Automated Passive Filter Design Using Multi-objective Genetic Algorithms with Variable Parameters

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ABSTRACT
A system to automate the design of passive filters using a multi-objective approach is presented on this work. A fixed but flexible structure is used to code the chromosome representing the circuit topology. An automated procedure is developed to size the circuit components from a given set of specifications. The novelty of this work is the multi-objective approach, where, for one side, priority is given to smaller circuits with less components, but, on the other side it must obey with the performance specifications. The ability of the proposed tool was tested on the design of several filter specifications.

Categories and Subject Descriptors
I.2.M [**Artificial Intelligence**]: Miscellaneous.

General Terms
Algorithms, Experimentation, Performance.

Keywords
Evolutionary Computation, Multi-objective Optimization, Pareto Front, Design Automation, Analog Circuit Synthesis, Passive Filter.

1. INTRODUCTION
Despite digital electronic is present in almost any decent and recent electronic device, the analogue circuits are still an indispensable part of almost any electronic gadget currently in use, from cell phones to car electronics. Unlike digital design, analogue design still requires the skills of specially trained designers and engineers. Circuit-level analog synthesis is a two step process, namely topology selection and component sizing [3]. In [1] Angan Dass*, & al.* (2007) presented a skeletal structure to automate the topology generation and component sizing of passive analog filters. The authors used a variable (in size) structure organized as a linked list to describe the chromosome representation of the circuit. In this work the authors do not mention how the size of the evolved circuits is controlled but this is important, because a chromosome of variable length is used, which can grow infinitively or in an uncontrolled way. This work proposes a new multi-objective genetic algorithm approach to explore both topology and sizing of passive filters.

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2. METHODOLOGY
The proposed system consists on a Genetic Algorithm coupled with a circuit evaluation module. The linking between the two is the fitness function based on the accomplishment of the desired circuit specifications.

2.1 Template Circuit
The proposed system generates complete circuits by evolving a connected network of passive components and subsequently placing this network in a predefined template circuit. This single-input single-output template circuit is shown in Figure 1.

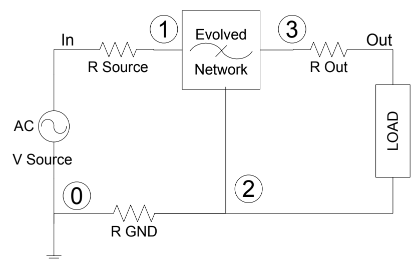

Figure 1. Circuit Template.

2.2 Chromosome Genetic Encoding Scheme
Each population of the Genetic Algorithm consists of multiple candidate solutions known as chromosomes. A chromosome consists of several genes. In this work, a gene symbolizes a circuit part. So each gene should contain the information pertinent to: 1- Value of the element; and: 2- Type of Element which can be: Resistor, Capacitor or Inductor, the possibility of it being a Short Circuit or an Open Circuit has been added to allow the evolution of different topologies. This work proposes the use of a circuit in the form of a matrix conforming to the topology represented in the Figure 2, where each Z represents a circuit element; it can be either: R, L, C, SC or OC. For the experiments presented in this study the maximum dimension is limited to a 4 by 3 matrix, but these limits can be changed by the user. It is true that this representation exclude certain circuit topologies, but it is still capable of generate a rich set of them counting many of the useful topologies seen in hand-designed circuits, furthermore it also increases the probability of generating structurally correct circuits.

2.3 Circuit Evaluation
An essential step, so that any evolutional strategy can work is the evaluation of the solution quality, in this case, the circuit topology. Here, two measures, objectives, will be considered: the error or distance to the desired performance and the circuit complexity.

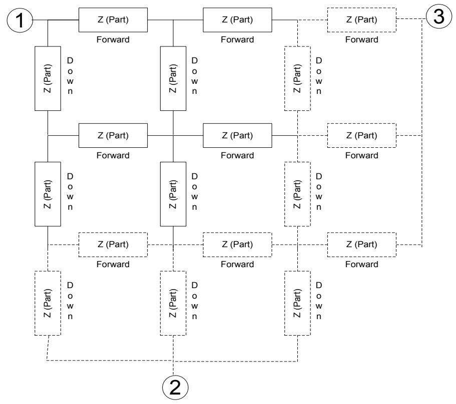

Figure 2. Topology of the Evolved Network.

2.3.1 Objective one

The performance evaluation of the filter circuits is performed by a frequency analysis, at the frequency points of interest with the NG-Spice tool. The quadratic deviation between the output of the circuit and the desired, according to the specifications, is calculated. Quantitatively the error is calculated according to equation 1:

$$Err = \sum \mu * (Ho - Hg)^2 \qquad (1)$$

Where μ denotes the penalty factor, Ho and Hg are the circuit attenuation obtained and desired respectively. This error is calculated and summed over all the frequencies (f) of interest. The penalty factor has been tuned after some preliminary experiments, and helps the convergence of the solutions towards the objective. For farther details see [1].

2.3.2 Complexity measure

The second optimization objective is the circuit complexity measured as the number of components. An arbitrary price factor has been incorporated by means of a weighting factor, as follows:

$$Complexity = \sum w \qquad (2)$$

Where w is the (arbitrary) part factor, this factor was made equal to 1 for R and C elements, and equal to 1.5 for the L elements.

2.4 Genetic algorithm

The NSGA–II [2] is used to implement the multi objective optimization. Many of the parameters are the same of the original NSGA-II implementation while some have been tuned after some preliminary experiments.

2.5 New Mutation Operator and Variable Parameters

A new mutation operator was used, with the goal of both introducing some problem specific knowledge and to help enlarge the population variety. During some trial testes the tool used with the default factors was especially fast in optimizing minor circuits on the first generations. Then, using a new mutation operator the tool evolved more complex circuits, but this at the cost of slower performance even with simpler circuits. So to keep the tool fast with the smaller circuits, and boast it to evolve also more elaborated circuits (diversity) the odds of applying the new mutation operator ware made variable. The details of the new mutation operator and how the parameters where adapted have been removed due to space limits on this short expose.

3. RESULTS

In order to validate the proposed tool the design of several filters were performed. Here, the results are illustrated for a high-pass filter specification.

In the template circuit, the values for RSource, RGND, ROut and LOAD have been fixed respectively to the following values: 1KΩ, 1mΩ, 1mΩ and 1KΩ. The selected high pass filter had the following specifications: Kp = 0.0 dB, Ks = 90.0 dB, fs = 1000 Hz and fp = 100 Hz, adopting the same conventions used in [1].

In Figure 3 the final population, as well as, the Pareto front (blue line) are presented. The solution with Complexity 17 got the best result on objective F1. The evolved filter circuit is presented on figure 4 which verifies the required specs.

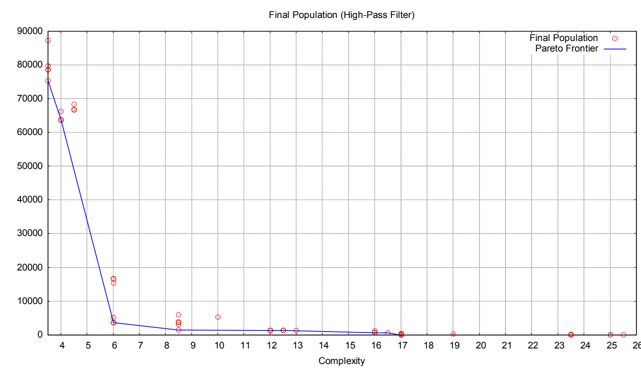

Figure 3. Pareto Frontier and Fitness of Final Population

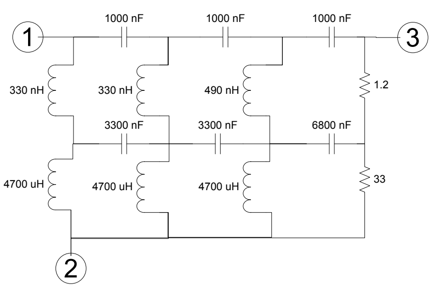

Figure 4. Evolved Network - High-Pass Filter

4. CONCLUSIONS

A methodology and a tool were proposed for the automatic topology generation and sizing of passive filters using the state-of-the-art multi-objective genetic algorithm. The proposed tool was demonstrated in the design of several filter specifications getting competitive results with the related work.

5. REFERENCES

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