RADIATION CHARACTERISTICS OF A CYLINDRICAL DIELECTRIC ROD PERIODICALLY COVERED WITH METALS

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1. Introduction

It is well known that the gain of a dielectric rod antenna [1] saturates with an increase in the rod length, and that the further increase results in a periodic variation of the gain [2],[3]. Although a tapered configuration can be used to overcome this problem [4], we need fine control of the tapered configuration. Another configuration of enhancing the gain (a so-called Dash-Hollow rod) has been proposed by Sueta *et al.* [5], in which a dielectric rod is periodically covered with metals. However, a theoretical study has not been carried out until the present time. In this paper, we analyze the Dash-Hollow rod antenna using the body-of-revolution finite-difference time-domain (BOR-FDTD) method [6]. We numerically demonstrate that high gain characteristics can be obtained with a simple configuration.

2. Configuration and numerical method

Fig. 1 shows the antenna configuration. A cylindrical dielectric rod is periodically covered with metals whose length is designated as L_m. The length of the bare dielectric rod is designated as L_d. The length of the dielectric rod at the open end, L_e, has not necessarily to be the same as L_d (A slight enhancement in the gain is observed when L_e is somewhat less than L_d). In this paper, however, L_e is chosen to be the same as L_d for simplicity.

The relative permittivity of the rod is chosen to be $\varepsilon_r = 2.54$ (Polystyrene). The bore of the metallic waveguide, which is the same as the diameter of the rod, is $2\rho_{rod} = 17.475$mm ($= 0.64\lambda_0$). The waveguide is excited with the TE_{11} mode at a frequency of 11 GHz ($\lambda_0 \cong 27.3$mm). To obtain smooth transition from the TE_{11} mode of the metallic waveguide to the HE_{11} mode of the rod, we tapered and inserted portion of the rod into the metallic waveguide. In this analysis, the taper length L_{in} is set to be $2.0\lambda_0$.

The BOR-FDTD method is used for evaluation of 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 $\Delta\rho = \rho_{rod} / 30$ ($\cong 0.29$ mm) and $\Delta z = \lambda_0 / 100$ ($\cong 0.27$ mm). As an absorbing boundary condition, the second-order Higdon operator is placed at the edge of the computational region.

3. Discussion

The lengths of L_d and L_m are determined in such a way that the radiation from each bare dielectric rod adds in phase toward the direction of the z-axis. This leads to the following relation [5]:

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$$2\pi\left(\frac{L_\mathrm{d}}{\lambda_g}+\frac{L_\mathrm{m}}{\lambda'_g}\right)-2\pi\left(\frac{L_\mathrm{d}+L_\mathrm{m}}{\lambda_0}\right)=2\pi \qquad (1)$$

where λ_g and λ_g’ are, respectively, the guided wavelengths in the bare dielectric rod and the rod with the metal. Fig. 2 shows the optimum values of L_d and L_m as a function of the number of metals N. L_d tends to decrease as the number of metals is increased, while L_m tends to increase.

The gain characteristics as a function of L_rod are shown in Fig. 3. For comparison, the gain without the metals is also presented. It is clear that the periodic change in the gain can be eliminated by the addition of the metals. Note that the location of the metals (the shaded region in Fig. 3) is expressed for N=4. The metal location almost corresponds to the portion where the dielectric rod causes a destructive effect on the gain.

Fig. 4 shows the gain observed when the number of metals N is further increased. The gain tends to increase as the number of N is increased. Within a range of this numerical analysis, a maximum value of 19.7dBi is obtained for $N = 12$ ($L_\mathrm{rod} = 40.3\lambda_0$) .

Figs. 5(a) and (b) present the typical radiation patterns in the E-plane for $N = 4$ and $N = 12$, respectively. The pattern for $N = 12$ has a shaper beam than that for $N = 4$. The half-power beamwidth decreases from ±9° to ±5° as the number of N is increased from 4 to 12.

Although the configuration shown in Fig. 1 is very simple and compact, we next consider the case where a launching horn is added to the metallic waveguide, as shown in Fig. 6. The parameters of the launching horn are taken to be $L_\mathrm{h} = 3\lambda_0$ and $\theta_\mathrm{h} = 15°$.

Fig. 7 shows the gain characteristics as a function of the number of metals N. For reference, the gain without the horn, which is the same as that in Fig. 4, is again plotted. It is found that the horn has the effect of increasing the gain. A gain of 20.3dBi is obtained for $N = 12$, which is higher than that without the horn by 0.6dB.

The higher gain for the rod with the launching horn is attributed to the fact that the sidelobes are somewhat reduced, particularly near the z-axis, as shown in Figs. 8(a) and (b). For example, the first sidelobe level is reduced from 7.5dB to 8.7dB due to the addition of the horn. Although not illustrated, similar effects are also observed in the H-plane. To further reduce the grating lobes observed for $\theta > 45°$, we have to change the permittivity with subsequent change in L_d and L_m.

4. Conclusions

The radiation characteristics of a cylindrical dielectric rod antenna periodically covered with metals (the so-called Dash-Hollow antenna) are investigated using the BOR-FDTD method. It is numerically demonstrated that the appropriate location of the metal almost corresponds to the region where the dielectric rod has a destructive effect on the gain. A gain of 19.7dBi is obtained with a simple configuration without a launching horn. We further consider the case where the launching horn is added to the metallic waveguide. As a result, a gain of 20.3dBi is achieved for the number of metals N =12.

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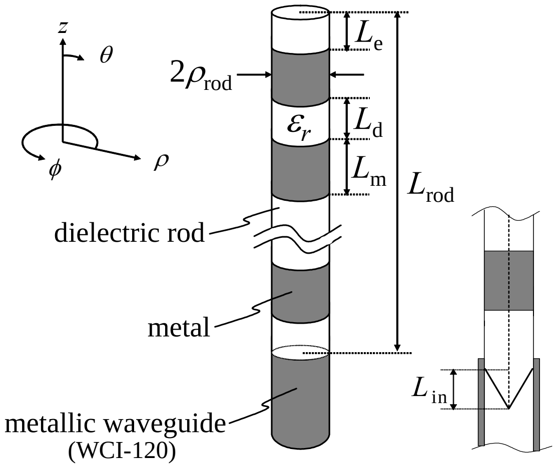


Fig. 1 Configuration.

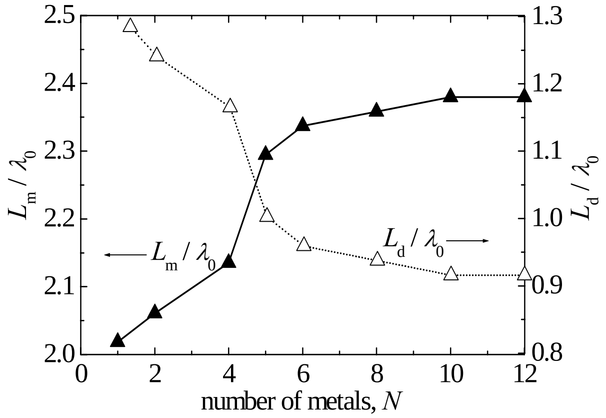


Fig. 2 Optimum values of L_d and L_m.

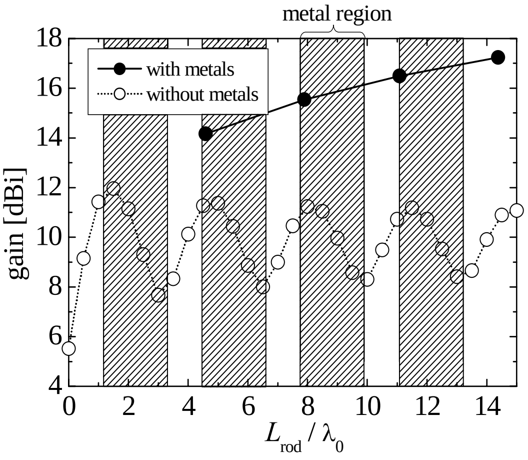


Fig. 3 Gain characteristics.

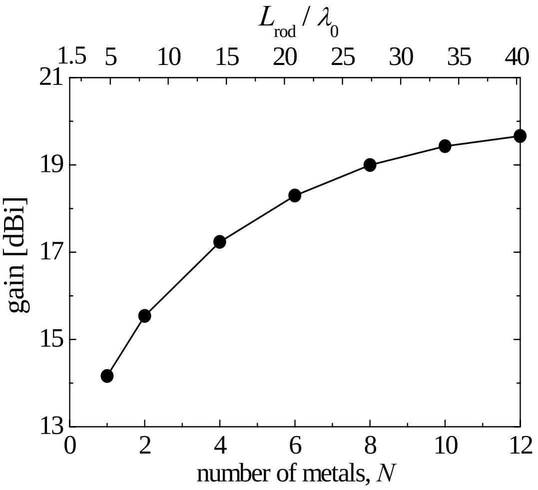
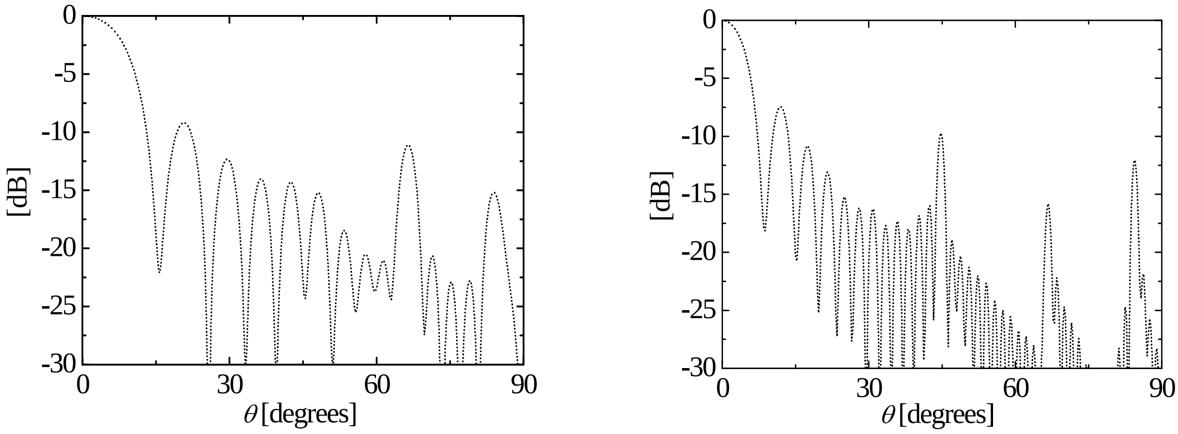


Fig. 4 Gain characteristics.



(a) $N = 4$ (b) $N = 12$

Fig. 5 Radiation patterns (E-plane).

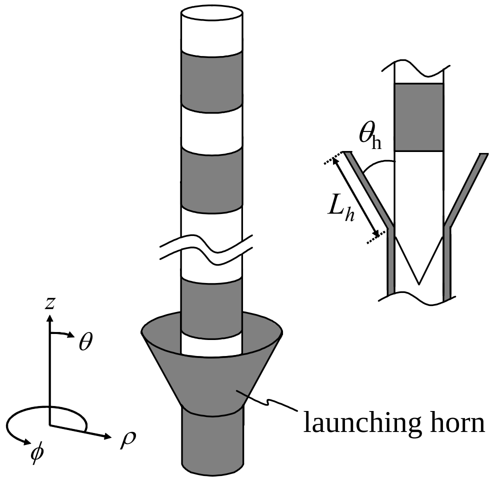


Fig. 6 Configuration.

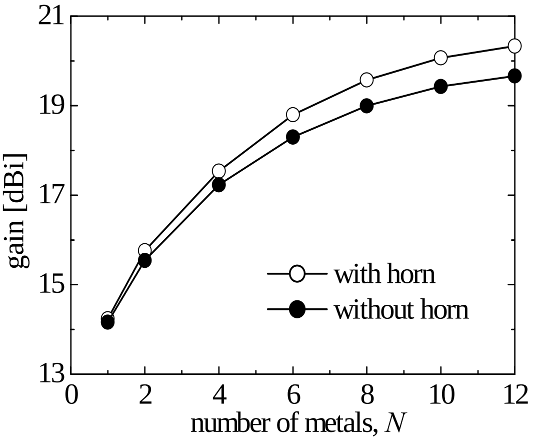
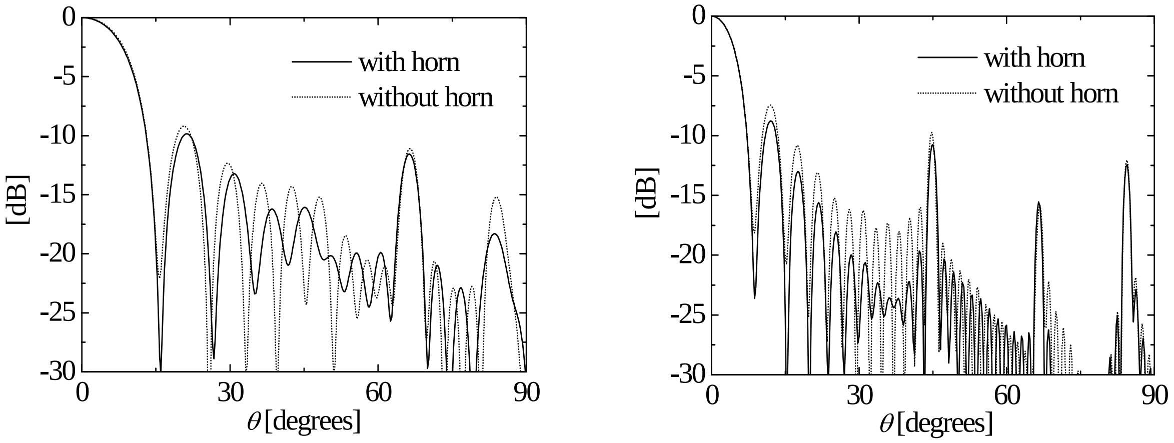


Fig. 7 Gain characteristics.



(a) $N = 4$

(b) $N = 12$

Fig. 8 Radiation patterns (E-plane).

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