An efficient low noise amplifier for biomedical applications based on LCSA

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Abstract: The low-noise amplifier (LNA) is a significant component in the analog front-end of a radio frequency (RF) receiver for several applications. In biomedical applications, the prime building block in analog electronics is an operational amplifier. In digital circuitry, the operational amplifier has a noteworthy role as logic gates in analog-circuit design. But, the LNA has a problem of shift frequency (SF) in the existing works. Though they found a solution for the compensation of the SF, their search for global optimal solution is poor. To avoid these difficulties, this paper proposed an efficient LNA for biomedical application centered LCSA algorithm. In this work, the implemented LCSA in optimizing disparate parameters of LNA like linearity, Noise Figure (NF), Gain, input and output matching simultaneously satisfies all the constraints. In experimental evaluation, the proposed LCSA is contrasted to the existing Firefly Algorithm (FA) and Particle Swarm Optimization (PSO) algorithm. Results depict the better performance of LCSA over FA and PSO.

Key words: *Levy based Crow Search Algorithm (LCSA), Low Noise Amplifier (LNA), linearity, Noise Figure, gain and input and output matching.*

1. INTRODUCTION

Biomedical Instrumentation encompasses developing new devices and procedures that tackle medical and health-associated problems by integrating their recent advancements in biology, medicine and engineering. These are done to enhance the human health via cross-disciplinary procedures that integrate the design concepts of medicine and biology and the engineering principles for healthcare purposes i.e. therapeutic or diagnostic [1]. Multiple biomedical instruments say, Electroencephalogram (EEG) [2], Electrocardiogram (ECG) [3], Defibrillator [4], Nebulizer [5], etc are developed.

The new bio-medical and surgical instruments aid physician to execute complex bio-medical treatments and surgeries with high-level medical quality. Some complicated biomedical treatments encompassing endoscopic and microsurgeries could be done via accurately controlled bio-medical instruments [6]. Since then, EEG has been broadly utilized for examining disparate neurological scenarios. As EEG recordings remain the widespread, inexpensive and non-invasive technologies with adequate temporal resolution and it is relevant for continual monitoring, the EEG recording systems has a noteworthy role in brain study, specifically in diagnosis of brain diseases like epilepsy, abnormal behaviour and sleeping disorder [7].

A biomedical instrumentation system comprises amplifier, transducer, and associated signal conditioning circuit. In amplifier, the LNA contains the SF problem. The utmost sensitive element in a system is the input signals, namely body temperature, blood pressure, heart beat rate or pulse [8]. Those signals are attained and transmuted into voltage signal with the amplitude of several millivolts. As the voltage signal is extremely low and vulnerable to noise, the amplifier amplifies signals to a significant value for signal processing [9]. Rapid advancement in multiple key science areas encompassing material sciences, artificial intelligence, software innovations, micro-circuitry design, digital electronic sensors design, and even electronic systems integration has inspired the development of electronic sensor technologies appropriate for diverse areas of human activities [10].

The remaining sections: Section 2 reviews the associated work regarding the proposed method. Section 3 presents a brief discussion about the proposed work. Section 4 analyzes the experimental outcomes. Finally, section 5 infers the paper.

2. RELATED WORK

al. [11] put forward a biasing optimized LNA for the analog front-end circuitry in brain-machine interface. In this approach, the current density, gate over-drive voltage, and trans-conductance efficiency g_m/I_D were utilized for transistor optimum biasing. The optimized over-drive voltage of the transistor was about 100-mV, which was inferred from the analysis of the trade-off amongst the gain, NF, efficiency and speed. LNS modeled with this technique evinced good performance.

Yali Su and Xuan Liu [12] presented a low noise pre-amplifier utilized for bio-medical signal acquisition. A “T-type feedback” operational amplifier topology structure was utilized centered on the conventional “AC coupling-capacitor feedback”. The attained amplifier constructed in SMIC 0.18 um standard CMOS, processes signals (0.2/25Hz -10kHz) with 0.96uVrms input-referred noise and 18.54uW power dissipation while occupying 0.065mm^2

of chip area. The simulation outcomes evinced that the preamplifier has proper bandwidth and gain, small chip area consumption and input-referred noise. It was appropriate for the applications in low noise, low power, and higher integration circuits utilized for biomedical signal acquisition.

EhsanKargaran*et al.* [13] recommended an ultra-low-voltage ultra-low-power LNA centered on boosting approach. The LNA was modelled utilizing 40nm CMOS technology and features a 14dB voltage gain, −8.6dBm IIP3 and 5.2dB NF. The performance was similar to a previous work, but with the minimal supply voltage lessened by a factor of 4x. The LNA was appropriate for wire-less medical body-area networks where the power budget was highly diminished.

Angelos Papadimitriou and Matthias Bucher [14] developed a framework for multi-objective RF- LNA optimization utilizing an analytical design of the MOS transistor along with the genetic computation. The LNA component values were initially extracted centered on the analytical design. A 5GHz common source LNA with the inductive degeneration was designed centered on the optimization and design approach. Lastly, the optimization procedure was also elucidated on disparate topologies including the common gate structures or cascode, as well as multi-level distributed and resistive shunt feed-back amplifiers.

David H. K. Hoe and Xiaoyu Jin [15] put forward the design of RF- LNAs centered on the GP (Geometric Programming) optimization approach. Short channel effects namely velocity saturation as well as channel-length modulation effects were also counted for in the optimization procedure. The method was employed to the inductive source de-generated common source amplifiers at the 90nm and 180nm technology nodes. The optimization outcomes were tested by contrasting to the numerical simulations utilizing Agilent's Advanced Design Systems (ADS) software.

3. PROPOSED METHODOLOGY

Bio medical signals have weak amplitude and low frequency, for example, the frequency of EEG signals is in a range of 0.1 to 100Hz while the amplitude is from 1 to 160μVpp. Thus, the signals are amplified first. The biomedical electronics detecting system is shown in Figure 2, which consists of electrodes, Amplifier (amp), Low Pass Filter (LPF), Sample and Hold (S/H) and Analog to Digital Converter (ADC). In this, the amplifier is the important building block. But in the LNA, the shift of the frequency is one of the problems.

To compensate this problem, this proposed methodology used Levy based Crow Search Algorithm (LCSA). The proposed LNA design and their frequency compensation using LCSA are explained in the below subsection.

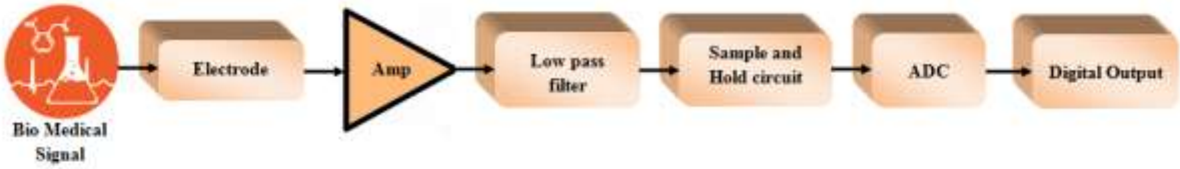


Figure 1: Biomedical electronics detecting system

3.1 LNA Design

The LNA is designed for 4.5 GHz whose simplified circuit is shown in Figure 2. The circuit consists of three inductors which are all on-chip spiral inductors and they are gate inductor J_g, source inductor J_s and drain inductor J_d, respectively. Roles contributed by the mention inductors in the designed LNA are (i) J_g helps in turning out the effect of the input capacitance (ii) performance of J_s help in achieving the input matching and (iii) gain of the LNA is improved with the use of J_d and also it is implemented to get output resonance with output capacitance. $N1$ and $N2$ are the input and Cascoding device, respectively. The main role of Cascoding device is to provide isolation between tuned output and tuned input. For, biasing circuit $N3$ and R1 are employed where they form the current mirror Ellinger.

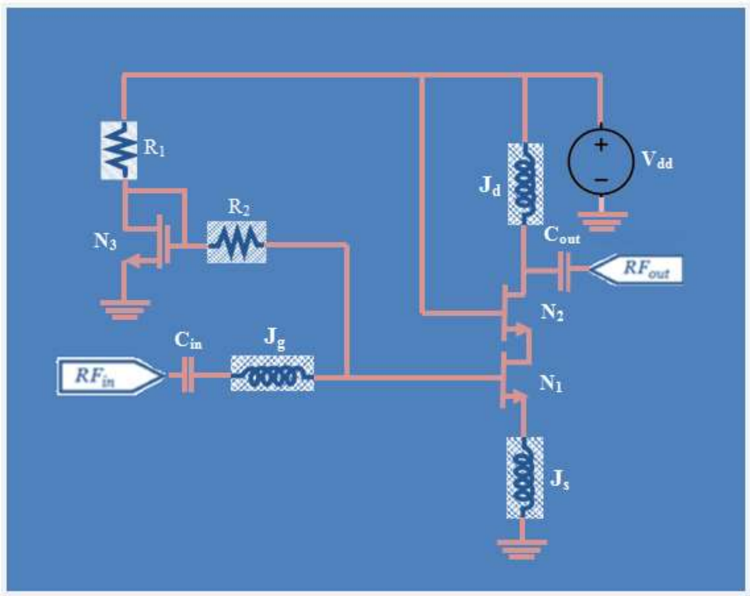


Figure 2: LNA design

The most crucial part of a LNA design is that there exist a trade-off between various parameters of LNA like Gain, linearity, and NF. High linearity requires higher current draw, while lowest possible NF is usually achieved at lower current levels. This proposed methodology optimizes inductive source degeneration LNA's structures considering the NF, linearity, Gain and matching by assigning the suitable weights (i.e) compensating the shift of the frequency. The LCSA is explained in the below section.

3.2 Levy Crow Search Algorithm (LCSA)

The Crow search algorithm is inspired on the intelligence behavior of crows. The CSA has demonstrated its potential to find the optimum solution for certain search spaces configurations. However, its convergence is not guaranteed due to the ineffective exploration of its search strategy. Under this condition, its search strategy presents great difficulties when it faces high multi-modal formulations. To overcome such difficulties, this proposed method uses the LCSA. The improvement is done by adding Levy fight (LF) for performing random movement. In LFs, the step size is controlled by a heavy-tailed probability distribution usually known as Lévy distribution. The LFs are more efficient exploring the search space than the uniform random distribution.

The CSA evolutionary process emulates the behavior conducted by crows of hiding and recovering the extra food. As an algorithm based on population, the size of the flock is conformed by M individuals (crows) which are of n-dimensional with n as the problem dimension. The position $C_{i,k}$ of the crow z in certain iteration k is described in Equation (1) and represents a possible solution for the problem:

$$C_{i,k} = \left[c_{i,k}^{1}, c_{i,k}^{2}, ..., c_{i,k}^{n}\right],\ i = 1,2,.........., N;\ k = 1,2,........, \max\ Iter \tag{1}$$

Where, $\max\ Iter$ indicates the maximum of iterations in the process. Each crow (individual) is assumed to have the capability of remembering the best visited location $L_{i,k}$ to hide food until the current iteration Equation (2):

$$L_{g,k} = \left[l_{z,k}^{1}, l_{z,k}^{2}, ..., l_{z,k}^{n}\right] \tag{2}$$

The position of each is modified according to two behaviors: Pursuit and evasion.

Pursuit: A crow h follows crow z with the purpose to discover its hidden place. The crow z does not notice the presence of the other crow, as consequence the purpose of crow h is achieve.

Evasion: The crow z knows about the presence of crow h and in order to protect its food, crow z intentionally takes a random trajectory. This behavior is simulated in Crow Search Algorithm (CSA) through the implementation of a random movement. In this proposed method, the random movement is done by using LF method.

The type of behavior considered by each crow z is determined by an awareness probability (AP). Therefore, a random value a_z uniformly distributed between 0 and 1 is sampled. Levy flights essentially provide a random walk, the random steps of which are drawn from a Levy distribution for large steps:

$$a_z = Levy \sim t^{-\lambda}, (1 < \lambda \leq 3) \tag{3}$$

If a_z is greater than equal to AP behaviour, 1 is applied, otherwise situation two is chosen. This operation can be summarized in the following model:

$$C_{z,k+1} = \begin{cases} C_{z,k} + a_z . D_{z,k} . (L_{h,k} - C_{z,k}) & a_z \geq AP \\ random & otherwise \end{cases} \tag{4}$$

The flight length $D_{z,k}$ parameter indicates the magnitude of movement from crow $C_{z,k}$ towards the best position $C_{h,k}$ of crow h, the a_z is a random number with uniform distribution in the range [0, 1].

Once the crows are modified, their position is evaluated and the memory vector is updated as follows:

$$C_{z,k+1} = \begin{cases} O(C_{z,k+1}) & O(C_{z,k+1}) < O(L_{z,k}) \\ L_{z,k} & otherwise \end{cases} \tag{5}$$

Where the $O(.)$ represents the objective function to be minimized. Pseudo code for the proposed LCSA algorithm is shown in Figure 3,

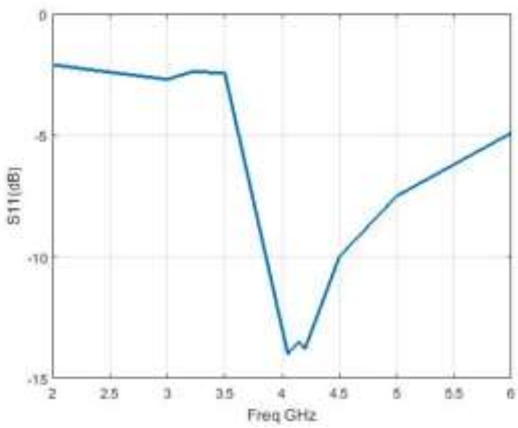
Input: Various parameter of LNA
Output: Compensate shift frequency

Begin
 Randomly initialize the position of a flock of M crows in the search space
 Evaluate the position of the crows
 Initialize the memory of each crow
 While $Iter < Iter_{max}$
  for $i = 1 : M$
   Randomly choose one of the crows to follow
   Define AP
   If $a_z \geq AP^{h,iter}$
    $C_{z,k+1} = C_{z,k} + a_z . D_{z,k} . (L_{h,k} - C_{z,k})$
   else
    $C_{z,k+1} = a \;\; random \;\; position \;\; of \;\; search \;\; space$
   end if
  end for
  Check the feasibility of new positions
  Evaluate the new position of the crows
  Update the memory of crows
 end while
End

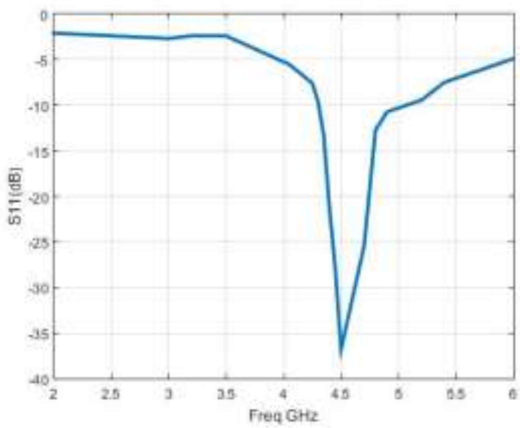
Figure 3: Pseudo code for proposed LCSA algorithm

4. RESULT AND DISCUSSION

In this section, the performance of the proposed system is analyzed. The proposed optimized LNA using LCSA for biomedical application is employed in the working platform of MATLAB/Simulink. In the present work, 5 objectives of LNA are optimized simultaneously by converting them into single objective function. Results are also compared with the existing FA and PSO algorithm.



(a)



(b)

Figure 4: $S_{11}(dB)$ in the present of parameter variations (a) without applying LCSA and (b) with applying LCSA

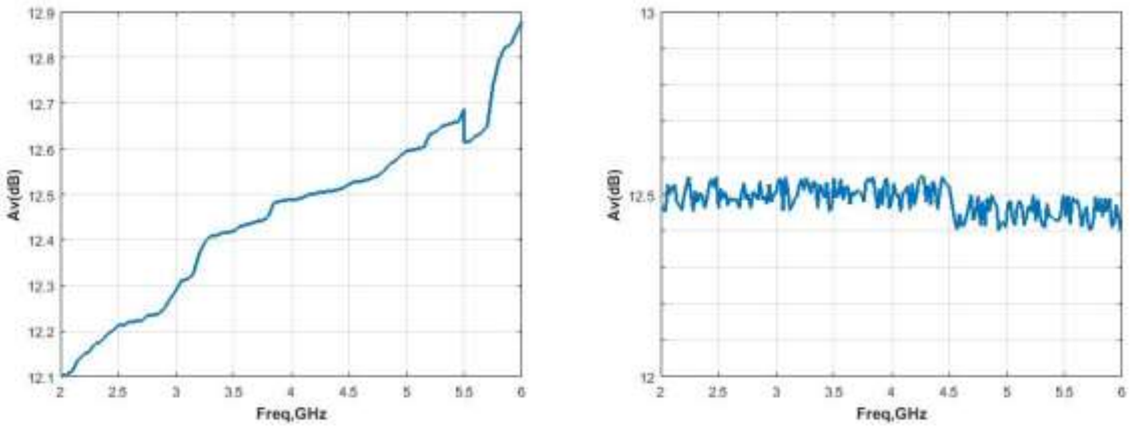


Figure 5: $A_v(dB)$in the present of parameter variations (a) without applying LCSA and (b) with applying LCSA

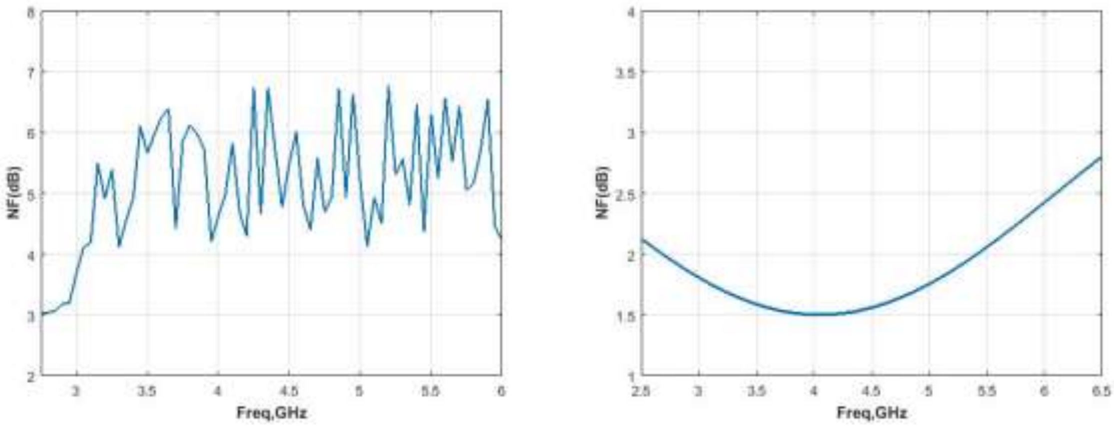


Figure 6: NF(dB) in the present of parameter variation (a) without applying LCSA and (b) with applying LCSA

Figure 4 shows the input return loss (S_{11}) with parameter variations. In Figure 4(a) the output is not optimum at the desired frequency of 4.5 GHz, but by the LCSA algorithm, as illustrated in Figure 4(b) it is optimum at the desired frequency. Figure 5(a) shows the voltage gain (A_v) of the proposed LNA with parameter variations. A_v without applying the LCSA algorithm is 12.45 with variation of ± 0.4 dB. Figure 5(b) illustrates the voltage gain by using the LCSA algorithm: Using this method, the flat voltage gain with flatness of 12.5± 0.02 dB can be attained. Its maximum voltage gain is 12.52 dB at the frequency of 4.5 GHz. The NF of the proposed LNA with exposing in parameter variations is depicted in Figure 6(a). The

NF variation is between 3 and 7.7 dB at the frequency range of 4 to 6 GHz. By applying the LCSA algorithm, minimum NF of 1.8 dB with low changes can be attained, as represented in Figure 6(b).

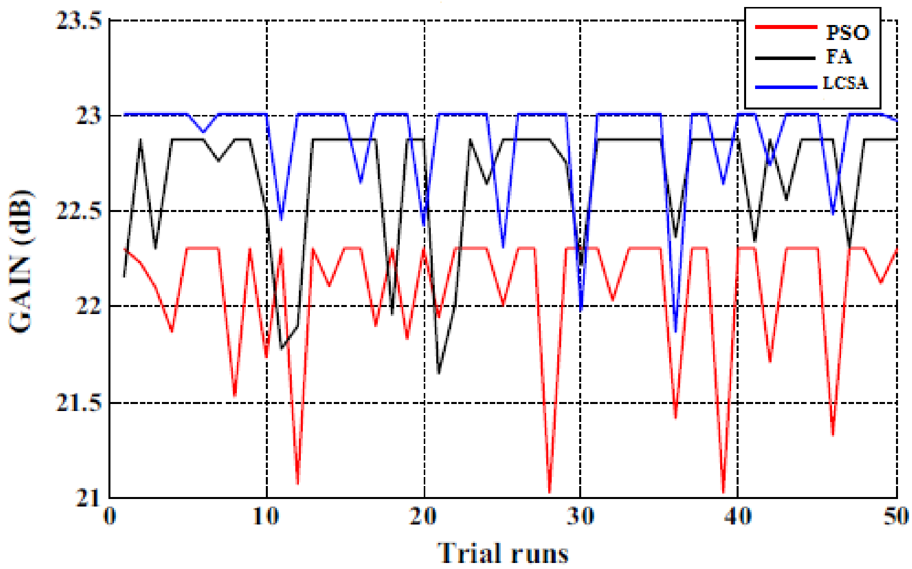


Figure 7: Demonstrate the trial run plot for gain

Figure 7 shows the trial run plot for different algorithms such as proposed LCSA, existing FA and existing PSO algorithm. The trial run ranges from 0 to 50 trial.

5. CONCLUSION

Bio-medical signals are essential for the physicians in diagnosing the medical conditions of patients. Nevertheless, the prime challenge in this process is that a patient is usually connected to the mains-powered instrument, which can reduce the patient's mobility and thereby creates a kind of discomfort. Moreover, this process limits the monitoring time of the patients and consequently affects the diagnosis of the disease. Therefore, there is an increasing need for small-size and low-power acquisition system. The bio-medical signals are normally very weak and they suffer as of the high common mode voltages. The very high quality instrumentation amplifier is necessary to insure excellent diagnosis. Generally, the LNA comprises SF problem. To compensate the SF problem, this paper proposed an LCSA based LNA system. The performance of the proposed system is shown and the proposed system is compared with the existing algorithms namely, PSO and FA. The results proved that the proposed system have better performance than the existing methodologies.

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