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## A Comparison of Metaheuristic Techniques for RF Passive Components Optimization

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### I- Introduction

The passive components have become essential devices in many circuits used in major radio frequency (RF) domains. The geometrical parameters optimization of RF square spiral inductor is still a delicate step for designers, so practice RF design engineers still often use error for the tuning sizing process. Consequently, optimization methods are required to realize practical radiofrequency designs [1].

The aim of this present work is to compare three metaheuristic algorithms for the optimal design of RF square spiral inductor (4 nH @ 2.4 Ghz) shown in Figure 1. The used algorithms are the Artificial Bee Colony algorithm (ABC) [2, 3, 4], the Ant Colony Optimization (ACO) [5, 6] and the Differential Evolution (DE) [7, 8]. The objective function is to maximize the circuit quality factor-Q (Minimization of  $Q_{req}=1/Q$ ). The computer-aided design tool Momentum-ADS [9] is used to check the viability of the optimization results.

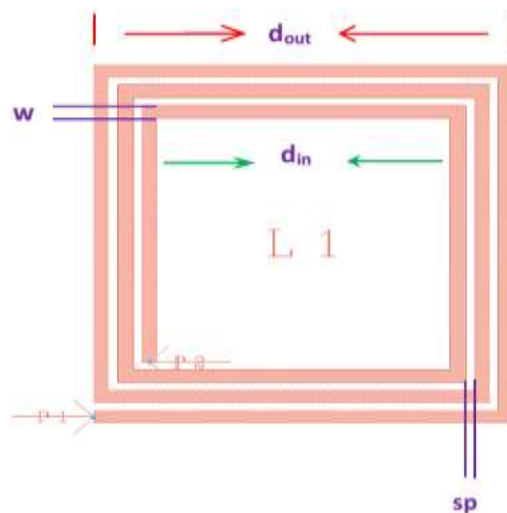


Figure 1. Geometric parameters of a square spiral inductor



Where: (n): Number of turns, (w): Trace width, (sp): Turn spacing,  $d_{out}$ : Outer diameter and ( $d_{in}$ ): Inner diameter

### II- Optimization methodology for inductor design

The design problem of the spiral inductor can be formulated as:

Maximize of Q-quality factor (Minimize  $Q_{req}=1/Q$ ):

The quality factor (Q) can be expressed as [10]:

$$Q = \frac{\omega L_s}{R_s} \cdot \frac{R_p}{R_p + \left[ \left( \frac{\omega L_s}{R_s} \right)^2 + 1 \right] R_s} \left[ 1 - \frac{(C_p + C_s) R_s^2}{L_s} - \omega^2 L_s (C_p + C_s) \right] \quad (1)$$

[Cost Function (CF) is done by equation (1)]

Subject to:

$$Q \geq Q_{L, \min}$$

$$L_s = L_{sreq} \quad ; \text{ Required inductance}$$

Independent geometry parameters constraints may be added such as:

- Number of turn :  $n \leq 4$
- Minimum value of the track width :  $w \leq 12 \mu\text{m}$
- Minimum of spacing :  $sp = 2.5 \mu\text{m}$
- Outer diameter :  $d_{out} \leq 231 \mu\text{m}$

For reducing the parasitic effect due to the proximity problem [11], we will respect this add constraint:

$$d_{in} > 5 \cdot w \quad \text{and} \quad 0.2 < (d_{in}/d_{out}) < 0.8 \quad (2)$$

The object function finds the global minimum CF for its expression:

$$CF = Q_{req} + 1.0e9 \cdot \text{abs}(L_s - L_{sreq}) + \text{penalty} \cdot \text{Sum}(Ct) \quad (3)$$

Where  $Q_{req}=1/Q$ , Penalty: Penalty of each constraint violation, Sum (Ct): Some of all constraints (Ct (1), Ct (2)...).

The minimum value of CF guarantees the maximal value for Q-factor for  $L_{sreq}=4 \text{ nH}$  and  $\text{Freq}=f_s=2.4 \text{ GHz}$ .

The technological parameters are summarized in table 1:



TABLE I. Technological parameters for inductor design

Name	Symbol	Value
Metal thickness	$t$	$2.8e-6$
Thickness of the oxide insulator between the spiral and underpass tM1-M2	$toxM1M2$	$0.4e-6$
Thickness of the oxide	$tox$	$5.42e-6$
Metal conductivity	$\sigma$	$1/2.65e-8$
Substrate conductance Gsub	$Gsub$	$2.43e5$
Permittivity of the oxide	$Eox$	$3.453e-11$
Substrate thickness	$tsub$	$700e-6$
Substrate resistivity	$\rho$	$28 \Omega.cm$
Substrate permittivity	$\epsilon r$	$11.9$
Magnetic Permeability of the free space	$u(mju)$	$1.256e-6$

The following Figure and Tables show the results comparison and simulation for the three metaheuristics.

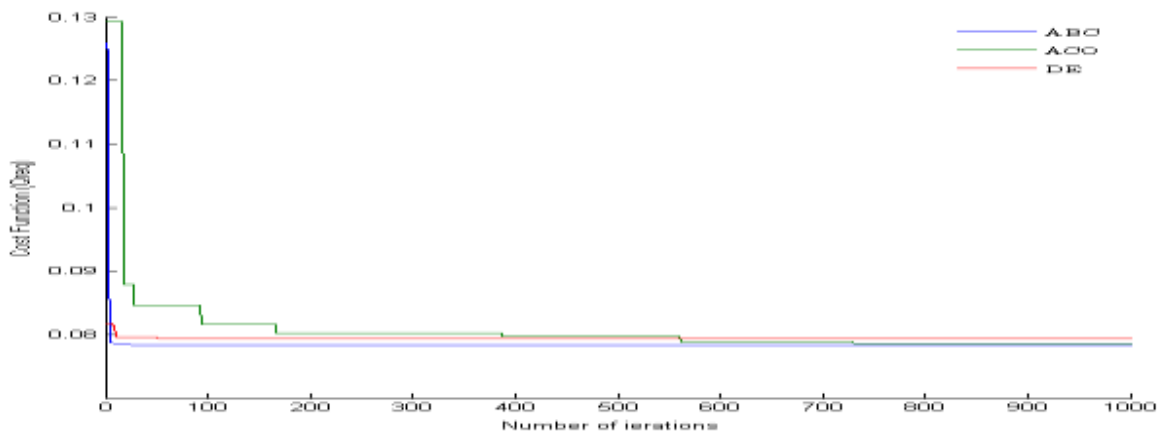


Figure 2. Cost function ( $Q_{req}$ ) Vs. Number of iterations of three algorithms

Table 2. Optimization results (Matlab)

Algo.	sp ( $\mu m$ )	w ( $\mu m$ )	n	d <sub>out</sub> ( $\mu m$ )	Q
ABC	2.5	11.15	3.5	231	12.71
ACO	2.5	11.149	3.5	185.75	12.66
DE	2.5	11.15	3.5	180	12.59

Table 3. Performances and Simulation Results

	L (nH)	L <sub>Mom.</sub> <sup>a</sup> (nH)	Error (%)	Q	Q <sub>Mom.</sub> <sup>a</sup>	Error (%)
ABC	3.96	3.95	0.25	12.71	12.25	3.75
ACO	2.64	2.61	1.15	12.66	12.61	0.40
DE	2.47	2.45	0.82	12.59	12.50	0.72

<sup>a</sup> Momentum-EM simulator

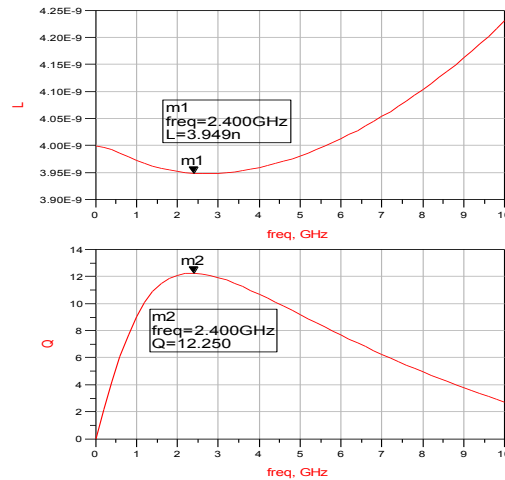


Figure 3. Momentum-ADS Simulation Results (Case of ABC algorithm)

From the above results, we notice that the Artificial Bee Colony algorithm gives better results than the other techniques.

### III- Resume

In this work, we have presented the design optimization of integrated square spiral inductor based on equation expression of quality factor-Q by taking consideration of design requirements and constraints. The comparison of performances by the ACO, DE methods and those obtained using ABC technique and Momentum simulation is in good accuracy, with error below to 4%. Finally, the designers can use this metaheuristic algorithms to design the higher quality of factor (Q) integrated spiral inductors with reduced development time.

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