Design and Simulation of X Band LNA for Aircraft Receiver

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Abstract

This paper proposes a highly linear low noise amplifier (LNA) for ultra-wideband applications. It focuses on linearization of the basic active gm-boosted common gate (CG) LNA circuit by exploring the non-linearity coefficients using the generalized nonlinearity model. Mathematical analysis shows that in active gm-boosted CG LNA, the third input intercept point (IIP3) of LNA depends on interaction between main and auxiliary amplifiers. Post-layout simulation results of the proposed LNA circuit in a 180 nm RF CMOS process show 5.19 dBm of IIP3 that indicates 4 dB improvement comparing with conventional structures. The proposed wideband LNA has a voltage gain of 18 dB, 4dB bandwidth from 8 GHz to 12 GHz, and minimum noise figure (NF) of 3.6 dB. The simulated S11 is better than -14 dB in whole frequency range while the LNA core draws 3 mA from a single 1.8 V DC voltage supply.

Keywords: Low noise amplifier, Common gate LNA, gm-boosted.

1. Introduction

Growing demand for high data transfer rate wireless communication systems has attracted great interest to ultra-wideband (UWB) transceivers in academia [1] and industry [2,3]. One of the most critical blocks in an UWB receiver is the low-noise amplifier (LNA), as in UWB transceivers hundreds of channels could enter the receiver without any pre-filtering, acting as in-band interferers. Moreover, nearby radios cause increased adjacent blockers, creating severe cross modulation, inter-modulation, and desensitization. Therefore, achieving high linearity over a wide frequency range is a big design challenge for UWB LNAs as the first block in receiver chain [4]. A number of techniques have been reported in [5] regarding linearity improvement of LNA. A well-known method for linearity improvement of LNAs is the derivative superposition (DS) technique [6].

In this method an auxiliary transistor operating in weak inversion region is added to cancel out the third-order nonlinearity of the main transistor. However, in this solution the best biasing point for linearity improvement is realized within a relatively low gate-source voltage (around 600 mV for main and 450 mV for auxiliary transistors in 180 nm CMOS process), results in low gain and in-creased NF in high frequencies.CG LNA is attractive for the UWB LNA design due to its low input impedance LNA wide band of frequency spectrum [7]. But, as a disadvantage, the NF tightly depends on input matching. Gm-boosting technique has been introduced to resolve this issue. Capacitor cross coupled (CCC) as a passive

gm-boosting technique efficiently breaks this trade-off [8]. As CCC needs a balloon to prepare differential inputs, it is not applicable in UWB structures. Active gm-boosting technique is a single-input solution for mentioned problem [9]. But using an active boosting in the signal path corrupts linearity of the LNA dramatically.

Another key challenge in UWB LNA is to provide a flat gain over the whole bandwidth. CMOS technology is viable for system-on-chip solutions even though its parasitic limits the performance of broadband amplifiers and motivate the use of bandwidth extension techniques such as distributed amplification [10]. However, distributed amplifiers consume large area and high power and are difficult to design owing to delay line losses that necessitate extensive modelling and electromagnetic simulation. In contrast, shunt peaking is a simple and low power technique which is commonly used in CMOS broadband applications to extend the bandwidth [11]. This technique gives the maximum bandwidth extension ratio (BWER) of 1.84 with 1.5 dB of peaking [12].A maximally flat gain is achieved for BWER of 1.72, that is not enough in some applications.

A highly linear UWB LNA based on the mathematical analysis is proposed in this paper. The linearity of active gm-boosted CG structure is improved based on mathematical analyses.

The rest of the paper is organized as follows: Mathematical analysis for linearity improvement of the gm-boosted CG LNA is presented in Section 2. Simulation results of an improved bandwidth extension and increasing of gain for the proposed LNA circuit in a 180 nm RF CMOS process are presented in Section 3. Section 4 concludes the paper.

2. Highly Linear gm-boosted CG LNA

Fig.1 shows an active gm-boosted CG amplifier with input Vin and output Vout. To analyze linearity of the amplifier, a weakly nonlinear model of transistor by the first three power series terms is used:

$$I_{ds} = g_{m1}V_{gs} + g_{m2}V_{gs}^2 + g_{m3}V_{gs}^3 \quad (1)$$

whereVgs is gate-source voltage, gm_1 is linear coefficient, and gm_2 and gm_3 are second and third order nonlinear coefficients of drain-source current Ids, respectively.

In deep submicron CMOS technologies, a large load resistance along with a low voltage supply push the transistor out of the deep saturation region, resulting a very significant increase in the third-order nonlinearity term of output conductance (g_{ds}) and cross-modulation nonlinearities which lead to a considerable increase in IM3 distortion [13]. It should be noted that by utilizing small load resistance to enhance the bandwidth, the nonlinearity of gds can be negligible in broadband applications.

Output voltage of the LNA (neglecting g_{ds}) can be obtained by:

$$V_{out} = (V_{in} - V_1) \times \frac{R_L}{R_s} \quad (2)$$

Here the main idea is to calculate nonlinearity coefficients of V1 and cancel the third nonlinear coefficient to improve IIP3. By performing some replacements, the relation between Vin and V1 in Fig. 1(a) can be obtained as:

$$V_{in} = V_1 - I_{dsM_1} \times R_s = V_1 - \left(g_{1_1} V_{gsM_1} + g_{2_1} V_{gsM_1}^2 + g_{3_1} V_{gsM_1}^3\right) R_s \quad (3)$$

$$V_{gsM_1} = V_A - V_1 = -\left(g_{1_A} V_1 + g_{2_A} V_1^2 + g_{3_A} V_1^3\right) R_A - V_1 \quad (4)$$

where g_{mi} and g'_{mi} are transconductance coefficients of M1 and MA transistors, respectively. The relation between Vin and V1 while applying input matching condition is given by:

$$V_{in} \approx aV_1 + bV_1^2 + cV_1^3 \quad (5)$$

where higher-order nonlinear coefficients have been neglected.

To calculate nonlinear coefficients of Vout/Vin, we need to calculate V1 as a function of Vin to replace in Eq. (2).

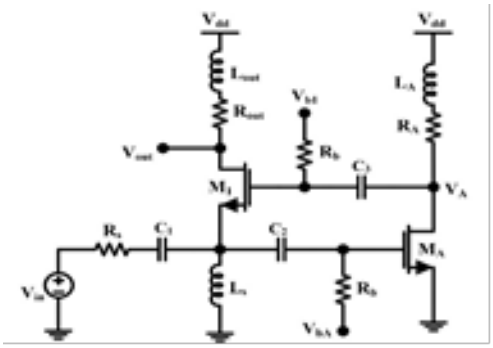

Fig. 1. Proposed wideband gm-boosted CG LNA.

Inverse function of Eq. (5) could be approximated by Vin power series up to the third term:

$$V_1 \approx a'V_{in} + b'V_{in}^2 + c'V_{in}^3 \quad (6)$$

a′, b′ and c′ can be calculated by combination of Eq. (4) and Eq. (5), and taking derivative:

$$a = 2 \quad (7)$$

$$b = -R_s\left(\frac{g_{2_1}}{g_{1_1}^2 R_s^2} - \frac{g_{2_A} g_{1_1}}{g_{1_A}}\left(\frac{1}{g_{1_1} R_s} - 1\right)\right) \quad (8)$$

$$c = R_s\left(\frac{g_{3_1}}{g_{1_1}^3 R_s^3} + \left(\frac{g_{3_A} g_{1_1}}{g_{1_A}} - \frac{2 g_{2_A} g_{2_1}}{g_{1_1} g_{1_A} R_s}\right)\left(\frac{1}{g_{1_1} R_s} - 1\right)\right) \quad (9)$$

$$\frac{V_1}{V_{in}} = a' + b'V_{in} + c'V_{in}^2 = \frac{1}{a + bV_1 + cV_1^2} \quad (10)$$

$$a' = \frac{V_1}{V_{in}}\Big|_{V_{in}=V_1=0} = \frac{1}{a}$$
$$b' = \frac{d(V_1/V_{in})}{dV_{in}}\Big|_{V_{in}=V_1=0} = -\frac{b}{a^3} \quad (11)$$
$$c' = \frac{1}{2} \times \frac{d^2(V_1/V_{in})}{dV_{in}^2}\Big|_{V_{in}=V_1=0} = \frac{2b^2 - ac}{a^5}$$

$$= \left(\frac{\left(1 - g_{1_1} R_s\right)\left(\left(1 - g_{1_1} R_s\right) g_{2_A}^2 - g_{1_A} g_{3_A}\right)}{16 g_{1_A}^2} + \frac{g_{2_1}^2 - g_{1_1} g_{3_1}}{16 R_s^2 g_{1_1}^4} \right) \tag{12}$$

$$= \left(\frac{\left(1 - g_{1_1} R_s\right)\left(\left(1 - g_{1_1} R_s\right) g_{2_A}^2 - g_{1_A} g_{3_A}\right)}{16} \times \frac{R_A^2}{A_x^2} + \frac{g_{2_1}^2 - g_{1_1} g_{3_1}}{16} \times R_s^2 A_x^4 \right) \tag{13}$$

$$\approx \frac{g_{2_1}^2 - g_{1_1} g_{3_1}}{16} \times R_s^2 A_x^4$$

$$V_{out} = ((1 - a')V_{in} - b'V_{in}^2 - c'V_{in}^3) \times \frac{R_L}{R_s} \tag{14}$$

To determine the linearity of amplifier, amplitude of input third intercept point (IIP3) is obtained by equating the fundamental and 3rd inter-modulation terms [14]:

$$A_{IIP3} = \sqrt{\frac{4}{3} \times \frac{a' - 1}{c'}} \tag{15}$$

3. Simulation results of proposed LNA

The proposed UWB LNA is designed with a commercial 0.18 µm RF CMOS technology and Cadence was used for simulations. All inductors are on-chip with spiral shape and capacitors are metal-insulator-metal type. Simulated S parameters and Noise Figure are shown in Figures 2 and 4. A power gain S21 of 17.5±3 dB in the frequency range of 8- 12 GHz is obtained. Input reflection coefficient S11 is below -14 dB. The NF of 3.83 dB occurs at 10 GHz. The noise figure is below 4.3 dB with the average value of 3.4 dB in the frequencyrange of 8 to 12 GHz. The LNA consumes 5.6 mW with a 1.8V supply voltage.

By using a gm-boosting scheme wherein inverting amplification is introduced between the source and gate terminals of M1, the power consumption and noise factor of UWB LNA can be significantly reduced. By employing the gm-boosting technique in the proposed LNA, the effective transconductance of M1, gm1, was boosted to 2gm1. All simulation results are shown by fig.2,3,4,5.

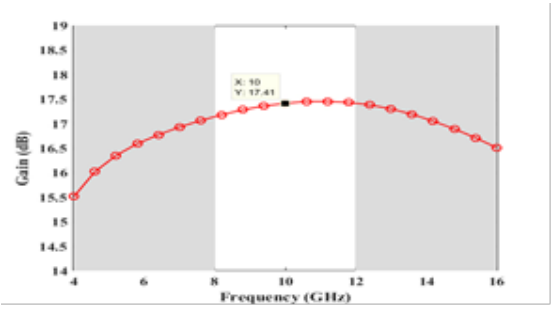

Fig 2. Post layout simulated Gain of the proposed LNA

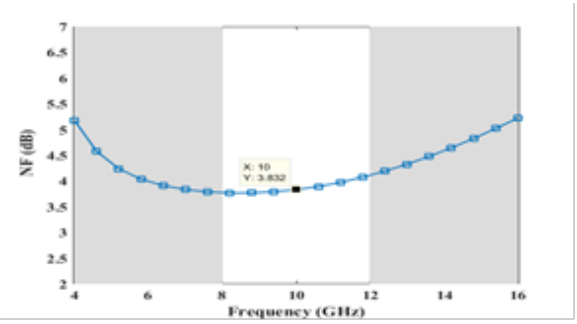

Fig 3. Simulated NF of the proposed LNA

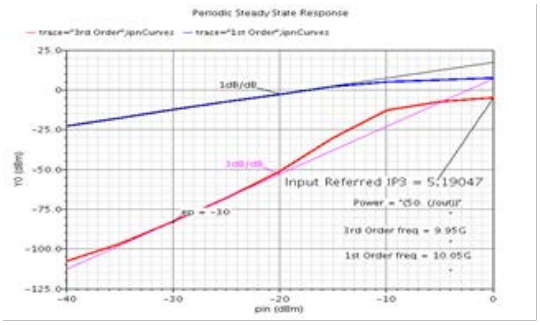

Fig4. Post layout simulated IIP3 of the gm-boosted

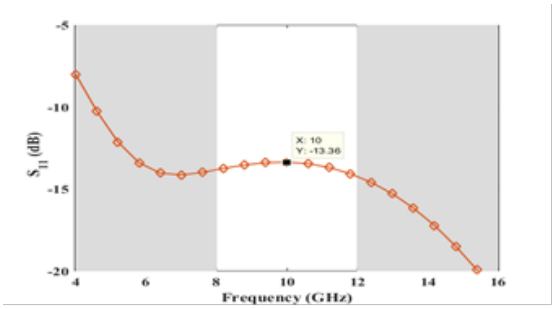

Fig.5. Post layout simulated S11 of the proposed LNA

4. Conclusion

This paper proposed a highly linear UWB low noise amplifier based on the mathematical analysis using the Feedforward technique. The interaction between main and auxiliary amplifiers was im-plemented to improve linearity of active gm-boosted CG LNA. Post layout simulation results of proposed LNA shows 5 dB linearity improvement compared to the basic active CG LNA . BW extension technique that enhanced 3dB BWER from 8 to 12 .Due to the low power of their input signals, UWB LNAs seldom suffer from gain compression. However, the IIP3 can be an important parameter of linearity in UWB LNAs, as strong narrow-band interferers can exist in the reception band. where a two-tone test is performed with 10 MHz spacing.

Linearity characteristic of the UWB LNA is attributed to the last stage of the LNA and can be improved at the expense of higher power consumption. Combination of noise canceling and gm-boosting techniques were employed to improve the noise performance of the proposed LNA, so that a good NF is obtained within the whole range of 8-12 GHz.

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