Evolutional Design of Waveguide Slot Antenna with Dielectric Lenses

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Abstract — This paper reports the design method of waveguide slot array antenna with dielectric lenses by using the evolutionary optimization. We adopt the micro-genetic algorithm (MGA) with the real-coded gene as the optimization method and the finite difference time domain (FDTD) method to evaluate the objective function. The major purpose of this study is to realize uniform aperture fields by optimizing slot length and offset parameters. It is shown that the optimized aperture field is sufficiently uniform, and the side-lobe levels are improved in comparison with those of the conventional antenna. It is confirmed that the proposed design method is a promising tool for the design of the antennas loaded with dielectric materials.

I. INTRODUCTION

To focus the electromagnetic waves over a waveguide slot antenna, we load small spherical dielectric lenses there. It is found that the radiation power is enhanced by loading the dielectric lens for 1-slot case, even when the lens diameter is chosen smaller than the wavelength [1]. To establish the design method of the waveguide slot array antenna loaded with the dielectric lenses is the purpose of this study.

Typical performances required for array antennas are high gain, low side-lobe levels, and low input SWR. It is known that the side-lobe level is determined by the near-field aperture distribution of the considering antenna [2]. For example, the ratio of the side-lobe level to the main-lobe maximum is greater than -12 dB in the case of uniform aperture distribution. Therefore, when we design wave-guide slot array antennas, it is necessary to control the slot conditions to realize a desirable aperture distribution.

In the conventional design of waveguide slot array antennas, the slot conditions are determined by calculating the equivalent slot admittance [3]. However, because the equation of the equivalent slot admittance must be derived by every different lens profile, the designer may be required to put a lot of effort into the derivation. Additionally, the lens dimensions must be taken into account as the constraint conditions for the design. For the reasons mentioned above, it comes to be difficult to apply the conventional method to the waveguide slot array antenna with the dielectric lenses.

We here apply the micro-genetic algorithm (MGA) to the design of waveguide slot array antennas with the dielectric lenses. MGA is one of the evolutional design methods, and can find nearly optimal solutions with relatively small number of function calls [4]. We also adopt the finite difference time domain (FDTD) method to analyze electromagnetic waves on which the objective function depends. This paper reports the evolutional design method by using MGA applied to 8-slot waveguide array antenna loaded with dielectric lenses.

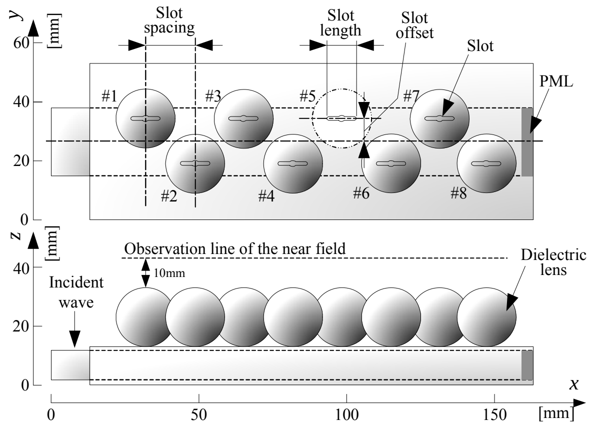

Fig. 1. Analysis model of FDTD method.

II. ANALYSIS MODEL

The analysis model of FDTD method is shown in Fig.1. The target antenna consists of the RG-52/U waveguide and dielectric lenses. The analysis region consists of 352 × 130 × 110 cells with cell size $\Delta x=\Delta y=\Delta z=0.5$ mm. The perfectly matched layers (PML) are used as the absorbing boundary conditions. The waveguide is excited by a dominant TE_{10} mode at the incident wall, and terminated at the end wall by a PML condition at $f = 12$ GHz.

The dimension of the spherical dielectric lenses loaded over the slots is 20 mm, which is smaller than the free-space wavelength. The lenses are made of polystyrene materials, where the relative permittivity and the loss tangent are supposed to be 2.2 and 10^{-4}, respectively.

The purpose of the design is to realize uniform field distribution on the observation line over the aperture as shown in Fig.1. As the antenna design parameters, the slot length, the slot spacing and the slot offset value are considered. To realize the uniform aperture distribution, all of these parameters are optimized by using MGA. The slot spacing is fixed at 16.5 mm; the number of the gene of MGA accordingly is 16 here.

III. MICRO-GENETIC ALGORITHM

The feature of MGA is that the population is smaller than the conventional GA [4]. In this paper the number of the population was chosen 5. MGA procedure is performed according to the flow chart shown in Fig.2.

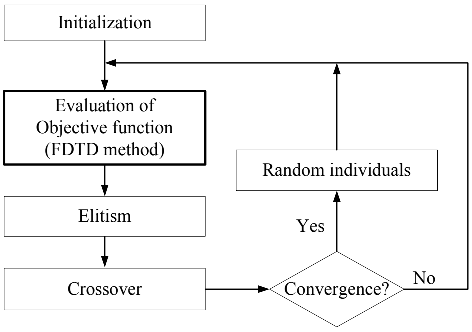

Fig. 2. Flow chart of micro-genetic algorithm.

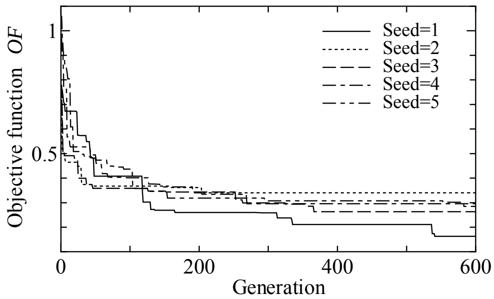

Fig. 3. Objective function versus the number of generation for different seeds.

TABLE I
DIMENSIONS OF OPTIMIZED ANTENNA DESIGN PARAMETERS

Slot No.	#1	#2	#3	#4	#5	#6	#7	#8
Slot length [mm]	9.5	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Slot offset [mm]	4.0	6.5	4.0	7.0	6.5	7.5	7.0	4.5

After the individuals are created randomly, MGA repeats the following operation; elitism, crossover with tournament selection and convergence checking. If the individuals converge each other, then the new individuals are created randomly.

We do not adopt the bit-coded gene but the real-coded gene, and crossover is performed by using BLX-0.5. The search space is 8.5 to 10.5 mm in the slot length, and 3.5 to 8.5 mm in the slot offset value. It is important to note that the search space is to be determined appropriately in order to obtain optimal solution.

The objective function *OF* is expressed by

$$OF = \frac{\sigma}{E_{ref}} + VSWR \times w \qquad (1)$$

The first term expresses the standard deviation for the reference electric field E_{ref}, w of the second term is a weight function, w=0.1. *OF* defined in (1) is minimized with respect to the optimization parameters mentioned above, subjected to the constraint that the adjacent lenses do not clash each other.

IV. RESULT

The evolutional history of *OF* for different random number seed is indicated in Fig.3. From the calculation done up to 600 iterations, it is found that the average value of the objective function is 0.26953, the best value being 0.16277 when the seed is chosen 1. The dimensions of the optimized antenna for seed=1 are shown in TABLE I.

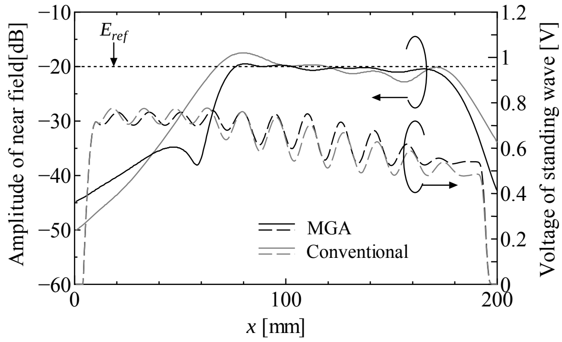

Fig. 4. Aperture distribution of the near field and the distribution of the standing wave into the waveguide. In conventional antenna, all slot length and offset is same dimension; slot length=10.5 mm and slot offset=7.5 mm.

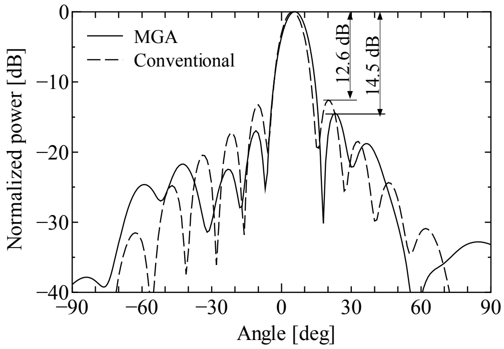

Fig. 5. *H*-plane far-field radiation patterns.

Fig.4 shows that the aperture field distribution of the optimized antenna is much more uniform compared with that of the conventional antenna. The side-lobe levels of the optimized antenna are also found to be improved in comparison with those of the conventional antenna as shown in Fig.5. The *VSWR* of both antennas is 1.099; the reflection at the input port is comparatively small.

V. CONCLUSION

We have demonstrated that the proposed optimization design by MGA is a promising and efficient tool for optimizing waveguide slot array antennas loaded with dielectric lenses.

Studies to be done further include; 1) optimization to realize other distribution, 2) speed up of computation.

VI. REFERENCE

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