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A sub-mW 2.9-dB noise figure Inductor-less low noise amplifier for wireless sensor network applications

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ABSTRACT

In this paper, a low power differential inductor-less Common Gate Low Noise Amplifier (CG-LNA) is presented for Wireless Sensor Network (WSN) applications. New Shunt feedback is employed with noise cancellation and Dual Capacitive Cross Coupling (DCCC) techniques to improve the performance of common gate structures in terms of gain, Noise Figure (NF) and power consumption. The shunt feedback path boosts the input conductance of the LNA in current reuse scheme. Both shunt feedback and current reuse bring power dissipation down considerably. In addition, the positive feedback is utilized to cancel the thermal noise of the input transistor. The proposed LNA is designed and simulated in 0.18 µm TSMC CMOS technology. Post layout Simulation results indicate a voltage gain of 16.5 dB with −3 dB bandwidth of 100 MHz–3 GHz. Also third order Input Intercept Point (IIP3) is equal to + 1 dBm. The minimum NF is 2.8 dB and the value of NF at 2.4 GHz is 2.9 dB. S11 is better than −13 dB in whole frequency range. The core LNA consumes 985 µW from a 1.8 V DC voltage supply.

1. Introduction

Nowadays ultra-low power RF receivers gained considerable interest for applications such as Internet of Things (IoT), Wireless Sensor Network (WSN) and biomedical sensors [1,2]. The WSNs become more popular recently due to their performance in environment monitoring, control, communications, intelligence targeting systems and biomedical applications. In addition sensing, physical security, process control, air traffic control, traffic surveillance, industrial and manufacturing automation, distributed robotics, weather sensing, and environment monitoring are the major fields where WSNs are very useful [3]. For WSN applications parameters such as size, cost and power consumption should be carefully considered.

As the first signal processing block in the receiver chain, an efficient low-noise amplifier (LNA) with low cost, low power and low noise is demanded [4,5]. Inductorless LNA is economic choice to reduce to area, cost and design complexity. Although inductors can resonate with parasitic capacitors to result higher bandwidth and less Noise Figure (NF), they often require large area [6]. One of the main challenges for LNA designers is reducing power consumption [7].

This article introduces a new wideband differential inductorless common-gate low-noise amplifier (CG-LNA) with multiple feedbacks for the IEEE 802.15.4 (Zigbee) standard. The techniques are utilized to alleviate the trade-off between input matching, NF and power consumption. Also, current reuse topologies have been applied to further reduction of power consumption. Moreover, the DCCC is used to append effect of g_{mb} of the amplifying transistors which can restrain the power. The proposed LNA can support multiple frequency bands, so it can be employed in other standards such as digital TV (450–850 MHz), GSM-900 and Zigbee standard.

This paper is organized as follows. In Section 2, the configuration of the reported LNA and its associated challenges are investigated. The concept of proposed LNA and its properties are explained in Section 3. Section 4 shows a mathematical analysis for the major LNA parameters including input matching, gain, noise, and bandwidth. Post layout Simulation results are presented in Section 5. Finally, the paper is concluded in Section 6.

2. Background

Recently, inductorless low power LNAs have been reported based on Resistor-terminated Common-Source (R-CS), Shunt-Feedback (SFB) and Common-Gate (CG) topologies Fig. 1 [8]. The main challenge in different structures is to provide high voltage gain and good input matching with low power consumption. Fig. 1 a shows the resistor-terminated common-source amplifier which R_T determines input impedance and provides input matching with low power consumption. However, R_T adds its own thermal noise at input node. Thus, the transconductance (g_m) of the device needs to be large enough to maintain an acceptable noise figure, which will result in more power

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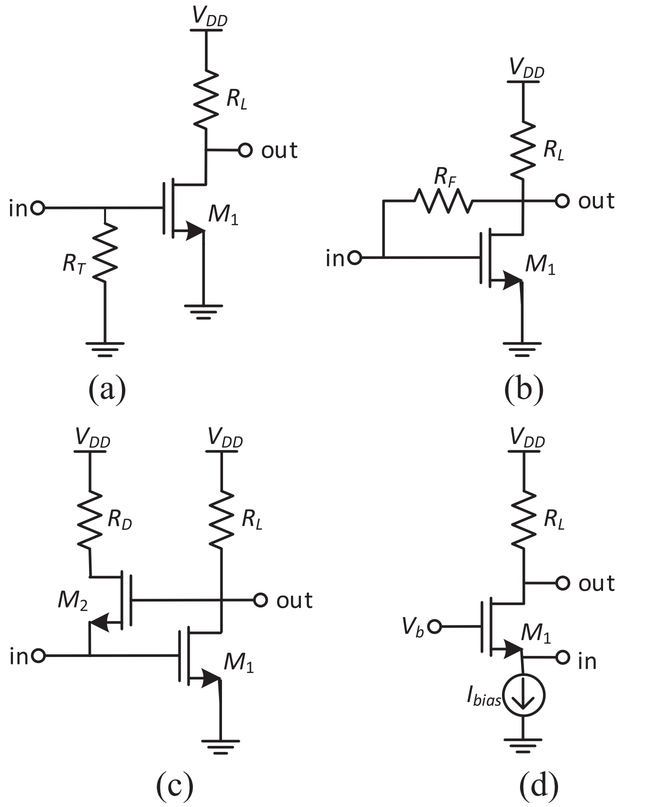

Fig. 1. Inductor-less LNAs: (a) Resistor-terminated Common-Source LNA, (b) Shunt-Feedback (SFB) LNA, (c) Source follower based SFB LNA, (d) Basic common gate LNA [11].

consumption [9]. So, it is not suitable for wireless sensor networks. The shunt feedback technique can be implemented with a pure resistor or a separate source follower feedback branch which are shown in Fig. 1b and c, respectively. In resistor based SFB structure, input impedance is provided with a feedback network. The main drawback of SFB with resistor is reduction of output impedance and the voltage gain. To achieve high gain larger g_{m1} value is needed which increases power consumption. The use of source follower solves the issue of output impedance, however, it needs extra P_{DC} for biasing of M_2. In addition the auxiliary transistor introduces its own noise [9,10]. Regarding of above mentioned problems, the SFB is not tolerable for low power applications.

One of the wideband LNA topologies that have been extremely investigated is CG. The CG amplifier is superior in linearity and stability to the SFB and R-CS LNAs due to its low output to input parasitic capacitance. Configuration of the basic CG circuit is illustrated in Fig. 1d.

The input impedance (R_{in}), the voltage gain (A_V) and the noise Factor (F) of this circuit are equal to

$$R_{in} = \frac{1}{g_m} \tag{1}$$

$$A_V = g_m R_L \tag{2}$$

$$F = 1 + \frac{\gamma}{2\alpha} + \frac{4R_S}{R_L} \tag{3}$$

where g_m is the transconductance of the transistor, α is the ratio between g_m and the zero-bias drain conductance g_{d0} and γ is the excess channel thermal noise coefficient. From (1) and (2), the amplifying g_m sets the gain and the input impedance simultaneously. Input matching condition forces g_m to be equal to 20 mS. Such high value for g_m imposes high power consumption of the circuit. The stringent constraint on transconductance results in less control on voltage gain and NF [12,13].

Moreover, the gate terminal of input transistor does not need to be a pure DC node for correct performance. Recent papers countered the shortcoming of the CG structure by applying active [10,14,15] or passive [16,17] g_m-boosting techniques. The g_m-boosting topology improves the performance of the main amplifier by applying signal to both gate and source nodes of amplifying transistor [11]. A negative gain (A_{NEG}) is inserted between the gate and source terminals of transistor and effective transconductance increases to $g_m(1 + A_{NEG})$. Thus, input impedance (R_{in}), the voltage gain (A_V) and the noise factor (F) are given by

$$R_{in} = \frac{1}{g_m(1 + A_{NEG})} \tag{4}$$

$$A_V = g_m(1 + A_{NEG})R_L \tag{5}$$

$$F = 1 + \frac{\gamma}{\alpha(1 + A_{NEG})} + \frac{4R_S}{R_L} \tag{6}$$

Although, the noise factor and needed power is reduced by a factor of $(1 + A_{NEG})$, the IIP_3 is deteriorated due to large voltage swing at the gate-source [18].

Recently several papers employ differential topology to improve performance of noise figure and second order nonlinearity [14]. The differential scheme of the CG-LNA is depicted in Fig. 2a. In this structure the differential voltage gain and input impedance are equal to $A_V = 2g_mR_L$ and $R_{in} = 2/g_m$, respectively. To eliminate the g_m-P_{DC} trade-off in differential CG amplifiers, a Capacitive Cross Coupling (CCC) technique is applied (Fig. 2b). This technique leads to a unit voltage gain ($A_{NEG} = 1$) and the effective transconductance boosts to $2g_m$ without no power cost [19]. In the CCC structure the differential input impedance (R_{in}), voltage gain (A_V) and noise factor (F) are equal to

$$R_{in} = \frac{2}{2g_m} = \frac{1}{g_m} \tag{7}$$

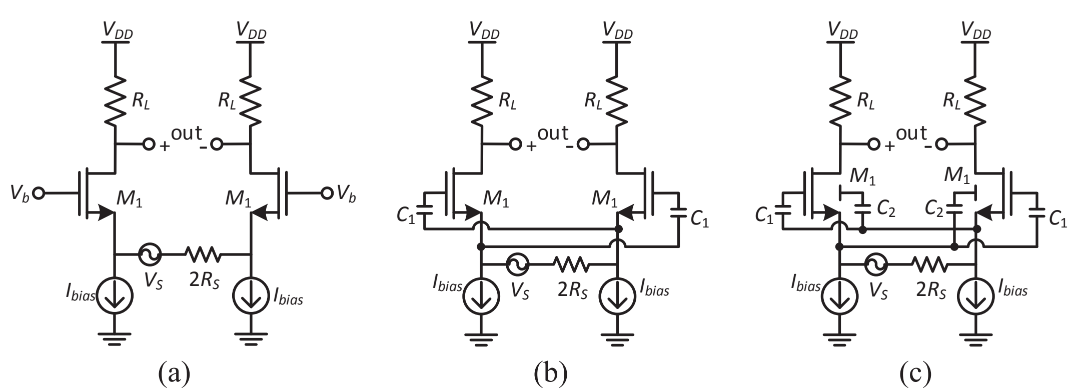

Fig. 2. (a) Conventional differential CGLNA, (b) Capacitive Cross-Coupling CGLNA, (c) Dual Capacitive Cross Coupling CGLNA [16].