BRIEF PAPER

A Wideband Noise Cancelling Low Noise Amplifier for 3GPP LTE Standard

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SUMMARY This paper presents the design of a wideband low noise amplifier (LNA) for the 3GPP LTE (3rd Generation Partnership Project Long Term Evolution) standard. The proposed LNA uses a common gate topology with a noise cancellation technique for wideband (0.7 to 2.7 GHz) and low noise operation. The capacitive cross coupling technique is adopted for the common gate amplifier. Consequently input matching is achieved with lower transconductance, thereby reducing the power consumption and noise contribution. The LNA is designed in a 0.18 μm process and the simulations show lower than −10 dB input return loss (S11), and 2.4∼2.6 dB noise figure (NF) over the entire operating band (0.7∼2.7 GHz) while drawing 9 mA from a 1.8 V supply.

key words: *common gate, CMOS, capacitive cross-coupling, highly linear gm, LTE, noise cancellation, wideband LNA*

1. Introduction

Recently, the traditional mobile communication industry has been challenged by new wireless broadband access techniques, such as IEEE 802.16e. 3rd Generation Partnership Project (3GPP), a collaboration between telecommunications associations, has been carrying out a long term evolution (LTE) project to meet the market demand since 2004. The objectives of LTE include reducing latency, achieving higher user data rates, improving system capacity and coverage, and reducing overall costs for the operator [1].

The LTE standard specifies operating frequency bands within a range of 0.7∼2.7 GHz. This is compatible with worldwide available mobile standards such as UMTS800/UMTS1700, IMT2000, and GSM/EDGE. With the overall goal of reducing power consumption, chip size, and cost, there is high demand to develop a single LTE RFIC receiver that covers the entire operating band of 0.7∼2.7 GHz. This brings about a very high requirement on linearity and noise figure (NF) of the LTE receiver.

In implementing a wideband receiver, the key block is a wideband low noise amplifier (LNA). Generally, the LNA design involves trade-offs among NF, gain, linearity, impedance matching, and power dissipation [2], [3]. A wideband LNA is normally implemented as a resistive shunt feedback or common gate topology [4], [5]. Resistive shunt feedback LNAs can show a low NF with a sufficiently large loop gain. However, due to the inherently low transconductance of CMOS, large power dissipation is required to achieve a high loop gain in a single stage, while stability and low linearity problems arise with multiple stages [4], [6]. Common gate LNAs provide considerable wideband input matching. However, due to the noise contribution of the common gate transistor, the NF is high [4], [7]. A noise cancellation technique has been presented to reduce the NF of common gate LNAs [7]. Nevertheless, the NF of the LNA remained high (3.5∼4 dB), and could not be adopted for the LTE receiver.

With the key points of low NF and high linearity, this paper presents the implementation of a wideband LNA for the 3GPP LTE receiver.

2. Wideband LNA

The simplified schematic of the proposed differential LNA is shown in Fig. 1. As can be seen in Fig. 1, the differential LNA consists of a common gate amplifier (M_1, M_2) and a common source amplifier (M_3 − M_6). The common gate amplifier provides wideband input matching for the LNA. The common source amplifier is realized to cancel noise generated by the common gate amplifier [7], [9]. The noise cancellation mechanism can be explained with the circuit shown in Fig. 2. As can be seen in Fig. 2, the noise source of M_1 ($I^2_{n,M1}$) creates two correlated, but opposite in phase, noise currents: the M_1 drain ($I^2_{n1,M1}$) and M_1 source ($-I^2_{n1,M1}$) noise currents [7]. The noise current at the source of M_1 creates a noise voltage ($V^2_{n,M1}$) at this node. This noise voltage

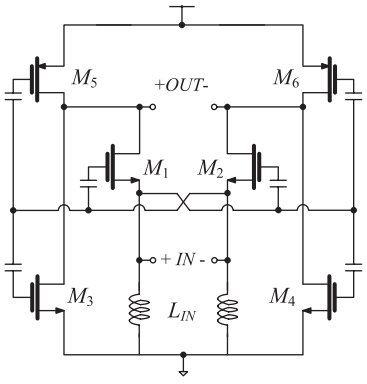

Fig. 1 Simplified schematic of the proposed wideband LNA.

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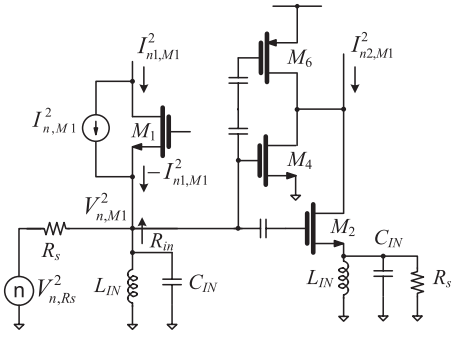

Fig. 2 The half of the proposed LNA for noise analysis.

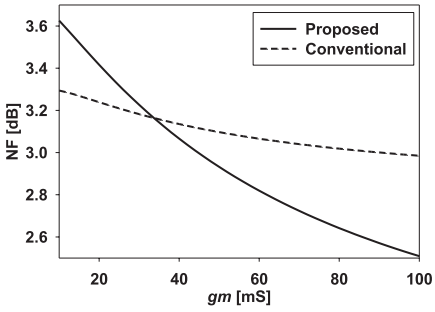

Fig. 3 Calculated NF as a function of transconductance of the common source amplifiers.

is amplified by M_4, M_6, and M_2, creating output noise current ($I^2_{n2,M1}$). And the noise current ($I^2_{n2,M1}$) is now in phase with noise current at the drain of M_1. Since the output current is differential, the noise current is partially cancelled.

Furthermore, in the proposed LNA, as can be seen in Fig. 1, the input common gate transistors (M_1, M_2) are capacitively cross coupled to achieve input impedance matching with lower transconductance [8]. The input impedance R_{in} is given as [8]:

$$R_{in} = 1/(2g_{mCG}) \tag{1}$$

where g_{mCG} is the transconductance of the common gate amplifier. Firstly, as can be seen in (1), due to the capacitive cross coupling configuration, the dissipating current needed to achieve specific $R_{in} = R_s$ is reduced by half. Consequently, the noise current is reduced by half, since $I^2_n = 4kTg_{mCG}$ [3]. Secondly, as can be seen in Fig. 2, due to capacitive cross coupling configuration, transistor M_2 works as common source amplifier like M_4 and M_6. So the required g_{mM4} and g_{mM6} to realize noise cancellation is lower. Therefore, noise currents produced by M_4 and M_6 are reduced. As a result of capacitive cross coupling configuration, the NF of the proposed LNA is reduced further in comparison with the NFs of the noise cancellation LNAs presented in [7] and [9]. The improvement in NF is shown in Fig. 3. This improvement is a result of a more quantitative understanding of the noise behavior of the proposed LNA, provided in the following. The noise analysis can be carried out for each half of the LNA, one of which consists of the common gate transistor M_1 and three common source transistors, M_2, M_4, and M_6, sharing the same positive input $IN+$, shown in Fig. 2. In Fig. 2, the total input parasitic capacitance is simply presented as C_{IN}. The output noise current created by R_s is given as [3]:

$$I^2_{nout,Rs} = 4kTR_s\left|\frac{Z_{IN}}{R_s+Z_{IN}}g_{mtotal}(f)\right|^2 = 4kTR_s \left|\frac{Z_{IN}}{R_s+Z_{IN}}\left(g_{mM4}+g_{mM6}+g_{mCGeff}+\frac{g_{mM2}}{1+Z_sg_{mM2}}\right)\right|^2 \tag{2}$$

where g_{mM4}, g_{mM6}, is the transconductance of the common source M_4, M_6, respectively, g_{mCGeff} is the effective transconductance of common gate M_1, R_{in} the input impedance of M_1, Z_{IN} the impedance of the parallel network $R_{in}//L_{IN}//C_{IN}$, Z_s the impedance of the parallel network $R_s//L_{IN}//C_{IN}$, and $g_{mM2}/(1+Z_sg_{mM2})$ the transconductance of the source degeneration M_2, respectively.

The output noise current caused by the common gate amplifier M_1 is given as [3], [7]:

$$I^2_{nout,M1} = \left|I_{n1,M1}-I_{n2,M1}\right|^2 = 4kT\gamma g_{mM1} \cdot\left|\frac{1}{1+g_{M1}Z_s}\left(1-Z_s\left(g_{mM4}+g_{mM6}+\frac{g_{mM2}}{1+Z_sg_{mM2}}\right)\right)\right|^2 \tag{3}$$

where γ is the noise access factor and g_{mM1} the transconductance of transistor M_1 ($=g_{mCGeff}/2$).

The output noise current created by M_2, M_4, and M_6 is given as [3]:

$$I^2_{nout,M1} = 4kT\gamma(g_{mM2}+g_{mM4}+g_{mM6})^2 \tag{4}$$

where g_{mM2} is the transconductance of amplifier M_2 ($=g_{mCGeff}/2$). The noise factor of the proposed LNA can be given as:

$$F = 1+\frac{\gamma g_{m,M1}\left|\frac{1}{1+g_{M1}Z_s}\right|^2\left|\left(1-Z_s\left(g_{mM4}+g_{mM6}+\frac{g_{mM2}}{1+Z_sg_{mM2}}\right)\right)\right|^2}{R_s\left|\frac{Z_{IN}}{R_s+Z_{IN}}g_{mtotal}(f)\right|^2} + \frac{\gamma(g_{mM2}+g_{mM4}+g_{mM6})}{R_s\left|\frac{Z_{IN}}{R_s+Z_{IN}}g_{mtotal}(f)\right|^2} \tag{5}$$

As can be seen in (5), the second term of the noise factor expression can be partially cancelled.

At the frequency of interest, L_{IN} tunes out the input parasitic capacitance C_{IN}, and $R_{in} = R_s$, therefore (5) can be rewritten as:

$$F = 1+\frac{\gamma g_{m,M1}\left[1-R_S\left(g_{mM4}+g_{mM6}+\frac{g_{mM2}}{1+R_sg_{mM2}}\right)\right]^2}{R_Sg^2_{m,total}} + \frac{4\gamma(g_{mM2}+g_{mM4}+g_{mM6})}{R_Sg^2_{m,total}} \tag{6}$$

In order to match the input impedance (R_{in}) of the LNA to R_s=50 Ohm, M_1, M_2 are sized to have transconductance $g_{mM1} = g_{mM2}$=10 mS (effective tran sconductance

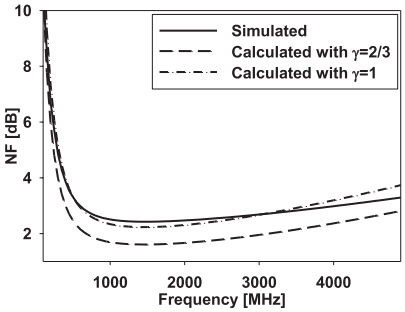

Fig. 4 Simulated and calculated NF of the proposed LNA.

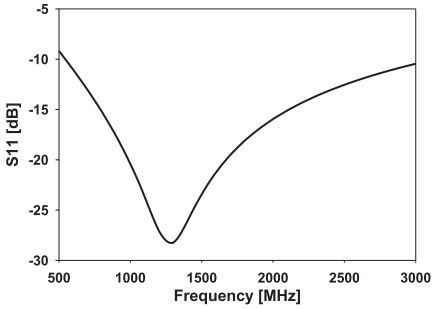

Fig. 5 Simulated input return loss of the proposed LNA.

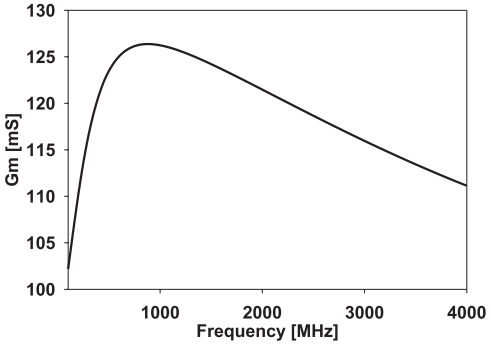

Fig. 6 Simulated Gm of the proposed LNA.

g_{mCGeff} will be 20 mS). For comparison, Fig. 3 shows the calculated NF, expressed in (6), of the proposed LNA and the NF of the noise cancellation LNA reported in [7] and [9]. The NFs are functions of the total transconductance ($g_{mCS} = g_{mM4} + g_{mM6}$) of the common source amplifier (M_4, M_6). As can be seen in Fig. 3, while the NF of the LNA reported in [7] and [9] slightly decreases, the NF of the proposed LNA significantly reduces as g_{mCS} increases. If a g_{mCS} of 100 mS is chosen, the improvement in NF is almost 0.5 dB.

In order to assess noise behavior of the proposed LNA in the entire operating frequency, the NF is calculated and studied using (5). In this design L_{IN} is chosen as 8 nH to completely tune out the input parasitic capacitance C_{IN} at the center of frequency band of interest (0.7~2.7 GHz), which is around 1.5 GHz. Thus C_{IN} is approximately 1.5 pF. g_{mM4}, g_{mM6} are chosen as 45 and 60 mS, respectively. The NF as a function of frequency, expressed in (5), is calculated and plotted in Fig. 4. The simulated NF of the proposed LNA is also shown in Fig. 4. As can be seen in this figure, the minimum NF is achieved at the resonating frequency of the *LC* network and increases slightly with frequency. In the operating band, the simulated minimum NF is 2.4 dB. The maximum NF is 2.6 dB at the maximum operating frequency (2.7 GHz).

To satisfy the system linearity, the LTE receiver should work in the current mode adopting the architecture as presented in [9]. Thus, the proposed LNA is designed as a transconductance stage, thereby remaining highly linear [9]. Moreover the mechanism leading to cancellation of the output noise can also lead to the cancellation of the nonlinearities of the devices [6]. Consequently, the proposed LNA shows very good linearity performance as well.

3. Simulation Results

The proposed LNA is implemented in a 0.18 μm CMOS process. The proposed LNA dissipates 9 mA from a 1.8 V supply.

Figure 5 shows the simulated input matching of the proposed LNA. As can be seen in this figure, the input return loss (S11) is lower than −10 dB in the operating band. Figure 6 shows the simulated Gm of the proposed LNA. Table 1 summarizes the simulation results of the proposed LNA in comparison with other published works. As can be seen here, the LNAs in [5] and [7] show ultra wideband but high NF. The LNA in [8] shows low NF and low power but poor linearity, and thus it cannot satisfy the LTE system requirement. The proposed LNA shows low NF and high linearity with moderate power consumption, and is thus suitable for adoption in the LTE receiver.

Table 1 Summary performances of the LNA.

	This work	[5]	[7]	[8]
Frequency [GHz]	0.7~2.7	3.1~10.6	1.2~11.9	0.02~1.6
S11 [dB]	<-10	-13.5	-11	-8
S21 [dB]/Gm [mS]	125mS	7~12 dB	9.7 dB	13.7 dB
NF [dB]	2.4~2.6	5.27~7	4.5~5.1	2.55~2.85
DC power [mW]	16.2	4.5	20	1.9
Technology [μm]	CMOS 0.18	CMOS 0.18	CMOS 0.13	CMOS 0.13

4. Conclusion

A low noise wideband amplifier design is presented. The circuit operates over a wide range of frequencies, 0.7–2.5 GHz. By adopting noise cancellation and a capacitive cross coupling technique, the NF of the LNA is significantly reduced. The frequency dependence of the noise behaviour of the proposed LNA is investigated. It has been shown that the NF of the proposed LNA slightly increases as the operating frequency increases. Simulated in 0.18 CMOS μm technology, the proposed LNA shows less than 2.6 dB NF while drawing 9 mA from a 1.8 V supply. The LNA shows good performance making it suitable for adoption in the LTE receiver.

Acknowledgments

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