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DESIGN OPTIMIZATION OF ULTRA WIDE BAND MICROSTRIP FILTER WITH DIFFERENTIONAL EVOLUTION ALGORITHM

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Abstract

One of the most important circuit stages in microwave applications is microstrip filters. In this work, Differentionaly Evolution Algorithm (DEA) that is used intensively in engineering problems is taken to solve design optimization problem of an ultra-wide band microstrip transmission line. Basically DEA is similar to genetic algorithm however its unique structure makes it more simple and effective than other counterpart evolutionary algoirthms. For design optimization problem the width and length of the transmission lines of microstrip filter are taken as optimization variables. First the ABCD parameters of each line is obtained then the equivalent circuit ABCD parameter is converted to Scattering parameters which will be used in cost function. As a result, it is seen that DEA algorithm is an effective tool for design optimization of microstrip filters for ultra-wide band applications.
Keywords: Differential Evolution Algorithm, Microstrip Filter, Ultra-Wide Band, Design Optimization

ÇOK GENİŞ BANTLI MİKROŞERİT BANDGEÇİREN FİLTRE TASARIMINA YÖNELİK DİFERANSİYEL EVRİM ALGORİTMASI UYGULAMASI

Öz

Mikrodalga devre tasarımında mikroşerit filtreler önemli bir yer tutar. Bu çalışmada mühendislik problemlerinin çözümünde etkin olarak kullanılmaya başlanan diferansiyel evrim algoritması (DEA) yöntemi kullanılarak çok-geniş bantlı filtre tasarımı gerçekleştirilmiştir. Temel olarak genetik algoritma tekniğine benzer çalışma prensibine sahip olan diferansiyel evrim algoritması, diğer sezgisel algoritmalara oranla yapısal olarak daha basit olmasına karşın optimum değerlere ulaşmada daha kararlı bir yöntemdir. DEA optimum bir mikroşerit ultra-geniş bantlı filtre tasarımı için, mikroşerit iletim hatlarının kalınlık w ve uzunluğunun l tespiti için kullanılmıştır. Öncelikle mikroşerit iletim hat modeli seçilmiştir. Daha sonra ise, DEA bu hatlara ait optimum kalınlık ve uzunlukların tespiti için ayarlanmıştır. Algoritma maliyet fonksiyonu aday devrenin saçılma parametrelerinin frekans bandı boyunca incelenmesi ile elde edilmiştir ve optimum sonucu verecek parametreleri elde edecek şekilde ayarlanmıştır. Son olarak, diferansiyel evrim algoritması ile mikroşerit band geçiren filtre tasarımı yapılarak sonuçlar tablo ve grafikler ile verilmiştir.
Anahtar Kelimeler: Diferansiyel Evrim Algoritmesı, Mikroşerit Filtre, Ultra Geniş Band, Tasarım Optimizasyonu

1 Introduction

Ultra-wideband (UWB) systems are able to transmit data over a wide spectrum of frequency bands for short distances with very low power and high data rates. UWB applications attract attention both in industry and academia, due to their increasing levels of sophistication and demand for advanced communication systems [1]. In recent years, the metaheuristic optimization algorithms are being used for design optimization problems in engineering fields [2-3]. Especially in design optimization problems where the number of variables are high and the relations between the parameters are relatively high. Although there are many type of metaheuristic optimization algorithms that are inspired from bird or ant colonies or behaviours of insects such as fire flies, one of the most commonly used type of metaheuristics are genetic based algorithms. Differentional evolution algorithm (DEA) one of the most commonly used genetic based metaherustic algorithms [4-6] which is applied in many engineering fields. Some example application of DEA algorithm in microwave circuit design problems can be named as: In [7] DEA algorithm is applied for design optimization of a Frequency selective surfaces, in [8] DEA algorithm is applied to design uniform amplitude unequally spaced antenna arrays. Basically DEA is similar to genetic algorithm however its unique structure makes it more simple and effective than other counterpart evolutionary algorithms. In this work, Differentional Evolution Algorithm (DEA) that is used intensively in engineering problems is taken to solve design optimization problem of an Ultra-Wide-band Microstrip Filter (UWBMF). For design optimization problem the width *w* and length of the transmission lines of microstrip filter are taken as optimization variables. For design optimization problem the width w and length of the transmission lines of microstrip filter are taken as optimization variables. First the ABCD parameters of each line is obtained then the equivalent circuit ABCD parameter is converted to Scattering parameters which will be used in cost function. As a result, it is seen that DEA algorithm is an effective tool for design optimization of microstrip filters for ultra-wide band applications. And finally the work ends with a study case and conclusion section.

2 Differential Evolution Algorithm

The DE algorithm was proposed by Kenneth Price and Rainer M. Storn and published as a technical report in [9]. It has become an attractive field for researchers and after establishing by Storn in 1997 a website [10]. Furthermore, novel computational technics such as parallel processing, make DE a powerful tool for stochastic optimization due to its parallelizable nature [11-16]. DE is a multidimensional mathematical optimization algorithm from the Evolutionary Algorithm (EA) class. This algorithm tries to find optimal solution of the problem by iteratively improving the candidate solution according the value of the user defined objective function.

2.1 Initialization

The first step is to initialize the population. In general, every member of the population is seeded uniformly within a given space. Most problems are considered to be box constrained since the variables are subject to boundary constraints. This leaves us with the following simple initialization formula for each component:

$$x_{i,0}^{j} = l^{j} + rand \times (u^{j} - l^{j}), \quad j = 1,2,\ldots,n \qquad (2.1)$$

where rand ϵ [0, 1] is a uniformly distributed random value generated for each j and uj and lj are the respective upper and lower limits for the jth variable.

2.2 Mutation

The defining characteristic of the DE algorithm is the method via which the new trial points are generated. At every generation g, each member of S (S={x_1,x_2,..., x_N}, solution space) is targeted to be replaced with a better trial point. Considering x_{ig} as the target point, the corresponding trial point y_{ig} is created using the target point and a mutated point $\overset{\Delta}{x}_{i,g}$. For the simplest case, a mutated point is created by adding the weighted difference of two population members to a third. However there are various other possible schemes for generating the mutated points. Some possible mutation schemes for the ith target point are given below:

$$\overset{\Delta}{x}_{i,g} = x_{p(1)} + F \times (x_{p(2)} - x_{p(3)}) \qquad (2.2)$$

$$\overset{\Delta}{x}_{i,g} = x_{b} + F \times (x_{p(2)} - x_{p(3)}) \qquad (2.3)$$

$$\overset{\Delta}{x}_{i,g} = x_{p(1)} + \lambda \times (x_b - x_{p(1)}) + F \times (x_{p(2)} - x_{p(3)}) \qquad (2.4)$$

where F and λ are scaling parameters and x_b is the best point in the current population. $x_{p(1)}$, $x_{p(2)}$ and $x_{p(3)}$ are randomly chosen points such that $p(1) \neq p(2) \neq p(3) = i$ i.e. all points are unique and none of these points corresponds to the target point $x_{i,g}$. There are other variants to the schemes described by equations (2.2) to (2.4). In order to distinguish between different schemes a standard notation is used to indicate the scheme type: DE/a/b/c. The variable “a” specifies the base vector used that will be perturbed is chosen. It can which can either be random e.g. $x_{p(1)}$, as is the case for equation (2.2) and (2.4) or the best vector is the population, x_b, as in equation (2.3). The second variable b indicates how many vector pairs form the difference vectors. For equations (2.2) and (2.3) the value for b is l while for equation (2.4) b is 2. The variable c indicates what type of crossover method is used. Binomial crossover is represented by the abbreviation b in and exponential crossover by exp.

2.3 Crossover

The target or parent point x_{ig} together with the new mutated points $\overset{\Delta}{x}_{i,g}$ are recombined to create the trial point y_{ig}. There are two popular types of crossover methods used with the DE algorithm, namely binomial and exponential. For the purpose of this thesis we only use the binomial method which will be discussed below. Binomial recombination starts at the first component of the vector and generates a random number rj ϵ [0, 1] for each component. If rj<cr then the jth component of y_{ig} is taken from x_{jig}, otherwise if rj>cr then the component is taken from x_{ig}. This process continues until all components from x_{ig} have been considered. In order to ensure that at least one component in y_{ig} is from x_{ig}, a random integer $I_i \in \{1,2,\ldots,n\}$ is generated. The component in y_{ig} corresponding to Ii is taken from x_{ig}. The trial vector can contain components from $x_{i,g}$ at multiple, separated points. Binomial recombination can be mathematically formulated as:

$$y_{i,g}^{j} = \left\{ \overset{\Delta}{x}_{i,g} \quad if\ r^{j} \le c_r \quad or \quad j = I_i, \right. \quad y_{i,g}^{j} = \left\{ \overset{\Delta}{x}_{i,g} \quad Otherwise \right.$$

(2.5)

2.4 Acceptance

At each iteration the DE algorithm replaces each point in S with a better point. Therefore at each generation g, N members are compared with each other to find the members of S for the next iteration. The ith competition is taken to replace $x_{i,g}$ in S. This is done by comparing the function values of the trial points $y_{i,g}$ to those of $x_{i,g}$, the target points. If $f(y_{i,g}) < f(x_{i,g})$ then y_{ig} replaces x_{ig} in S, otherwise S keeps the original $x_{i,g}$.

$$x_{i,g}^{j} = \left\{ \overset{\Delta}{y}_{i,g} \quad if \ f(y_{i,g}) < f(x_{i,g}) \right. , \quad x_{i,g}^{j} = \left\{ \overset{\Delta}{x}_{i,g} \quad Otherwise \right. \qquad (2.6)$$

The DE algorithm maintains a greedy selection scheme that ensures that the current generation is equal to or better than the previous generation.

2.5 Stop Criteria

Main criteria is if the current best cost/Fitness value is reached to the requested value and if the maximum iteration limit is reached.

In the next chapter, the DEA is used to determine the optimal design parameters of a SIW antenna for high performance measures such as low input reflection and high gain.

By considering all the above requirements the DE algorithm appears to be one of the most appealing choices as an underlying global optimizer. Next section descript the DE algorithm.

3 Design Optimization Problem of an Ultra-Wide Band Microstrip Filter

The design parameters of an ultra-wide band microstrip filter can be named as: the height *h*and dielectric constant ε_r of the substrate which are very important parameters that should be choose wisely according to the requested performance of the design. Other than substrate parameters, the width *w* and length *l* of the microstrip transmission lines and the total number of the transmission lines N are other design variables which can be taken as optimization parameters. In this work, a few assumptions are taken to reduce the complexity of the design optimization problem listed as:

- The substrate of the design is chosen as FR4 (*h*=1.6, ε_r =4.6).
- Total number of microstrip lines are taken as 10 (N=10), so the total number of optimization variables would be 20.
- The length of all transmission lines *l* are taken equal. Thus, the total number of optimization variables reduced to 11.
- The circuit design would have a symmetrical design type in which the first line’s width would be equal to last transmission line’s width. Similarly the case would be applied to the second and ninth transmission lines, third and eighth and so on. By this mean the total optimization

variable number is reduced to 6 defined in Equations (3.1-3.2).

$$0.3 \le L \le 10 \tag{3.1}$$

$$0.3 \le w_i \le 10 \qquad i = 1, 2, \ldots, 5 \tag{3.2}$$

In order to define the cost function of design optimization problem belong to UWBMF, firstly the ABCD parameters belong to each transmission lines will be calculated with the following equation (3.3) [17].

$$\begin{bmatrix} \cosh(\gamma l) & Z_0 \sinh(\gamma l) \\ \frac{1}{Z_0}\sinh(\gamma l) & \cosh(\gamma l) \end{bmatrix} \tag{3.3}$$

After obtaining the ABCD parameters of each transmission line, the multiplication of all 10 ABCD matrix would provide the equivalent ABCD parameter of the filter design. Then by using Eqs. (3.4-3.7) the Scattering parameter of the design is obtained.

$$S_{11} = \frac{AZ_{N2} + B - CZ_{N1}^{*}Z_{N2} - DZ_{N1}^{*}}{AZ_{N2} + B + CZ_{N1}Z_{N2} + DZ_{N1}} \tag{3.4}$$

$$S_{12} = \frac{2(AD - BC)\sqrt{\mathrm{Re}\{Z_{N1}\}\mathrm{Re}\{Z_{N2}\}}}{AZ_{N2} + B + CZ_{N1}Z_{N2} + DZ_{N1}} \tag{3.5}$$

$$S_{21} = \frac{2\sqrt{\mathrm{Re}\{Z_{N1}\}\mathrm{Re}\{Z_{N2}\}}}{AZ_{N2} + B + CZ_{N1}Z_{N2} + DZ_{N1}} \tag{3.6}$$

$$S_{22} = \frac{-AZ_{N2}^{*} + B - CZ_{N1}Z_{N2}^{*} + DZ_{N1}}{AZ_{N2} + B + CZ_{N1}Z_{N2} + DZ_{N1}} \tag{3.7}$$

Where Z_{Ni} is taken as 50 ohm. Then by using the obtained scattering parameters, the cost function belong to the design optimization problem of UWBMF can be form as:

$$\mathrm{Cost}_S = e^{S_{21}dB} + |S_{11}dB| \tag{3.8}$$

$$\mathrm{Cost}_T = e^{S_{11}dB} + |S_{21}dB| \tag{3.9}$$

The scattering parameters in the cost function are taken as dB for ease of use. Since microstrip filters are passive and reciprocal circuits the S_{11}=S_{22}, S_{12}=S_{21} and $-\infty < S_{ij} \le 0$ .Eq. (3.8) define the suppressing bands where the S_{21} should ideally be $-\infty$ and the S_{11}=0dB. Similarly, Eq. (3.9) defines the cost function of transmission band where the S_{11} should ideally be $-\infty$ and the S_{21}=0dB. In next section, DEA algorithm is applied to obtain an optimal solution for design optimization problem of UWBMF.

4 Study Case

In this section, the DEA algorithm with given parameters in table 1 and 2 are applied to find the optimal values of width and lengths of 10 transmission lines with FR4 substrate for the design of an ultra-wide band microstrip filter with the given targeted performance criteria in table 2. In Fig. 1 the Cost iteration performance of the DEA algorithm for filter design problem. The obtained values from DEA is then applied in a 3D EM simulation tool CST to check the reliability of the proposed design optimization method. Figures 2-3 present the layout of the UWBMF design obtained from DEA algorithm. The performance results of the DEA algorithm for S11 and S21 are given in Figure 4 alongside of the CST simulation results.

Table1.Parameters of DEA.

Maximum iteration	30
population	60
Requested Cost	0
Other Parameters	Default

Table2.Targeted Performance Criteria's of UWBMF.

Band	f_{LC}		Transmission Band		f_{UC}	
Frequency GHz	1	3.3	3.6	9	9.4	12
S_{21} dB	-10<		0=		-10<	
S_{11} dB	0=		-10<		0=	

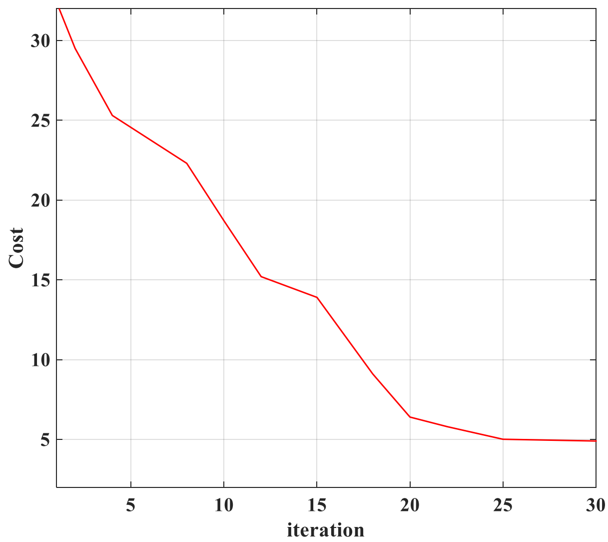


Figure1.Cost-iteration performance of the DEA algorithm.

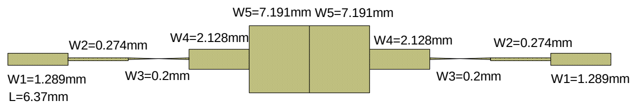


Figure2.2D Layout and Parameter Values of UWBMF Obtained From DE Algorithm

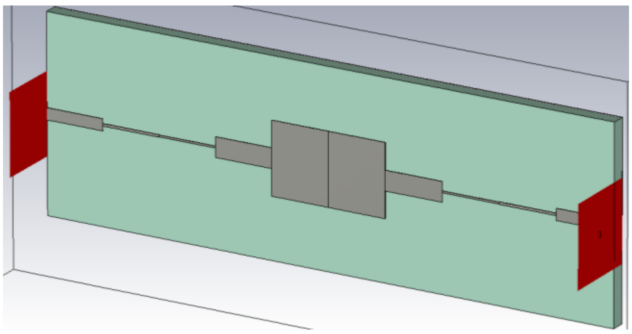
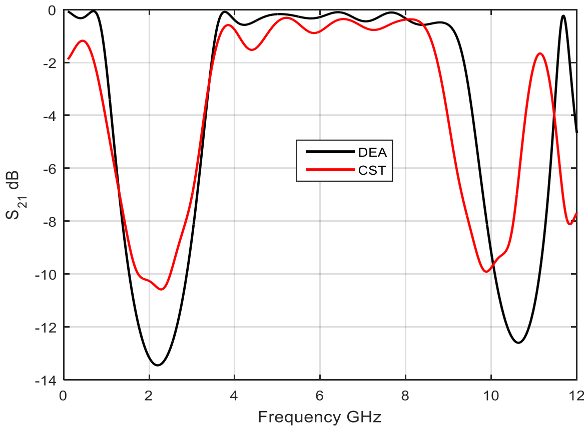
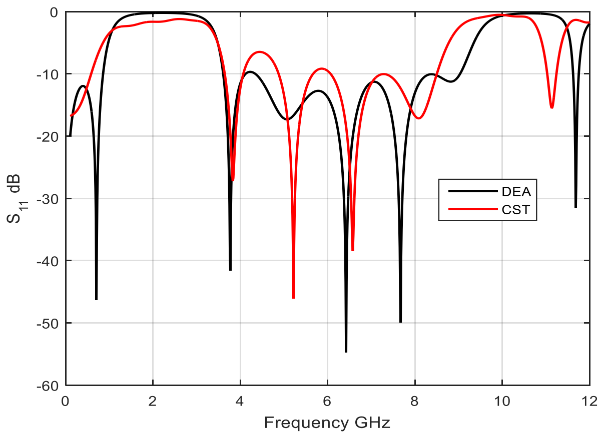


Figure3.3D Layout of The UWBMF Obtained From DE Algorithm CST Environment.



(a)



(b)

Figure4.Simulation results of DEA&CST (a)S_{21}, (b)S_{11}

5 Conclusion

As it seen from the results in section 4, the DE algorithm is an effective tool for design optimization of ultrawide band microstrip filters. The convergence between DE algorithm results and 3D EM simulator tool suggests that this method can also be used in design optimization problem of other microwave circuit stages such as antennas, power dividers and matching networks. In future works, it is aimed to use the DE algorithm and CST simulator tool simultaneously to propose a more effective design optimization method for design of more complex microwave circuit stages.

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