Automated Electronic Circuit Design for Low Pass Filter Based on Genetic Algorithms

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Abstract:

In this paper a proposed method to design electronic circuits by using software approach based on genetic algorithms is presented. The method is implemented to design low pass filter with a minimal knowledge about the design (the response of the filter and cutoff frequency). Butterworth filter type is chosen because of its smooth response. This method provides impressive results and the circuits obtained provide higher efficiency than the circuits which might be designed by the expert engineer. This method allows the topology, the component values, and the number of the component of the circuit to be evolved by using genetic algorithms (GAs) without human interference. Therefore, the proposed method can be expandied to be used with any analog (passive or active) circuit by making a few changes in the program steps (i.e. by changing the fitness function and improving the simulation of the circuits). MATLAB (Ver. 7) language is used in programming the genetic algorithm. The circuits created by genetic algorithms are built using EWB program to make sure that the obtained results are true and accurate.

نمذجة التصميم الالكتروني لمرشحات الترددات الواطئة باستخدام الخوارزميات الجينية

الخلاصة

يقدم البحث طريقة لتصميم الدوائر الالكترونية بواسطة مقاربة برمجية تعتمد على الخوارزمية الجينية . تم تطبيق هذه الطريقة لتصميم مرشحات امرار الترددات الواطئة باستخدام معلومات قليلة عن التصميم (استجابة المرشح وتردد القطع) . تم في التصميم اختيار المرشحات من نوع بترورث كونه يتميز باستجابة سلسة خالية من التموجات . قدمت الطريقة المقترحة في التصميم نتائج جيدة والدوائر الالكترونية التي يتم الحصول عليها من خلالها تكون أفضل من تلك التي يمكن أن يصممها المهندس الخبير. حيث تسمح هذه الطريقة لهيكلية الدائرة الالكترونية وقيم العناصر الداخلة فيها وكذلك عدد هذه العناصر بان تتطور بالاعتماد على الخوارزمية الجينية دون تدخل بشري . يمكن توسيع هذه الطريقة في تصميم أي من الدوائر الالكترونية التماثلية (سواء أكانت تحوي على عنصر فعال أم لا) و ذلك باجراء بعض التغييرات الطفيفة على الخطوات البرمجية (أي بتغيير دالة قياس المناسبة و تحسين طريقة محاكاة الدوائر الالكترونية) .لقد تم استخدام المختبر الرياضي MATLAB (Ver. 7) في برمجة الخوارزميات الجينية. تم التحقق من الدوائر الالكترونية الناتجةمن استعمال الخوارزميات الجينية ببرنامج (EWB) للتأكد من كون النتائج التي تم الحصول عليها صحيحة و دقيقة.

1. Introduction

Genetic algorithms (or simply GAs) are powerful and widely applicable stochastic search and optimization methods based on the concepts of natural selection and natural evaluation. Genetic algorithms were first invented by John Holland in 1960s and were developed by Holland

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and his students and colleagues at the university of Michigan in the 1960s and the 1970s[1]. GAs work on a population of individuals represents candidate solutions to the optimization problem. These individuals consist of strings (called chromosomes) of genes. The genes are a practical allele (gene could be a bit, an integer number, a real value or an alphabet character…, etc depending on the nature of the problem).

GAs apply the principles of survival of the fitness, selection, reproduction, crossover (recombining), and mutation on these individuals to get, hopefully, a new butter individuals (new solutions). GAs are applied to those problems which either can not be formulated in exact and accurate mathematical forms and may contain noisy or irregular data or it takes so much time to solve or it is simply impossible to solve by the traditional computational methods.

GAs have been used to solve many of the scientific and real world problems (for example, TSP or traveling salesman problem, machine learning, neural network design… etc). GAs also have been used in solving electronic and electrical engineering problems such as design and layout of VLSI (very large scale integrate), design arithmetic and logic circuits…, etc. Analog circuits are of great importance in electronic system design since the world is fundamentally analog in nature [2]; also most of digital circuits need an analog circuit as an interface with the outer world. Therefore, in the last few years a number of interest researches were focused on how to design analogue electronic or electric circuits by using genetic algorithm. In [3-6] the rearchers used a master-slave type of parallel genetic algorithms (cluster of six engineering workstations, 1996Sun Ultra) to design analog circuit and allow it to evolve the topologies, components size and values. They used binary encoding to encode the circuit and external simulation program (SPICE). The max size of the circuit is about 100 component and max population size about 18000 individual. However, this work limited the allowed topologies to a small part of search space because the instructions that direct the connection of components are limites to a small number of nodes. In [7] the resercher uses genetic algorithms to find the topology of the circuit and use a numerical optimization method to find the value of the component of the circuit. Also the max number of individual is between 80-200 individual. In [8, 9] researcher use genetic programming (GP) instead of genetic algorithms(GAs) to evolve analog circuit (GP is a development of GAs in which a population of computer programs, rather than design solutions, is subject to evolution; when executed each computer program generates a design solution.) A SPICE simulator, the code for which has been incorporated into the genetic programming system, evaluates design solutions created. The max population size is 640,000 individual and a few hundred generations. The genetic program runs on a parallel computer system consisting of 64 PowerPC 601 processors arranged in a toroidal mesh hosted on a Pentium PC.

2.The Proposed Method of Automated Circuit Design Based on GA

The main goal to achieve in this search is to use pure genetic algorithms to design any passive electronic circuit

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and allow the topology, the component values, and the size of the circuit to evolve without any human interfere. The related goal is to make it possible to any person with a little experience in design; (only information about the response of the circuit to be design) to use the genetic algorithms easily without needing expensive instruments (this means without needing several computers or expensive programmable chips). To achieve these goals, a program based on the concepts of the genetic algorithms; which are selection, crossover, and mutation; has been used to design passive electronic circuits. MATLAB (Ver.7) language used to write this program (in M-file form) because it's a powerful language with many good instructions for plotting and calculation. In this work, a single personal computer (Pentium IV) was used to run the program. The program was implemented to design low pass filter which is frequency selective circuit that passes the signals with a frequency lower than cutoff frequency and blocks any other signals[10].

Butterworth filter type has been chosen because it has a maximally flat pass-band, with moderately sharp cutoffs, that means there is minimum ripple in either the stop-band or the pass-band. Fig. (1) shows the step of the program.

Hybrid selection method (Roulette wheel selection, elitism selection, and worst individual elimination selection) has been used to select the individuals (circuits) that will survive to the next generation depending on the fitness of each individual. The fitness of each circuit is measured by comparing the circuit response (by simulation) with the target response (by fitness function) at a number of points in the frequency domain, also a windowing method has been used to ignore the unwanted circuits (its fitness will be reduced to a small value) and at the same time to limit the wanted response by a boundary (in this work, the wanted response must be between 0.75-1.25 of the target response at any point tested).

In this work, one point crossover is applied to any pair of chromosomes (parents) selected randomly and replaced by the resulted pair of chromosomes (offspring). The crossover rate could take any value from 0-1 (typically 0.7). One point mutation was modified to wok on any individual and changes any gene value depending on the gene type and location. Mutation rate, like crossover rate, could take any value from 0-1 (typically 0.5). Integer number encoding is used to encode the circuits. The individuals (circuits) are two dimension (C x 4) matrixes, where C is the number of chromosomes. Each chromosome represents an element in the circuit (resistance, capacitance, or inductance). The chromosome consists of four genes.

The first gene represents the type of the element; the second one represents

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the instruction that will direct the connection of the element; the third and the fourth genes will give the value of the element depending on the type of the element. The five instructions used to direct the movement of element are the as that used by [2-4] but the instruction is modified to act alone and does not depending on the type of element.

The move-to-new instruction places one end of a component at the active node and the other at a newly created node (the "active" node is the current location of the automaton). The newly created node then becomes the active node. The cast-to instructions place one end of the component at the active node and the other either at the ground, input, output, or previously-created node. After executing a cast-to instruction, the automaton remains at the active node. The input and output nodes are the overall input and output nodes of the circuit as opposed to the input and output of the placed component [2]. The meanings of each instruction are summarized in Table (1).

However, these instructions limit the ability of topologies to little part of the cases in the search space because the connections between the components are limited either to the main nodes (input node, output node, ground node) or the previous node or it will create new node. Therefore, to overcome these limitations new four instruction are proposed in this work, the free-to-move instruction placs one end of the component at the active node and the other at any of the previous nodes (selected randomly). The input-to-ground instruction will not have effect on the active node and will only connect the component from input to ground. The output-to-ground instruction will act the same input-to-ground instruction but the first end of the component will connect to output node instead of the input node. The Change active (N) is a special instruction that will connect the active node to ground or output (if it is not connected to either of them by cast-to-ground or cast-to-output instructions) and at the same time it will change the active node and make any of the past nodes become the new active node and the connections of the component will depend on (N)which is a random integer number limited between (1 to 8) ,for example if N equals 3 then the instruction will perform its work then it will act like cast-to-ground instruction. The meanings of these new proposed instructions are illustrated in Table (2).

By using the new instructions illustrated in Table (2), the circuit may take the form of any topology and at the same time it will be guarantied that these topologies are valid and not have unconnected branches. In this work, the resistance values are between (0.01ohm to 1000000 ohm), the capacitance values are between (1e-6 Henry to 10 Henry), and the capacitance values are between (1e-2 farad to 1e-12 farad). The general circuit of will be as shown in Fig. (2).

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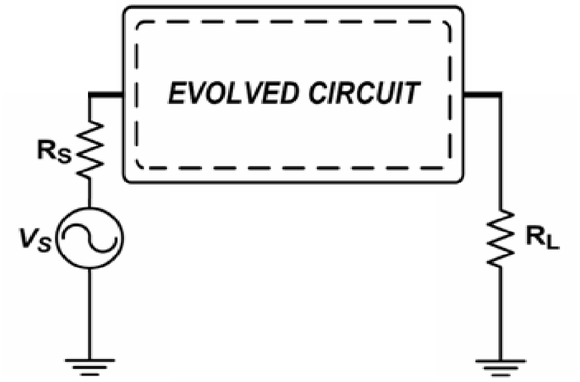


Fig. (2) General construction of the evolved Circuit.

The output voltage will be calculated by internal simulation program written within the main program of genetic algorithms. The simulation based on a modified nodal method. Therefore, it will take little time and it's able to test large number of point (about 10000) comparing to the using of external simulation program like spice or other programs as in [2, 10].

3. Computer Simulation Results

Butterworth low pass filter (lpf) response chosen to be the target response of the evolved circuit to test the effectiveness of proposed method. The output magnitude response of Butterworth low pass filter is:

Gain (f) = {1 / (1+ (f/fc) ^ (2n))} ^ (-0.5)

Where f is the input frequency to the filter, fc is the cutoff frequency and n is the order of filter (the number of low pass filter poles).

Two filters were chosen to evolve. The specifications of these filters are illustrated in Table (3).

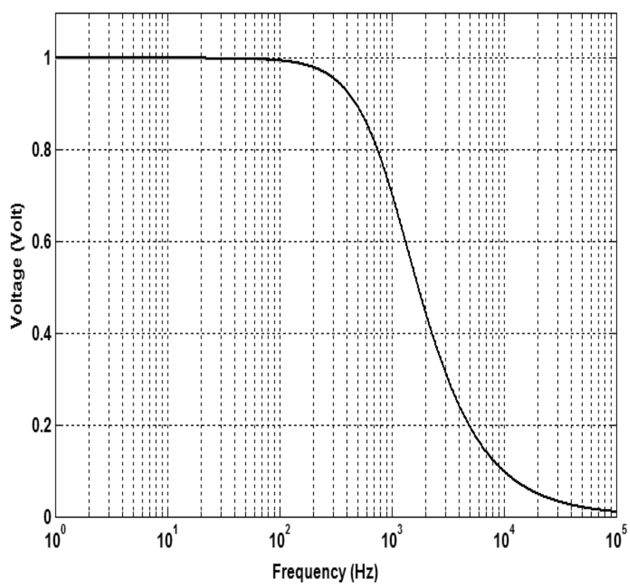
The set of GAs operators and control parameters are defined for each design case differently to show the power of the program and its ability to work with different population size over the entire search space.

Case1:-

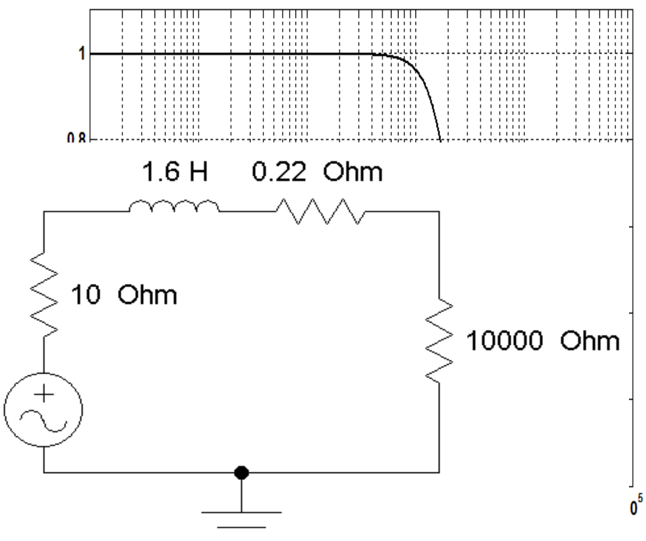
The first circuit to design is an order one low pass filter (Butterworth type). This circuit has the following setting:

The number of the generations=20

The number of the individuals (circuits) = 1000



The number of the chromosomes (components) = 2



The signal voltage is=1 volt
The Rs is= 10 ohm
The Rl is= 10000 ohm
The frequency range is between (1-100000) Hz
The cutoff frequency for low filter =1000 Hz
The order of the filter is= 1

After the 6 generation termination condition was satisfy and the resulted circuit was:

[3	1.6	1	2
1	0.22	2	1000]

The fitness of this circuit is equal to 99.905% of the target response, while the total elapsed time was about 10 min. The resulted circuit is shown in Fig.(3).

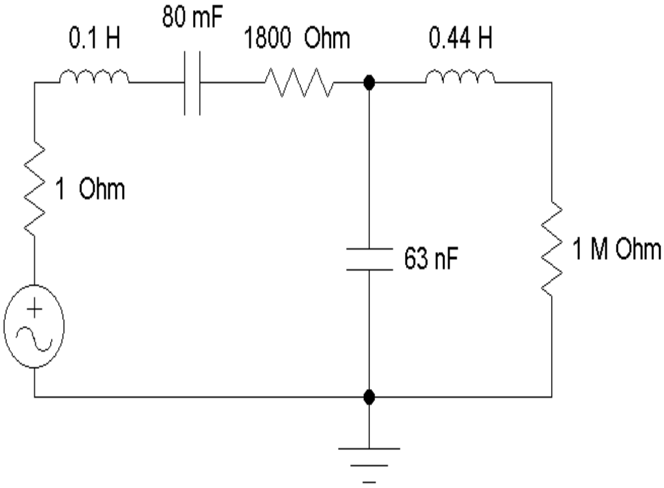
Fig. (3) The evolved circuit of the Butterworth low pass filter (order one).

The output magnitude response of the circuit are shown in Fig. (4).

Fig.(4) The output magnitude response of the circuit against the frequency of the Butterworth low pass filter (order one).

Case 2:-

The second circuit to evolve is second order low pass filter (Butterworth type). The setting of this circuit is:
The number of the generations=1000
The number of the individuals is= 15000
The number of the chromosomes is= 5
The signal voltage is=1 volt
The Rs is= 1 ohm
The Rl is=1e6 ohm
The cutoff frequency for low pass filter=2000 Hz



The order of the filter is: 2
The resulted circuit after satisfy termination conditions in generation 709 is =

[3	0.1	1	2
2	0.08	2	3
1	1800	3	4
2	6.3e-008	0	4
3	0.44	4	1000]

The fitness of the circuit is 99.626 % from the target response with a total elapsed time about 25 min. The design of the circuit is shown in Fig (6).

Figure (6) The evolved circuit of the Butterworth low pass filter (order two).

The output magnitude response of the circuit is shown in Figure (7)

Figure (7) The output magnitude response of the circuit against the frequency of the Butterworth low pass filter (order two).

Conclusions

This work shows that design of electronic or electric circuits in automated manner can be done on a single computer without needing a very expensive programmable chips or large number of computers, at the same time it gives very good results with high efficiency and accuracy (the similarity between the actual response and the target response is between 99.626 - 99.905 for the tested circuits).

The using of modified encoding approach with new instructions to direct movement of each component in the circuit makes it possible that the circuit could take any topology and at the same time guaranteed that all these topologies are valid, also the values ranges of each component cover a wide area in search space.

The modified hybrid selection approach used in this work (roulette wheel selection, elitism, and worst elimination) improves the selection process by direct the evolution to best solutions and eliminate the worst.

This work uses anew method to make use of both genetic algorithm operators (crossover and mutation) to evolve the circuit by considering each operator as main force in evaluation, unlike past work of other searchers in the automated electronic circuits design field, this work uses two simulation steps in each generation (one after crossover and the other after mutation) to make sure no losses in best solutions (circuits) by mutation or crossover.

As future work this modified program can be used to evolve other type of filter like high, band pass, and band reject filters of the type Butterworth or other filter types, and also could be implementing to design oscillator or voltage controller or any other type of circuit.

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