

MOEA/D-GO+FDTD for Optimization Design of Fragment-Type Structure

Da-Wei Ding*, Xiao-Dong Ding, Jing Xia, and Li-Xia Yang

Abstract—Fragment-type structure has been used to design antennas and microwave circuits. Special optimization technique, including optimization algorithm and EM software (electromagnetic) simulator, is necessary for the design of this kind of structure. In this paper, a novel optimization technique, MOEA/D-GO+FDTD, is proposed, where MOEA/D-GO (multiobjective evolutionary algorithm combined with enhanced genetic operators) serves as the optimization algorithm and Finite-Difference Time-Domain (FDTD) method serves as the electromagnetic simulator. As an example, a compact bandpass microstrip filter is designed by using MOEA/D-GO+FDTD. Firstly, numerical simulation of the fragment-type microstrip filter by using FDTD method is investigated. Secondly, a microstrip filter operating at 3.8 GHz–6.5 GHz is designed through optimizing return loss, insertion loss, and out-of-band rejection. Finally, comparison of the computational costs between different electromagnetic simulators verifies high efficiency of the proposed MOEA/D-GO+FDTD.

1. INTRODUCTION

Fragment-type structure has great flexibility to suit any given design space [1]. As illustrated in Fig. 1, a design space can be gridded into many cells. Each cell can be assigned with either “1” or “0”, where “1” and “0” mean to be metalized and non-metalized, respectively. According to the distribution of “1” and “0”, a fragment-type structure is represented by a 0/1 design matrix.

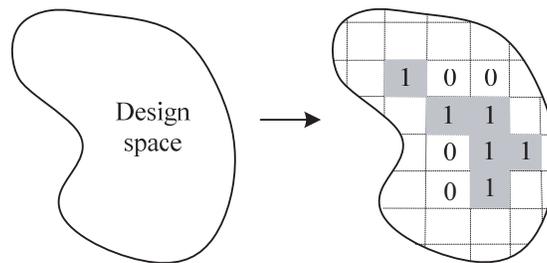


Figure 1. Fragment-type structure in an arbitrary design space.

Fragment-type structure has found some successful applications in both antenna and microwave circuit designs [1–6]. In [1], fragment-type isolation structures between MIMO (multiple-input and multi-output) PIFAs (planar inverse-F antennas) are designed. In [2], both broadband and dual-band microstrip antennas are designed by using fragment-type structure. In [3], a fragment-type circular

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polarization microstrip antenna is designed. In [4], a compact fragment-type antenna is designed. In [5], broadband directional couplers with high-directivity are designed by using fragment-type structure. In [6], compact fragment-type microstrip filters with low insertion loss are designed.

In order to design a fragment-type structure, special optimization searching technique, including optimization algorithm and electromagnetic simulator, is required because there is few physics theory on this kind of antenna structure. During the optimization, optimization algorithm determine specific 0/1 design matrix (i.e., a fragment-type structure), while electromagnetic simulator is utilized analyze its electromagnetic parameters in order to evaluate this fragment-type structure.

In terms of optimization algorithm, there are level set approach, topology gradient method, and population-based metaheuristics (e.g., genetic algorithm) [7]. However, these methods dealing with single objective function is not suitable for a practical engineering problem which often refers to several objective functions with conflict or unknown relationship [1]. In [8], a novel population-based metaheuristic, MOEA/D-GO (multiobjective evolutionary algorithm based on decomposition combined with enhanced genetic operators), is proposed. The features of MOEA/D-GO consist of the enhanced genetic operators, mainly including selection operator, where the best individual in neighborhood is utilized to guide the global-search, which leads to fast convergence rate, and the crossover among three individuals reinforces the population diversity. It is proved in [8] that MOEA/D-GO has fast convergence, good population diversity, and good algorithm stability by combining the ability and efficiency of MOEA/D [9] for dealing with multiobjective optimization problems with topology optimization functionality of genetic algorithm.

In terms of electromagnetic simulator, HFSS (High Frequency Structure Simulator) [1, 5, 6], CST (Computer Simulation Technology) Microwave Studio [10], FDTD (Finite-Difference Time-Domain) method based simulation tools [4, 11, 12] are commonly used. The selection of electromagnetic simulator should make balance of computational cost and simulation accuracy. Both HFSS and CST could provide accurate simulation results, while they're expensive and often unaffordable computationally. FDTD method based source code could simulate fragment-type structure accurately and fastly, especially when fragment cell is small enough [13]. In addition, FDTD method based source code also has the following features [13],

- 1) it is easy to obtain electrical characteristics at several frequencies in a single run, and
- 2) those cells of the fragment-type structure could be consistent with the generated cells in the FDTD implement.

Therefore, the multiobjective optimization technique, combining MOEA/D-GO with FDTD method based source code, is promising for the design of fragment-type structure in the practical engineering problems.

In this paper, a multiobjective optimization technique MOEA/D-GO+FDTD, along with some design guidelines, is proposed in Section 2. As an example, a compact bandpass microstrip filter is designed by using MOEA/D-GO+FDTD in Section 3. In Section 3, numerical simulation of the fragment-type microstrip filter by using FDTD method based source code is investigated to verify its accuracy at first. Secondly, the microstrip filter operating at 3.8 GHz–6.5 GHz is designed through optimizing return loss, insertion loss, and out-of-band rejection. Thirdly, comparison on the computational cost between MOEA/D-GO+HFSS and MOEA/D-GO+ FDTD verifies the high-efficiency of MOEA/D-GO+FDTD.

2. MOEA/D-GO+FDTD

2.1. Framework of MOEA/D-GO+FDTD

Figure 2 illustrates the framework of MOEA/D-GO+FDTD. During optimization, objective function evaluation plays a vital role, and two topics are often referred, objective function setting and electromagnetic simulator selection. The selection of simulator should make balance of computational cost and simulation accuracy.

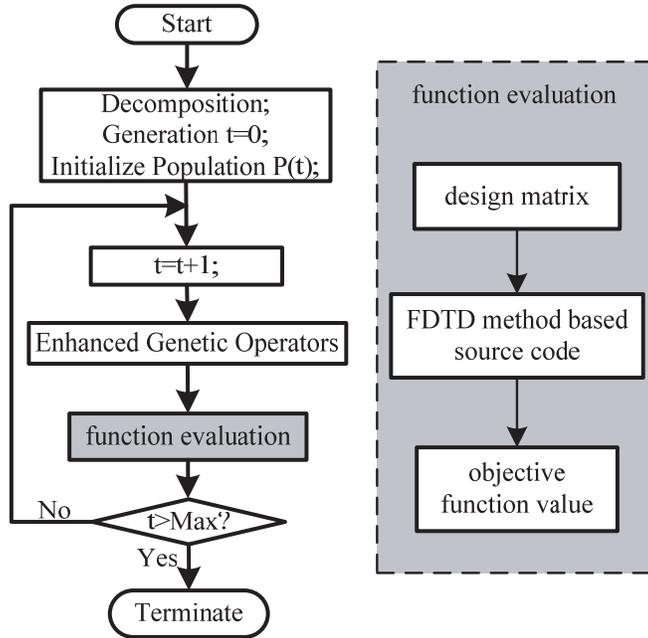


Figure 2. Framework of MOEA/D-GO+FDTD.

2.2. Design Guidelines

Some design guidelines for the fragment-type structure antenna by using MOEA/D-GO+FDTD are summarized as following.

- 1) Determine design space and its mesh generation according to practical engineering application.
- 2) Set objective functions to evaluate the antenna according to design requirements.
- 3) Run MOEA/D-GO+FDTD, then output both design matrix and the corresponding fragment-type structure.

The guideline for objective function setting is that the better the performance of the design is, the smaller its objective function value is, for a minimization optimization problem.

3. DESIGN OF A COMPACT BANDPASS MICROSTRIP FILTER

3.1. Numerical Simulation of the Fragment-Type Microstrip Filter by Using FDTD Method

In [13], the numerical simulation of the fragment-type microstrip antenna by using FDTD method is investigated. And the agreement between the simulated and measured return losses is observed. In this subsection, the numerical simulation of the fragment-type microstrip filter by using FDTD method will be implemented.

The basic configuration of the fragment-type microstrip filter considered in this paper is shown in Fig. 3. During the numerical simulation of FDTD method, the media is assumed to be lossless and isotropic for simplicity. All parameter settings, including space step, time step, source, and absorption boundary, are the same as those in [13]. The only difference between these two configurations is that it is a two-port network, rather than single-port network. Fig. 3(a) illustrates the integration path of both voltage and current of the two ports (denoted as C_1 , C_2 , C_3 , and C_4 , respectively) on the reference plane, where the reference plane is $15\Delta y$ far away from the port plane (i.e., $L_3 = 15\Delta y$) to eliminate evanescent waves [14]. The voltage and current of the two ports could be calculated in time domain as Eqs. (1)–(4). Then S parameters in frequency domain could be calculated through Fourier transform as Eqs. (5)–(7) [14]. In Eq. (6), Z_0 is the characteristic impedance of the microstrip feed line.

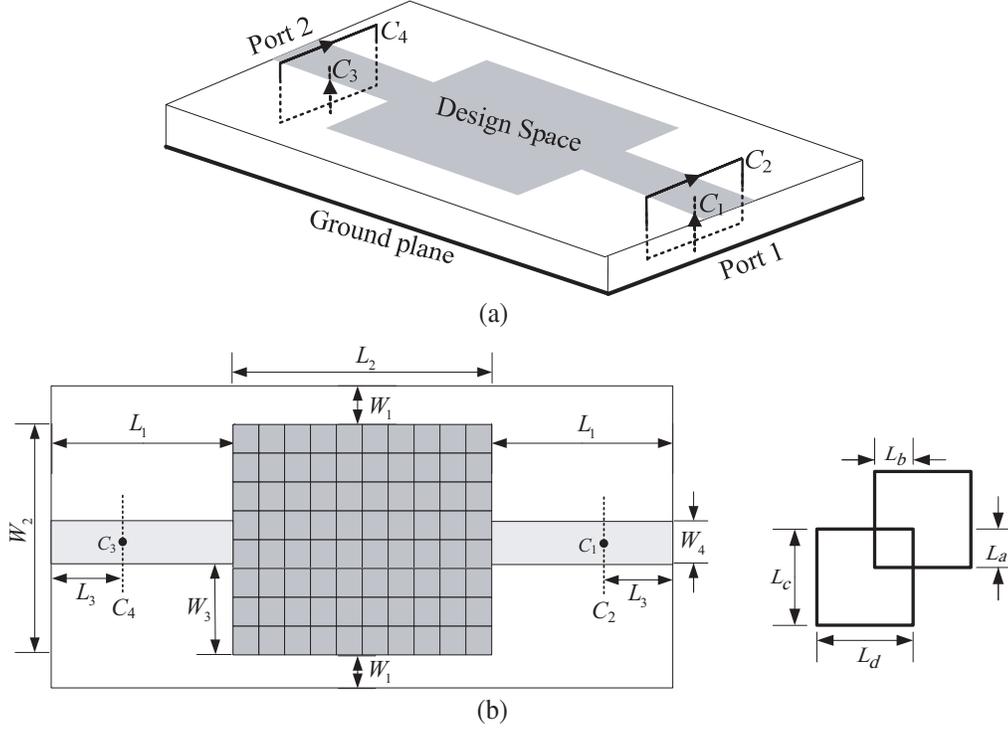


Figure 3. Configuration of fragment-type microstrip filter.

Time domain:

$$V_1 = \int_{C_1} E \cdot dl \quad (1)$$

$$V_2 = \int_{C_3} E \cdot dl \quad (2)$$

$$I_1 = \oint_{C_2} H \cdot dl \quad (3)$$

$$I_2 = \oint_{C_4} H \cdot dl \quad (4)$$

Frequency domain:

$$Z_{in} = \frac{\mathcal{F}(V_1)}{\mathcal{F}(I_1)} \quad (5)$$

$$S_{11} = \frac{Z_{in} - Z_0}{Z_{in} + Z_0} \quad (6)$$

$$S_{21} = \frac{\mathcal{F}(V_2)}{\mathcal{F}(V_1)} \cdot (1 + S_{11}) \quad (7)$$

In order to verify the accuracy of the numerical simulation of the above FDTD method based source code for fragment-type microstrip filter, a randomly-generated fragment-type filter with 30×40 cells is simulated, fabricated, and tested in Fig. 4. For comparison, the simulation by using HFSS is also implemented. Great agreement between the simulation and measurement results is observed, except for some frequency shifts in high frequencies, which is believed to be caused by the fabrication and measurement error. Therefore, the above FDTD method based source code could provide accurate numerical simulation of fragment-type microstrip filter.

Table 1 exhibits the computational cost by using HFSS and FDTD method based source code. Both of these simulations are run on a PC with Intel Core 2@2.99 GHz, and automatic modeling of

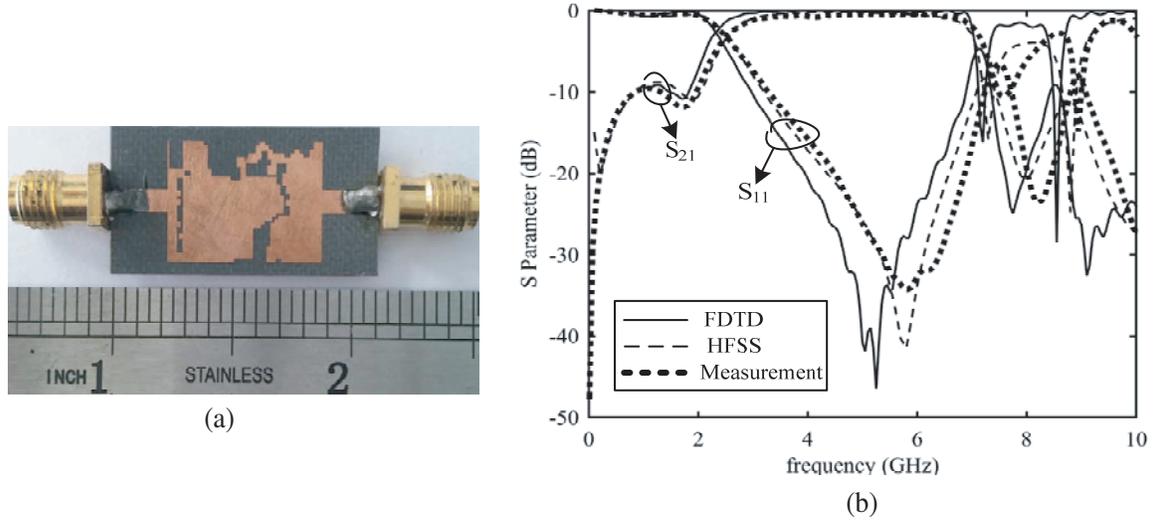


Figure 4. A randomly-generated fragment-type microstrip filter. (a) Photograph of the fabricated filter, and (b) numerical simulation and measurement results.

HFSS is implemented through vbscript. From Table 1, it is obviously seen that the simulation by using FDTD method based source code is highly efficient when design matrix is large, which is consistent with the conclusions in [13] and is also useful for practical engineering applications.

Table 1. Comparison on computational cost. (units: minute).

HFSS			FDTD
Modeling	Simulation	Total time	Total time
12.2	3.5	15.7	6.5

3.2. Design of a Compact Bandpass Microstrip Filter

In this subsection, a microstrip filter operating at 3.8 GHz–6.5 GHz is designed by using MOEA/D-GO+FDTD following the above configuration (overall size is $0.21\lambda_0 \times 0.27\lambda_0$, where λ_0 is the wavelengths at 5.15 GHz in free space). Through optimization, return loss of more than 10-dB and insertion loss of less than 1-dB over 3.8 GHz–6.5 GHz, along with out-of-band rejection of more than 20-dB at 2.8 GHz and 7.5 GHz, are required. In this paper, the following objective functions are considered.

$$f_1 = \frac{10}{\min_{\omega \in [\omega_1, \omega_2]} |S_{11}(\text{dB})|}, \quad (8)$$

$$f_2 = \max_{\omega \in [\omega_1, \omega_2]} |S_{21}(\text{dB})|, \quad (9)$$

$$f_3 = \frac{20}{\min(|S_{21}(\text{dB})|_{\omega=\omega_{\text{low}}}, |S_{21}(\text{dB})|_{\omega=\omega_{\text{up}}})}, \quad (10)$$

where S_{11} (dB) represents the return loss in dB, S_{21} (dB) the insertion loss in dB, $[\omega_1, \omega_2]$ the operating band 3.8 GHz–6.5 GHz, and $\omega_{\text{low}}, \omega_{\text{up}}$ denote lower and upper cutoff frequencies. It is obviously seen that when f_i ($i = 1, 2, 3$) is smaller than 1, return loss is more than 10-dB, the insertion loss less than 1-dB, and the out-of-band rejections at both lower and upper cutoff frequencies are more than 20-dB. According to the above requirements, ω_{low} and ω_{up} are set at 2.8 GHz and 7.5 GHz, respectively.

In MOEA/D-GO, population size and neighborhood size are set at 45 and 8, respectively. After the 50 iterations of MOEA/D-GO+FDTD, several designs are obtained. One of them is fabricated

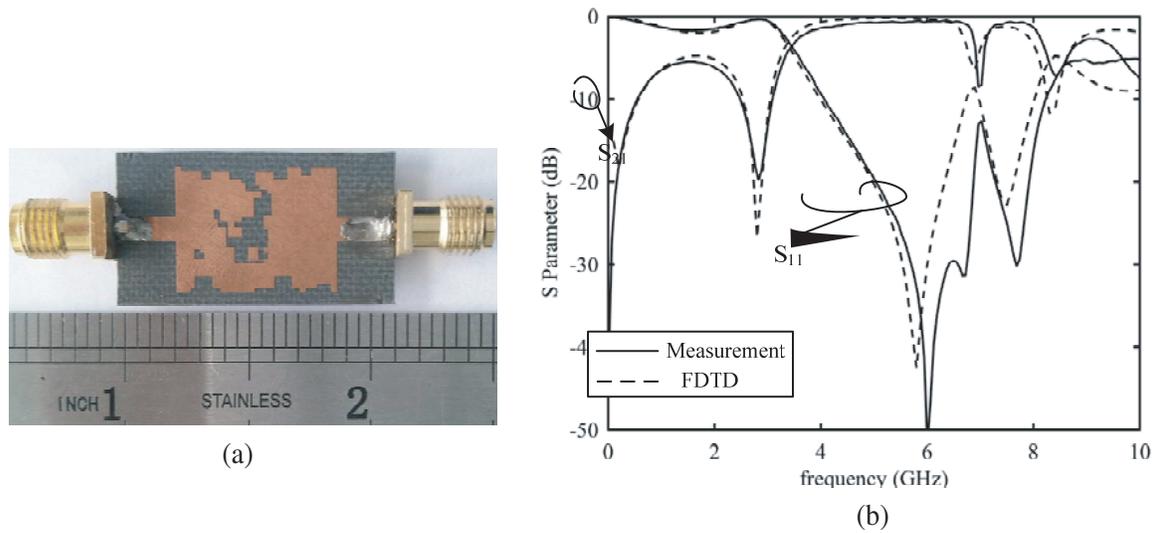


Figure 5. The optimized fragment-type microstrip filter. (a) Photograph of the fabricated filter, and (b) numerical simulation and measurement results.

and tested in Fig. 5. From Fig. 5, great agreement between simulation and measurement is observed. The slight difference between the simulated and measured results is attributed to the fabrication and material tolerances. Measured results show that the return loss over 3.8 GHz–6.5 GHz is more than 10-dB, and the insertion loss is less than 1-dB. In addition, the out-of-band rejection at 2.8 GHz is more than 20-dB, while it just achieves 9.8 dB at 7.5 GHz, which could be further improved as the iteration increases. Therefore, MOEA/D-GO+FDTD is promising for the optimization design of fragment-type structure.

3.3. Comparison

In this subsection, the optimization efficiency of MOEA/D-GO+FDTD is investigated. The same work as those in Section 3.2 is repeated here by using MOEA/D-GO+HFSS. Fig. 6 shows the increase of the computational cost by using MOEA/D-GO+FDTD and MOEA/D-GO+HFSS against iteration

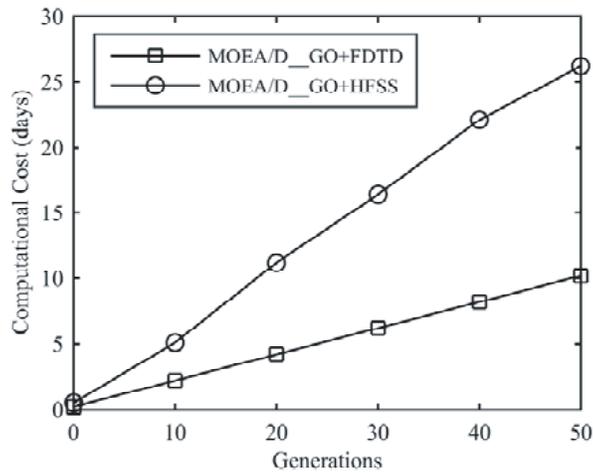


Figure 6. Comparison on the computational cost by using MOEA/D-GO+FDTD and MOEA/D-GO+HFSS.

number (i.e., generation in Fig. 6). It is shown that MOEA/D-GO+HFSS has the computational time being 2.5 times longer than that of MOEA/D-GO+FDTD, which is also proved in Table 1. Therefore, MOEA/D-GO+FDTD is highly-efficient than MOEA/D-GO+HFSS.

4. CONCLUSIONS

In this paper, a novel and highly-efficient optimization technique, MOEA/D-GO+FDTD, is proposed, which combines the high searching efficiency of MOEA/D-GO and the simulation efficiency of FDTD method based source code. As an example, a compact bandpass microstrip filter is designed by using MOEA/D-GO+FDTD. Firstly, numerical simulation of the fragment-type microstrip filter by using FDTD method is investigated. Secondly, a microstrip filter operating at 3.8 GHz–6.5 GHz is designed. Finally, comparison on the computational cost between MOEA/D-GO+FDTD and MOEA/D-GO+HFSS verifies the high-efficiency of our proposed MOEA/D-GO+FDTD. Stopband attenuation and spurious passband suppression of the microstrip bandpass filter will be our future work.

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