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Letters

Designing and modeling of ultra low voltage and ultra low power LNA using ANN and ANFIS for Bluetooth applications

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ABSTRACT

This paper reports the design of an ultra low voltage and ultra low power RF CMOS LNA using a two-stage common source-common gate topology with source inductive degeneration. The proposed structure reduced the supply voltage and power consumption. Considering the complexity of the analysis, it is necessary to simulate a neural model with high speed and accuracy. The proposed LNA is accurately modeled using ANN (MLP and RBF) and ANFIS. The model accuracy is evaluated for all the input–output parameters in the Bluetooth frequency range. A model of low voltage and low power LNA using ANN for Bluetooth applications is developed. The results show the average errors of 0.106%, 0.093% and 7.18×10^{-5}% using MLP, RBF and ANFIS, respectively. It is observed that the ANFIS model is better than ANN for developing the model and increasing the input parameters.

1. Introduction

Since Bluetooth system takes low power signals in ISM (industrial devices, scientific and medical) band, the application of this system for reducing interference is not satisfactory. Therefore, low noise amplifier (LNA) is necessary for the Bluetooth system [1–4]. The present paper reports the design of an ultra low voltage and ultra low power LNA in TSMC 0.18 μm CMOS technology for Bluetooth applications. LNAs play a critical role in the overall performance of the system and their design is governed by the gain, stability, noise figure, impedance matching, linearity, power dissipation and other parameters necessary for RF circuits design. In practice, most of these parameters trade with each other and this makes the design a multi-dimensional optimization problem. Therefore, choosing the optimized value of design parameters, to fine-tune the design, is very time-consuming and unexciting. As a result, neural networks can be very useful for solving the problem. Artificial neural networks (ANN) are recently used as a conventional alternative at various levels of RF and microwave CAD including modeling, simulation and optimization. ANN is capable of accurately learning RF/microwave characteristics of active devices and nonlinear circuits [5–10]. Fuzzy logic and neuro-computing led to the development of neuro-fuzzy systems. Neuro-adaptive learning techniques provide a method for the fuzzy modeling procedure to learn information about a data set [11–16]. While circuit-level simulation provides accurate results, it requires extensive computation over extended time periods, especially when RF/microwave and nonlinear devices and circuits have to be designed. Moreover, behavioral modeling techniques are insufficient to represent the RF/microwave circuits accurately and require a prodigious amount of time to be developed. So, ANN and ANFIS can be exploited as trade-offs between simulation time and accuracy. They can also be employed in tackling with RF/microwave computer aided design (CAD) problems. Also the paper exploits a novel modeling approach for RF/microwave circuits using neural network model. This paper is organized in five sections. Designing a Low noise amplifier for Bluetooth applications and its simulation results in ADS are presented in Section 2. A brief explanation of the neural networks, e.g., MLP, RBF, ANFIS and the proposed model are presented in Section 3. Results, comparison and discussion are presented in Section 4. The main contribution of the paper is summarized in Section 5.

2. Designing low noise amplifier for Bluetooth applications

As shown in Fig. 1, a two-stage common source-common gate topology with source inductive degeneration is adopted to reduce the supply voltage in our design. In this structure, at low supply voltage 0.36 V, the NMOS transistors are still in weak inversion region, which can lead to increased noise figure (NF). A solution to the threshold voltage problem is the forward body bias technology.

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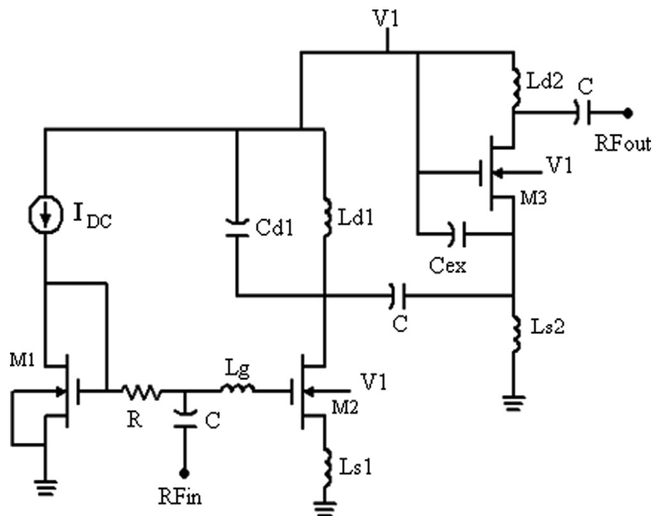

Fig. 1. Proposed LNA, for ultra low voltage and ultra low power applications [1].

The threshold voltage of MOSFET is known as

$$V_{th} = V_{th0} + \gamma\left(\sqrt{2\varnothing_f - V_{BS}} - \sqrt{2\varnothing_f}\right) \quad (1)$$

where V_{th0} is the value of V_{th} with $V_{BS}=0$, γ is the bulk threshold parameter and $\varnothing_f$ is the strong inversion surface potential of the NMOS. The forward body bias causes the threshold voltage to decrease. Further details about the proposed structure can be found in [1]. The gate width of the first stage MOSFET is the traded off among power consumption, NF and gain. The smaller size of the second stage MOSFET is for noise and gain considerations. L_{s2} is connected to source to improve the NF and stability of the circuit. However, S_{11} gets worse when L_{s2} increases. This effect limits the amount of inductance ($L_{s2}=2.4763$ nH). C_{ex} is added to the second stage gate-source terminal for more design flexibility and achieving a good trade-off between power gain and other performances, which causes the power gain to increase, but the NF is lost. A good trade-off between power gain and NF is established by choosing $C_{ex}=1.14$ pF in this study.

Values for the components and device sizes are listed in Table 1.

2.1. Simulation result of the proposed LNA

The proposed circuit is simulated with ADS simulation tools in TSMC 0.18 μm CMOS process with RF MOSFET model BSIM3. The circuit is designed for 2.45 GHz ISM frequency band. The proposed LNA has 2.27 dB NF at operation frequency. The results showed a power gain of 19.36 dB and input return loss (S_{11}) of −105.971 dB at 2.45 GHz for the proposed LNA. This work is compared with other recently reported (2–2.45) GHz LNAs in Table 2.

Table 1
The final values for the components.

M_1	$W \times L=37$ μm × 0.46 μm
M_2	$W \times L=425.227$ μm × 0.18 μm
M_3	$W \times L=47.27$ μm × 1.4 μm
DC supply voltage	0.36 V
R	40 kΩ
L_{s1}	0.28 nH
L_{g1}	1.715 nH
L_{s2}	1.4763 nH
C_{ex}	1.14 pF
C_{d1}	1.1 pF
L_{d1}	4.6 nH
L_{d2}	10 nH

Table 2
Comparison of various LNAs.

Ref.	Tech. (μm)	Freq. (GHz)	NF (dB)	S_{21} (dB)	V_1: supply voltage (V)	Power (mW)
[2]	0.18	2.4	1.56	13.8	0.6	1.5
[3]	0.25	2	4	25.67	1	5.13
[4]	0.12	2.4	3.9	20	1	22.6
[5]	0.25	2.2	3	14.9	1.2	–
This work	0.18	2.45	2.27	19.36	0.36	2.56

3. Neural network

There are different ways in which information can be processed by a neuron, as well as different ways to connect them. Several neural network structures and algorithms have been proposed including multilayer perceptions (MLP), radial basis function networks (RBF) [11], and adaptive neuro-fuzzy inference system (ANFIS), which have been used for microwave modeling and design.

3.1. Proposed model

Identification of inputs and outputs is the first step for neural network development. Input–output parameters are determined based on the object of applied neural model. Considering the fact that the aim of this paper is LNA modeling for Bluetooth applications, we swept frequency with a 1 MHz step in the frequency range from 2.4 GHz to 2.4835 GHz. In effect, we designed the proposed LNA structure with a 1 MHz step in the Bluetooth frequency range for 85 times. We tried to consider Bluetooth requirements (e.g., consuming power less than 50 mW and noise figure less than 2.5 dB) for all of the 85 designs. Apart from that, having a suitable impedance matching and inverse isolation were our another goal. The whole data for training and testing the network was 85. In recent similar studies, the input parameters were biasing transistor parameters or magnitude and phase of S-parameters while in this work we considered applied parameters, i.e., NF and power gain as input parameters. Definitely, using these parameters as inputs makes the model more applicable and tangible. Any change in the value of the capacitors, inductors and dimensions of transistors (W and L) can affect S-parameters, NF and total current of supply voltage (I_{DC}). Here, the elements (W_1, L_{g1}, L_{g2}, L_{s1}, L_{s2}, W_2, W_3, and C) which have more influence on determining NF, S-parameters and I_{DC} have been considered as output variables. Moreover, some circuit elements with less effect on outputs were assumed constant. These included $W_1=37$ μm, $L_1=0.46$ μm, $R=41$ kΩ, $L_2=L_3=0.18$ μm, $C_{ex}=1.14$ pF, $C_{d1}=1.1$ pF, $L_{d1}=4.6$ nH and $L_{d2}=30$ nH. To evaluate sensitivity of the proposed circuit to changes in process parameters, power supply voltage and temperature, we simulated the designed circuit by varying these parameters in the proper range.

Simulation results showed that the sensitivity of this model to variations of power supply voltage, temperature and process parameters is low. Tables 3 and 4 show the sensitivity results of the proposed LNA to variations of supply voltage and temperature, respectively. Therefore, these parameters are presumed constant in this work. Data generated from ADS were used for neural network training. In order to have an authentic design, the key design parameters and the design criterion parameters were considered as input and output in the proposed model. The proposed input–output model for LNA is shown in Fig. 2.