Optimization of Filter and Operational Amplifier Based on Evolutionary Strategy

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Abstract. Optimization of analog circuits relies on engineers’ experience and intuition to find suitable parameters to satisfy circuit specifications. This job is highly labor-intensive, highly repetitive, and time-consuming, but the optimized circuit is sub-optimal. In this paper, the evolutionary strategy is proposed to optimize analog circuit design strategy. The filter designed by engineers and operational amplifier with random generated instances’ parameters are included, and the S parameters of the filter and the gain and dynamic power consumption of the operational amplifier are optimized respectively. The simulation results show that the filter and operational amplifier can be further optimized by using the evolutionary strategy. This method can greatly reduce the workload of analog circuit designers, improve the performance of analog circuits and shorten the design cycle.

1. Introduction

Analog circuits are the basis of electronic circuits, which process continuous signals and provide interfaces with digital circuits. Analog circuits have large parameters needed to be adjusted to optimize performances. However, the relationship between parameters and performances is uncertain, and engineers lack formulas or rules to follow. Analog design octagon illustrates that performance indices are interrelated, improving one performance will lead to other performances decaying [1]. Hence engineers require rich experience to weigh and consider balance based on circuit requirements. Moreover, the huge parameters space and long simulation time make the exhaustive method impossible. Repeatable operation greatly increases the workload of engineers during optimization.

Several existing approaches, such as Bayesian Optimization[2], Gaussian process[3] and simulated annealing[4], have been used to optimize analog designs. Machine learning is another promising method to solve parameter optimization. Electronic design automation (EDA) companies have already integrated machine learning into software tools to improve design efficiency, for instance, Cadence Innovus, Project Virtus and Mentor’s Solido Design Automation. Google recently reported a method of chip placement based on deep reinforcement learning, which could generate placements in under 6 hours, whereas human experts needed to take several weeks[5].

Previous studies on machine learning in circuit design are most applied in digital design. A few papers are focusing on the optimization of analog circuit design with machine learning. Differential evolution algorithm[6] and non-dominated sorting genetic algorithm (NSGA-II)[7] are adopted to optimize analog circuit design.
This paper provides a method based on evolutionary strategy to tune parameters and optimize performances of analog circuits. The filter designed by engineers and an operational amplifier (OPA)\cite{8} with randomly generated instance parameters can be optimized by this method to improve performances.

2. Methodology

We have a schematic diagram, and the parameters of instances in the schematic diagram are provided by engineers or generated randomly. There are some design rules in analog circuits, such as geometry range parameters of instances. The Evolution Strategy (ES)\cite{9} program sets the range of parameters such as width and length according to design rules. These parameters are set to various genes of the schematic diagram, and the (1+1)-ES is selected to simulate the evolution process. For (1+1)-ES, the population contains only one individual, and only the mutation operation is used to produce an offspring. The offspring is compared with the parent, then the better one is the parent of the next mutation operation according to the fitness function.

The parameter vector provided by the engineer or the randomly generated parameter vector is taken as the initial population. Firstly, the computer runs the simulation tool (Spectre) with the initial parameters to record performance metrics of interest. Then the program randomly selects one parameter in the parameter vector to mutate, and randomly generates a new parameter value in the range of 90%~110% of the original parameter value to replace it and generate a new parameter vector. The new parameter vector is written into the schematic and the same performance metrics are recorded after simulation. The better one of the parent and offspring is the new parent of the next generation. The fitness functions of the filter and OPA are respectively presented below.

\[
f_{\text{filter}} = \frac{1}{100} \sum_{i=1}^{100} 20 \log (S11(1 + (100 - i) \times 3 \times 10^6))
\]

\[
\text{Power}_{\text{OPA}@20KHz} = 1.8 \times \text{RMS}(I_{\text{VSS,trans}})
\]

\[
f_{\text{OPA}} = \frac{1}{\text{Power}_{\text{OPA}@20KHz}} \times \frac{1}{91} \sum_{i=0}^{90} 20 \log \left( \frac{V_F(V_{\text{out,AC}})}{10^{\frac{i}{20}}} \right)
\]

The optimization program was written in Python and Cadence SKILL languages. Python scripts are used to randomly generate instances’ parameters and execute (1+1)-ES. The SKILL script is used to modify instances’ parameters in the circuit, run the simulation and output fitness values.

![Figure 1. The filter schematic provided by the engineer.](image-url)
$S_{11}$, $I_{(V_{SS},tran)}$, $V_{F(V_{out},LAC)}$ are waveforms generated by Cadence Spectre and can be read the ordinate on the given horizontal coordinate value.

3. Simulation and optimization

3.1. Optimization of Filter

In the filter simulation and optimization, we focus on S parameters, and the rule is “the smaller the better” for $f_{filter}$. We run the ES program (4000 generations) and simulation for about five hours. Fig. 1(a, b) display initial parameters and optimized parameters. The S parameters ($S_{11}$, $S_{21}$) are finally simulated by Advanced Design System (ADS) and Cadence Spectre with the initial parameters and optimized parameters. As shown in Fig. 2, the ES program gets more optimized parameters compared to the engineer.

![Figure 2. S11(a) and S21(b) simulation. The green lines are for initial parameters provided by the engineer. The red lines are for optimized parameters after 4000 generations.](image)

3.2. Optimization of OPA

In the OPA simulation and optimization, we focus on power ($Power_{OPA@20kHz}$) and gain (dB20), and the rule is “the larger the better” for $f_{OPA}$. We run the ES program (30000 generations) and simulation for about sixty hours, and the results have been plotted in Fig. 3 and Fig. 4. The optimization is fast in budding generations. With the increase of generations, the optimization becomes more and more unapparent. The optimum individual is the 27126th generation in Fig. 4(b).

![Figure 3. The simulation and calculation results of every generation. Power(a), gain(b).](image)
4. Conclusion
We propose to use evolutionary strategy to automatically optimize analog circuits parameters. Compared with the supervised learning, ES only needs a small training set or even an initial parameter vector. We have proven this method on the filter (S-parameter) and OPA (gain and power), which can be applied to the automatic optimization of analog circuits including analog integrated circuits. In the future, more performances will be calculated in the ES program.

Figure 4. The $f_{OPA}$ calculation results of every generation.

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