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Optimization of 5.5 GHz inductive source degeneration LNA using multi objective PSO

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Abstract: Particle swarm optimization is the most flexible, efficient and simple optimization technique. In this paper presents a optimization of tradeoff between linearity and noise Figure of low noise amplifier of cascode inductive source degeneration amplifier using multi objective particle swarm optimization, and this has validate using UMC .18um CMOS Technology in cadence spectre tool. We got gain 14.1dB, S11 -23.65 dB, S22 -15.2dB noise Figure 1.24 dB, IIP3 2.48 dBm with power supply of 1.8v, and power consumption is 10.8mw.

Key words: Heuristics; Particle swarm optimization; Multi objective; Low noise amplifier; Linearity

1. Introduction

Low noise amplifiers (LNAs) are highly used in wireless communications. They can be found in almost all RF receivers in commercial applications. Linearity, power, noise, and gain are important design issues in the LNA design for modern wireless receivers. Since the LNA is the first block in the receiver chain, it must be sufficiently linear to suppress interference and maintain high sensitivity. Optimal sizing of LNA circuits is a very complex and time consuming work. Indeed, circuits must be sized to follow with required performance specifications. Several techniques and algorithms are reported in the literature, such as local search (Aarts, 2003), simulated annealing (Kirkpatrick 1983), genetic algorithms (Dréo, 2006), etc. for optimization. However these techniques do not offer general solution strategies that can be applied to problem formulations where divergent types of variables, objectives and constraint functions are used. The increasing complexity of circuit design (different types of objectives and constraint functions, large number of parameters etc.) has demanded the authors to look after novel techniques that overcome drawbacks of the above mentioned techniques. Recently, a new class of algorithms was proposed to solve continuous optimization problems; it is inspired from the collective behavior of fragmented, self-organized systems. These algorithms are part of Swarm Intelligence (Bonabeau, 1999). They focus on the social behavior of insect conduct living in a swarm. The "particles" of the swarm use a direct way of communication in order to build a solution to the considered problem, based on their collective experience. Most famous such SI techniques are Ant Colony Optimization (Dorigo, 1999) and Particle Swarm Optimization (PSO) (Kennedy 1995). Among these two techniques, PSO is the most flexible and easy. Thus, in this work we deal with the use of the PSO technique to optimize performances of LNAs. Knowing that performances of RF circuits have contradictory and non-commensurable behaviors, the multi objective PSO technique is used for the purpose of optimizing LNAs' performances: NF and IIP3.

The rest of the paper is organized as follows. Section 2describe the design of inductive source degeneration LNA. In Section 3 we describe the multi objective optimization using PSO. In section 4, we discuss the LNA simulation Results of 5.5 GHz LNA using the proposed optimization methods. And finally, conclusions are given in section 5

2. Design of CMOS LNA

The complete schematic of the 5.5 GHz LNA is shown in Fig 1, where Lg, Ls, and Ld are all implemented with on-chip spiral inductors. Lg is gate inductor and it is used for tuned out the effect of input capacitance and Ls is source degeneration inductor is used for input match and Ld is drain inductor provide output resonance with output capacitance and also play an important role to achieving high gain. The method employed here is inductive source degeneration. Cascoding transistor M2 issued to reduce the interaction of the tuned output with the tuned input, and to reduce the effect of the gate-drain capacitance Cgd of M1. At first, the sizes of the main CS FET and cg are selected considering the noise and bias current Lee, (2002). The inductors Lg and Ls are chosen to provide the desired input resistance. M_3, and R_1 form a bias circuit. MOSFET M_3 essentially forms a current mirror with M_1, here its width is one tenth of the width of M_1 in order to minimize the power overhead of the bias circuit Razavi, (1997). Cin and Cout are DC blocking capacitors.

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In this paper, we optimize LNA's structures regarding the noise Figure and the linearity.

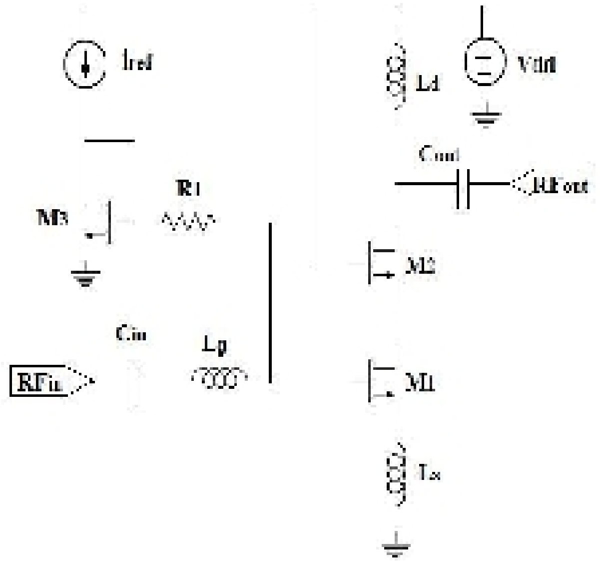

Fig. 1: Inductively Source Degenerated LNA

3. Multi-objective optimization

This section mainly presents basics on multi-objective optimization and Multi-Objective Particle Swarm Optimization.

Let's consider a Multi-Objective Optimization problem of the form:

Minimize ($f_1(x)$, $f_2(x)$, $f_3(x)$....... $f_i(x)$)

Subject to $h_k(x) \le 0, k = 1 \dots \dots (m)$ (1)

Where $x = (x_1, x_2, x_3 \dots x_n) \in x$

Where $x \subset \Re^n$ is the decision space for the variables, $f_n(xi)$: $\Re^n \to \Re$ n=1 P(P≥2) are objective functions and $h_k(x) \le 0, k = 1 \dots \dots (m)$ are performance constraints. Frequently, the objectives in (1) contradict each other, so, no point in x minimizes all the objectives at the same time. One has to balance them. The best tradeoffs among the objectives can be defined in terms of Pareto front [15]. A Pareto front is a set of solutions that are no dominated with respect to each other.

3.1. MOPSO Algorithm

Several MOO algorithms are based on PSO, which was designed for solving single objective optimization problems. In order to design a high performances circuits the main target is to optimize the size of the analog components (Fakhfakh, 2010) and this optimization method involve solving of various variables, objectives and constraints function simultaneously. Due to this complexity the Classical Optimization technique is not a good option. One optimization technique that is well suited for such type of approach is nature inspired heuristic optimization algorithm called Particle Swarm Optimization which centered on the intelligence of swarm. A comparison of Classical and Heuristic optimization technique is shown in Fig (2).

PSO is a heuristic search technique inspired by the social behavior of birds flocking. Among those algorithms that extend PSO to solve MOO problems is Multi-objective Particle Swarm Optimization (Fakhfakh, 2010). In this work, we use the Multi-objective Particle Swarm Optimization technique proposed in (Raquel 2005). The idea is illustrated by the flowchart (Fakhfakh, 2010) shown in Figure 3. The algorithm was programmed using MATLAB software.

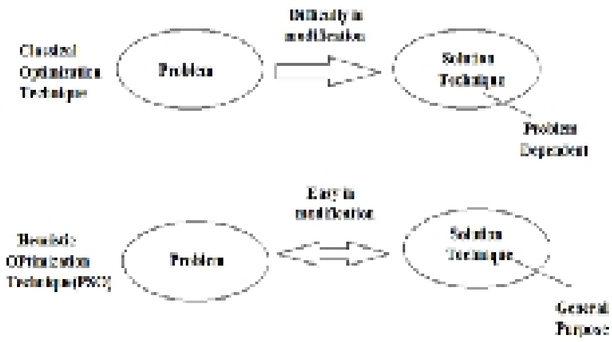

Fig. 2: Comparison of classical and modern heuristic optimization techniques

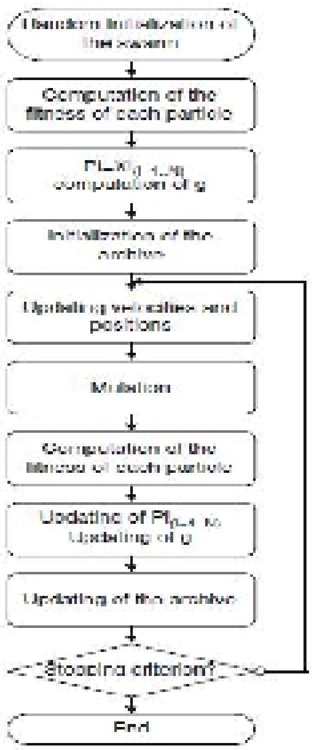

Fig. 3: Flowchart of a MOPSO

4. LNA optimization and simulation

A tradeoff between the noise Figure (NF) and IIP3 and while insuring both input and output matching (via the scattering parameters: S11, S22). High IP3 requires higher current draw, while lowest possible noise Figure is usually achieved at lower current levels.

Expression of Noise Figure is taken from Lin, (1999):

$$F = 1 + \frac{\beta'\left(Q^2+1/2\right)\left(Q\frac{4}{3}\omega_o R_s C_{ox} W L\right)^2 + \gamma'/4}{R_s Q^2 \sqrt{2\mu_{eff}' C_{ox} W I_{ds}/L}} \quad (2)$$

As indicated in (Leroux 2005), the IIP3 in watt is given by

$$IIP3 = \frac{1}{8Rs}\frac{4}{3}\frac{V_{OD}\left(2+\theta V_{OD}\right)\left(\left(1+\theta V_{OD}\right)^2\right.}{\theta}\frac{1}{Q^2} \quad (3)$$

Where Rs is the input resistance, V_{OD} is the overdrive voltage, θ is normal field mobility degeneration factor and Q is quality factor of input matching circuit. Here IIP3 of the LNA circuit increases with the overdrive voltage and reduction of Q.

Table 1: Specification

IIP3	To maximize
NF	To minimize
$\lvert S_{11}\rvert$ and $\lvert S_{22}\rvert$	<-15 dB

Table 2: Parameters of MOPSO algorithm

Size of swarm	No of iteration	C_1	C_2	w
50	10,000	1	1	.4

Table 3: Parameter value of optimal solution

Component	MO PSO Optimized value
W1	250um
W2	170um
W3	25um
L_g	3.39nH
L_s	200pH
L_d	2.8nH
C_{in}	2pf
C_{out}	130fF
R_1	2.4KΩ

In this section, the simulation results of a 5.5 GHz LNA with the cascode architecture are presented. It is conducted by the Cadence spectre with the CMOS 180 nm UMC technology. In the schematic design the calculated width (W) of M1 is 250um, and M2 is 180 um. In Figure 4 we present Pareto fronts obtained using MOPSO algorithms.

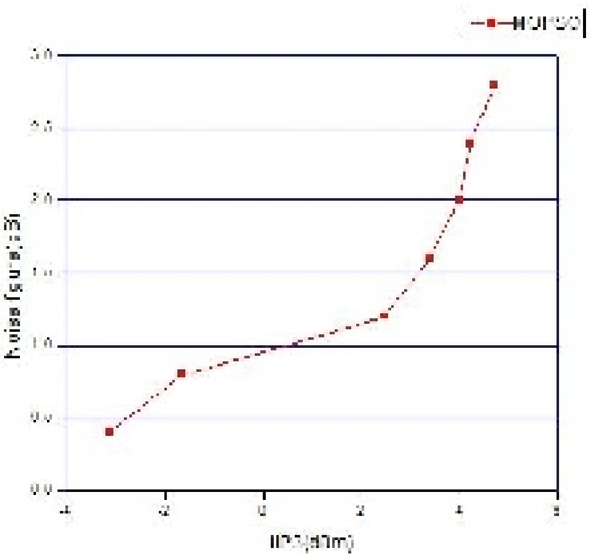

Fig. 4: Paterofront of Low Noise Amplifier

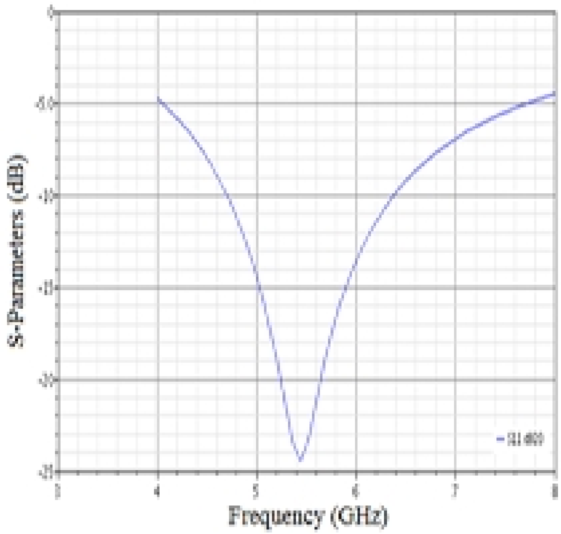

Fig. 5: S11

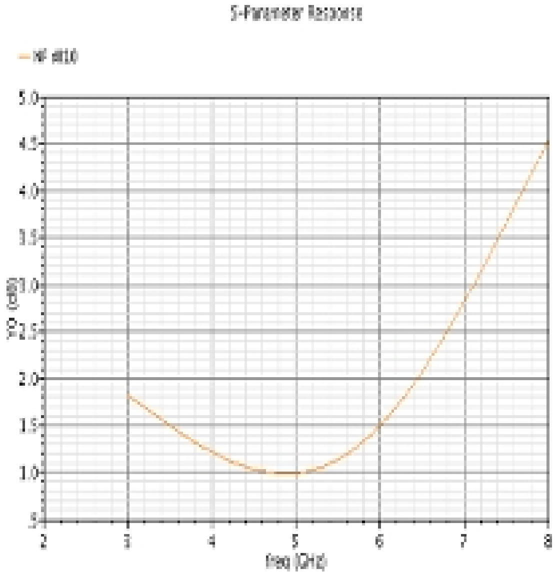

Fig. 5: Noise figure

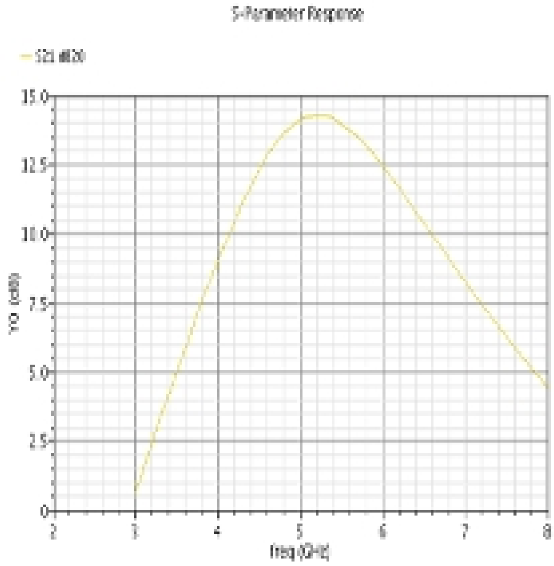

Fig. 6: S21

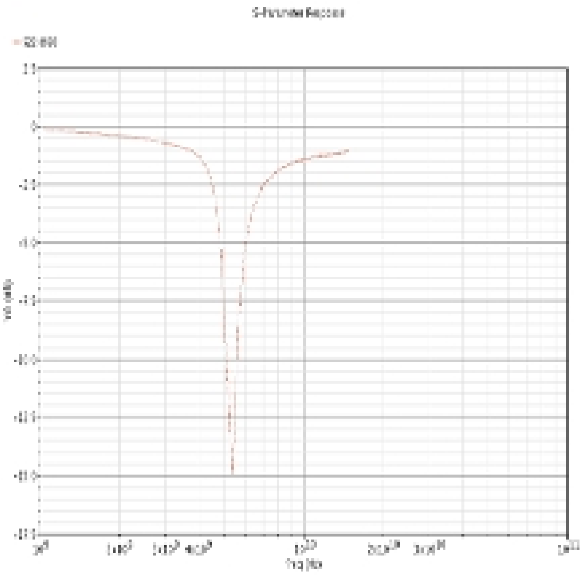

Fig. 7: S22

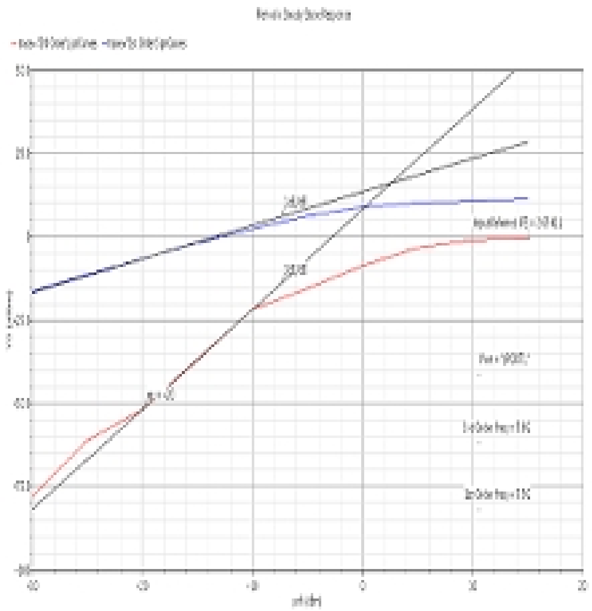

Fig. 8: IIP3

S11also known as input refection coefficient defined how much incident power is reflected back to the source from the amplifier. As shown in the Fig 4 the value of S11 is -23.65dB for 5.5 GHz. The simulated values of noise Figure is 1.24 dB and S21 (power gain) is 14.1dB which is shown in Fig 5 and Fig 6 respectively.

Table 4: Simulated result

Parameter	Simulated result
Frequency	5.5 GHz
Technology	.18 um
Vdd	1.8 V
S11	-23.65dB
S22	-15.2dB
S21	14.1dB
NF	1.24dB
IIP3	2.48 dBm
Power consumption	10.8mw

5. Conclusions

This Paper is mainly employed to optimize the linearity and noise Figure of cascode inductive source degeneration CMOS LNA at 5.5 GHz. As a result the Designed LNA could be potentially used in high-frequency and high-linearity applications. After simulation we got gain 14.1 dB, S11 -23.65 dB, S22 -15.2 dB NF 1.24 dB, IIP3 2.48 dBm and power consumption is 10.8mw.

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