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High-speed, Automatic and Optimal Design of Microwave Filter Using Genetic Algorithms

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***Abstract* - Automatic design optimizations using the evolutional computing such as genetic algorithms (GAs) are applied to many practical problems. However, it is necessary to speed up calculations by a parallel processing technique since evaluations of fitness in GA take much time. In this paper, we discuss two kinds of genetic algorithm, parameter-free GA and micro-GA, whose parallelization are proposed and compared with each other for the automatic and optimal design of dichroic filters using the finite-difference time-domain technique.**

***Index Terms* — evolutionary computing, genetic algorithm, dichroic filter, FDTD technique, parallel processing.**

I. INTRODUCTION

Computer simulations are effectively and widely used in the research and manufacturing and contribute to improve their qualities as well as cost reduction. Recently, evolutionary computing such as genetic algorithms (GAs) becomes widespread for automatic and optimal design of practical problems with improvement of computer hardware and software. It can find sub-optimal parameters within the numerical electromagnetic simulations [1]. On the other hand, it is necessary to solve some problems related to the automatic and optimal design methods based on the evolutionary computing. For example, if the run time of a computer simulation corresponds to several ten minutes to several hours and simulations of a hundred generations are required, it takes several days to several months to obtain a sub-optimal design parameters. So speed-up by parallel processing is essentially required in the evolutionary computation. Therefore, we try to achieve an elapsed time reduction for both of evolutionary computations and numerical simulations by employing a parallel processing technique. At first we discuss how to parallelize two algorithms, the parameter-free GA (PfGA) [2] and micro-GA (MGA) [3], and show which GA is suitable for parallelization based on the comparison of their speed-up ratios. Here the numerical electromagnetic simulations of dichroic filter structures [4] are examined using the finite-difference time-domain (FDTD) technique [5].

II. SIMULATION METHOD OF DICHROIC FILTER

A dichroic filter consists of a metal plate dotted with a large number of equidistant cylindrical holes operating in the microwave frequency band to a millimeter wave band [4]. The structure is regarded as many circular waveguides being arranged. Since an electromagnetic simulation of whole dichroic filter is a time-consuming problem, a square segment shown in Fig. 1 is treated numerically assuming that it is repeated periodically. The frequency dependence of the transmission is determined by the hole diameter d, the hole spacing distance s, and the plate's thickness l. In the FDTD simulation we discretize the problem space by a cubical cell of 5 um. The segment is approximated by number of cells, N_s, N_d and N_l. Figure 1 also depicts the relationship between the coordinate axes and the FDTD problem space. The problem space is terminated with the CPML absorbing boundary condition at the both ends of z-axis and the periodically boundary condition is assumed at the interface of the x- and y-axis. The filter is placed in the middle of problem space. An incident plane wave such as a Gaussian pulse is generated in the front of filter and the time response of transmitted and reflected wave are stored at different two locations.

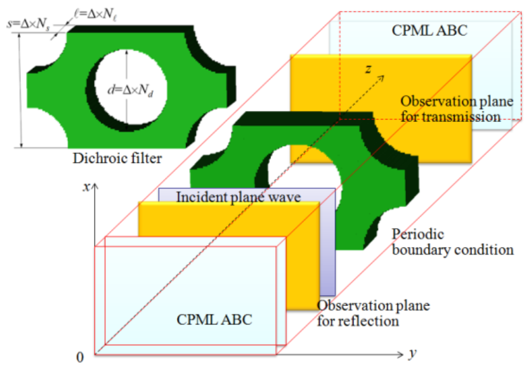


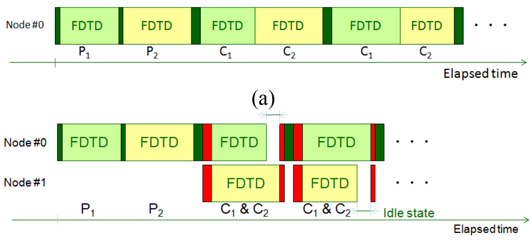
Fig.1. Geometry and dimensions of a periodic segment and a problem space for FDTD simulation terminated by four periodic boundary conditions and two CPML absorption boundary conditions.

III. PARALLELIZATION OF PFGA AND MGA

We consider PfGA and MGA which have properties such as a real-coded gene, small number of populations, high searching ability without setting appropriate values of GA parameters, and so on. A parallelization of the two GAs is applied to individuals because evaluations of their fitness value are carried out independently each other. Assuming that the number of populations is set four for PfGA and five for MGA, the number of parallel processes becomes two and four respectively.

Figure 2(a) shows a sequential procedure for the optimal design using PfGA. P_1 and P_2 denote the parents, and C_1 and C_2 denote the children. Dark and narrow portions present the processing time to determine a combination of design parameters, and the term FDTD denotes an elapsed time of numerical electromagnetic simulation. It is clear from Fig. 1(a) that it is possible to evaluate the individuals C_1 and C_2 at the same time because they are determined simultaneously by PfGA and independent of each other. Figure 1(b) shows the steps executed in parallel by using the two operation nodes for the evaluation of C_2 and C_1.

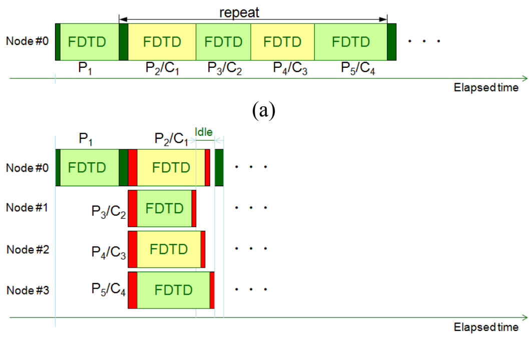
Next we discuss the parallelization of MGA. Figure 3(a) depicts a sequential procedure by MGA assuming that number of individuals in a family is five, P_{max} = 5. First, individuals P_1 to P_5 or C_1 to C_4 are evaluated in order. Figure 3(b) shows the parallelization of MGA. Since the parameters related to C_1 to C_4 are determined in advance and also they are independent of each other, they can be evaluated at the same time in parallel. In other words, it is possible to conduct (P_{max}-1) parallel processing for MGA.



(a)

(b)

Fig. 2. Concepts of serial and parallel processing of PfGA. The serial processing is performed in accordance with the order shown in (a). Fitness values for the children are calculated at the same time in (b).



(a)

(b)

Fig. 3. Concepts of serial and parallel processing of MGA where number of individuals are assumed to be five. The serial processing is performed in accordance with the order shown in (a). Fitness values for initial parent #2 to #5 and children are calculated at the same time in (b).

IV. Numerical Simulations and Results

We show numerical results of speed-up ratio when the fitness function is computed as the differences between specified and calculated cut-off frequencies. Figure 4 shows speed-up characteristics for both GAs. It is clear from the figure that PfGA realizes the speed-up of 11.4 with the twenty-six operation nodes. On the other hand, MGA performs the speed-up of 25.7 with the fifty-two operation nodes. Both of PfGA and MGA show similar speed-up characteristics with less than twenty-six nodes, but MGA can increase the speed-up ratio by twice compared with PfGA because the four individuals are evaluated with MGA simultaneously.

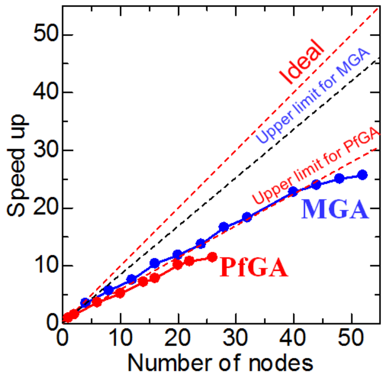


Fig. 4. Comparison of speed-up ratios related to PfGA and MGA.

V. Conclusion

In this paper we proposed the parallel processing technique of automatic and optimal design combining the genetic algorithms with numerical electromagnetic simulations. First we showed the parallelization of two GAs and how effective the proposed method is by numerical dichroic filter design. Both GAs can realize the speed-up combined with parallel numerical electromagnetic simulation. Also it was clarified that MGA gave the better speed-up ratio than PfGA. In order to prove the versatility and ability of the method in future works, we apply the technique to design of other devices.

Acknowledgment

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