Electromagnetic Field Simulation of Dielectric Lens Antenna

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1 Introduction

Generally, the larger an antenna aperture size, the higher the gain of the antenna becomes. However, by loading a dielectric lens on the antenna aperture, the antenna gain is expected to be improved even for the small aperture antenna; which is called a dielectric lens antenna. The problem of a dielectric lens antenna is bulky, because the diameter of a lens ϕ is usually larger than the wavelength λ; for example, ϕ is one to five times as large as λ [1]. To develop a small planer antenna system, we load small spherical dielectric lens over the slot aperture of the waveguide slot antenna [2]. The features of the proposed lens include; (1) the diameter is smaller than the wavelength, (2) the shape is not the ordinary extended hemisphere but sphere. The small spherical lens has the advantage that the miniaturization of the antenna becomes easy in comparison with the conventional lens.

To evaluate the performance of the antenna with the proposed lenses, we calculate the electromagnetic field of the waveguide slot antenna by using finite-difference time-domain (FDTD) method [2]. As the FDTD method is a powerful tool for the transient analysis, it is possible to analyze the radio wave propagation from the antenna numerically and to visualize it. This paper describes the FDTD modeling of the dielectric lens and the convergence effect of the proposed lens.

Next, we apply the FDTD method to the design of the waveguide slot antenna. It would be difficult to apply theoretical approaches to the analysis and design of the dielectric lens antennas. However, the FDTD method allows us to design even novel antennas loaded by dielectric lenses. This paper reports the usefulness of the design by the FDTD method for a 10-slot waveguide slot array antenna.

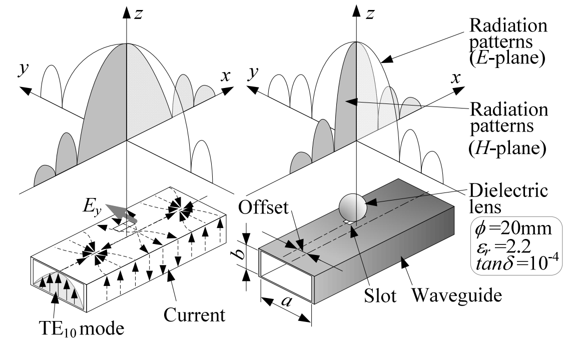
2 Simulation of Dielectric Lens Antenna

2.1 Simulation Model

Fig.1 shows the operation of the waveguide slot antenna and the image of its radiation patterns both with and without the dielectric lens. The slot which is cut in the wall of the waveguide becomes the radiator, since the slot intercepts the current flow on the wall. The radiation power from the slot increases as the offset from the center of the waveguide increases [3][4]. When the dielectric lens is loaded over the slot aperture, the beam width of the radiation patterns becomes narrower, and the radiation power in the far-field is enhanced.

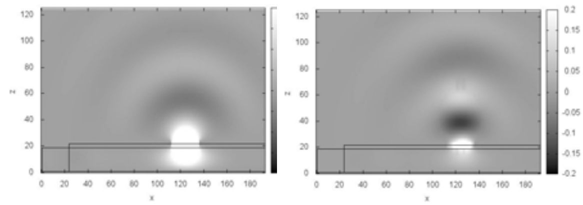
In this paper, the analysis condition of the waveguide slot antenna is set as follows: (1) the waveguide inner size $a \times b$ is 22.90×10.2 mm, (2) the waveguide is excited by TE_{10} mode, and (3) the target frequency is 12 GHz. Next, the proposed dielectric lens is defined as follows: (1) the diameter of the dielectric lens ϕ is 20 mm which is smaller than the wavelength λ = 25 mm, (2) the relative permittivity ε_r and the loss tangent $\tan\delta$ are 2.2 and 10^{-4}, respectively. In the FDTD modeling of the dielectric lens, the sphere shape is approximately divided into the rectangular parallelepiped cells whose size Δ is 0.5 mm. Hence, because the ratio Δ/ϕ is very small (Δ/ϕ =0.025), the proposed lens consists of adequate number of the cells. The dielectric loss of the proposed lens is assumed to be negligible. Substitution of the condition in Fig.1 into the equation (1) yields the conductivity σ=1.469×10^{-4} S/m.

$$\sigma = \omega \varepsilon_r \varepsilon_0 \tan\delta \quad (1)$$



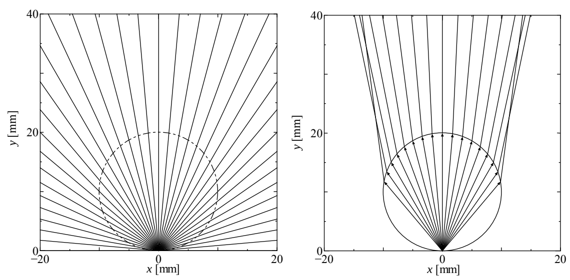
(a) Without lens (b) With lens

Fig. 1. Operation of the waveguide slot antenna and the image of the radiation patterns with the dielectric lens.



(a) Without lens (b) With lens

Fig. 2. Visualization of the radio wave propagation from the waveguide slot antenna by the FDTD method (500 time steps).



(a) Without lens (b) With lens

Fig. 3. The calculation results of the ray which is radiated from the point source by using the ray tracing method.

2.2 Convergence Effect of Dielectric Lens

We confirm both validity of the FDTD modeling of the dielectric sphere and convergence effect by visualizing the radiation from the slot. The perfectly matched layers (PML) are used as the absorbing boundary conditions. The calculation time step is 9.623×10^{-13} s. As shown in Fig.2, the radiation with the dielectric lens is found to be focused in the center compared with that without the lens. To evaluate the lens convergence, we calculate the radiation from the slot by using another simulation method. Fig.3 shows the calculation results by the ray tracing method assuming the point wave source. It is demonstrated that the ray with the proposed lens converges in the center as well as the results by the FDTD method.

Even though the diameter of the dielectric lens is smaller than the wavelength, we confirm that the radiation converges in the center. Additionally, it is thought that the FDTD modelling of the dielectric sphere is valid.

3 Antenna Design

3.1 Design of Resonant Array Antenna

We apply the FDTD method to the waveguide slot array antenna design. Fig.4 shows a 10-slot waveguide slot array antenna which has the short terminator with distance $\lambda_g/4$ from the last slot, because the target antenna is operated as the resonant array. The design parameter is the slot length, the slot spacing, and the slot offset. To simplify the design, the slot length and the slot spacing are fixed to the resonant length as shown in Table 1, where the slot length with the dielectric lens becomes shorter than the half wavelength [5]. Consequently, the antenna design in this section is equivalent to determining the slot offset value. Therefore, by varying the slot offset value, we find the optimal slot offset value by using the FDTD method.

Table 1. Antenna Design Parameter

Parameters	With lens	Without lens
Slot length L	10.5 mm ($<\lambda/2$)	12.5 mm ($=\lambda/2$)
Slot spacing d	15 mm ($=\lambda_g/2$)	

3.2 Design Results

Fig.5 shows the calculation result of the radiation power and the voltage standing wave ratio (*VSWR*). The radiation power is defined as the maximum value of the radiation patterns. The radiation power with the dielectric lens increases monotonously as the slot offset increases. In contrast, the radiation power without the lens has the peak value at x=3.5 mm. Usually, the slot offset is chosen to minimize *VSWR* [4][5]. The slot offset which minimizes *VSWR* shows different value between with and without the dielectric lenses.

Fig.6 shows the calculated radiation patterns of the designed antennas whose offset value is chosen from Fig.5. The electromagnetic field simulation by using the FDTD method demonstrates good performance for the resonant array design, since the side-lobe level of both antennas becomes about 13 dB. Also, the enhancement of the radiation power by loading the proposed lens is confirmed.

4 Conclusion

We have applied the FDTD method to demonstrate the features of the proposed dielectric lens on the waveguide slot antenna. By visualizing the radiation from the slot, the convergence effect of the proposed lens has confirmed. Also, we have demonstrated the usefulness of the design method based on the FDTD method as an example of the dielectric lens antenna. The present design method is simpler and more convenient than the conventional design method [3][4] and is useful to develop novel antennas.

Additionally, to design the electromagnetic devices, the evolutional design method by combining the FDTD method and the genetic algorithm (GA) is proposed [6][7]. The evolutional design of the non-resonant waveguide array antenna with the proposed lens has been reported in [7]. The establishment of the antenna design method by the electromagnetic field simulation is the subject in future.

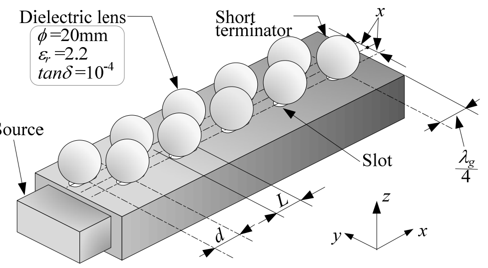


Fig. 4. The design parameter and analysis model of 10-slot waveguide slot array antenna with dielectric lenses.

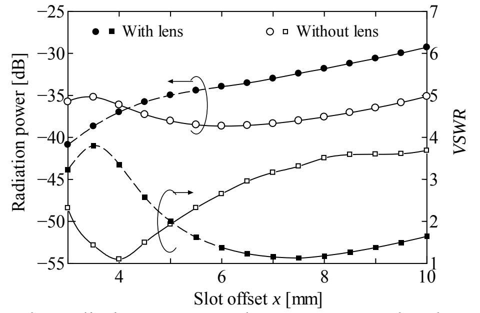


Fig. 5. The radiation power and *VSWR* versus the slot offset.

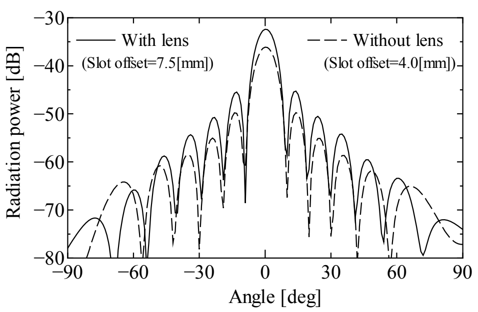


Fig. 6. The comparison of the radiation patterns of the designed antennas.

Acknowledgements

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