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 \( 2\rho_{rod} = 17.475\text{mm} (= 0.64\lambda_0) \). The waveguide is excited with the TE\(_{11}\) mode at a frequency of 11 GHz (\( \lambda_0 \approx 27.3\text{mm} \)). 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 \( \Delta\rho = \rho_{rod} / 30 \) (\( \approx 0.29 \text{ mm} \)) and \( \Delta z = \lambda_0 / 100 \) (\( \approx 0.27 \text{ mm} \)). 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]:
where $\lambda_g$ and $\lambda'_g$ 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 19.7 dBi is obtained for $N = 12$ ($L_{rod} = 40.3 \lambda_0$).

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 $\pm 9^\circ$ to $\pm 5^\circ$ 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 $L_h = 3 \lambda_0$ and $\theta_h = 15^\circ$.

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 20.3 dBi is obtained for $N = 12$, which is higher than that without the horn by 0.6 dB.

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 7.5 dB to 8.7 dB 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 $\theta > 45^\circ$, 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 19.7 dBi 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 20.3 dBi 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.

Fig. 5 Radiation patterns (E-plane).
Fig. 6 Configuration.

Fig. 7 Gain characteristics.

Fig. 8 Radiation patterns (E-plane).

References