A Novel Approach to Design of Microstrip UWB Bandpass Filter Using Modified Genetic Algorithm

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Abstract—A novel approach to design microstrip ultra-wideband (UWB) bandpass filter (BPF) using modified genetic algorithm (MGA) is proposed in this paper. To achieve high efficiency and accuracy, conventional GA is modified. By improving the fitness evaluation, selection, crossover, and mutation, the two possible drawbacks of conventional GA, i.e., slow rate of convergence and local-best solution, are overcome. The modified genetic algorithm is then applied to simultaneously search for the appropriate circuit topology and the corresponding electrical parameters with UWB characteristic. To demonstrate the effectiveness of the novel approach, a new microstrip UWB BPF is designed and fabricated. Measurement results agree well with the design index and full-wave EM simulated results.

1. INTRODUCTION

In 2002, the U.S. Federal Communications Commission (FCC) authorized the unlicensed use of ultra-wideband (UWB, from 3.1 GHz to 10.6 GHz) for a variety of applications, such as high data-rate wireless communications, high accuracy radars, imaging systems, and indoor systems [1]. UWB BPFs, as one of the essential components of the UWB systems, have gained much attention in recent years. There are many methods presented to design UWB bandpass filters. For example, multiple-mode resonator (MMR) [2, 3], multilayer coupled structure [4, 5], defected ground structure (DGS) [5, 6], defected microstrip structure (DMS) [7], and the cascaded low-pass/high-pass filters [8] have been widely used to achieve UWB characteristics. However, the design efficiencies and performance of the filters mentioned above need to be improved.

Many kinds of algorithms such as conjugate gradient method, annealing algorithm, and genetic algorithm (GA) are studied to enhance the efficiency and performance of the filter synthesis [9–12]. The powerful heuristic of the GA is widely used in science and engineering problems. And it is particularly effective to solve complex electromagnetic problems. In [11], Sanada et al. presented a method for designing transmission line filters with shunt-connected open circuit stubs and matching circuits with continuously varying nonuniform transmission lines using GA. In [12], Nishino and Itoh, proposed a scheme to describe the physical parameters and topology of the circuit composed of microstrip-line segments and then integrated this representation scheme with conventional GA. However, there have been few published papers about UWB bandpass filters designed based on algorithm so far.

This paper provides a novel approach to design microstrip UWB using modified genetic algorithm (MGA) for better efficiency. The modified genetic algorithm overcomes two possible drawbacks of conventional GA, i.e., slow rate of convergence and local-best solution. The optimization algorithm is then applied to simultaneously search for the appropriate circuit topology and the corresponding

electrical parameters with UWB characteristic. Finally, a new microstrip UWB BPF is designed, fabricated, and measured to validate the effectiveness of the MGA. Compared with the approach to design UWB filter based on conventional GA, the electrical size of the presented UWB filter is reduced by 55%. The study is completed on a computer with a 2-GHz microprocessor, and the computing time of the example is only 2 min.

2. GENETIC ALGORITHM

An arbitrary two-port microstrip circuit shown in Fig. 1(a) can be decomposed into basic circuit elements [13, 14] shown in Fig. 1(b). The circuit can be expressed as a data structure shown in Fig. 1(c). The data structure is composed of three parts. The first and second parts coded in integer represent the topology of basic element and the way of connection to the previous element, respectively. The third part coded in floating number represents the corresponding electrical parameters. In the MGA, a set of basic circuit elements can be seen as a chromosome [15, 16]. Thus, an arbitrary two-port circuit can be represented by a chromosome. Table 1 shows the details of the basic circuit elements [17–19]. A special gene named *Empty* is introduced, which enables the representation scheme to describe a circuit with an arbitrary number of basic circuit elements and orders. In this work, the modified genetic algorithm is employed to design a new microstrip UWB BPF with improved design efficiency.
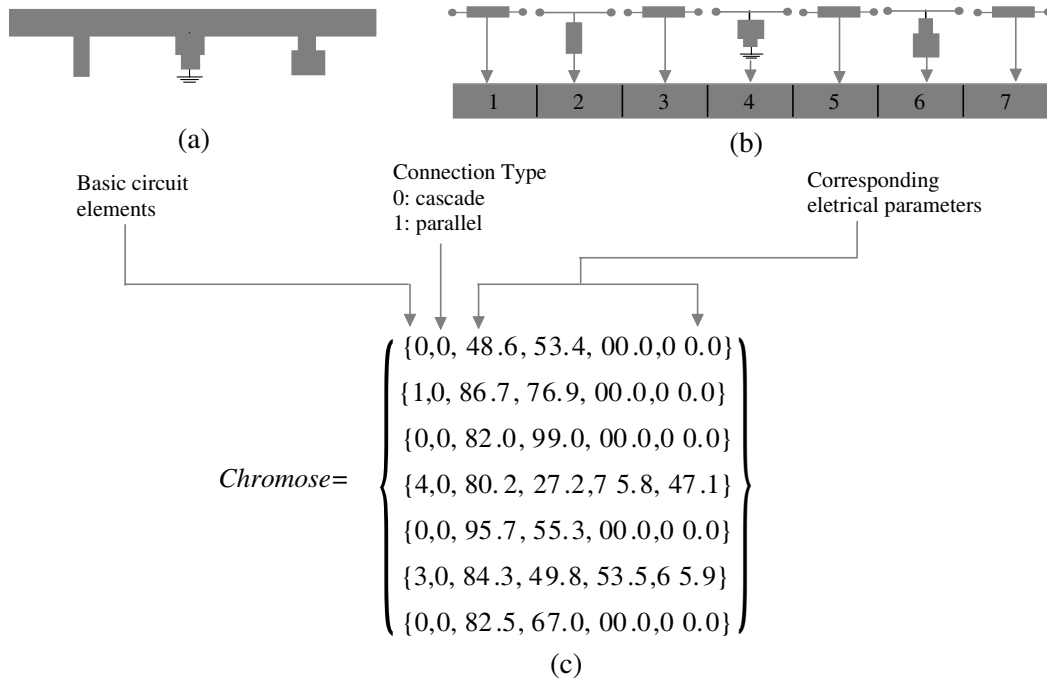

Figure 1. Representation scheme in the modified genetic algorithm: (a) a typical microstrip circuit, (b) decomposition of the circuit in (a) into basic circuit elements, (c) chromosome of the circuit in (a).

2.1. Initialization

The initial population has an effect on the convergence, thus we make every chromosome randomly initialize within the specific electrical parameters range of every basic element for better convergence in this scheme. In addition, it is necessary to assign upper and lower limits according to various designs and engineering requirements. Due to the tolerance of the fabrication, the minimum width is limited to 0.1 mm, which corresponds to a microstrip line with a characteristic impedance of 137 Ω. Meanwhile, to lower the junction discontinuity effects, the maximum line width is chosen to be 2 mm, which corresponds to a microstrip line with a characteristic impedance of 40 Ω.

Table 1. Details of the basic elements in the modified genetic algorithm.

Category	Type	Name	Network Topology	Electrical Parameters
	0	TL		Z_{01} θ_{01}
	1	Open		Z_{01} θ_{01}
Basic Circuit Elements	2	Short		Z_{01} θ_{01}
	3	SIR_Open		Z_{01} θ_{01} Z_{02} θ_{02}
	4	SIR_Short		Z_{01} θ_{01} Z_{02} θ_{02}
	5	Empty		0 0 0 0

2.2. Fitness Evaluation

The transmission-line models are used to calculate scattering parameters to effectively evaluate the frequency response of a chromosome. We make $ABCD$ matrix multiplication as cascade no matter the basic element is in parallel or series connection. It should be mentioned that the gene named *Empty* represents unit matrix. The method will improve the calculation speed of procedures and efficiency of algorithm. The desired function is shown in Fig. 2, and the fitness value is defined by:

$$F = \sum_{i=1}^{N} w_i f_i \tag{1}$$

where w_i represents the weighting value at the ith sampling point, f_i the square deviation between the calculated scattering parameter and the desired value at the ith sampling point, and N the number of sampling points. When the evolution count reaches the maximum value or one of the fitness values of a chromosome in a solution pool gets in the target fitness value, the modified genetic algorithm terminates. Here, the target fitness value is specified as zero.
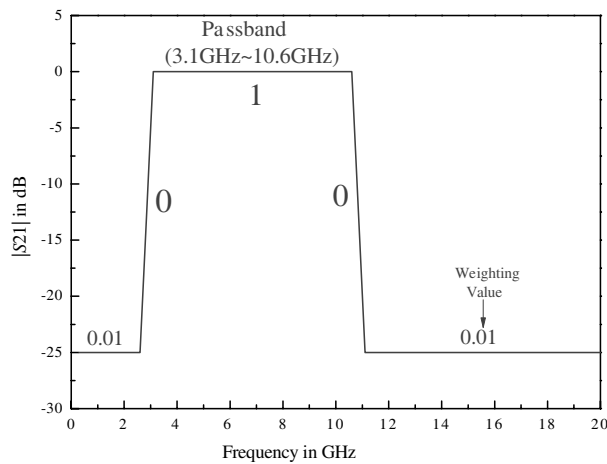

Figure 2. The desired function of the proposed initial UWB BPF.

2.3. Genetic Operator

Although the roulette wheel selection based on the proportionate selection is widely used in the GA, there is a drawback that the type of fitness function has an effect on the convergence. Thus, in this work, the tournament selection is used.

Crossover operator is an important operator and plays a decisive role in global convergence of the algorithm. It decides whether we can find the optimal solution and the speed of finding the optimal solution. Thus, the scheme employs a high efficiency crossover method of combining bubble sort with single-point crossover, as illustrated in Fig. 3. Firstly, in order to get high efficiency, we sort relative fitness of all individuals from small to large. Secondly, we use a high crossover rate on individuals with low relative fitness and a low crossover rate on individuals with high relative fitness. Compared with the method of simplex single-point crossover, this method overcomes the disadvantage of slow convergence rate with better efficiency to find global optimal solution.
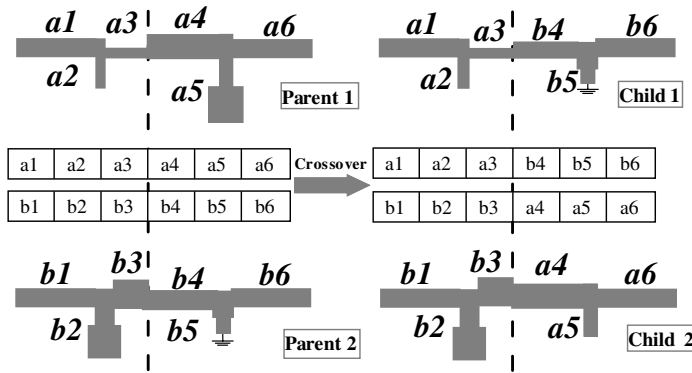

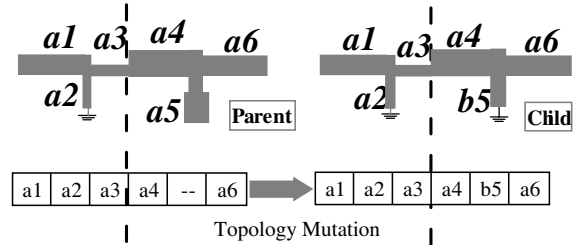**Figure 3.** Schematic of the one-point crossover operator in the modified genetic algorithm.

Figure 4. Schematic of the topology mutation in the modified genetic algorithm.

Mutation as a reproduction operator has a key role of getting out from the trap of the local optimum solution and keeping the diversity of population. In this work, mutation is carried out to randomly alter the values of genes in a parent chromosome with probability. Fig. 4 and Fig. 5 illustrate the circuit topology and electrical parameters mutation in a chromosome, respectively.
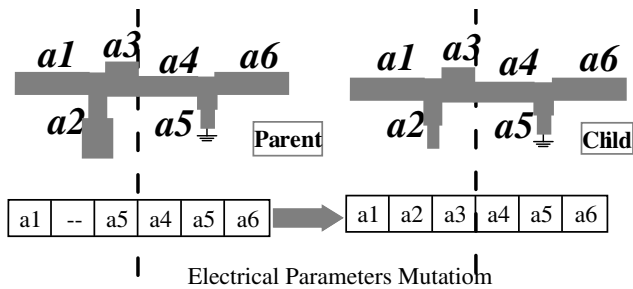

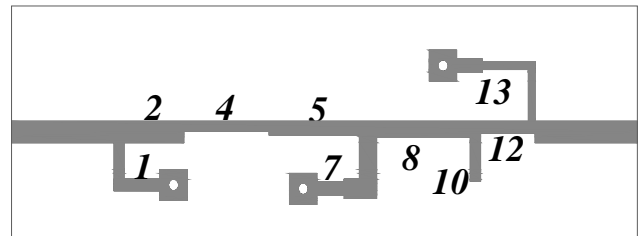**Figure 5.** Schematic of the electrical parameters mutation in the modified genetic algorithm.

Figure 6. Layout of the proposed UWB BPF.

3. DESIGN EXAMPLE

Here, an initial microstrip UWB BPF is desired by the modified genetic algorithm. For the design, the best chromosome after 18 generations consists of four empty elements, five transmission lines, and four stubs. The proposed filter is realized on the substrate Duroid 5880 ($\varepsilon_r = 3.38$, $h = 0.508$, $\tan \delta = 0.0027$). Table 2 lists the electrical and final physical parameters.

Table 2. Electrical and physical parameters of the proposed UWB BPF.

No.	Name	Electrical Parameters (at $f_0 = 6.85$ GHz)				Physical Parameters in mm			
		z_{01}	θ_{01}	z_{02}	θ_{02}	W_{01}	L_{01}	W_{02}	L_{02}
1	Short	97.8	70.3	0	0	0.3	5.4	0	0
2	TL	52.2	47.8	0	0	1.1	3.5	0	0
3	Empty	0	0	0	0	0	0	0	0
4	TL	72.7	66.7	0	0	0.6	5	0	0
5	TL	67.3	71.0	0	0	0.7	5.3	0	0
6	Empty	0	0	0	0	0	0	0	0
7	SIR_Short	52.2	66.9	67.3	21.4	1.1	4.9	0.7	1.6
8	TL	58.6	74.3	0	0	0.9	5.5	0	0
9	Empty	0	0	0	0	0	0	0	0
10	Open	72.7	20.6	0	0	0.6	1.5	0	0
11	Empty	0	0	0	0	0	0	0	0
12	TL	72.9	37.3	0	0	0.6	2.8	0	0
13	SIR_Short	87.3	84.0	67.3	20.1	0.4	6.4	0.7	1.5

It should be mentioned that the values in Table 2 are calculated by the following steps: Firstly, we transform the chain of $ABCD$ matrix for the chromosome to the scattering matrix. Secondly, we search for the optimal solution by optimizing the topology and its corresponding electrical parameters according to the design specification shown in Fig. 2. Thirdly, we convert the achieved electrical parameters to original physical parameters according to the corresponding relationship. Finally, we construct the filter model in HFSS, i.e., the proposed initial UWB BPF layout in Fig. 6, according to the original physical parameters. Notice that we have slightly adjusted some initial physical parameters considering the discontinuity effects and fringing capacitances.

The designed UWB BPF is measured with an Agilent N5244A vector network analyzer. Fig. 7 shows the comparison between the simulated and measured results. Referring to Fig. 7, the proposed UWB BPF has an insertion loss better than 3 dB over 3.44–11.55 GHz bandwidth, and the upper-stopband with −10 dB attenuation is up to 20 GHz. In addition, the return loss is under −20 dB over most part of the passband. The minor discrepancy between simulation and measurement results are mainly due to the reflections from the SMA connectors and the finite substrate. Fig. 8 shows a photograph of the fabricated UWB BPF.
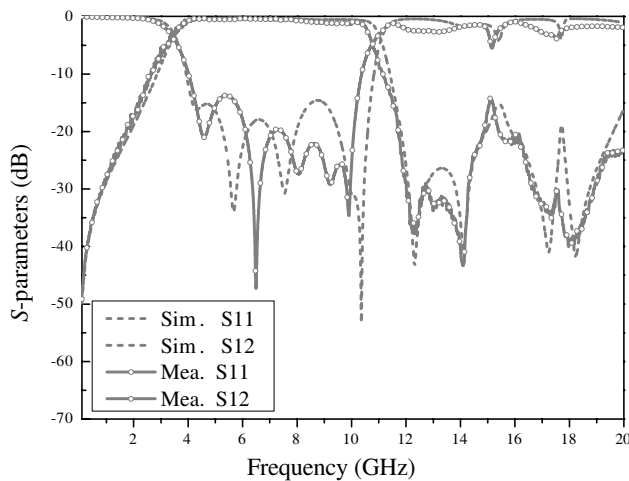

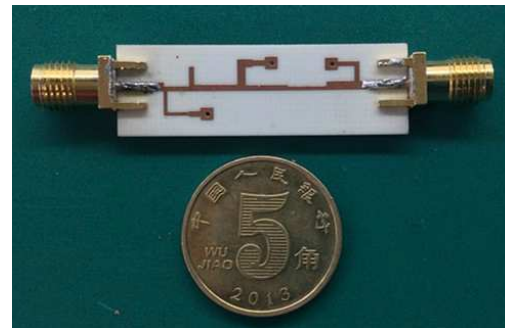**Figure 7.** Simulated and measured S-parameters of the designed UWB BPF.

Figure 8. Photograph of the fabricated UWB BPF.

4. CONCLUSION

A novel approach to design microstrip UWB bandpass filter based on modified genetic algorithm is proposed in this paper. The modified genetic algorithm overcomes two possible drawbacks of conventional GA, i.e., slow rate of convergence and local-best solution. The algorithm is then applied to guide UWB bandpass filter design. A new microstrip UWB bandpass filter has been designed and measured to verify the proposed efficient design method. Results indicate that a class of filters can be designed using the proposed modified genetic algorithm. Due to its distinct properties of simple topology, compact size, and good performance, the designed filter has a great potential to be applied to modern UWB wireless communication systems.

ACKNOWLEDGMENT

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