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# Optimal Design of CMOS 0.18µm Low Noise Amplifier using Multi-Objective Artificial Bee Colony Algorithm

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## ABSTRACT

This paper presents, an optimal design of the CMOS Low Noise Amplifier (LNA)for Radio Frequency (RF) receivers using the Multi-Objective Artificial Bee Colony (MOABC) Algorithm. The main aim of this work is to find the optimal device sizes of an LNA cascode with inductive source degeneration structure to achieve high voltage gain (Av) while maintaining low noise figure(NF).The considered LNA operates at 2.4 GHz and implemented in a 0.18µm CMOS process with 1.8V power supply. The results of optimization are validated using Advanced Design System (ADS) software and confirm that MOABC technique effectiveness to determine device size and optimize LNA design.

**Key words:** Multi-Objective, optimization, MOABC, CMOS process, Cascode structure, LNA, Noise figure, Voltage gain.

## 1. INTRODUCTION

The Analog circuit design optimization problems, of which approximately 75% require much more time and expertise. Therefore, the development of reliable automatic tools in integrated circuit design seems to be a priority highly attractive[1,2,3].One solution to this problem is employing the meta-heuristics based on the intelligence of animal swarms [4] that are a relatively new techniques for solving NP-hard problems by reducing the number of redesign iterations and computing time needed to optimize the problem parameters. The most used are the Particle Swarm Optimization technique (PSO) [5], Artificial Bee Colony algorithm (ABC)[6,7] and Ant Colony Optimization technique (ACO) [8,9], that imitate the social behavior of birds, bees or ants.

The problems of analog circuits are usually formed by at least two conflicting performance parameters. That means that improving one performance, habitually leads to the degradation of another one [10]. It is therefore essential to deal with these optimization problems using multi-objective techniques In order to solve the multi-objective analog circuits problems, several meta heuristics algorithms have been proposed, such as Multi-objective Optimization Particle Swarm Optimization (MOPSO) [11], Ant Colony Optimization (MOACO) [12], etc.

In this work, we propose an application of MOABC algorithm [13] in order to optimize the sizing of an LNA circuit that is the fundamental building block of most receiver's front-end [14].The main function of this block is to amplify the incoming weak signals from the antenna without adding noise. The most important characteristics of LNA circuit are high voltage gain, low noise figure, and low power consumption. The reason we choose the multi-objective technique for optimization is that LNA circuit have several parameters, which are in conflict with each other and designers must make trade-offs between these objectives such as voltage gain, noise figure and power consumption …[4] (see Figure 1).

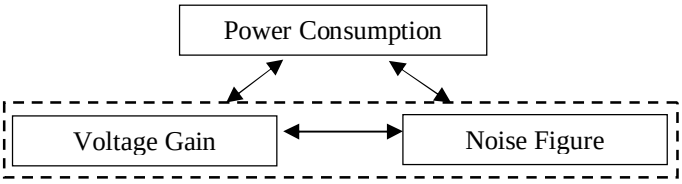


**Figure 1:** CMOSLNA Design Trade-Offs.

A simplified block diagram of a basic architecture used in many RF receivers is shown in Figure 2.

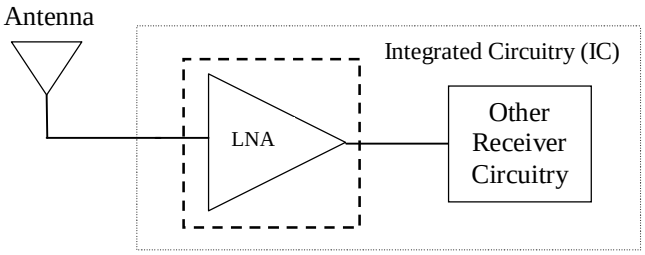


**Figure 2:** Location of RF-LNA block in receiver architecture

This paper is organized as follows: in Section 2,the concept of multi-objective optimization is described; InSection3, brief introduction of the proposed MOABC meta heuristic optimization algorithm is presented; Section 4, describes the design methodology of LNA circuit using MOABC algorithm; In Section 5, the results of the LNA design and discussions are provided .Conclusion and future works are given in Section 6.

## 2. MULTI-OBJECTIVE OPTIMIZATION PROBLEM

The Multi-objective Optimization Problem can be defined as the problem of finding [5][6]:
A vector of decision variables that satisfies constraints and optimizes a vector function whose elements represent several objective functions.

### 2.1 Formulation of a multi-objective problem

Formally, a multi-objective optimization problem can be defined as follows:

Find the vector $\overrightarrow{x^*} = (x^*_1, x^*_2, \ldots, x^*_n)$ which satisfies the (m) inequality constraints:

$$g_i(\vec{x}) \geq 0 \quad , i = 1,2 \ldots m. \qquad (1)$$

the (p) equality constraints,

$$h_i(\vec{x}) = 0 \quad , i = 1,2, \ldots, p. \qquad (2)$$

and optimizes the vector function,

$$\vec{f}(\vec{x}) = \left(\vec{f_1}(\vec{x}), \vec{f_2}(\vec{x}), \ldots, \vec{f_k}(\vec{x})\right) \qquad (3)$$

Where,

$\vec{x}$ is a n-dimensional vectorial decision variable. $\vec{f}(\vec{x})$ is ak-dimensional objective vector.

### 2.2 Notion of pareto optimum

The existence of more than one optimum (or trade-off) solution in multi-objective optimization problems makes necessary a different notion of Pareto optimum [5][6]:

- Pareto Dominance : A vector $\vec{u} = (u_1, u_2, \ldots, u_k)$ is said to dominate $\vec{v} = (v_1, v_2, \ldots, v_k)$ (denoted by$\vec{u} \leq \vec{v}$) if and only if u is partially less than v, i.e.,$\forall i \in \{1 \ldots k\} u_i \leq v_i \cap \exists i \in \{1 \ldots k\} u_i < v_i$ .
- Pareto Optimal Set: For a given MOP $\vec{f}(\vec{x})$, the Pareto optimal set $P^*$ is defined as:

$$P^*: \{x \in \Omega / \exists x' \in \Omega \, \vec{f}(x') \leq \vec{f}(x)\}$$

- Pareto Front: For a given MOP $\vec{f}(x)$, and Pareto optimal set $P^*$ the Pareto Front $PF^*$is defined as:$PF^*: \{\vec{u} = \vec{f} = (f_1(x), f_2(x), \ldots, f_k(x)) / x \in P^*\}$.

## 3. MLTI-OBJECTIVE ARTIFICIAL BEE COLONY ALGORITHEM (MOABC) PROPOSED

The Multi-Objective Artificial Bee Colony (MOABC) is one of the most recent meta-heuristic algorithms. This is a new population based approach that has shown good performance in dealing with different types of optimization problems [7].

In this MOABC algorithm, A food source position represents a possible solution to the problem to be optimized. The quantity of nectar of a food source corresponds to the quality of the solution represented by that food source. The colony of artificial bees is classified into three types with certain responsibilities[7]:

Employed bees, Onlooker bees and Scout bees.

The algorithm structure of the MOABC optimization proposed is given as follows:

- Initialization stage:

In initialization stage, the scout bees initialize a set of (NCS) food sources position randomly and the external archive (AR) well be initialized. NCS is equal to the number of colony size of the employed and on looker's bee.Each member of the population represents a solution to the problem, noted by $food_i$(i=1...NCS).

- Employed bees' stage:

In the employed bee's stage, for each employed bee finds a new food source position ($sol_i^*$) in the neighborhood of its current food source position ( $food_i$). The new food source is generated by the following expression:

$$sol_i^j = food_i^j + rand[-1;1] * (food_i^j - food_k^j) \qquad (4)$$

Where,

$$i \neq k \, ; i \in (1,2, \ldots, N)$$

N is the number of employed bees

j, k is selected randomly.

$food_i^k$is neighbor bee of$food_i^j$.

Each of employed bee compares the current food source position with a neighbor food source position and chooses out the better one using a greedy selection technique. The selected non-dominated solutions are stored in an external archive (AR).

- Onlooker bees' stage:

In the onlooker bees stage, for each bee( $food_i$) ,itrandomly selected and learn from an external archive(AR) produced by employed bee stage, The new food source( $sol_i^*$ ) is generated by the following expression:

$$sol_i^{rp*} = food_i^{rp} + rand[-1;1] * (AR_k^{rp} - food_i^{rp}) \qquad (5)$$

Where,

$i \in (1,2, \ldots, Foodnumber)$/ Foodnumber is equal to half of the number of colony size (NCS).

$k \in (1,2, \ldots, m)$is randomly selected .m is the size of the external archive (AR).rp is randomly selected from (AR).

After producing the new solution($sol_i^{rp*}$) ,the greedy selection is applied to decide which solution enters in the external archive (AR).

- Scout bees' stage

In the scout bees' stage, the scout bee is responsible for finding a new food source position and evaluate the quality of their nectar. when the scout bee finds the food source , she converts to the employed bee .In this step, if the food source isn't improved by the trail number (trail number for a release food source is higher than a control parameter 'Limit'), then that food source is exhausted by its employed bee and this one becomes a scout bee .

### 3.1 Flowchart of the proposed MOABC algorithm

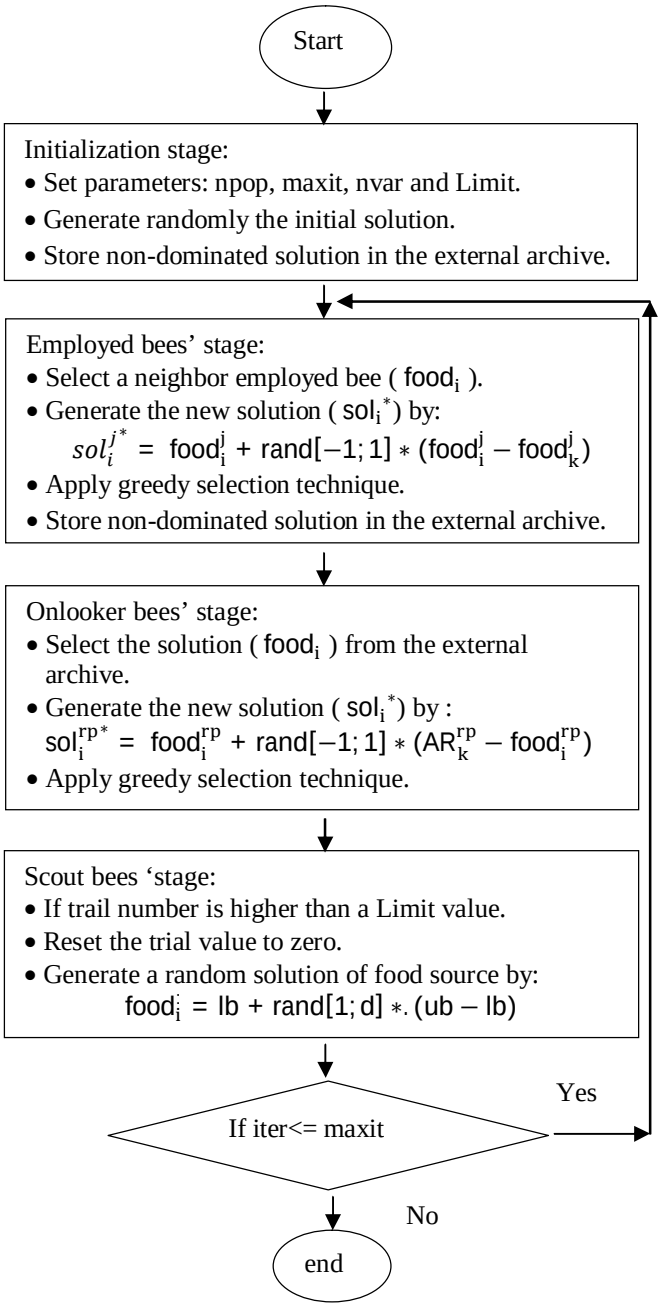


**Figure 3:**Flowchart of the proposed MOABC algorithem.

## 4. DESIGN METHODOLOGYOF RF-LNA USING MOABC ALGORITHM.

### 4.1 RF-LNA optimization

The most widely RF-LNA topology used is cascode structure with source inductive degeneration, because it can satisfy requirements for both noise and Gain simultaneously (see Figure 4) [8] [9].

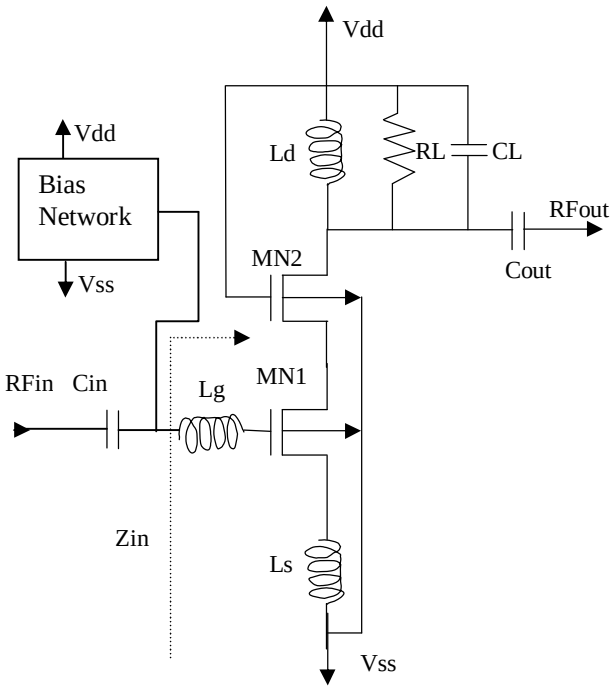


**Figure 4:**LNA Cascodewith inductive source degeneration.

The input impedance (Zin) of this structure is given by the first stage, (see Figure 4):

$$Z_{IN} = j\omega(L_g + L_s) + \left(1/_{j\omega C_{gs}}\right) + \left(g_m/_{C_{gs}}\right)L_s \quad (6)$$

The input matching criteria formed by Lg and Ls are estimated by ignoring Miller effect of Cgd1 of transistor NM1 and effective gate resistance Rg:

$$L_s = R_s C_{gs}/_{g_m} \quad (7)$$

$$L_g = \left(1/_{\omega_0{}^2 C_{gs}}\right) - L_s \quad (8)$$

Where,
Ls and Lg are the gate input inductor and source degeneration inductor respectively.
Rs is the source resistance (~50Ω).
ω0 is the operating frequency.
gm and Cgs are the transconductance and gate-source capacitance of nmos transistor (NM1) respectively.
The voltage gain (Av) is equal to the product of the circuit's transconductance Gm and the load resistance RL figure 4:

$$A_V = V_{out}/_{V_{in}} = G_m * R_L = R_L/_{2L_s\omega_0} \quad (9)$$

The noise figure (NF) of the cascode CS stage can be formulated as a function of width (W), drain current (Id)[10] [11][12].

$$NF = 1 + {(A + B + C + D)}/{E} \quad (10)$$

Where,

$$A = \left({1}/{4}\right) * \gamma * g_{d0} \quad (11)$$

$$B = {g_m}^2 * \left({C_{gs}}/{C_{tot}}\right)^2 * \left(Q^2 + {1}/{4}\right) * {\beta}/{(5 * g_{d0})} \quad (12)$$

$$C = g_m * c * \left({C_{gs}}/{C_{tot}}\right) * \sqrt{{(\gamma * \beta)}/{20}} \quad (13)$$

$$D = {1}/{R_L} \quad (14)$$

$$E = {g_m}^2 * R_s * Q^2 \quad (15)$$

Where,

- γ is the white noise factor, approximately equal to 1.05 for 180nm technology.
- β is gate noise parameter, approximately equal to 3.8.
- c is correlation coefficient,
- Cgs is intrinsic gate capacitance,
- Ctot is sum of Cgs, Cd and parasitic capacitance.
- Q is input quality factor of the circuit.

The Approximated expressions of gm and gd0 can be expressed as follows [12]:

$$g_m = A_0 * L^{A_1} * W^{A_2} * {I_d}^{A_3} \quad (16)$$

$$g_{d0} = B_0 * L^{B_1} * W^{B_2} * {I_d}^{B_3} \quad (17)$$

Where, L, W and Id refer to length and width of MOS transistors, and drain current respectively
The values of constants are shown in table 1.

**Table 1:**Value of constants for calculating gm and gd0

| $A_0$ | $A_1$ | $A_2$ | $A_3$ |
|---|---|---|---|
| 0.0463 | -0.4489 | 0.5311 | 0.4689 |

| $B_0$ | $B_1$ | $B_2$ | $B_3$ |
|---|---|---|---|
| 0.0096 | -0.5595 | 0.5194 | 0.4806 |

### 4.2 RF-LNA design methodology using MOABC algorithm

The optimization problem is solved by an iterative loop between an optimization algorithm (mono-objective or multi-objective) and a performance evaluator (analytical equations or simulators) [14]. At each iteration, the optimization algorithm produces new sets of design variables: transistor size (width and length), resistance, capacitor and inductor value, …, (see Figure 5).
In this paper, a MOABC optimization algorithm is used to optimize two objective functions of RF-LNA circuit, voltage gain and noise figure [15][16]. In order to achieve a good trade-off, have to:

- Maximize the voltage gain,
- Minimize the noise figure.

With respect to the constraints design and target specifications [16], as presented in Table 2

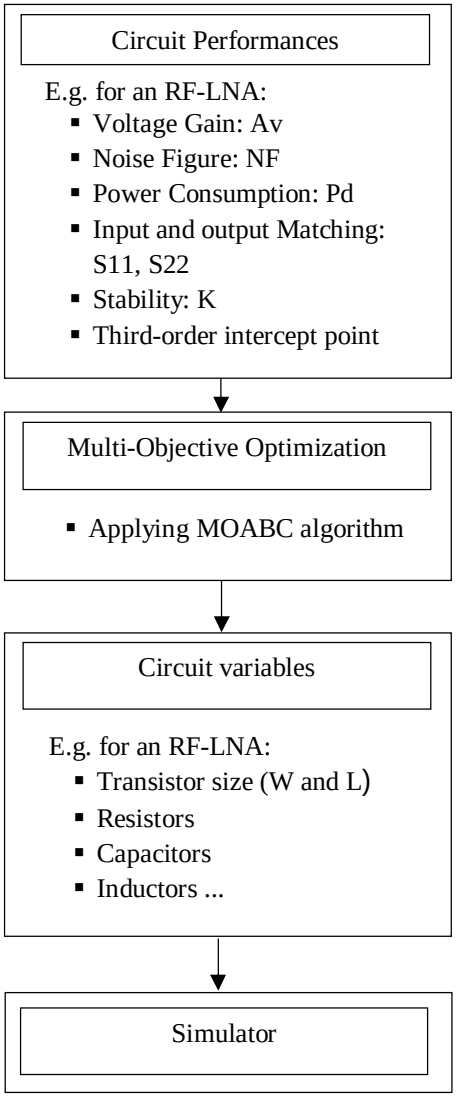


**Figure 5:**Flowchart of RF-LNA design methodology

**Table 2:** CMOS LNA Specifications

| Parameters | Specification |
|---|---|
| **Process** | 0.18µm CMOS |
| **Power supplyVdd** | 1.8V |
| **Operating Frequency (F)** | 2.4GHz |
| **Voltage Gain (Av)** | >=15dB |
| **Noise Figure (NF)** | <3dB |
| **Noise Figure min (NFmin)** | <2.5dB |
| **Power dissipation** | <=11mW |
| **S11** | <-10dB |
| **S22** | <-10dB |
| **IIP3** | >-10dBm |
| **Stability factor (K)** | >1 |

Table 3 shows the MOABC algorithm setting parameters.

**Table 3:**Parameters adopted for the MOABC algorithm

| MOABC settings | Value |
|---|---|
| **Max Iteration (MaxIt)** | 100 |
| **Dimension of the solution space(D)** | 2 |
| **Limit (=Number of onlooker's bees*D)** | 100 |
| **Size of the external archive (AR)** | 50 |
| **Number of colony size (NCS)** | 100 |
| **Number of employed bees (50 % of NCS)** | 50% |
| **Number of onlooker's bees (50 % of NCS)** | 50% |
| **Number of scouts** | 1 |

## 5. SIMULATION RESULTS AND DISCUSSIONS

### 5.1 Simulation results using MOABC/Matlab

The parameters values for MOABC algorithm used for this optimization problem are shown in Table 3.
The MOABC algorithm was applied to generate the Pareto front, illustrated in Figure 6.

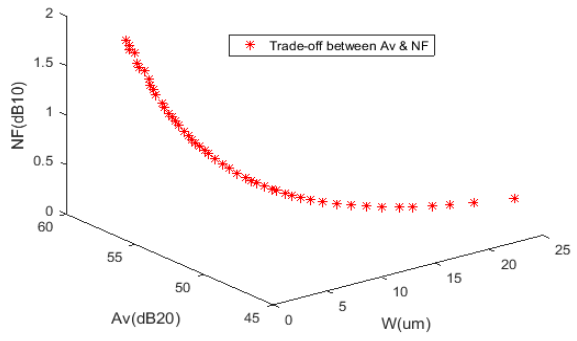


**Figure 6:**Optimal Pareto front obtained by MOABC

The optimal sizing of 4 solutions chosen from the archive (AR)are shows in Table 4.

**Table 4:** Parameters values of 4 optimal solutions

| Parameters | Solution° | | | |
|---|---|---|---|---|
| | **@1** | **@2** | **@3** | **@4** |
| **W(µm)** | 23.3 | 20.3 | 18.5 | 15.8 |
| **L(µm)** | 0.18 | 0.18 | 0.18 | 0.18 |
| **Ls(pH)** | 132.3 | 121.08 | 115.92 | 107.66 |
| **Lg(nH)** | 183.39 | 210.53 | 231.03 | 270.54 |
| **Ld(nH)** | 10 | 10 | 10 | 10 |
| **CL (fF)** | 439.76 | 439.76 | 439.76 | 439.76 |
| **RL(Ω)** | 753.98 | 753.98 | 753.98 | 753.98 |
| **Cin(pF)** | 10 | 10 | 10 | 10 |
| **Cout(pF)** | 10 | 10 | 10 | 10 |
| **Qin** | 4 | 4 | 4 | 4 |
| **Qout** | 5 | 5 | 5 | 5 |
| **Id(mA)** | 2 | 2 | 2 | 2 |
| **Vdd(V)** | 1.8 | 1.8 | 1.8 | 1.8 |
| **F(GHz)** | 2.4 | 2.4 | 2.4 | 2.4 |

### 5.2 Simulation results using ADS

The initial startup values given after executing the MOABC algorithm has been used for the design of RF-LNA based on 0.18µm CMOS process. The design is finally simulated with ADS (Advanced Design System) software. And its simulation results of Av and NF for 4 solutions are presented in Table 5.

**Table 5:** Simulations results of Av and NF

| Performance | | Solution° | | | | Spec |
|---|---|---|---|---|---|---|
| | | **@1** | **@2** | **@3** | **@4** | |
| **ADS Results** | **Av** | 20.96 | 18.59 | 17.76 | 15.86 | >=15dB |
| | **NF** | 2.25 | 2.47 | 2.52 | 2.62 | <3dB |

Figures 7,8,9,10and 11 shows the simulation results of the voltage Gain, the noise figure, input-output matching (S11,S22) and stability factor (K) based on the best optimal solution(@1) obtained by MOABC algorithm.

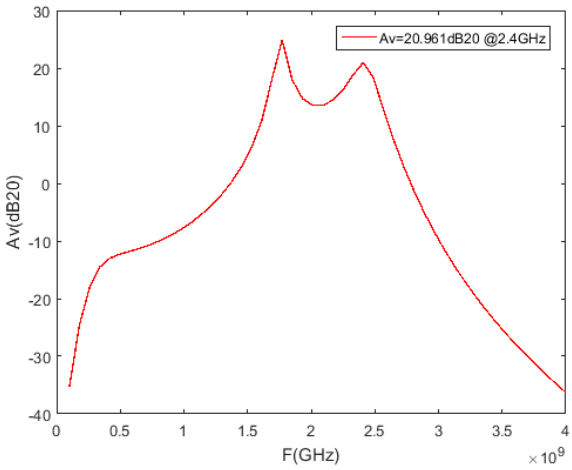


**Figure 7:** Voltage gain vs. frequency of@1

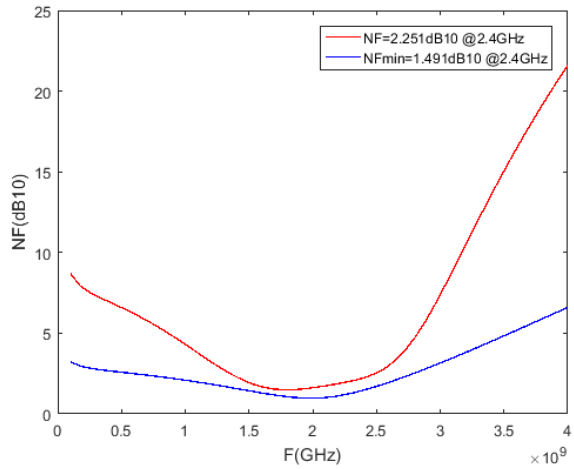


**Figure 8:** Noise figure vs. Frequency of@1

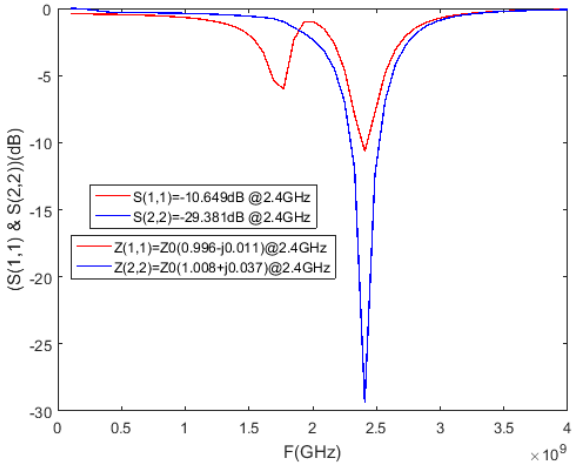


**Figure 9:** S11 and S22 vs. frequency of@1

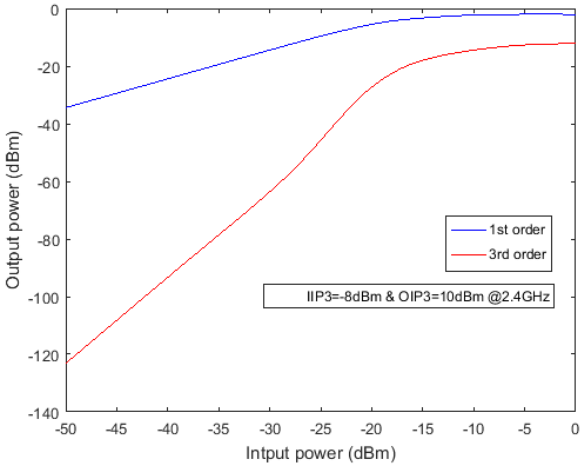


**Figure 10:** IIP3 of @1

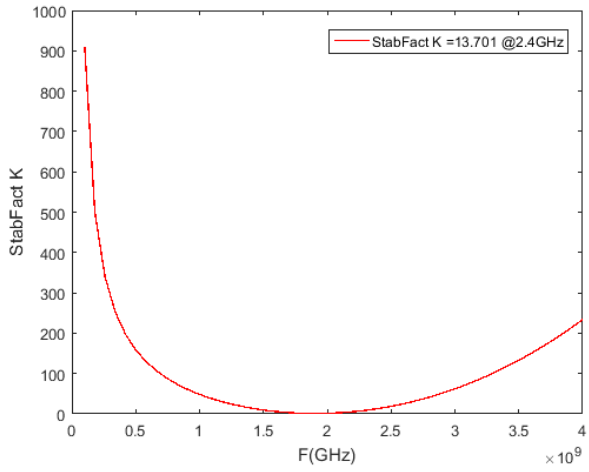


**Figure 11:**Stability factor (K) vs. frequency of@1

From figures 7,8,9,10and 11and Table 4, we notice that simulation results are in good agreement with the target specifications:

- Good matching at both poles,
  - Zin =Z0*(0.996-j0.011) ~50Ω
  - Zout=Z0*(1.008+j0.037) ~50Ω
- High voltage gain,
  - Av=20.96dB>=Av_Spec
- Acceptable noise figure,
  - NF=2.25<NF_Spec
  - NFmin=1.491<NFmin_Spec
- Low power dissipation,
  - Pd=3.9mW<Pd_Spec
- Third-order intercept point IIP3
  - IIP3 > IIP3_spec
- Stability
  - K=13.701>K_Spec

## 6. CONCLUSION

In this paper, we have presented an application of the ABC algorithm for with the use in the multi objective optimization problems resolution. It has been considered to optimize two trade-offs RF-LNA performances, the voltage gain (Av) and the noise figure (NF) simultaneously. The viability of the proposed MOABC algorithm was shown through the generation of the Pareto front (NF vs. Av). The obtained results demonstrate the utility and reliability of the automatic design methodology. In addition, ADS simulations were highlighted. Now we are focusing on the application of the MOABC technique in more popular and complex integrated circuits.

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