INTEGRATION, the VLSI journal 52 (2016) 316–322

Contents lists available at ScienceDirect

INTEGRATION, the VLSI journal

journal homepage: www.elsevier.com/locate/vlsi

An Inductor-less Sub-mW Low Noise Amplifier for Wireless Sensor Network Applications

Atiyeh Karimlou [a,*], Roya Jafarnejad [b], Jafar Sobhi [a]

[a] Faculty of Electrical and Computer Engineering, University of Tabriz, Tabriz, Iran
[b] Faculty of Electrical and Computer Engineering, Tarbiat Modares University, Tehran, Iran

ARTICLE INFO

Available online 29 July 2015

Keywords:
Low Noise Amplifier (LNA)
Inductor-less
Shunt feedback
Dual Capacitive Cross Coupling (DCCC)
Wireless Sensor Network (WSN)

ABSTRACT

This paper presents a Sub-mW differential Common-Gate Low Noise Amplifier (CGLNA) for ZigBee standard. The circuit takes the advantage of shunt feedback and Dual Capacitive Cross Coupling (DCCC) to reduce power consumption and the bandwidth extension capacitors to support 2.4 GHz ISM band. An amplifier employing these techniques has been designed and simulated in 0.18 μm TSMC CMOS technology. The Simulation results show a gain of 18.2 dB, an IIP3 of −4.32 dBm and a noise figure of 3.38 dB at 2.4 GHz. The proposed LNA consumes only 967 μW from a 1-V supply.

1. Introduction

Wireless Sensor Networks (WSNs) are considered as one of the most important technologies for the recent years which are used in various fields such as: health monitoring, factory automation, and security surveillance [1]. WSN standards like IEEE 802.15.4 requires achieving simplicity, low cost, and low power consumption with the ability to operate months or even years [2]. Most of the circuits based on ZigBee standard are powered by battery. The most important challenge of these networks is Low Power (LP) design which is able of operating for several years using a single battery. The IEEE 802.15.4 standard uses the three license-free frequency bands of 860 MHz, 920 MHz and 2400 MHz [2] among which the 2.4 GHz band is operated worldwide.

The conventional LNA circuits use multiple inductors to support frequency bands such as 2.4 GHz [3–5] which causes the chip to take more space and expensive RFIC. Removing them leads to reduce the costs. On the other hand low power inductor-less LNAs cannot offer the narrowband and low Noise Figure (NF) as well as inductor-based LNAs [6]. So designing such low cost circuits that have small size and achieve large voltage gain in low power condition is very challenging.

LNA, as the first building block in the receiver, should qualify good impedance matching, high gain, and low noise figure across the frequency band. Moreover, high linear, low area and low power LNAs are needed for high-performance and low-cost applications. An inductor-less CGLNA with shunt feedback technique to improve the power consumption is presented in this paper. The shunt feedback provides a new degree of freedom to adjust the input impedance of the LNA; thus g_m of the amplifying transistors can be further reduced that consequently results in the lowering of the power dissipations. Also the DCCC technique is applied at the main transistors of the amplifying stage in order to improve the effective transconductance of them. This low g_m value is obtained with low current consumption, resulting in lowering of the power dissipation. It also uses a bandwidth improvement technique to support 2.4 GHz ISM band. This circuit supports other frequency bands of ZigBee standard and also various wireless standards such as WLAN, GSM, DECT, Bluetooth, Wi-Fi and GPS due to its inductor-less nature.

2. Review of traditional inductor-less amplifiers

The conventional amplifiers which provide voltage gain and input impedance matching without any inductors are the Resistor-terminated Common-Source (R-CS) amplifier, Shunt-Feedback (SFB) amplifier and Common-Gate (CG) amplifier (Fig. 1). Almost majority of published LNAs are based on either of these structures or the combination of them [7–9]. The resistor-terminated common-source amplifier which provides input impedance matching using R_T and achieves the lowest power consumption is shown in Fig. 1(a). In this circuit, the resistor R_T adds its own thermal noise and increases the noise figure extremely, which is not tolerable for Wireless Sensor Network Applications. Fig. 1(b) shows the impedance-based SFB amplifier which in this case feedback impedance provides real input impedance matching. In this circuit the input impedance matching is obtained because of the LNA voltage

* Corresponding author. Tel.: +989141643150; fax: +984436251149.
E-mail address: a.karimlou91@ms.tabrizu.ac.ir (A. Karimlou).

http://dx.doi.org/10.1016/j.vlsi.2015.07.009
0167-9260/

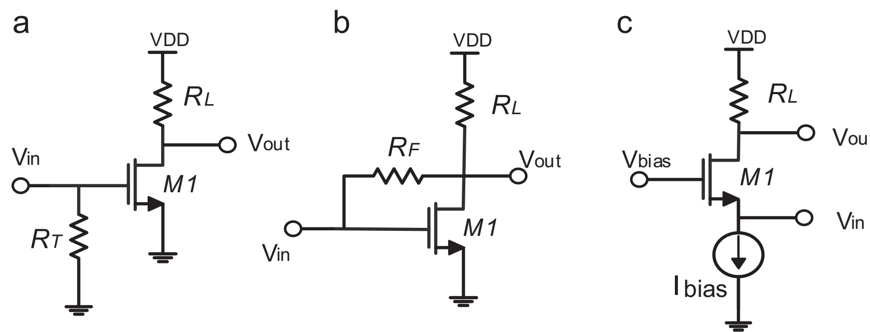

Fig. 1. Traditional inductor-less amplifiers: (a) Resistor-terminated common-source amplifier, (b) shunt-feedback amplifier, and (c) common-gate amplifier.

gain. The main disadvantage of impedance based SFB amplifiers is degradation of the output impedance ($R_F /\!/ R_L$) due to feedback path which decreases the voltage gain of the LNA. Thus, to achieve high gain, larger g_m value is needed and as a result, P_{DC} increases. To isolate the output from the feedback impedance authors in [10,11] offer a feedback path with a source follower. Although the disadvantage of last circuit has been solved, but in this case the feedback path needs extra power consumption which is not good for low power purpose.

The basic CG circuit is shown in Fig. 1(c) [12]. Input impedance of CG amplifier is the source terminal impedance ($1/g_m$) of the amplifying transistor, so the trans-conductance of the input transistor and thus the gain of the amplifier are set by the input matching condition. CG circuit shows better linearity than SFB since its input voltage gain is lower than SFB circuit. The available accessibility of the gate terminal in CG circuit is another advantage of it which cause low power operation. Actually, this node does not require being pure DC node for correct operation [6]. Therefore the CG circuit is preferred due to achieving lowest possible power dissipation.

Since the substrate of the LNA and baseband digital circuits are the same in CMOS process, in most of the systems a differential structure is preferred to improve the second order nonlinearity and to eliminate the on-chip switching noise. The differential scheme of the CGLNA is shown in Fig. 2(a). In this circuit, the differential voltage gain and the differential input impedance are given by: $A_{V-diff} = g_{m1}R_L$, $R_{in-diff} = 2/g_{m1}$, respectively [13]. The noise factor in the perfect matching condition ($R_{in} = 2R_s = 100\ \Omega$) is then given by: $F = 1 + (\Upsilon/\alpha) + 4R_S/R_L$ which g_{m1} is the trans-conductance of the input transistor $M1$, Υ is the excess channel thermal noise coefficient, and α is the ratio between g_m and the zero-bias drain conductance g_{d0} [13]. With the low supply voltages of modern CMOS processes, the load resistance must also be low due to stringent headroom condition, resulting in low gain and increased noise figure. Furthermore, due to input matching conditions the constant trans-conductance of the common-gate amplifier, prevents improvement of the noise figure and power consumption.

In order to overcome the disadvantages of the common-gate amplifier in terms of noise and power consumption the Capacitive Cross-Coupling (CCC) technique was introduced [13–15]. The Capacitive Cross-Coupling structure is shown in Fig. 2(b). Cross-coupling capacitors are used in circuit in the feedback path between the gate and source nodes of the amplifying transistors ($M1$). The effective transconductance (g_{m1}) is boosted to $2g_{m1}$, so the differential voltage gain and the differential input impedance are given by: $A_V = 2g_{m1}R_L$, $R_{in} = 2/(2g_{m1}) = 1/g_{m1}$, respectively. The noise factor of this circuit is then given by: $F = 1 + (\Upsilon/2\alpha) + 4R_S/R_L$. As shown in the noise equations the impact of $M1$ noise is fallen by half. Furthermore g_{m1} value is half of the CGLNA due to the input matching condition so the power consumption is reduced by using of CCC technique.

Fig. 2(c) indicates the Dual Capacitive Cross-Coupling CGLNA (DCCC-CGNA). The DCCC circuit is applied at the main transistors of trans-conductance stage by connecting body and gate nodes of each transistor to each other's source terminal in order to further reduction in power consumption [16]. The effective g_{m1} is increased to $2(g_{m1}+g_{mb1})$ by using of DCCC technique. In this circuit by assuming that the ratio of g_{mb1} to g_{m1} is about 15%, effective g_{m1} can be improved to 15% without any additional power consumption in comparison of CCC technique. The improved voltage gain resulted by this technique causes a better noise performance of the LNA in low power design.

This work offers an additional degree of freedom to obtain input impedance matching of the LNA, consequently the g_m of the input transistor can be reduced more, resulting in the lowering of the power consumption.

3. Proposed LNA circuit topology and analysis

3.1. Basic Idea

Fig. 3(a) shows the simplified single ended model for the proposed inductor-less CGLNA with shunt feedback path to improve the power dissipation of CGLNA. The main idea of shunt feedback path is to add a degree of freedom on input impedance expression of the CGLNA. g_m of the amplifying transistor ($M1$) can be reduced more by using of the shunt feedback. This low g_m value is obtained with low current consumption, resulting in lowering of the power dissipation. Also the DCCC technique is applied at the main transistors of the amplifying stage in order to further reduction in power dissipations. The differential configuration of the proposed circuit is shown in Fig. 3(b). The main DCCC-CGLNA is made by $M1$ and R_L. The shunt feedback path which helps to improve the input impedance matching condition is made by $M3$ and $R3$. Furthermore to have an acceptable voltage gain, with low g_m values the output impedance of the LNA must be high enough which degrades the bandwidth of the LNA. In order to overcome this drawback, the outputs of the main and feedback path are capacitively coupled through $C4$ for bandwidth enhancement purpose [6,17]. The shunt feedback path which is used to satisfy input matching also reduces the effective trans-conductance of the amplifying transistors. This low g_m value can be achieved with low current condition. So the voltage drop through R_L will be reduced which degrades the limitations of the voltage headroom, thus the power supply can be cut down which results in low power consumption. The various metrics of proposed technique and the effect of low power supply are discussed in the next section.

3.2. Input Matching

The equivalent half circuit model for the proposed LNA is shown in Fig. 3(a). By applying the shunt feedback path to the