Synthesis of Parallel Coupled Band Pass Microstrip Filter Using Genetic Algorithm

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Abstract

In this article, we present our proposed method in design of parallel coupled band pass microstrip filter using Genetic Algorithm (GA). After the design of this filter by Chebyshev approximation to determine the characteristics of these filters , we adapted GA to band-pass filter design problem . The proposed method for design microstrip filters presents better results compared to classical methods in terms of losses in the pass-band and stop-band .

Keywords : parallel coupled band pass microstrip filter, Genetic Algorithm, Chebyshev approximation .

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1-Introduction

Filters play an important role in many applications in the microwave field. They are used to separate or combine different frequencies. Emerging applications in the microwaves field continue to challenge filters with stricter requirements, higher performance, smaller size, lighter weight and lower cost [1].

According to the requirements and specification, microwave filters can be designed as circuits to localized or distributed elements the can be designed in various transmission line structures such as waveguide, coaxial line and the microstrip [1-2]

In application where the transport high power signals is not an essential element, the use of planar technology is the solution to address congestion problem and weight volumetric structures [3] .

Planar filters are very attractive on two points but they are also on the implementation costs which are lower their good reproducibility and their interconnection facilities with other circuits including the active circuits [4].

One of the planar technology, microstrip technology is widely used in microwave systems, the advantages of this technology is insensitive to manufacturing tolerances, a wide range of bandwidth and easy design process.

In recent years the research is focused on methods for optimized design of microwave devices [5-8].

Genetic algorithm (GA) is a well-known algorithm, which is inspired from biological evolution process [9-10]. GA mimics the Darwinian theory of survival of fittest in nature. GA was proposed by J.H. Holland in 1992. The basic elements of GA are chromosome representation, fitness selection, and biological-inspired operators. Holland also introduced a novel element namely, Inversion that is generally used in implementations of GA [9,11]. Typically, the chromosomes take the binary string format. In chromosomes, each locus (specific position on chromosome) has two possible alleles (variant forms of genes) - 0 and 1. Chromosomes are considered as points in the solution space. These are processed using genetic operators by iteratively replacing its population. The fitness function is used to assign a value for all the chromosomes in the population [9-10]. The biological-inspired operators are selection, mutation, and crossover. In selection, the chromosomes are selected on the basis of its fitness value for further processing. In crossover operator, a random locus is chosen and it changes the subsequences between chromosomes to create off-springs. In mutation, some bits of the chromosomes will be randomly flipped on the basis of probability [9-12]. The further development of GA based on operators, representation, and fitness has diminished

In this research paper we proposed a procedure for design parallel coupled band pass microstrip filter using genetic algorithm

2- Theory of microstrip filter

According to the position of the bandwidth and attenuated bands in the frequency response, filters can be classified into four categories: low-pass, high-pass, band-pass, and band-stop filters [1].

The specifications of a filter are generally provided based on required specifications, which indicates the type of filter and the electrical characteristics (centre frequency, bandwidth, rejection level in the passband, insertion loss). Filters are typically composed of capacitors and inductors, as indicated in Figure 1.

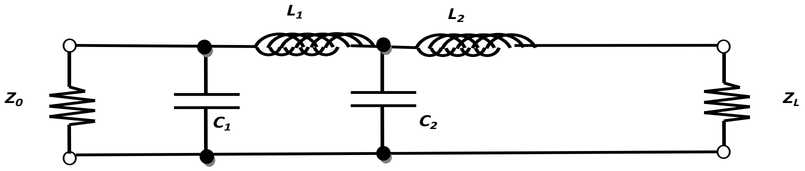

Fig.1 Localized element filter

These localized element filters (C and L) cannot be directly implemented in the microwave domain because the component values are low, and the availability of localized elements is very limited in this domain [4]. Therefore, it is necessary to transform these elements into distributed elements (transmission lines, cavities, etc.) in order to realize microwave filters.

To transform localized elements into distributed elements, there are two tools, namely the Richards transformation and the Kuroda identities [1].

Today, there are several technologies for the physical implementation of microwave filters, each of which will have characteristics in terms of complexity, cost, and electrical performance, making its use particularly suitable for specific applications.

Microstrip technology currently occupies a privileged position in the design of passive microwave circuits such as filters. It is easy to design resonators with interesting performances with reduced dimensions by playing on the dimensions of the lines. The geometry of a microstrip line is shown in Figure 2. It consists of a metal strip located on the upper surface of a dielectric substrate, with the ground plane located on the lower surface.

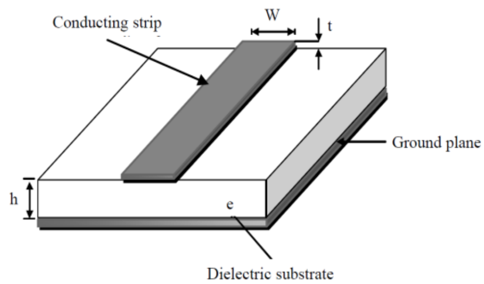

Fig.2 : The geometry of a microstrip line

The main parameters that characterize the microstrip structure are the permittivity εr, and the geometric parameters W, t, and h.

Usually the first step in design of filters is to choice the transfer function that approximates the required specification , the most common transfer functions are Butterworth, Chebyshev, elliptic, quasi-elliptic, and generalized Chebyshev [1].

3- Genetic algorithm

In the 1960s, John Holland studied evolutionary systems, and in 1975, he introduced the first formal model of genetic algorithms [11]. He explained how to add intelligence to a computer program with crossovers and mutation . This model would serve as a basis for further research and would be particularly taken up by Goldberg, who published in 1989 [13] a popularization of genetic algorithms and added the following ideas to the theory of genetic algorithms:

- An individual is linked to an environment by its DNA code.

- A solution is linked to a problem by its quality index.

Figure 3 depicts the flowchart of a genetic algorithm. It aims to simulate the evolution of a diverse population of individuals to which various operators (recombination, mutations, etc.) are applied and subjected to selection at each generation. Selection is based on the fitness function, and the population tends to improve [14]. Such an algorithm does not require any knowledge of the problem: one can represent it as a black box with inputs (variables) and outputs (objective functions). The algorithm merely manipulates the inputs, reads the outputs, manipulates the inputs again to improve the outputs, and so on [15]. A genetic algorithm searches for the extreme value(s) of a function defined on a data space. To use it, one must have the following five elements:

Coding the elements of the population. There are two types of coding: binary coding was widely used originally, and real coding is now widely used, particularly in for optimizing problems with real variables.

Generating the initial population. The choice of the initial population is important because it can make the convergence to the global optimum more or less rapid. In cases where nothing is known about the problem to be solved, the initial population be distributed across the entire search space.

An objective function to be optimized. This function returns a value called fitness or evaluation function of the individual.

Operators to diversify the population across generations and explore the search space. The crossover operator recombines the genes of existing individuals in the population, and the mutation operator aims to ensure the exploration of the search space.

Sizing parameters: population size, total number of generations or stopping criterion, probabilities of applying crossover and mutation operators.

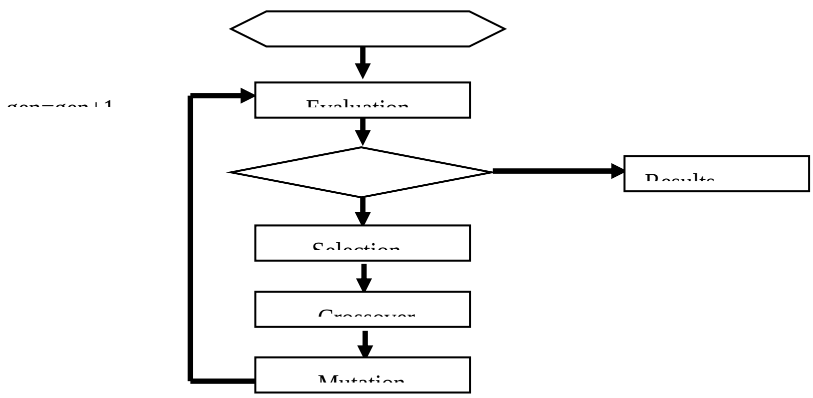

Fig.3 . Flowchart of the genetic algorithm.

4- Method And Résultat

Our application was designed for a filter with the following characteristics are:

- Center frequency = 4.1GHz
- Attenuation in the passband = 0.1 dB
- Fractional bandwidth = 48.7% (Bandpass = [3.1-5.1] GHz)
- Load impedance Z_0 = source impedance Z_L = 50 ohms.

Firstly we design this filter by Chebyshev approximation to determination the order of filter , The electrical characteristics..etc

We use the microstrip line formulas found in the literature [] we find the dimensions shown in the figure 4.

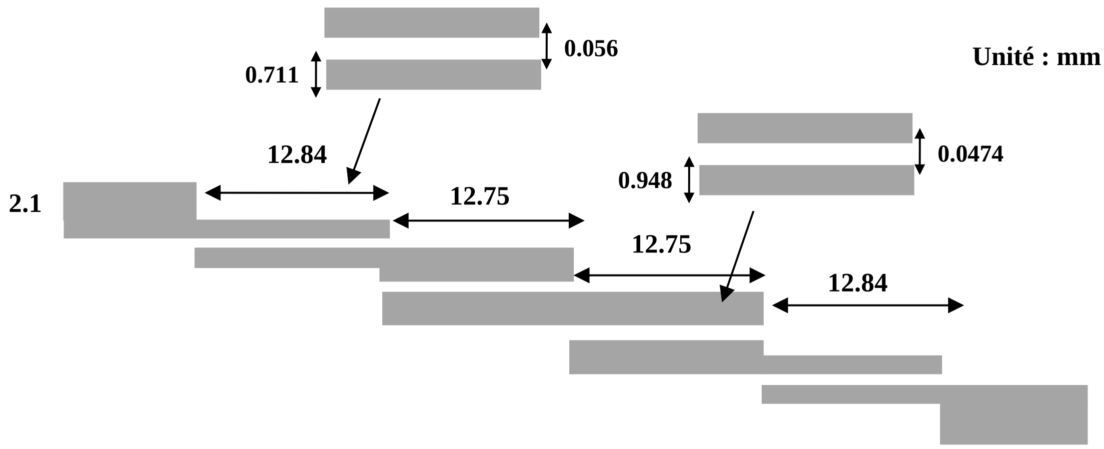

Fig.4. layout of band pass microstrip filter designed by chebyshev method

The filter presented previously it is consists of discontinuity steps and parallel coupled lines and we can calculate the transmission and reflexion coefficients by the multiplication of matrix ABCD of discontinuity steps and parallel coupled lines.

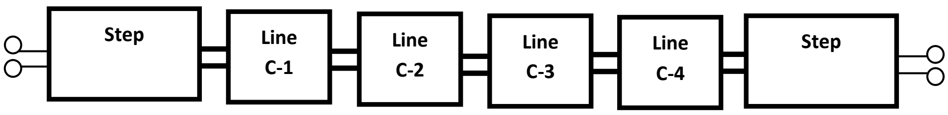

Fig.5. Structure of the microwave bandpass filter.

The ABCD matrices for the discontinuity step given by:

$$\begin{bmatrix} 1-\omega^2 CL_1 & (j\omega L_1 + j\omega L_2) - j\omega^3 CL_1 L_2 \\ j\omega C & 1-\omega^2 CL_1 \end{bmatrix}$$

(1)

$$C = 0.00137\, h \frac{\sqrt{\varepsilon_{re1}}}{Z_{c1}} \left(1 - \frac{W_2}{W_1}\right) \left(\frac{\varepsilon_{re1} + 0.3}{\varepsilon_{re1} - 0.258}\right) \left(\frac{\frac{W_1}{h} + 0.264}{\frac{W_1}{h} + 0.8}\right) \quad (\text{pf})$$

(2)

$$L_1 = \frac{L_{W1}}{L_{W1} + L_{W2}} L$$

(3)

$$L_2 = \frac{L_{W2}}{L_{W1} + L_{W2}} L$$

(4)

$$L_{Wi} = Z_{ci} \sqrt{\varepsilon_{rei}/c} \qquad i=1,2$$

(5)

$$L = 0.000987\, h \left(1 - \frac{Z_{c1}}{Z_{c2}} \sqrt{\frac{\varepsilon_{re1}}{\varepsilon_{re2}}}\right)^2 \quad (\text{nH})$$

(6)

The ABCD matrices for the parallel coupled line are given by:

$$A = D = \frac{Z_{0e} \cot\theta_e + Z_{0o} \cot\theta_o}{Z_{0e} \csc\theta_e - Z_{0o} \csc\theta_o}$$

(7)

$$B = \frac{j}{2} \frac{Z_{0e}^2 + Z_{0o}^2 - 2 Z_{0e} Z_{0o} \left(\cot\theta_e \cot\theta_o + \csc\theta_e \csc\theta_o\right)}{Z_{0e} \csc\theta_e - Z_{0o} \csc\theta_o}$$

(8)

$$C = \frac{2j}{Z_{0e} \csc\theta_e - Z_{0o} \csc\theta_o}$$

(9)

where Z_{0e} and Z_{0o} are the characteristic impedances of the even and odd modes. Θe and θo are the electrical lengths of the two modes.

The ABCD matrix of this filter is given by :

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \prod_{i=1} \begin{bmatrix} A & B \\ C & D \end{bmatrix}_i$$

(10)

And the transmission coefficient $S_{2,1}$ is calculated as follows:

$$S_{2,1} = \frac{2}{A + B/Z_0 + CZ_0 + D}$$

(11)

Let's assume that the dielectric is homogeneous, θe=θo=θ, then the ABCD matrices of the subnetworks of the coupled line can be rewritten as follows:

$$A = D = \frac{(Z_{0e} + Z_{0o})\cot\theta}{(Z_{0e} - Z_{0o})\csc\theta}$$

(12)

$$B = \frac{j}{2}\frac{Z_{0e}^2 + Z_{0o}^2 - 2Z_{0e}Z_{0o}\left(\cot^2\theta + \csc^2\theta\right)}{(Z_{0e} - Z_{0o})\csc\theta}$$

(13)

$$C = \frac{2j}{(Z_{0e} - Z_{0o})\csc\theta}$$

(14)

According to S_{21}, the design of the bandpass filter can be considered as a function of Z_{0e}, Z_{0o}, and θ'.

Such that:

$$\theta' = \theta / f = \frac{2\pi}{300}\sqrt{\varepsilon_{re}}\, l$$

(15)

The following points describe the adaptation of the genetic algorithm to the design of bandpass microstrip filter:

1. The population is the set of chromosomes, and the chromosome is composed of genes. In our program, the population is the set of filters, and each filter is characterized by impedances and electrical lengths. Therefore, the genes in our case are the impedances and electrical lengths.

2.The encoding we used in our program is real encoding. In the second application, the filter is defined as follows:

Filtre =(Z_{0e} ,Z_{0o} ,θ')

3.Genetic algorithms work on a limited space; therefore, defining the search space is an important criterion, the search space is defined as follows:

$80 \le Z_{0e} \le 200$ (Ohms), $20 \le Z_{0o} \le 80$ (Ohms), and $0.2 \le \theta' \le 0.7$ (radians).

4. The objective function we used the error function, which is evaluated after the calculation of S_{21} and defined by the expression: $\sum_{i=1}^{n} Er_i$

$$Er_i = \begin{cases} |S_{2,1}| & f < f_{p1} \\ |S_{2,1} - 1| & f_{p1} \leq f \leq f_{p2} \\ |S_{2,1}| & f > f_{p2} \end{cases}$$

(16)

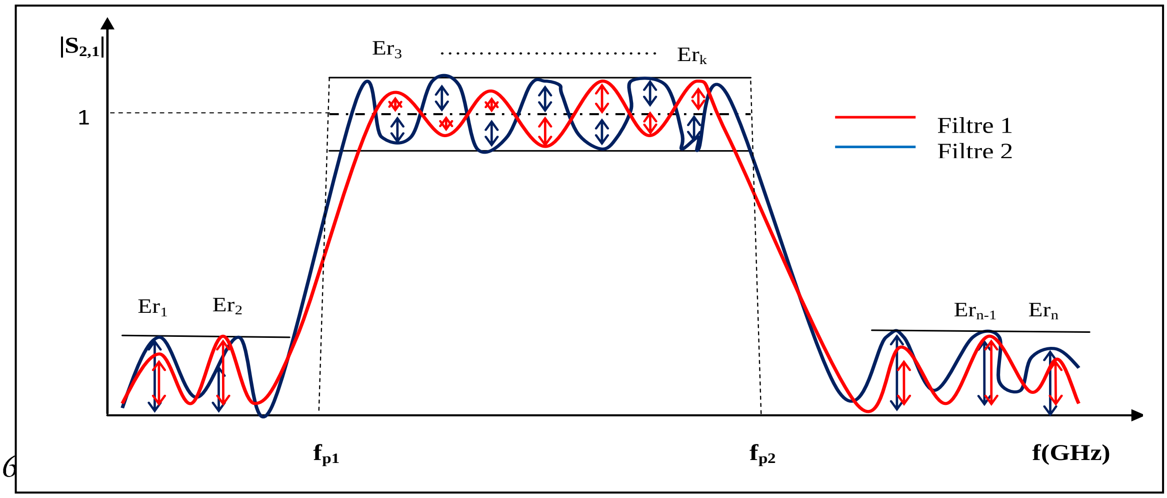

Fig.6

5. The selected method of selection is biased lottery selection.

6. The crossover considered in our program is uniform crossover.

7. The mutation we used involves initializing some genes in the population. These genes are chosen randomly.

Figure 7 shows the variation of the minimum error as a function of iterations. As mentioned previously, this study helps to determine the number of iterations in our program to obtain an optimal filter.

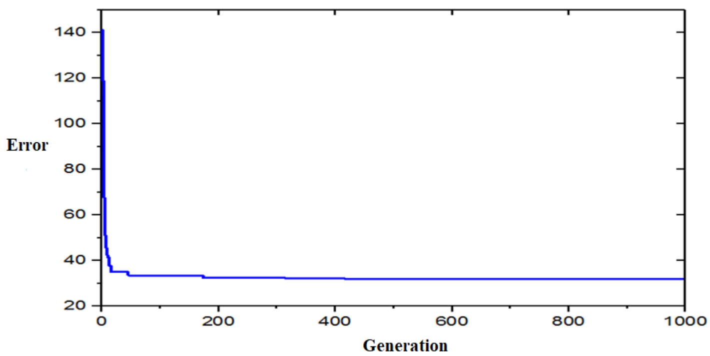

Fig.7 . Effect of generations on the minimum error.

The genetic algorithm quickly converges to acceptable solutions within the range of 13-50 generations; then its convergence slows down between 50 and 416 generations. After 416 generations, the algorithm stabilizes on error equal to 33.17. In our case, the number of generations has been set to 500.

The best microstrip bandpass filter obtained by the GA algorithm has the following characteristics: Z0e = 176.41 (Ohms), Z0o = 80 (Ohms), and θ' = 0.38 (radians) with an error of 32.02 when the filter designed by chebyshev method present an error of 85.2. Figure 8 represents the transmission coefficient (S_{21}) and reflection coefficient (S_{11}) of the two microstrip bandpass filters (the filter designed by GA and the Chebyshev filter).

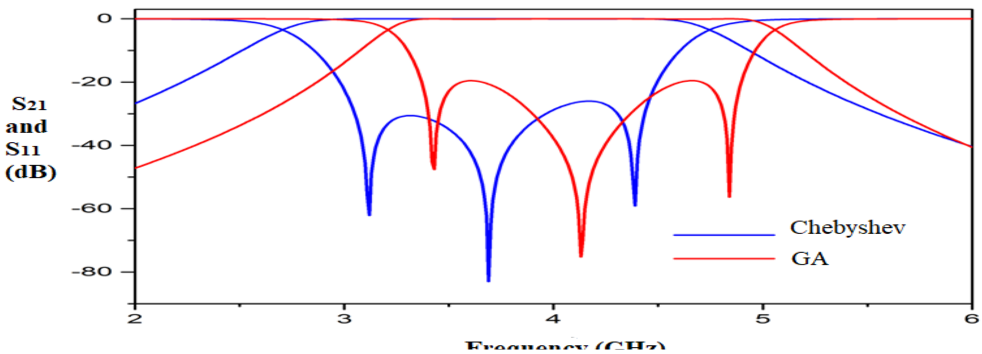

Fig.8 . Performance of the microstrip bandpass filter designed by GA and the Chebyshev method

For the implementation of the microwave bandpass filter designed by GA on a microstrip structure with a substrate of height h=0.79 mm and a relative dielectric constant ε_r = 2.5, The dimensions of this filter are illustrated in Figure 9 . For the calculation of the width W and spacing S of the coupled microstrip lines, refer to [1] : W=0.316 mm and S = 0.225 mm. And for the length l, we have: ε_{re}=1.89, θ' =0.38 and $l = \frac{300\theta'}{2\pi\sqrt{\varepsilon_{re}}}$. we find l=13.31 mm.

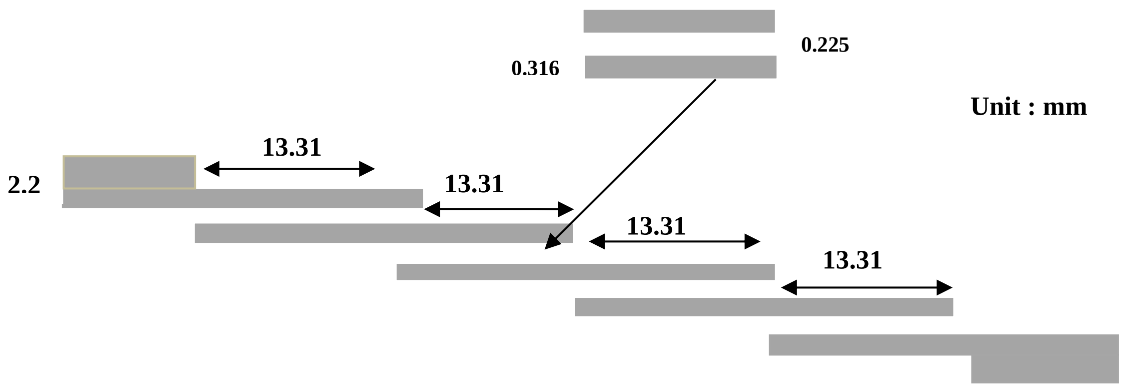

Fig.9 . layout of the bandpass microstrip filter designed by GA

5-Conclusion

This study presents the design of parallel coupled band pass microstrip filter by the genetic algorithm.

The genetic algorithm has certain characteristics such as the concepts of reproduction, mutation, and crossover. These operations allow the algorithm to search for the optimal solution in the search space.

The genetic algorithm is easily applied in many fields, you need only to adapt the optimization problem .The main parameters to be define are ; individuals, coding , crossover , mutation , search space and the objective function.

The design of filter by a classical method (butterworth , chebyshev ,..etc) is firstly done and then we adapt the optimization problem. We choose the individual as a filter and these chromosomes represents the characteristic impedances and electrical lengths of the filter.

The search space is chosen from the values of characteristic impedances and electrical lengths of the filter and the objective function we used the function sum of the errors on the magnitude response of filter .

The simulation results showed the effectiveness of the algorithm , the filer designed by GA present a 32.02 in the objective function when the filter designed by chebyshev a 85.2 in the objective function.

The use of GA for designing microstrip filters it is possible and yields better results.

The generalization of our contribution to the many devices with different structures is possible

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