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Review

Optimal components selection for active filter design with average differential evolution algorithm

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ABSTRACT

Component selection in electronic circuit design is an important issue to achieve a targeted performance and quality level. Particularly in filter circuits, changes in gain and phase response of the circuit are directly dependent on the component values of the filter. Therefore, the selection of component values must be done carefully. In this article, a differential evolution (DE) algorithm with a new mutation strategy, named as average DE (ADE), is introduced for analog active filter design. The ADE algorithm minimizes the total design error of the state variable filter (SVF) for the optimal selection of component values. Simulation results indicate that the proposed algorithm reduces the design error when compared to other methods.

1. Introduction

Active analogue filters have been widely used in electronic systems because they have certain advantages. They offer the flexibility of gain and frequency adjustment. Active filters can be designed to provide required gain by using amplifier, and hence no attenuation as in the case of passive filters [1]. They can be smoothly tuned and adjusted over a wide range. An analog active filter uses amplifiers and transistors with resistors and capacitors added. Amplifiers used in active filter design can improve the performance of the filter. Therefore, researchers continue to study optimal sizing and power optimization in design [2–5]. On the other hand, the selection of passive components such as resistors and capacitors used in filter design is also a critical issue. The stability of the filter and its ability to suppress noise depend on directly the selection of values of these resistors and capacitors. Therefore, component selection becomes an important issue in analog filter design and this paper focus on this issue. It is both difficult and time consuming to solve all possible resistor and capacitor combinations by hand. On the other hand, component values can be arbitrarily selected in theory for a specialized design. However, in practice, these values should be fixed in component values in the manufactured series. Because, industrial component values such as E12, E24, E96 series are standardized. As a result, the selection of component transforms a discrete optimization problem. Both manufacturing constraints and expanded time with the increasing number of components leave traditional methods helpless to solve this problem. As an alternative to solving this problem, intelligent search algorithms recently have provided considerable improvement. Reported studies in this area can be summarized as follows: In [6], a second-order SVF active filter has been designed. Component values of filter have been estimated over genetic algorithm (GA). The parallel tabu search algorithm (PTSA) is proposed for component selection of active filter [7]. The proposed method has been shown to reduce design errors compared to traditional methods. In [8], the performances of PSO, GA and ABC algorithms in active filter design have been investigated. Comparisons based on different manufacturing series have emphasized that heuristic algorithms reduce design errors. In the other work, HS and DE algorithms applied to optimal filter design [9]. The comparative results of proposed algorithms and other methods are analyzed in terms of execution time and total error value. Since the selection of component values from manufactured series require a discrete calculation, intelligent search algorithms have also been shown in other studies that offer more feasible solutions in active filter design [10,11].

This work suggests the ADE algorithm for optimal active filter design. The proposed algorithm is used for component selection of active filter. A second-order SVF topology is used because it was discussed in the literature.

Because the ADE algorithm is a DE algorithm with a new mutation operator, firstly, comparisons of ADE and famous DE algorithms were performed over a benchmark set in simulation studies. Then, the ADE based active filter design has been realized. Obtained results are discussed in comparison with the other methods.

2. State variable filter (SVF) design methodology

SVF's are amplifier circuits consisting of cascade connected

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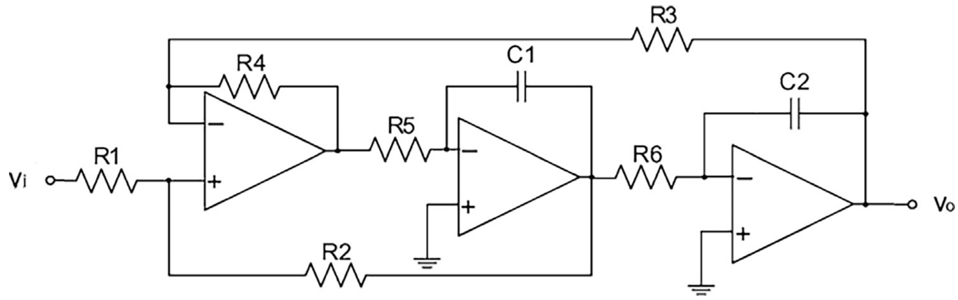

Fig. 1. Second-order SVF topology.

integrators. They continue their popularity in electronic systems because they can offer high input impedance, low output impedance and ideally any arbitrary gain. Furthermore, the gain, cut-off frequency and quality factor of the filter can be adjusted or set independently without affecting the filters performance [12]. In the literature, the state-space models of SVF can be found in detail [13]. Fig. 1 shows the basic design circuit for a second-order SVF topology used in this work. In this schematic, the low-pass output is considered a desired output.

According to the topology shown in Fig. 1, the response of the filter circuit is characterized by the cut-off frequency and the filter quality factor. These values depend on the values of resistors and capacitors, which are passive components in the circuit, as defined in (1) and (2). The aim here is to select the values of these components in order to obtain a target cut-off frequency and quality factor.

$$\omega_{SVF} = \sqrt{\left(\frac{R_4}{R_3}\right)\left(\frac{1}{R_5 R_6 C_1 C_2}\right)} \tag{1}$$

$$Q_{SVF} = \frac{(R_1 + R_2)R_3}{(R_3 + R_4)R_1}\sqrt{\frac{R_4 R_5 C_1}{R_3 R_6 C_2}} \tag{2}$$

Component values that make up the cut-off frequency and quality factor of the SVF mentioned above should be chosen at the feasible values for a desired output. Therefore, component selection becomes an optimization problem. To solve this problem, the objective functions defined in (3) is given in the literature [7–10].

$$f_{SVF} = Total\ Error = 0.5E_{\omega SVF} + 0.5E_{QSVF} \tag{3}$$

In this equation representing the total design error, $E_{\omega SVF}$ is a cut-off frequency error, E_{QSVF} is a quality factor error. And they are calculated by the following equations:

$$E_{\omega SVF} = \frac{|\omega_{SVF} - \omega_t|}{\omega_t} \tag{4}$$

$$E_{QSVF} = \frac{|Q_{SVF} - Q_t|}{Q_t} \tag{5}$$

Here, Q_t is a target quality factor, ω_t is a target cut-off frequency.

The total design error given in (3) is the objective function of the optimization problem. Therefore, the task of heuristic algorithms is to determine the most appropriate combination of component values to minimize this error. Ideally, this combination can be infinite. However, in practice, component values must be chosen according to manufacturer's standards. In this case, the resistor and capacitor values to be selected must be the values in the manufactured series such as E12, E24 and E96. As shown in the second-order SVF circuit shown in Fig. 1, there are a total of 8 components, 6 resistors and 2 capacitors. For probable values of these components in the search process, a coding scheme defined as below is used in the range of 10^3–$10^6(\Omega)$ and 10^{-6}–10^{-9}(F) for resistors and capacitors, respectively.

$$\begin{aligned} R_1 &= A \times 100 \times 10^a\ (\Omega), & R_2 &= B \times 100 \times 10^b\ (\Omega) \\ R_3 &= C \times 100 \times 10^c\ (\Omega), & R_4 &= D \times 100 \times 10^d\ (\Omega) \\ R_5 &= E \times 100 \times 10^e\ (\Omega), & R_6 &= F \times 100 \times 10^f\ (\Omega) \\ C_1 &= G \times 100 \times 10^g\ (\text{pF}), & C_2 &= H \times 100 \times 10^h\ (\text{pF}) \end{aligned} \tag{6}$$

According to this coding scheme, the design constraints of the resistors and capacitors are given in (7), (8) and (9) respectively for the series E12, E24 and E96.

$$0.1 \leqslant A, B, C, D, E, F, G, H \leqslant 0.82 \ \text{ and } \ 2 \leqslant a, b, c, d, e, f, g, h \leqslant 4 \tag{7}$$

$$0.1 \leqslant A, B, C, D, E, F, G, H \leqslant 0.91 \ \text{ and } \ 2 \leqslant a, b, c, d, e, f, g, h \leqslant 4 \tag{8}$$

$$0.1 \leqslant A, B, C, D, E, F, G, H \leqslant 0.976 \ \text{ and } \ 2 \leqslant a, b, c, d, e, f, g, h \leqslant 4 \tag{9}$$

The sensitivity is an important issue in analog circuit design. Some changes in design parameters can transform a feasible solution to a non-feasible one. It is desired that a design has a low sensitivity [14]. In this paper, multi-parameter sensitivity analysis is performed for filter sensitivity [2].

In general, the relative or normalized sensitivity S can be defined as the cause and effect relationship between the circuit elements variations, and the resulting changes in the performance response (objective function) [2].

Consider $f_i(x)$ be an objective function, where $\overrightarrow{X} = [x_1, \ldots x_n]^T$ is the vector of design variables. It is possible to relate small changes in the objective function (∂f_i, $i \in [1, m]$) to variations in design variables (∂x_j, $j \in [1, n]$). It leads to the single parameter sensitivity definition given by following [15,2]:

$$S_{xj}^{f_i} \approx \frac{\partial f_i / f_i}{\partial x_j / x_j} \approx \frac{x_j}{f_i}\frac{\partial f_i}{\partial x_j} \tag{10}$$

It is possible to define the multi-parameter sensitivity, which sums the different single sensitivities regarding the different variables for each objective function as follows [2]:

$$S^{f_j} = \sqrt{\sum_{i=1}^{n} |S_{x_i}^{f_j}|^2 \sigma_{x_i}{}^2} \tag{11}$$

where $\sigma_{x_i}$is a variability parameter of $x_i$and the square root is used to preserve the same units. That way, the multi-parameter sensitivity for the SVF can be calculated as follows:

$$S^{f_{SVF}} = \sqrt{\sum_{i=1}^{6} |S_{R_i}^{f_{SVF}}|^2 \cdot \sigma_{R_i}{}^2 + \sum_{i=1}^{2} |S_{C_i}^{f_{SVF}}|^2 \cdot \sigma_{C_i}{}^2} \tag{12}$$

where x_i is replaced by variable resistor parameter R_i and variable capacitor parameter C_i.

3. Basic DE algorithm

DE is a population-based algorithm that uses some genetic process [16]. This method, which improves individuals in population by using random selection and alterations throughout generations, is an effective