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# A novel Alienor-based heuristic for the optimal design of analog circuits

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ABSTRACT

A heuristic for solving (non-linear and constrained) analog optimization problems is proposed. The method is based on an approximation of multi-variable multi-objective problems by a mono-objective problem of one variable: the Alienor technique and a normalization technique are used for this purpose. Application to the optimal design of an inverted CMOS current conveyor and a class AB grounded gate switched current memory cell are given.



## 1. Introduction

Analog circuits are key components of mixed-signal systems. Despite their importance, analog design automation still lags behind digital design automation, so that analog design is often a bottleneck in the mixed design flow [1,2]. The analog design flow is composed of three major steps: topology selection, component sizing and layout generation [3]. The sizing task is a slow, tedious and complicated process. It generally relies on the designer experience [4]. This is mainly due to the following two facts:

- The optimization problem is seldom mono-objective; it is generally a set of several (contradictory) objectives that must be satisfied simultaneously.
- The circuit design parameters are multiple.

Common approaches are generally either fixed topology and/or statistic-based techniques (see for instance [5–8]). They generally start with finding a "good" DC operating point which is provided by the analog "expert" designer. Then, a simulation-based tuning procedure takes place. However, these statistic-based approaches are time consuming. Besides, they do not guarantee the convergence to the global optimum solution. Some mathematical heuristics were also used, such as local search [9,10], simulated annealing [10–13], tabu search [14,15], scatter search [16], genetic algorithms [17–19], particle swarm optimization technique [20–24], ant colony optimization [20,25], etc. However, these techniques do not offer general solution strategies and are delicate to be adapted to different problems.

A general optimization problem can be defined in the following format:

$$\begin{aligned}&\text{minimize}\, \vec{f}(\vec{x}) \quad \vec{f}(\vec{x}) \in \Re^k,\\&\text{such that}: \ \vec{g}(\vec{x}) \leqslant 0 \quad \vec{g}(\vec{x}) \in \Re^m,\\&\text{where}\ \vec{x} \in C \subset \Re^n\end{aligned} \tag{1}$$

with $k$ objectives to optimize; $m$ constraints to satisfy; $n$ parameters to manage, where $x_{Li} \leqslant x_i \leqslant x_{Ui}$, $i \in [1, n]$.

$C$ represents a subset of the parameter space set associated with inequality (and equality) constraints as well as explicit bounds.

In this paper it is presented an approach which is quite promising. It consists of transforming the aforementioned $n$-variable multi-objective problem into a mono-objective mono-variable problem, thus making easy computing the optimal solution of the optimization problem.

The problem given by (1) will be transformed into the form

$$\begin{aligned}&\text{minimize}\, f(\theta) \quad f(\theta) \in \Re^k,\\&\text{such that}: \ \vec{g}(\vec{x}) \leqslant 0 \quad \vec{g}(\vec{x}) \in \Re^m,\\&\theta \in \Re^*\end{aligned} \tag{2}$$

The proposed approach consists of the following two crafts:

- Reducing different unknowns, i.e. the variables, involved in the sizing problem to a single variable, with the help of the Archimedes' spiral.
- Transforming the multi-objective problem into a mono-objective one, using a 'normalization' technique.

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It is to be mentioned that both techniques are not new, but the novelty of the proposed work consists of the combination of the normalization technique and the Alienor technique, which, according to the knowledge of the author, has not been used in the analog design field.

The proposed heuristic is simple; it does not need an optimization background from the user in order to be handled and adapted to different applications.

The remainder of the paper is structured as follows: Section 2 presents the reducing technique, i.e. the Alienor technique. In Section 3, the approach used to transform a multi-objective problem into a mono-objective one is presented. The proposed heuristic is also detailed in this section. Section 4 deals with two application examples. Finally, Section 5 summarizes the presented work.

## 2. The basic Alienor method

The Alienor reducing transformation method can be summarized as follows [26]:

$$\text{Minimize}\left[\underset{(x_1,x_2,\ldots,x_n)\in\prod_{i=1}^{n}[x_{i\,\min},x_{i\,\max}]}{f(x_1,x_2,\ldots,x_n)}\right] \quad (3)$$

where ($x_1$, $x_2$, …, $x_n$) refers to the circuit unknown parameters, such as width and length of MOS transistors. $x_{i\,\min}$ and $x_{i\,\max}$ denote minimum and maximum values of the $i$th variable, respectively.

The approach consists of constructing a parameterized curve ($g(\theta)=g_1(\theta)$, $g_2(\theta)$,…,$g_n(\theta)$), $\alpha$-dense[1] in $\prod_{i=1}^{n}[x_{i\,\min}, x_{i\,\max}]$ for $\theta\in[0, \theta_{\max}]$, where $\theta_{\max}$ is the supernum of the domain of definition of the function $g$ when it $\alpha$-densifies the hyper-rectangle [26].

The minimization problem (3) is then approximated by the problem

$$\text{Minimize}\left[\underset{\theta\in[0,\theta_{\max}]}{f^*(\theta)}\right] \quad (4)$$

where $f^*(\theta)=f(g(\theta))$.

Functions $g_i(\theta)$ are explicitly defined in function of sinus and cosinus [26,27].

The transformation allows expressing $n$ variables into a single variable. To do that, Archimedes' spirals, expressed in polar coordinates, are used.

For instance, for $n=2$, it is set:

$$\begin{aligned} x_1 &= r\cos(\theta)\\ x_2 &= r\sin(\theta)\\ \theta &> 0 \end{aligned} \quad (5)$$

where $r$ and $\theta$ are the polar coordinates.

Then $r$ and $\theta$ are linked by the Archimedes' spiral. Expression (5) becomes

$$\begin{aligned} x_1 &= a\theta\cos(\theta)\\ x_2 &= a\theta\sin(\theta) \end{aligned} \quad (6)$$

$a$ is a fixed parameter which ensures convergence when it goes to zero.

$x_1$ and $x_2$ are thus expressed as functions of the single variable $\theta$. Fig. 1 illustrates the Archimedes' spiral.

Expression (6)may be considered as the restriction of $\Re^2$ to the Archimedes' spiral $r=a\theta$: any point of $\Re^2$ is at a maximum distance ($\pi a$) of a point of the Archimedes' spiral (Fig. 2).

[1] Definition of $\alpha$-density is given in Appendix.

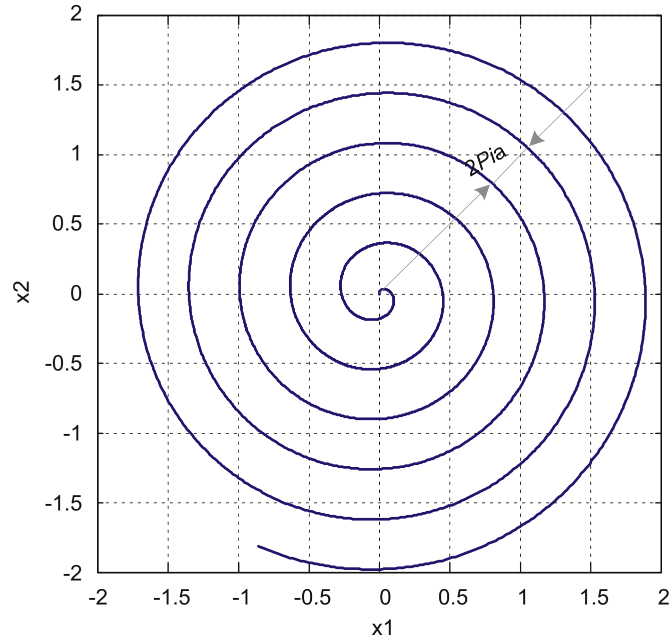


**Fig. 1.** The Archimedes' spiral.

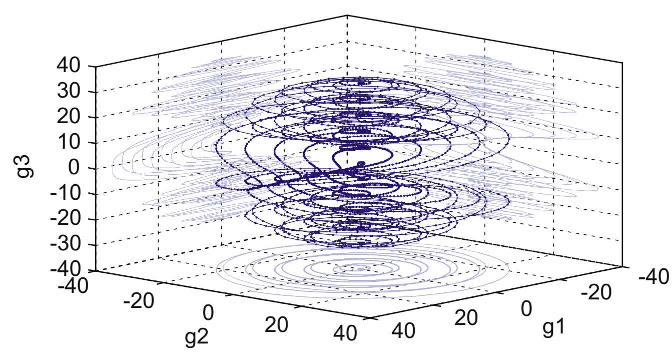


**Fig. 2.** The Alienor technique ($n=3$).

For the case of three variables ($x_1$, $x_2$, $x_3$), $x_1$ is linked to $x_2$ with $\theta_1$:

$$\begin{aligned} x_1 &= a\theta_1\cos(\theta_1)\\ x_2 &= a\theta_1\cos(\theta_1) \end{aligned} \quad (7)$$

After that $x_3$ is linked to $\theta_1$ with $\theta$:

$$\begin{aligned} \theta_1 &= a\theta\cos(\theta)\\ x_3 &= a\theta\sin(\theta) \end{aligned} \quad (8)$$

Thus, the parameterized curve $g(\theta)=(g_1(\theta), g_2(\theta), g_3(\theta))$ is obtained:

$$\begin{aligned} g_1(\theta) &= a^2\theta\cos(\theta)\cos[a\theta\cos(\theta)]\\ g_2(\theta) &= a^2\theta\cos(\theta)\sin[a\theta\cos(\theta)]\\ g_3(\theta) &= a\theta\sin(\theta) \end{aligned} \quad (9)$$

Fig. 2 illustrates a plot of three variables.

More generally, it is possible to state that the technique involves a tree structure as it is illustrated in Fig. 3. So, if $n$ variables are considered, previous transformations could be iterated, leading to

$$\underset{i\in[1,n]}{x} = h_i(\theta) \quad (10)$$