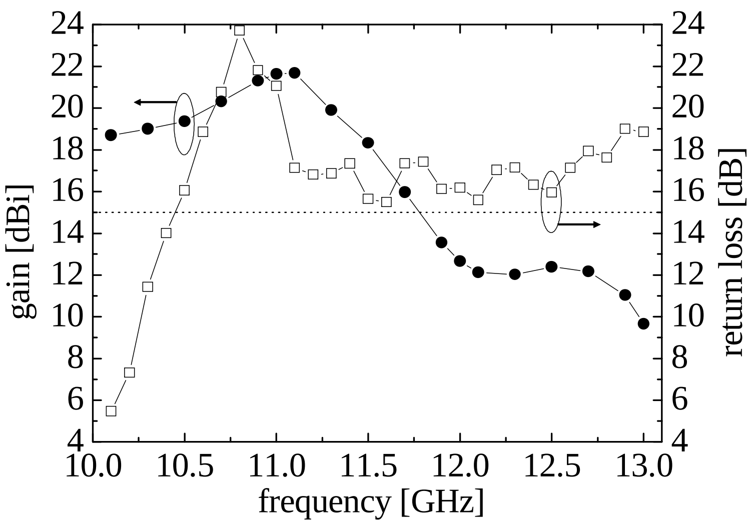


Fig. 7: Frequency responses of the gain and the return loss (modified FZPs)

References

[1] H. W. Ehrenspeck, “The short-backfire antenna,” Proc. IEEE, vol. 53, no. 8, pp. 1138-1140, 1965.

[2] A. Kumar and H. D. Hristov, *Microwave Cavity Antennas*, Artech House, Norwood, 1989.

[3] H. D. Hristov, *Fresnel Zones in Wireless Links, Zone Plate Lenses and Antennas*, Boston: Artech House, 2000.

[4] J. C. Wiltse, “History and evolution of Fresnel zone plate antennas for microwave and millimeter waves,” IEEE Int. Antennas and Propagat. Symp. Dig., vol. 2, pp. 722-725, 1999.

[5] J. Yamauchi, S. Nakano, and H. Nakano, “Radiation characteristics of a short cylindrical dielectric rod with Fresnel zone plates,” Int. J. Microw. Opt. Technol., vol. 1, no. 2, pp. 827-831, 2006.

[6] A. Taflove and S. C. Hagness, *Computational Electrodynamics*. *The Finite-Difference Time-Domain Method*, 2nd edition, Boston: Artech House, 2000.

[7] G. von Trentini, “Partially reflecting sheet arrays,” IRE Trans. Antennas Propagat., vol. AP-4, no. 4, pp. 666-671, 1956.