New Adaptation of the ACO Algorithm for the Analog Circuits Design Optimization

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Abstract

We propose a novel adaptation of the Ant Colony Optimization (ACO) Technique to optimize analog circuits sizing and design. The proposed algorithm is first tested and its performances are highlighted by using some mathematical test functions. This new adaptation of the ACO algorithm is then directly applied to optimize the design of typical analog circuits, namely CMOS current conveyors. SPICE simulation results are given to show the validity of the proposed algorithm.

Keywords: *ACO, CMOS class AB CCII, Metaheuristic, test function.*

1. Introduction

Nowedays, the realization of more and more complex integrated electronic circuits and systems is possible thanks to the evolution of integrated circuits technologies. Analog circuit design became so complicated and delicate process, because it is related not only to the placement and the routing of the components, but also to their sizing. Generally, the analog circuit sizing is a slow, tiresome and iterative process, and carried out thanks to the experiment and the intuition of the designer. The best-known approaches in literature are based on fixed topologies and/or statistical techniques [1]. The problem with these methods is that they are often very slow and they don't guarantee convergence to a global optimum. The use of new methods is required.

Methods based on the use of heuristics appeared then to resolve optimization problems [2]. Among these heuristics, some are adaptable to many different problems referred to as Meta heuristics. They always offer approximate solutions for optimization problems at a very reasonable times [3]. Some (meta-)heuristics are also proposed in the literature and are used by the designers, such as Tabu Search [4,5], Genetic Algorithms (GA) [6], local search (LS) [7], etc…, the efficiency of these methods is highly dependent on the algorithm parameters, the number of variables, the constraint functions and the dimension of the solution space.

In order to overcome drawbacks of the aforementioned optimization approaches, a new set of nature inspired heuristic optimization algorithms was proposed. These techniques are resourceful, efficient and easy to use. They are known as Swarm Intelligence (SI) [8]. They focus on animal behavior and insect conduct in order to develop some metaheuristics which can mimic their problem solution abilities, namely, Particle Swarm Optimization (PSO) [9,10], Bacterial Foraging Optimization (BFO) [11] and Ant Colony Optimization (ACO) [12-14].

In the domain of metaheuristic methods, an important interest has been paid to the Ant Colony Optimization algorithm for solving optimization problems. Many variants of it have been developed, leading to the formulation of Ant were previously proposed by the authors [15,16]. In this work, we focus on the use of a novel adaptation depending on two pheromones distributions, one on the vertex and the other on the summit of the graph.

The remainder of the paper is structured as follows: The second section presents an overview of the ACO technique. The third section deals with the proposed adaptation of the ACO technique for solving combinatorial optimization. The fourth section presents the algorithm viability by test functions. The fifth section deals an application example, i.e. optimal sizing of a CMOS Class AB CCII based on a differential pair. Finally, the sixth section summarizes the presented work and highlights some perspectives.

2. Ant colony optimization technique: An overview

ACO technique is inspired by the collective behavior of deposit and monitoring of slopes that is observed in insect colonies [12,14], such as ants. Figure 1 shows an illustration of the ability of ants to find the shortest path between food and their nest. It is illustrated through the example of the appearance of an obstacle on their path. Ants communicate indirectly through dynamic changes in their environment (pheromone trails).

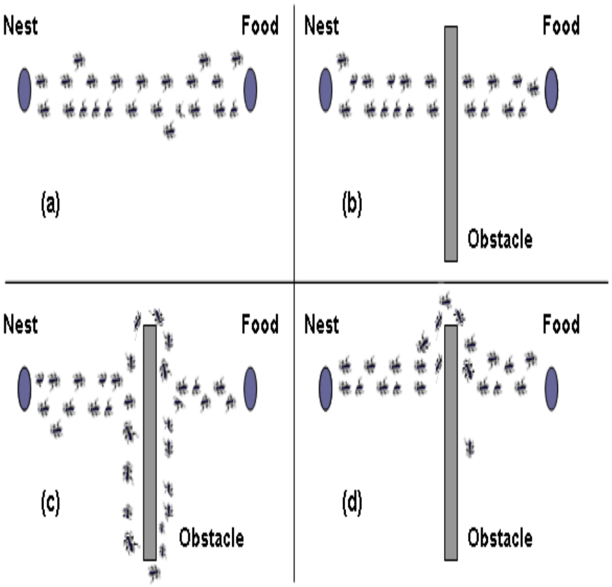


Fig. 1 Self-adaptive behavior of a real ant colony.

(a) ants follow a path between nest and food source; (b) An obstacle appears on the path: ants choose, with equal probability, whether to turn left or right; (c) higher amount of pheromone is deposited on the short path; (d) the majority of ants have chosen the shortest path.

ACO was initially used to solve graph related problems, such as the traveling salesman problem (TSP) [17], vehicle routing problem [18]... For solving such problems, ants randomly select the vertex to be visited. When an ant k is in a vertex i, the probability of going to vertex j is given by expression (1) [14,19,20].

$$p_{ij}^{k} = \begin{cases} \dfrac{(\tau_{ij})^{\alpha}.(\eta_{ij})^{\beta}}{\sum_{l \in J_i^k} (\tau_{il})^{\alpha}.(\eta_{il})^{\beta}} & if \quad j \in J_i^k \\ 0 & if \quad j \notin J_i^k \end{cases} \tag{1}$$

where J_i^k is the set of neighbors of vertex i of the k^{th} ant, τ_{ij} is the amount of pheromone trail on edge (i, j), α and β are weightings that control the pheromone trail and the visibility value, i.e. η_{ij}, whose expression is given by (2).

$$\eta_{ij} = \frac{1}{d_{ij}} \tag{2}$$

d_{ij} is the distance between vertices i and j.

The pheromone values are updated each iteration by all the m ants that have built a solution in the iteration itself. The pheromone τ_{ij}, which is associated with the edge joining vertices i and j, is updated as follows:

$$\tau_{ij} = (1-\rho) \cdot \tau_{ij} + \sum_{k=1}^{m} \Delta \tau_{ij}^{k} \tag{3}$$

where ρ is the evaporation rate, m is the number of ants, and $\Delta \tau_{ij}^{k}$ is the quantity of pheromone laid on edge (i, j) by ant k:

$$\Delta \tau_{ij}^{k} = \begin{cases} \dfrac{Q}{L^k} & \text{if ant k used edge (i, j) in its tour,} \\ 0 & \text{otherwise} \end{cases} \tag{4}$$

Q is a constant and L^k is the length of the tour constructed by ant k.

3. Adaptation of the ACO technique

The proposed algorithm consists of constructing a graph that imitates the movement of the ants. For this purpose we construct a graph composed of the discretized variable vectors. The vertices of the graph correspond to these variable values. Thus, each ant will construct its path by a random move from a variable value to another, as it is shown in Figure 2. *V1, V2, V3…VN* are the discrete variable vectors.

In short, each ant k will randomly choose a path (values of *V1, V2 …*), according to the probability given by expression (1) with $\beta=0$, and form a non-connected directed graph while randomly generating (two structures) a rate of pheromone at the formed graph edges and summits. At each iteration, the path giving the minimum value of the objective function (OF) sees its rate of summit increase, in contrast with the other paths and summits which pheromone rates are partially evaporated with respect to expression (3).

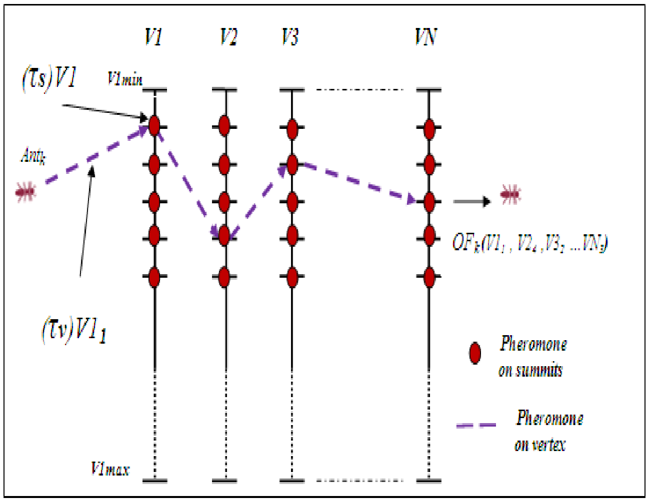


Fig. 2 A pictorial graph showing the mouvement of the ants.

The proposed algorithm operates as it is be shown in Figure 3.

It mainly consists of including computing the movement probability of each ant, computing and updating the pheromone rates.

4. Typical test functions

In order to check the performances of the proposed algorithm, two test functions [21,22] were used for this purpose. Their expressions are given in Table 1 and Figures 6 and 7 show their plots.

Table 1: The test functions

	Variable Bounds	Objective Functions
F1	$-4 \le x, y \le 4$	$f(x,y)=(1.5-x+xy)^2+\left(2.25-x+xy^2\right)^2+\left(2.625-x+xy^3\right)^2$
F2	$0 \le x, y \le 10$	$f(x,y)=x\sin(4x)+1.1y\sin(2y)$

Table 2 gives ACO algorithm parameters.

Table 2: Parameters of ACO algorithm

Number of iterations	500
Number of Ants	25
Evaporation rate (ρ)	0.1
Quantity of deposit pheromone by the best ant (Q)	0.2
Pheromone Factor (α)	1

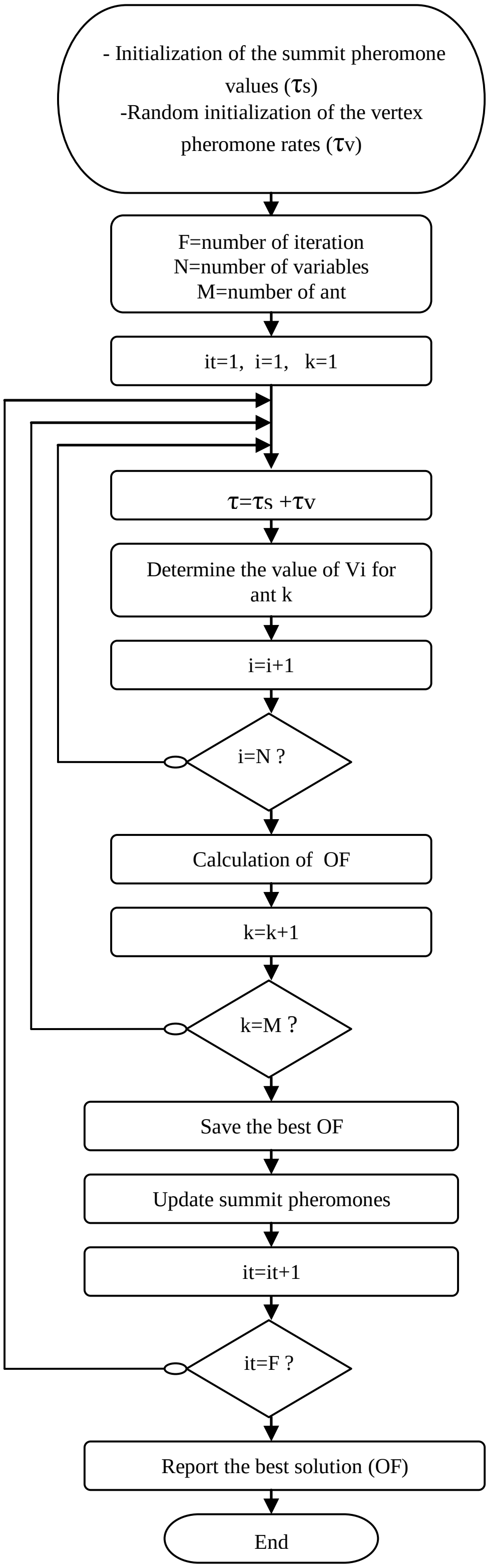


Fig. 3 Flowchart "Adaptation of the ACO technique".

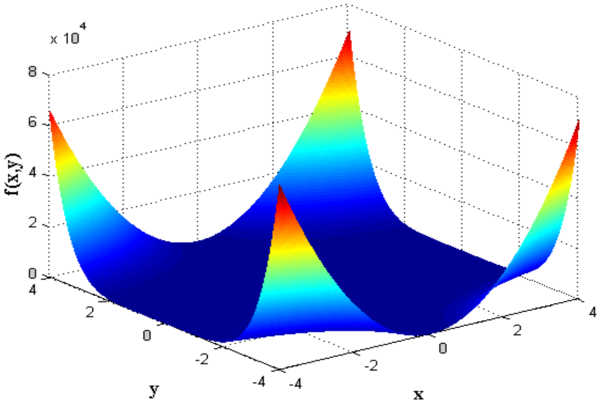


Fig. 5 Function F1.

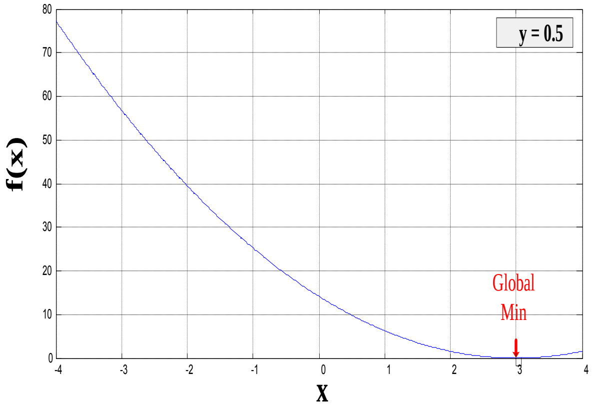


Fig. 6 F1=f(x)y=0.5

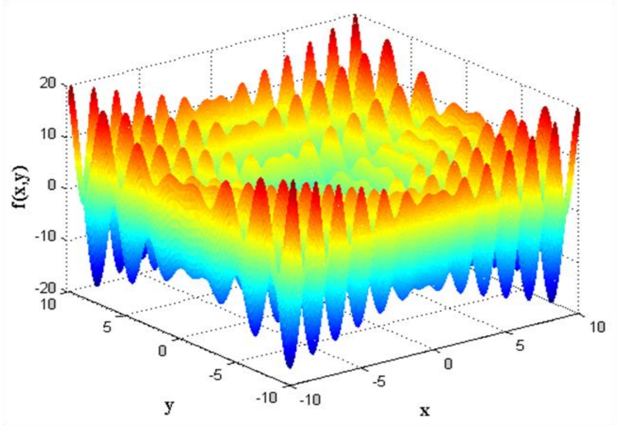


Fig. 8 F2=f(x,y).

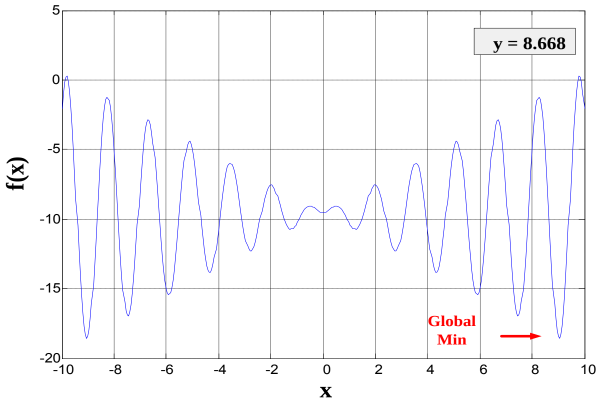


Fig. 9 F2=$f(x)_{y=8.668}$

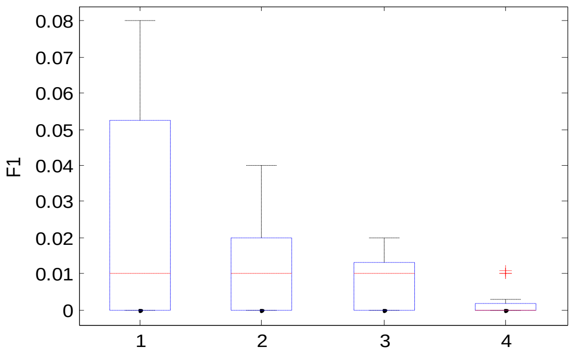
Table 3 presents a comparison between ACO algorithm and theoretical results.

Table 3: Comparison of aco algorithm and theoritical results

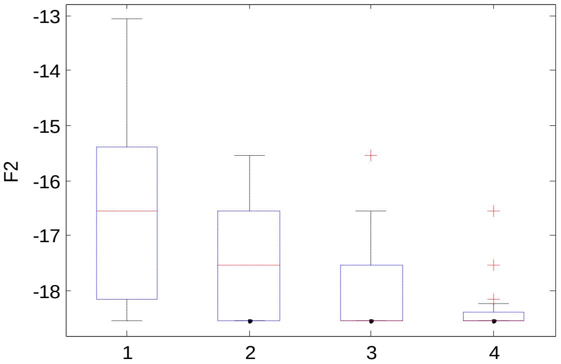
	theoretical results		ACO Algorithm	
	Minimum	Objectif Function	Minimum	Objectif Function
F1	(3,0.5)	0	(3,0.5)	0
F2	(9.039,8.668)	-18.5547	(9.039,8.668)	-18.5547

Good agreement between theoretical results and those obtained using the proposed MATLAB-implemented ACO algorithm.

In order to check the convergence rate of the proposed algorithm, a robustness test was performed. i.e. the algorithm was applied a hundred times for optimizing each objective function. In Figure 9 we present the obtained results for F1 (a) and F2 (b) for different number of generations. One can clearly notice the relatively high convergence ratio to the (same) respective 'optimal' value.



(a)



(b)

Fig. 10 Box plot for 100 runs of the algorithm, (a) for f1, (b) for f2 (1,2,3 and 4 for 50,100,200,500 generations respectively).

Table 4 summarizes and highlights the error rate (%), for different iterations, of F1 and F2 compared to the global optimum. We can clearly note that 500 iterations for the algorithm are sufficient to reach the global minimum.

Table 4: Error rate (%)

	Number of iterations			
	50	100	200	500
F1	1.23	0.06	0.00	0.00
F2	2.38	0.12	0.00	0.00

5. Application example

The proposed ACO algorithm was used to optimize the sizing of MOS transistors constituting one of the most popular analog circuits; the second generation current conveyor. The circuit is designed as a Class AB CCII based on a differential pair (AB-CCII) and is shown in Figure 10 [23]. Two objectives functions are considered: minimizing input X-pole parasitic resistance (*Rx*) and maximizing the dominant pole (*fp*) value of the current transfer function between X and Z poles. Symbolic expressions of *Rx* and *fp* of the AB-CCII are given by equations (5) and (6), respectively.

$$Rx = \frac{1}{go_P + go_N + \dfrac{gm_N\left(gm_N + gm_P\right)}{2go_N}} \qquad (5)$$

$$fp = \frac{1}{2\pi}\sqrt{\frac{\left(gm_P + gm_N\right)gm_N + \left(go_N + go_P\right)^2}{Cgs_N Cgs_P}} \qquad (6)$$

Where $Cgs_{N,P}$, $gm_{N,P}$ and $go_{N,P}$ refer to the parasitic grid to source capacitance, the transconductance and the conductance of the MOS transistor, respectively. Indexes *n* and *p* refer to the NMOS and PMOS transistors, respectively. The technology under consideration is the AMS 0.35µm with a voltage power supply (V_{DD}/V_{SS}) of +1.5V/-1.5V and a bias current, I_{bias} of 20µA.

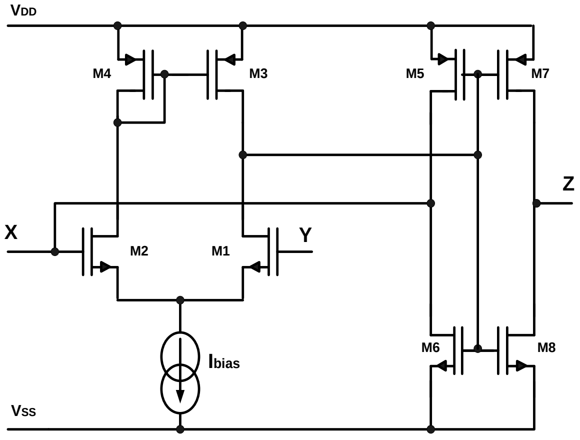


Fig. 10 Class AB CCII based on a differential pair.

Table 5 show the optimal transistors sizes obtained by the proposed algorithm application, using the optimal parameters of the ACO, namely *Q*=0,18 and *ρ*=0,1. These results were obtained with 25 ants at the ACO average computing time of 3s for a 500 generation algorithm.

Table 5: Optimal sizes of transistor dimensions (µm)

W_N	W_P	L_N	L_P
20,00	25,50	0,55	0,35

The values of W_N, W_P, L_N and L_P listed in the table above (Table 5) were used in the schematic design used in the spice environment. The obtained values of R_x and *fp* are shown in Table 6. That the obtained simulation results are in good agreement with those obtained using the proposed ACO adaptation.

It can be clearly noticed that the proposed adaptation of ACO technique globally offers competitive results in terms of objectives and gives better computation time, than these given in [16].

Table 6: Optimal performances of the AB-CCII

	Rx (Ω)	*fp* (Ghz)
Matlab(ACO)	6,8	1,468
PSPICE	6,6	1,435

A technological constraint consists of taking equal channel, widths L_N and L_P. In Table 7 we present the optimal sizes obtaining in this condition (L_N=L_P) as well as the optimal parameters obtained both by the proposed algorithm and SPICE simulations.

Table 7: Optimal sizes and performances of the AB-CCII

Optimal sizes (µm)	L_N=L_P=0,35 W_N=20,00 W_P=40,00
Matlab (ACO)	*Rx* (Ω)=7,5 *fp* (Ghz)=1,836
PSPICE	*Rx* (Ω)=7,3 *fp* (Ghz)=1,828

Again the simulation results are in good agreement with those obtained by using the ACO proposed adaptation.

Figures 11 and 12 show respectively the SPICE simulations of *Rx* and current gain performed by using the sizes given in Tables 5 and 7.

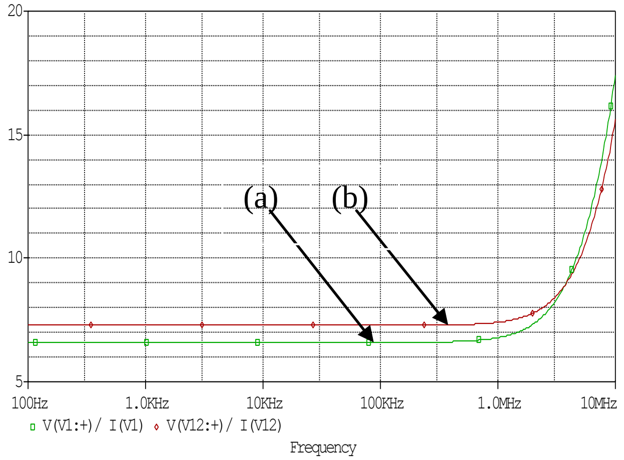


Fig. 11 Rx-pole resistance (Ω) vs. frequency (Hz), (a) for Ln≠Lp , (b) for Ln=Lp

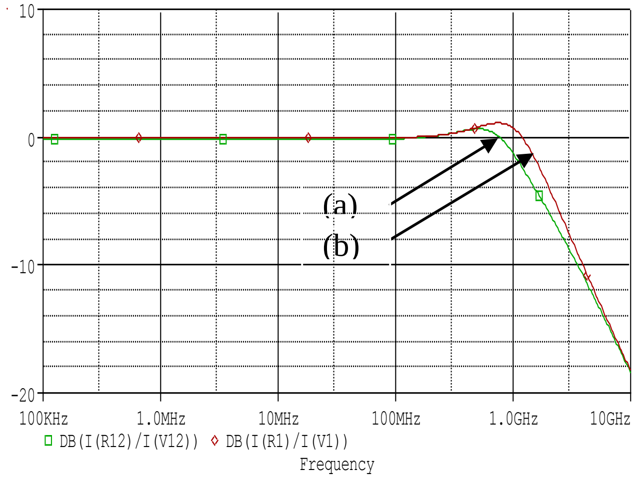


Fig. 12 Current gain (dB) vs. frequency (Hz), (a) for Ln≠Lp , (b) for Ln=Lp

The algorithms were applied a hundred times for the objectives (*Rx* and *fp*) optimization in order to check their robustness. In Figure 13 we present the obtained test results.

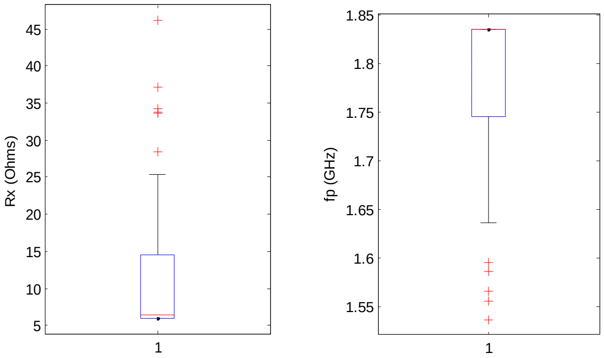


Fig. 13 Box Plot of *Rx* and *fp*.

It is then demonstrated that the proposed algorithm gives best spacing between the values which lead to a low degree of dispersion. In addition, despite the probabilistic aspect of the algorithm, one can easily notice the good convergence ratio.

6. Conclusion

The presented work proposes a novel adaptation, with two pheromone distribution, of the ant colony optimization technique for dealing with the optimal sizing of analog circuits. The proposed algorithm was validated by thru mathematical test functions and applied to optimize performances of a CMOS second generation current conveyor. The reached performances were proven via SPICE simulations. The good robustness is also demonstrated. It is shown that the proposed adaptation of ACO algorithm is faster; with two pheromone structures, the novel adaptation provides better communication system between ants to guides it towards the target solution. Now, we are focusing on transforming the proposed ACO mono-objective algorithm into a multi-objective one.

References

[1] F. Medeiro, R. R. Macías Fernández, F.V.R. Domínguez Astro, J.L. Huertas, A. R. Vázquez, "Global design of analog cells using statistical optimization techniques", Analog integrated circuits and signal processing, Vol. 6, No. 3, 1994, pp. 179-195.

[2] C.R. Reeves "Modern heuristic techniques for combinatorial problems", Blackwell Scientific Publications, Oxford, 1993.

[3] I.H. Osman, J.P. Kelly (Eds.), "Meta-heuristics: theory and applications", Kluwers Academic Publishers, Boston, 1996.

[4] F. Glover, "Tabu search-part I", ORSA Journal on computing, Vol. 1, No. 3, 1989, pp. 190-206.

[5] F. Glover, "Tabu search-part II", ORSA Journal on computing, Vol. 2, No. 1, 1990, pp. 4-32.

[6] J. B. Grimbleby, "Automatic analogue circuit synthesis using genetic algorithms", IEE Proceedings-Circuits, Devices and Systems, Vol. 147, No. 6, 2000, pp. 319-323.

[7] E. Aarts, K. Lenstra, "Local search in combinatorial optimization", Princeton: Princeton University Press, 2003.

[8] F. T. S. Chan, M. K. Tiwari, "Swarm Intelligence: focus on ant and particle swarm optimization", I-Tech Education and Publishing, 2007.

[9] J. Kennedy, R. C. Eberhart, "Particle swarm optimization", The IEEE International conference on neural networks, WA, Australia, November 27–December 1, 1995.

[10] M. Fakhfakh, Y. Cooren, A. Sallem, M. Loulou, P. Siarry "Analog Circuit Design Optimization through the Particle Swarm Optimization Technique", Journal of Analog Integrated Circuits & Signal Processing. Vol. 63, No. 1, Springer April, 2010, pp. 71-82.

[11] A. Chatterjee, M. Fakhfakh, P. Siarry, "Design of Second Generation Current Conveyors Employing Bacterial Foraging Optimization", Microelectronics Journal, Vol. 41, Elsevier, 2010, pp. 616-626.

[12] M. Dorigo, G. DiCaro, L. M. Gambardella, "Ant algorithms for discrete optimization". Artificial Life Journal, Vol. 5, 1999, pp. 137-172.

[13] M. Dorigo S, Krzysztof "An Introduction to Ant Colony Optimization" a chapter in Approximation Algorithms and Metaheuristics, a book edited by T. F. Gonzalez. 2006.

[14] J. Dreo, A. Pétrowski, P. Siarry, E. Taillard, "Metaheuristics for hard optimization: Methods and case studies", New York: Springer, 2006.

[15] B. Benhala, A. Ahaitouf, M. Kotti, M. Fakhfakh, B. Benlahbib, A. Mecheqrane, M. Loulou, F. Abdi, E. Abarkane "Application of the ACO Technique to the Optimization of Analog Circuit Performances", book; Analog Circuits: Applications, Design and Performance, Ed., Dr. Tlelo-Cuautle, NOVA Science Publishers, Inc. 2011, pp. 235-255.

[16] B. Benhala, A. Ahaitouf, M. Fakhfakh, A. Mechaqrane, B. Benlahbib "Optimal Analog Circuit Sizing via Ant Colony Optimization Technique", IJCSNS International Journal of Computer Science and Network Security, Vol.11, No. 6, June 2011, pp. 223-231.

[17] Y. Jinhui, S. Xiaohu , M. Maurizio, L.Yanchun, "An ant colony optimization method for generalized TSP problem", Progress in Natural Science, Vol. 18, No. 11, 2008, pp. 1417-1422.

[18] B. Yu, Z. Yang ,B. Yao, "An improved ant colony optimization for vehicle routing problem" European Journal of Operational Research 196, 2009, pp. 171-176.

[19] D. Marco, B. Mauro, S. Thomas "Ant Colony Optimization", IEEE computational intelligence magazine, november 2006.

[20] S. D. Shtovba "Ant Algorithms: Theory and Applications", Programming and Computer Software, Vol. 31, No. 4, 2005, pp. 167-178.

[21] R. L. Haupt, S. E. Haupt, "Pratical Genetic Algotithms", Willey, Second Edition, 2004.

[22]www.optima.amp.i.kyotou.ac.jp/member/student/hedar/Hedar_files/TestGO_files.

[23] G. Ferri, N. C. Guerrini "Low-voltage low power CMOS current conveyors" eBook ISBN: 0-306-48720-9, Springer Science + Business Media, Inc. 2004.

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