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A new input matching technique for ultra wideband LNAs

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Abstract: A noise reduction input matching technique for broadband low noise amplifiers (LNAs) is presented. The proposed LNA employs a positive active feedback network besides of the conventional common-gate (CG) amplifier to achieve both wideband input signal matching and low noise figure (NF), simultaneously. Compared to the conventional broadband noise cancellation techniques, the presented approach achieves the same NF with much less power consumption and high linearity. Circuit level analysis and simulation results are provided to verify the usefulness of the proposed LNA technique. In contrast to the traditional noise cancellation circuit, the proposed LNA does not degrade the linearity and its IIP3 is similar to the simple common-gate LNA. The proposed technique is applied to an LNA operating in 2∼6.5 GHz bandwidth.

Keywords: Ultra wideband LNA, wideband input matching, noise figure, noise cancellation

Classification: Integrated circuits

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1 Introduction

The need for multi-purpose receivers instead of a few narrow-band receivers calls for wideband design in order to lower the overall power and area in use. The LNA as the first block of the receiver must provide low noise figure (NF), high linearity, reasonable gain over the whole bandwidth and a low power consumption. Besides, good input matching should be considered. The common-gate structure is a well-known method to provide a wideband input matching [1]. But, this robust matching network suffers from poor noise performance owing to limited g_m of the CG transistor to 20 mA/V.

A rather new method for lowering the noise figure is to utilize a noise cancellation technique which usually includes two different paths with similar polarity for signal and different polarity for channel noise of CG transistor. This results in cancellation of the CG transistor channel thermal noise at the summation point. Both paths are usually realized by active elements, i.e. transistors [2, 3, 4]. The overall output noise in these designs is limited to other transistors in the signal path. These structures suffer from high power consumption since there are several branches drawing the current from the power supply.

In this paper, a new wideband input matching technique is presented. This structure employs an active feedback in the conventional CG LNA to reduce the NF as well as to achieve the wideband input matching. It is shown that by using this method the input impedance of the proposed LNA stays in matching with 50 Ω antenna while increasing the g_m of the CG transistor as high as desired. As a result, the channel noise of the CG transistor is significantly reduced. So, this technique focuses on the noise reduction instead of the noise cancellation.

2 The common gate LNA and traditional noise cancellation technique

2.1 Common gate LNA

Figure 1 (a) shows a common-gate LNA. The input impedance of this circuit is ${g_m}^{-1}$. At complete input matching (${g_m}^{-1}$ is set equal to the source

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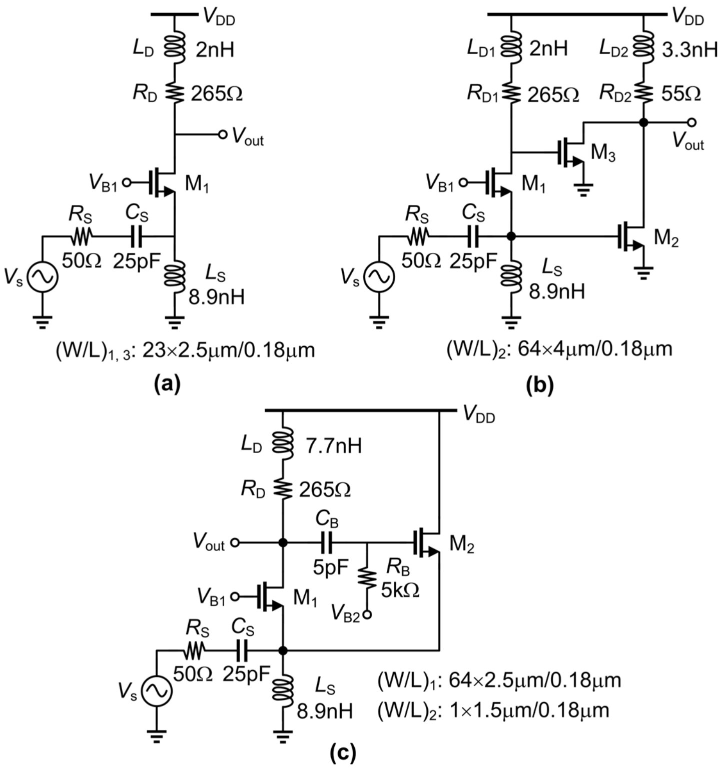

Fig. 1. (a) Common gate LNA, (b) conventional noise cancellation technique (the bias circuits of M2 and M3 not shown), and (c) proposed LNA.

impedance, R_S), the gain and noise factor of this circuit are given by $A_v = 0.5g_{m1}|Z_D|$ and $F = 1 + \gamma/\alpha + 4R_D/g_{m1}|Z_D|^2$, respectively, where $Z_D = R_D + j\omega L_D$, γ and α are process dependant parameters and for a CMOS technology with minimum channel length of 0.18 μm they are about 1.3 and 1, respectively [5]. The second term in noise factor relation is the dominant one which represents the channel noise of M_1. The third term belongs to the thermal noise of the output resistor, R_D. When the output impedance is high enough to make the third term negligible, the noise figure would still be more than 3.6 dB. In practice, due to limited voltage headroom, such conditions cannot be satisfied and the noise figure of a CG LNA will be about 4.5 dB.

2.2 Traditional noise cancellation technique

Shown in Fig. 1 (b) is the traditional noise canceling structure [4]. The input impedance of this structure is similar to that of the simple CG. The channel noise of M_1 has different polarities on two paths. Therefore, with appropriate choice of R_{D1} and device sizes, this channel noise can be cancelled out. The voltage gain and noise factor of this structure when the input node is fully matched with the antenna (${g_{m1}}^{-1} = R_S$) are, respectively, given by:

$$A_v = -0.5(g_{m1}g_{m3}|Z_{D1}| + g_{m2})|Z_{D2}| \tag{1}$$

$$F = 1 + \frac{(g_{m3}|Z_{D1}| - g_{m2}R_S)^2}{R_S(g_{m1}g_{m3}|Z_{D1}| + g_{m2})^2}\frac{\gamma}{\alpha}g_{m1} + \frac{g_{m2}|Z_{D2}|^2}{{A_v}^2 R_S}\frac{\gamma}{\alpha} + \frac{(g_{m3}|Z_{D2}|)^2}{{A_v}^2}\frac{R_{D1}}{R_S} \tag{2}$$

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where $Z_{D1} = R_{D1} + j\omega L_{D1}$ and $Z_{D2} = R_{D2} + j\omega L_{D2}$. The three last terms in (2) represent the thermal noise of M_1, M_2, and R_{D1}, respectively. Other sources of noise are considered to be negligible. As Eq. (2) clearly reveals if the criterion $g_{m1}|Z_{D1}| = g_{m2}R_S$ is completely satisfied, the channel noise of M_1 will be suppressed. This structure has a high power consumption and poor linearity in comparison with the CG structure. In applications with high linearity requirements, some methods of distortion cancellation must be applied [2].

3 Proposed technique

Figure 1 (c) shows the proposed LNA structure. M_1 is a CG amplifier and responsible for signal amplification and M_2 is an active feedback network. The input impedance of this LNA is given by:

$$Z_{in} = \frac{1}{g_{m1} - g_{m2}(g_{m1}Z_D - 1)} \tag{3}$$

where $Z_D = R_D + j\omega L_D$. In the presented LNA there is a positive feedback loop. Nonetheless, it is stable when the loop gain is less than one. This condition can easily be satisfied by properly choosing the value of g_{m2} and R_D as it is also seen in relation (3) to ensure the real part of the input impedance to be positive to maintain the stability [6].

According to Eq. (3), for appropriately chosen values of g_{m2} and Z_D, g_{m1} can be chosen up to any arbitrary value and the input matching criterion ($R_{in} = R_S$) will be still satisfied. This increment in g_{m1} reduces the contribution of M_1's thermal noise in overall NF of the LNA. When the input impedance is fully matched to the source resistance, the voltage gain and the noise factor are, respectively, given by:

$$A_v = \frac{g_{m1}|Z_D|}{1 + R_S {R_{in}}^{-1}} = 0.5 g_{m1}|Z_D| \tag{4}$$

$$F = 1 + \frac{\gamma}{\alpha}\frac{1}{g_{m1}R_S} + \frac{4R_D}{R_S {g_{m1}}^2 |Z_D|^2} + \frac{\gamma}{\alpha} g_{m2} R_S \tag{5}$$

In relation (5), the second and third terms represent the thermal noise of M_1 and R_D, respectively. The last term shows the thermal noise contribution of M_2. This term can be neglected when g_{m2} is very small as it is also used to ensure the stability. A low g_{m2} also results in much less power consumption in M_2. According to the relations (4) and (5), both amplifier's gain and NF can be improved by increasing g_{m1}. This is not possible in conventional CG LNAs where g_{m1} is constrained by the input matching condition. Of course, g_{m1} is limited by the power considerations in the presented LNA.

4 Simulation results

To prove the usefulness of the proposed LNA, circuit level simulations were performed with Spectre RF using a 0.18 μm RF-CMOS technology. Both conventional CG amplifier and CG structure with noise cancellation technique shown in Figs. 1 (a) and (b) were also simulated to provide a fair comparison.

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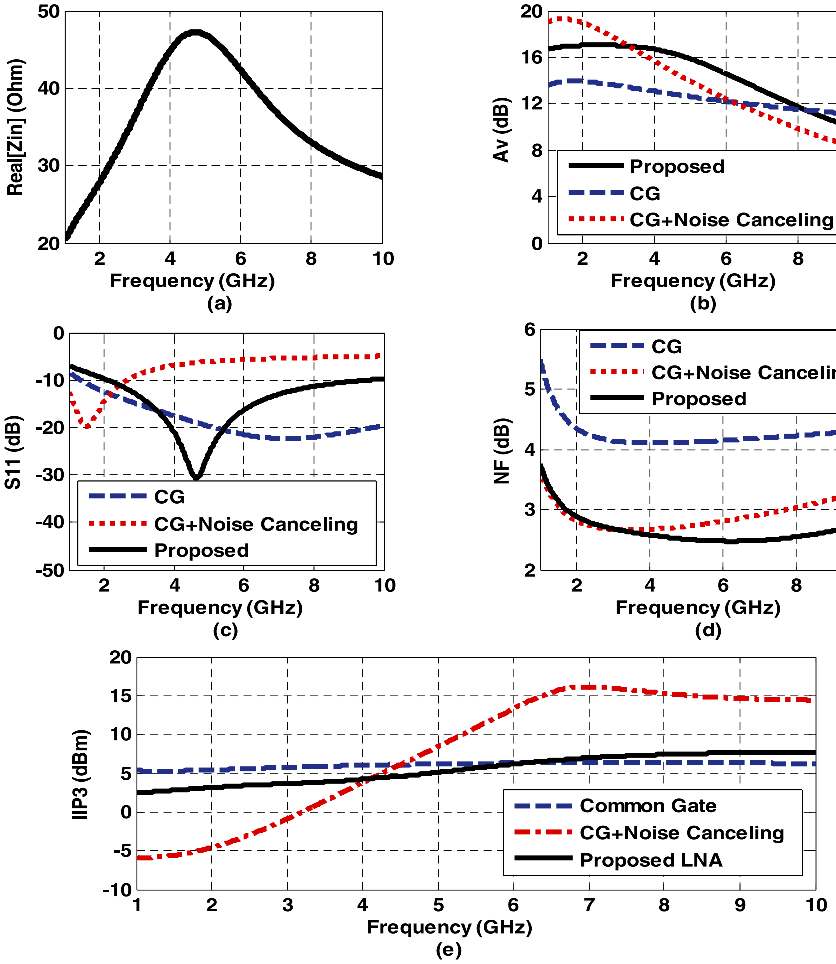

Fig. 2. (a) Real part of input impedance, (b) voltage gain, (c) S11, (d) noise figure and (e) IIP3 of simulated LNAs.

The design is targeted to achieve a lower NF and power consumption over a very wide 3 dB bandwidth from 2 GHz to 6.5 GHz.

To examine the stability of the proposed LNA, the simulated real part of the input impedance is shown over a wide frequency range in Fig. 2 (a). As is clear, the real part of Z_{in} is positive over the whole bandwidth. Figure 2 (b) illustrates the voltage gain of the simulated amplifiers. A maximum voltage gain of 17 dB is achieved for the proposed LNA. The voltage gain of conventional CG amplifier is lower owing to its small g_m. The input matching of simulated LNAs is shown in Fig. 2 (c). The proposed LNA achieves S11 < -10 dB over 2∼9.5 GHz bandwidth. In the noise cancellation LNA, the large parasitic capacitances of common-source transistor degrade the Av and S11 dramatically when the frequency rises.

In this design, the g_{m1} and g_{m2} of the proposed LNA are set to 50 mA/V and 2 mA/V, respectively. According to device sizes shown in Fig. 1 (c), the terms of Eq. (5) are 0.52, 0.07 and 0.13 at 5 GHz, respectively. So, the NF of 2.3 dB is achieved from the relation (5). As shown in Fig. 2 (d), the NF of the proposed LNA is about 2.5 dB with a variation less than 0.2 dB over 3∼10 GHz as theoretically expected and which is about 1.7 dB less than the

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simple CG amplifier. The minimum NF of the noise cancellation LNA is 0.2 dB more than that of the proposed structure, while the noise canceling technique consumes three times more power.

A sweeping two tone test with 20 dBm input power and 100 MHz frequency spacing is performed over 1∼10 GHz frequency range. Figure 2 (e) indicates the IIP3 of the simulated LNAs versus the intermodulation frequency. The IIP3 of proposed LNA over 3 dB BW is in the range of +3.6∼+6.5 dBm. In the worst case, it is just 2.1 dBm less than the simple CG LNA. Figure 2 (e) also shows, in contrast to the proposed LNA, the traditional noise cancellation structure suffers from poor linearity performance. Its IIP3 falls to 5.6 dBm over 3 dB BW. The sharp increase of IIP3 in noise cancellation LNA is according to its rapid voltage gain fall (Fig. 2 (b)).

The performance results of simulated LNAs and a few prior published state-of-the-art broadband LNAs are summarized in Table I. As is seen, the proposed LNA achieves better NF with much less power consumption than the previously reported best NF in [2]. This is mainly due to the simple structure used to reduce the NF instead of a two path structure for noise cancellation. To compare the proposed LNA with the others, the figure of merit (FOM) defined as:

$$FoM = \frac{A_{v,avg} \times BW\,[\mathrm{GHz}]}{(F_{avg} - 1) \times P_{dc}\,[\mathrm{mW}]} \tag{6}$$

is used where $A_{v,avg}$ is the average gain, F_{avg} is the average noise factor over the frequency range and P_{dc} is the dc power consumption of the LNA [7]. As is seen, the proposed LNA also achieves a good FOM compared to the other previously reported best LNAs listed in Table I.

Table I. Performance comparison.

Ref.	**CMOS Process**	**BW (GHz)**	**S11 (dB)**	**A_v (dB)**	**NF (dB)**	**IIP3 (dBm)**	**V_{DD} (V)**	**Power (mW)**	**FoM**
Proposed LNA	0.18 μm	2.0∼6.5	< -10	17	2.5∼2.7	3.4∼5.4	1.8	7.6	4.25
CG	0.18 μm	1.8∼9	< -11	14	4.1∼4.8	5.2∼6.3	1.8	4.6	2.69
Noise Canceling	0.18 μm	1.4∼3.7	< -7.5	19	2.7∼3.5	−5.6∼1.1	1.8	21.6	0.73
[1]	0.18 μm	0.4∼10	< -10	18.4*	4.4∼6.5	−6	1.8	12	2.18
[2]	0.13 μm	0.8∼2.1	< -8.5	20.5*	2.6	16	1.5	17.4	0.82
[3]	65 nm	0.2∼5.2	< -14	15.6	< 3.5	> 0	1.2	21	1.16
[4]	0.18 μm	1.2∼11.9	< -11	15.7*	4.5∼5.1	−6.2	1.8	20	1.38
[8]	0.13 μm	2.6∼10.7	< -11	13.5	2.7∼4.2	5	1.2	13.5	1
[9]	0.13 μm	2∼9.6	< -9.5	17*	3.6∼4.8	−7.2	1.5	19	1.45

*The power gain was reported. Here the insertion loss (6 dB) from the buffer is deembedded.

5 Conclusion

A new input matching technique for ultra wideband LNAs was presented. It achieves the same NF of broadband noise cancellation techniques but with much less power dissipation and high linearity by employing an active feedback network in the conventional CG amplifier. The presented technique can be used in the design of high performance broadband CMOS low noise amplifiers.

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