DIELECTRIC ROD ANTENNA FED BY IMAGE NRD GUIDE

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1. INTRODUCTION

There has been increasing interest in millimeter-wave band in recent years. This is partly due to the need for exploitation of new frequency spectra to ease the frequency jam occurring in the microwave and lower frequency band. High-performance and low-cost antennas are strongly required to develop millimeter-wave applications such as high-speed wireless LANs and automobile collision avoidance radar. A dielectric rod antenna is an attractive candidate for these systems, and has been studied extensively in many literatures[1]-[3]. The antennas can be fed by various kinds of waveguides. Metallic waveguide feed is commonly adopted in most of investigations reported previously[1],[2]. But in the millimeter-wave band it is preferable to use a dielectric waveguide instead of the metallic one from the viewpoint of the transmission loss, which is serious concern in the millimeter-wave region[3].

The purpose of this paper is to propose a rod antenna based on an image NRD guide[4], which is a class of the dielectric waveguide and is developed from the conventional NRD guide proposed by Yoneyama *et al*. [5]. To realize a smooth pattern and reasonable gain, a transition from the image NRD guide to the rod antenna is investigated, and its effective performance is confirmed by FDTD analysis. Measured results obtained at 30 GHz band are also presented to validate the numerical considerations.

2. CONFIGURATION OF ANTENNA

Fig. 1 shows the configuration of a dielectric rod antenna fed by an image NRD guide to be considered in this paper. A metallic trough of depth h = 15mm and of width a = 4mm is composed of parallel plates and an image plane. An image NRD guide is constructed by inserting a rectangular dielectric rod into the bottom of the trough. The cross section of the dielectric rod is held at constant value of $a \times b = 4 \times 3\,\mathrm{mm}^2$ along the image NRD guide area. The dielectric rod is extruded from the end of the guide into the free space to form a rod antenna. The antenna has the length of d, and is tapered linearly in only the yz-plane. A transition from the image NRD guide to the rod antenna is formed with linearly tapered parallel plates and image plane. The length of the transition is designated as l.

In the following discussion the dielectric constant of the rod is chosen to be 2.08, which is corresponds to the value of PTFE. In this case, cutoff frequencies of the dominant LSM_{10} and next order LSE_{11} modes are 29.16 and 34.12GHz, respectively.

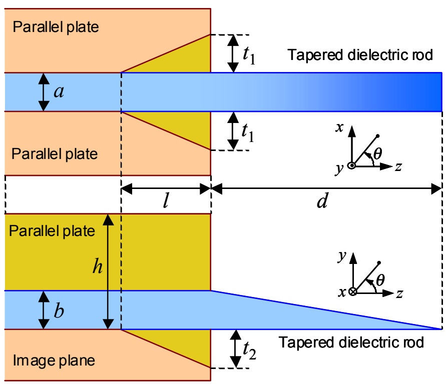


Fig. 1. Configuration of a dielectric rod antenna fed by an image NRD guide.

3. ANTENNA CHARACTERISTICS

Characteristics of the dielectric rod antenna were evaluated using FDTD technique. The dimension of the Yee cells used in the following analysis are chosen to be $\Delta x = \Delta y$ =0.25mm and Δz = 0.5mm. PML[6] having 4 layers is employed as the absorbing boundary condition to absorb the radiated outgoing waves. Tapered portions of the rod antenna and the transition are expressed using a simple stepped-edge model.

We first analyze the configuration with the case of $t_1 = t_2 = 0$, or without the transition. The length of the rod is set to be d = 90mm, which corresponds to $10\lambda_0$ at 34GHz (λ_0: free space wavelength). Fig. 2 shows the gain evaluated in the endfire ($\theta = 0^\circ$) direction. Radiation patterns calculated at 34GHz are shown in Fig. 3 with solid lines. Measured results are also indicated in these figures as broken lines. The frequency shift is caused in the measured gain by some fabrication tolerance of the image NRD guide. But the discrepancy between the simulated and the measured gain is less than 0.3dB above 32GHz. The calculated beamwidth of the E- and H-plane patterns is 24°, which identical to the measurements. The degradation of the pattern shape is observed in both of the E- and H- plane.

The gain of a dielectric rod antenna having a linear taper is approximately given by the following formula[2].

$$G \approx 7\left(d / \lambda_0\right) \qquad (1)$$

For the case of d = 90mm the gain is estimated to be 18.7dBi at 34GHz. In Fig.2 simulated and measured gain at 34GHz is 15.7dBi, which is –3dB below with respect to the value expected from (1). Fig. 4 shows the intensity distribution of the electric field calculated in the yz-plane. Unwanted radiation is observed at the guide-to-antenna discontinuity for both of E_y and E_z components. This leads to the degradation of the radiation patterns seen in Fig. 3. As for the E_y component, it can be seen that the radiation is occurred mainly in the region near the feeding point, and that the energy does not delivered to the apex side of the rod. These

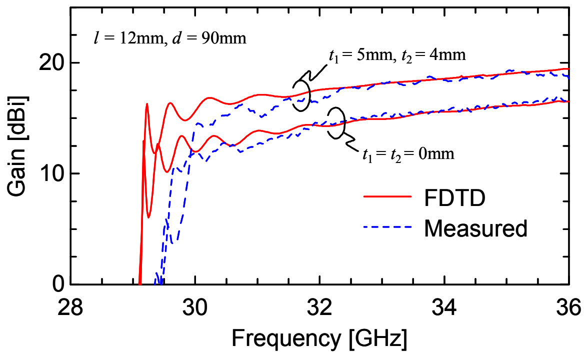
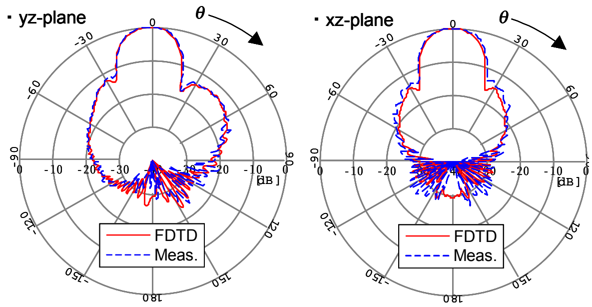


Fig. 2. Gain observed in the endfile direction.



(a) E-plane (b) H-plane

Fig. 3 Radiation patterns without transition.

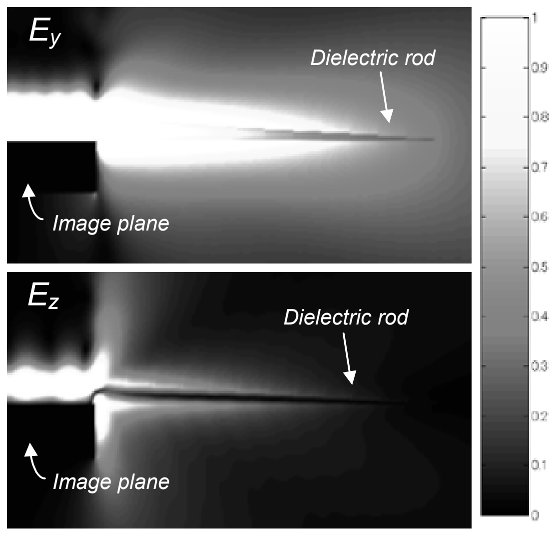


Fig. 4. Electric field intensity distribution in yz-plane calculated at 34GHz.

facts imply that the effective aperture area of the antenna is smaller than that of ideal one. This is the reason for the decrease of the gain. So when we use the image NRD guide as a feeder of the dielectric rod antenna, we have to use the guide-to-antenna transition to obtain a smooth pattern and reasonable gain, just like the case for the metallic waveguide[1] or the conventional NRD guide[3].

Next we investigate the characteristics of the dielectric rod antenna with the transition having the length of l = 12mm. The distance between the end of the transition and the dielectric rod is chosen to be t_1 = 5mm in x-direction and t_2 = 4mm in y-direction. The antenna length is hold at the same value (d = 90mm) assumed in the previous analysis so as to evaluate the effect of the transition.

Fig. 5 shows the electric field distribution in the yz-plane. By comparing these results to Fig. 4, we can see that the unwanted radiation from the discontinuity is reduced for both of E_y and E_z components, and that a much more energy is delivered to the apex side of the dielectric rod. Consequently, the increase of the gain and the improvement of the pattern shape are expected when the transition is adopted.

The calculated and measured gain for the case with the transition is shown in Fig. 2 with solid and broken lines, respectively. The predicted and measured results at 34GHz are 18.9 and 19.1dBi, respectively. These values are nearly the same as the value expected from equation (1).

Fig. 6 compares the calculated and measured patterns for the case with the transition. It can be fond that agreement of the shape is good for both of E- and H-plane, and that the unwanted radiation observed in Fig. 3 is suppressed. In both of E- and H-plane the calculated and measured beamwidth is 22°.

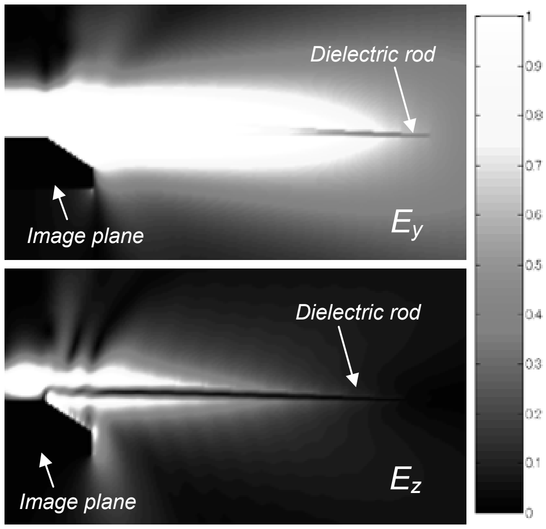
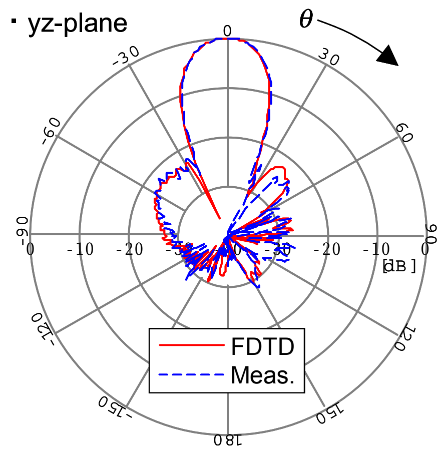
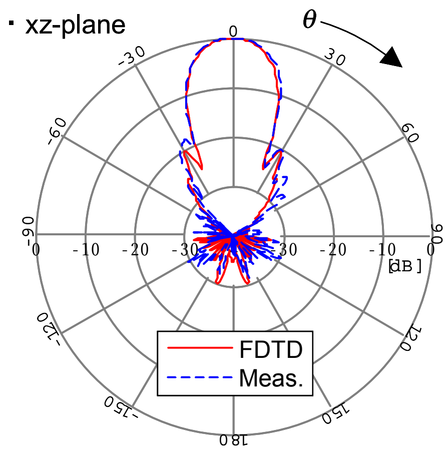


Fig. 5. Electric field intensity distribution when the guide-to-antenna transition is used. Analysis is carried out at 34GHz.



(a) E-plabe



(b) H-plane

Fig. 6. Radiation patterns for the case with the transition (f = 34GHz).

Finally, we evaluate the variation of the gain and the beamwidth against the antenna length. Figs. 7 and 8 show the gain and the beamwidth as a function of the antenna length normalized by the free space wavelength. In both figure, results evaluated by using FDTD are indicated as circular marks. Analysis is done for the case when d = 60, 90 and 120mm at the frequency of 34GHz. The approximated curves given by the equation (1) and the following formula [2] are indicated as solid lines.

$$BW \approx 68\sqrt{\lambda_0 / d} \qquad (2)$$

For both of gain and beamwidth, the values calculated by FDTD agree well with curves of the formulae. Consequently, the reasonable gain and beamwidth is obtained for any antenna length by applying the proposed transition to the rod antenna.

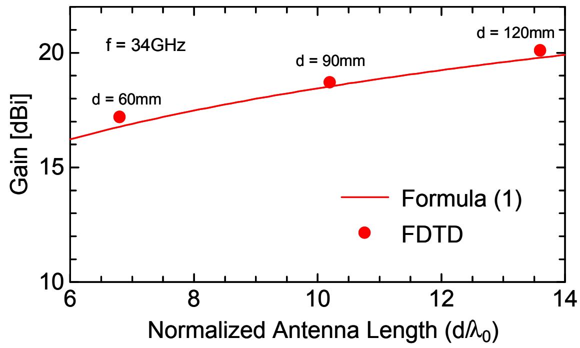


Fig. 7. Gain observed in endfire direction as a function of the antenna length.

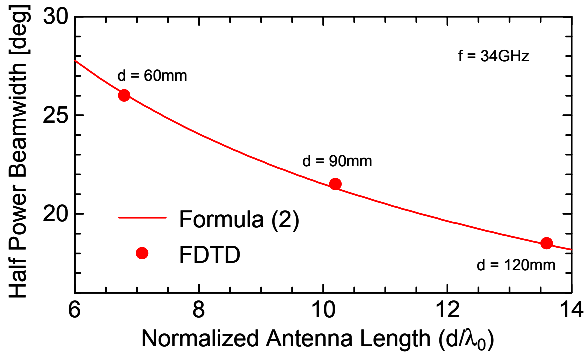


Fig. 8. Beam width versus antenna length.

4. CONCLUSIONS

In this paper the dielectric rod antenna with the image NRD guide feed has been proposed, and its characteristics are revealed using FDTD technique. To realize a smooth pattern and reasonable gain expected from the antenna size, a transition from the image NRD guide to the rod antenna has been investigated. Its effectiveness has been confirmed with the numerical results. Measured results at 30 GHz band have been also presented to validate the numerical considerations.

ACKNOWREDGEMENT

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