Use of Evolutionary Algorithm Approaches in Analog Integrated Circuit Design

Jasmeet Kaur
Assistant Professor, GNDEC, Ludhiana
jasmeetkr.90@gmail.com

Abstract: As VLSI Industry is progressing towards integration of mixed analog-digital circuits for a complete system-on-chip solutions, automated analog circuit design methodologies are gaining attention. Automatic sizing of transistors has become an area of focus for the EDA industry. A lot of research effort has been put in by the designers for developing different techniques for obtaining optimal circuit topologies and sizes of analog circuits satisfying desired specifications. But from past few years, evolutionary algorithm (EA) approaches have emerged as an excellent tool for solving optimization problem in analog circuits. This paper presents a review of various EAs used for optimization. Firstly, Genetic algorithm along with some discussion on its applications is presented. Also two other algorithms namely Particle Swarm Optimization and Ant Colony Optimization have been discussed. Besides discussion on these algorithms, various applications from literature are given.

Keywords: Circuit sizing, Evolutionary algorithm, Genetic Algorithm (GA), Particle Swarm Optimization (PSO), Ant Colony Optimization (ACO).

Introduction

In the past decade, the analog circuit sizing has been the main focus of circuit designers [1]. This is due to the difference in number of parameters involved in analog and digital circuit design. Where, a digital circuit design mostly involves parameters like speed, delay and power; an analog circuit has a large number of parameters to deal with. In order to meet specifications like power, gain, bandwidth, slew rate etc. the circuit parameters like transistors widths, bias currents, values of passive components etc. need to be adjusted [2]. Therefore, a circuit designer needs to optimize parameters for achieving desired specifications.

For simpler circuits, optimization can be done using manual calculations and simulations. But as the complexity of circuits increases, the process becomes time consuming and challenging [3]. Thus need for automation in analog circuit designing arises. Basically, automated analog circuit designing is to find optimum solutions while satisfying the required performance, that too in minimum time. In the absence of automated synthesis or sizing methodology, the designing of an analog circuit becomes complex, time consuming and costly[4]. During past few years, a lot many Analog Design Automation (ADA) tools emerged, with the aim of achieving optimal topology and transistor sizes to fulfill desired specifications for any analog IC [5].

The designing of any analog circuit can be divided into two phases; first phase involves the construction of circuit topology, while second phase deals with circuit sizing [3]. The literature, mainly discuss about two analog circuit design automation techniques: Knowledge based and optimization based [6]. The authors in [6], have summarized both the techniques for analog circuit design automation. The knowledge base approach, involves the generation of synthesis rules with the expert knowledge, that are further incorporated into an algorithmic procedure which leads to a design solution; whereas, a search algorithm is used in the optimization based approach, which leads the design in the direction of a solution specified by designer. A combination of optimization techniques with expert systems can also be effective [6] .

The problem of analog circuit sizing can be single objective or multi-objective. For an instance, the single objective problem can involve minimization (maximization of an objective can be converted in to minimization problem) of one objective subjected to some constraints; whereas, in multi-objective sizing problem, more than one performance is simultaneously optimized to get pareto-optimal front[4].

Over the past few years, evolutionary algorithms are serving as a desired optimization tool for all kinds of optimization problems [1]. Also in the field of automated analog IC design, these algorithms are gaining huge popularity [2,6].

Evolutionary Algorithms

EAs are basically the search algorithms that use repetitive transformations for evolving a population of solutions where operators performing transformations are drawn from evolution in nature. A score is associated with each solution, which is a measure of its fitness [7]. In other words, it deals with the principle of evolution and how individuals evolve with time [5].

Evolutionary algorithm always begins with the formation of initial population, which is basically a collection of randomly generated solutions. Since it is randomly generated it is expected to have good as well as bad characteristics. Every time algorithm will produce a new generation from the previous one using suitable operators. The algorithm will direct its search towards solution with superior characteristics [7].

Genetic Algorithms (GA)

Genetic algorithms are one of the most widely used evolutionary algorithms. Also in the area of automation of analog circuit design, this algorithm has efficiently solved many complex optimization problems. The genetic algorithm search method is based on the principles of natural selection and genetics. The solutions for a search problem are known as chromosomes. The objective function serves as a measure for distinguishing good solutions from the bad ones, so as to give rise to new population. They use selection, crossover and mutation operators for generating new and better population [8] .The algorithm repeats until the termination condition is satisfied.

The following are the steps that explain the operation of genetic algorithm:

1. **Initialization:** The first step involves the creation of a random initial population. This algorithm creates a sequence of new population by performing the following steps:

   i) ***Evaluation:*** This step involves the evaluation (calculation) of fitness values of each member and then the raw fitness scores are scaled accordingly to convert them into more usable values depending upon the problem involved. Evaluation is performed on the evaluation function. Actually evaluation function provides measure of performance with respect to a particular set of parameters whereas fitness function transforms that measure of performance into allocation of reproductive opportunities. Evaluation of a string is independent of evaluation of other strings whereas fitness of a string is defined with respect to other strings[9].

   ii) ***Selection:*** Based on the fitness value evaluated, the members that are supposed to be parents are selected. The basic idea of this selection step is to separate good solutions from the bad ones. Solutions with the better fitness value are selected in accordance with the rule of survival of the fittest. Only the individuals in the current population that have better fitness are chosen as elite and are passed to the next generation.

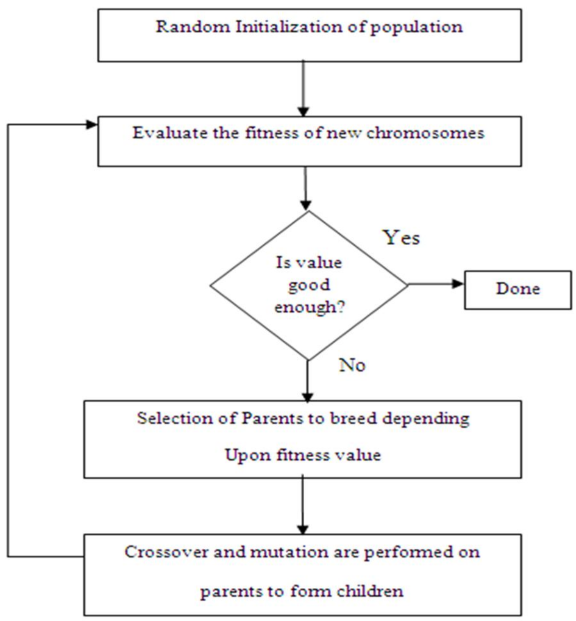

Figure 1. Flow diagram for the operation of Genetic Algorithm

   iii) ***Crossover and mutation:*** This step involves reproduction of children from the parents i.e. combination of two individuals for forming a child for next generation. When the children are produced by making random changes to a single parent this is called *mutation* and if children are produced by combining the vector entries of a pair of parents this is called crossover.

   iv) ***Replacement:*** After the selection, mutation and crossover are over the new population replaces the previous one.

   The steps (i- iv) are repeated until one of the **stopping criteria** is met [8]. The Fig.1 shown above depicts the flow of the operation of genetic algorithm.

Use of GAs for Analog Circuit Design

In ref. [10], authors have discussed the principles, strengths and weaknesses of genetic algorithms used for sizing of analog circuit parameters while meeting desired performance specifications. Also a GA-spice program was developed as a software implementation. The program developed was further used for finding the solution of various practical analog circuit applications. Designs of BJT and CMOS operational amplifiers, a CMOS operational transconductance amplifier (OTA), and a impedance matching network was carried out in [10]. It was observed that GA was able to find solutions for many designs in a much shorter time than trial and error methods.

A modified genetic algorithm has been used in ref. [11], for analog circuit design automation. For applying GA to any analog design circuit, it is required to represent the circuits as chromosomes and component of the circuit or its parameters can be represented as genes. A low pass circuit was designed and results obtained with modified GA were compared with results from traditional GA. It was shown that modified version was more efficient.

Literature comprises of a large volume of research on automation in designing of analog circuits using GAs.

Particle Swarm Optimization (PSO) technique and its applications in ADA

Like Genetic algorithms, there are many another evolutionary optimization techniques which are widely gaining acceptance among the research industry. Particle Swarm Optimization (PSO) technique is a also population-based searching method inspired by mechanisms in nature. The emulation of the flocking behavior of birds is useful for solving he optimization problems [12]. The feasible solutions are represented by a swarm of particles in an efficient way. In this technique each particle has its own position and velocity which are repeatedly updated by tracing the local best position and the global best position found so far. The Fig. 2 shown below represents the flowchart of the operation of PSO [3].

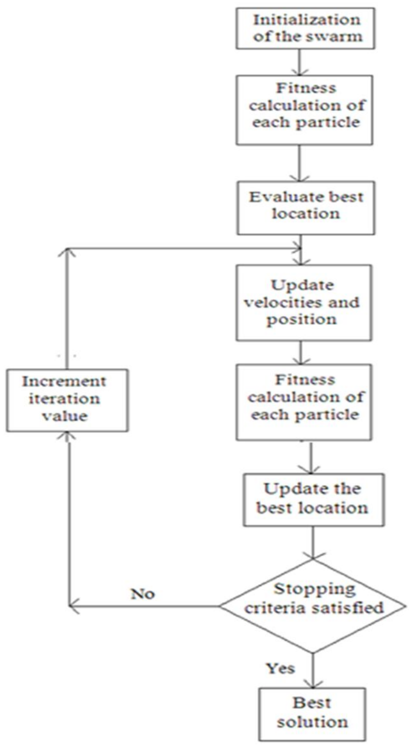

Figure 2. Flow diagram for the operation of PSO [3]

A Particle Swarm Optimization (PSO) technique has been used in [3] for the optimization in the designing of analog circuits. A two-stage Miller Operational Trans-conductance Amplifier (OTA) was considered for the synthesis and was subjected to certain design specifications. Simulation Program with Integrated Circuit Emphasis (SPICE) circuit simulator was used to evaluate the performance and optimize the device sizes using the proposed optimization technique. It was concluded that PSO is a promising approach for device sizing in analog circuits.

In [13] authors have designed an Inductively Degenerated Cascode Low Noise Amplifier (IDCLNA) at 0.13 µm RF CMOS technology and PSO algorithm is used for optimizing the LNA using equation based approach.

Ant Colony Optimization (ACO)

This is another evolutionary algorithm, which is nowadays, finding applications in automated transistor sizing. It was first introduced in early nineties. Deneubourg and his co-workers proposed a model for explaining the foraging behavior of ants which served as the main source of inspiration for the development of ant colony optimization. Like previously discussed algorithms, this one are also inspired by nature and its encouragement is foraging behavior of ants. Authors in [14], have provided the detailed description of this algorithm. Actually in many species of ants, while bringing food from the food source to their nest, ants deposit a substance on the ground which is known as pheromone. Other ants use this pheromone on ground to reach to food source. Therefore, using pheromone ants can communicate effectively with each other. As a result, this served as a main encouragement behind the development of this algorithm.

In ACO algorithm, artificial ants develop solutions to the presented optimization problem. Thus like real ants pass information from one ant to another; the artificial ants pass the information about quality of the constructed solution to other ants in the same manner [2].

In [2], a modified version of ACO (for continuous domain) has been implemented for optimization of transistor sizes. The ACO algorithm was tested on an Analog to Digital Converter (ADC) whose performance was improved by optimizing the widths of the transistors for minimizing the error in its output. A comparison with Genetic Algorithm was also carried out for the given circuit specifications. It was concluded that ACO was much better than GA in terms of consistency and efficiency in terms of time.

This work mainly discusses about GA, PSO and ACO evolutionary algorithms, but there are many more evolutionary approaches finding applications in analog circuit design.

Conclusion

This paper briefly discusses about the need of automation in analog design industry. As the complexity of circuits is increasing day by day, the designing of analog circuits has become a challenging issue for the circuit designers. Currently the main focus of Electronic Design Automation (EDA) industry is on developing methodologies for ICs design to obtain optimal circuit topologies and sizes of circuits satisfying desired specifications. And for solving such complex multi-objective optimization problems, the use of evolutionary computation is widely gaining popularity. A review of some popular evolutionary algorithms (GA, PSO, and ACO) has been presented in this paper. The literature shows that these evolutionary approaches are successful to a large extent in the finding optimum solutions for many analog circuit designs. Thus they can be thought of as a good solution for design problems arising in the field of automated analog design. And it is hoped that in coming future, new algorithms will be developed by the researchers thus leading to progress in this domain.

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