Design of Low Voltage Low Noise Amplifier for 800MHz WSN Applications

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Abstract: This paper presents a 1V low noise amplifier (LNA) for 700–900MHz WSN applications in 0.18μm RF CMOS process. The LNA uses capacitor cross-coupled, current-reused and noise cancellation techniques to reduce noise and power consumption. The simulation results are as follows: The voltage gain is variable with high gain at 22dB and low gain at 0dB. At low gain mode, the input referenced 1dB compression point (IP1dB) is -15dBm and the input 3rd intercept point (IIP3) is 1dBm. The noise figure (NF) at high gain is 2.85dB (@800MHz). It consumes about 0.9mA current from 1V power supply.

Key words: low noise amplifier; low voltage; low power consumption; capacitor cross-coupled; current reuse;

Recently, research of wireless sensor network (WSN) has become more and more popular. WSN nodes are powered by batteries. In order to extend battery life, the power consumption of WSN receivers should be reduced. At the same time, the other performance of the receivers should be remained unchanged. As the first stage of the receivers, the LNAs greatly impact on the performance of the entire receivers. [1-2]

Two types of CMOS LNA topologies have become mainstream circuit implementations: common-source LNAs (CS-LNAs) and common-gate LNAs (CG-LNAs). In recent years, CG-LNAs have gained popularity because the

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input impedance is fully or partially resistive. As a result, the impedance matching can be easily accomplished. Additionally, the impedance matching bandwidth of CG-LNAs is wider than that of CS-LNAs due to the resistive input impedance. Nevertheless, CS-LNAs have the best noise performance. Efforts have been made in the last few years to improve the noise performance of CG-LNAs. Solutions include the transformer-coupled and capacitor cross-coupled. [3-5]

1. Circuits Structure

The schematic of the proposed LNA is shown in Fig.1. Three pairs of MOSFETs adopt capacitorcross-coupled, which increases the effective $G_m$ and decrease noise and power consumption. $M_{1,2}$ and $M_{3,4}$ are amplifying MOSFETs. The differential signal is inputted to the source of $M_{1,2}$ and the gate of $M_{5,6}$. $M_1$ and $M_5$, $M_2$ and $M_6$ adopt current-reuse structure to decrease power consumption.

1.1 Capacitor cross-coupled

Effective $G_m$ is increased by adopting capacitorcross-coupled technique. The schematic of the boosting effective $G_m$ is shown in Fig.2(a). The structure of the capacitor cross-coupled CG-LNA is shown in Fig.2(b).

As shown in Fig.2(a), an inverting amplifier is set between the gate and the source of the MOSFET. The inverting amplification value is $A$. Through the derivation, we can get the expression of the NF [5]:

$$ F = 1 + \frac{g_m}{g_m} \left( \frac{1}{1 + A} \right) R_c A g_m = 1 + \frac{g_m}{\alpha(1 + A)} \left| (1 + 1)_{R_c R_m} \right| $$

As shown in Fig.2(b), we can deduce [5]:

$$ A = \frac{C_c}{C_c + C_{gs}} \approx \frac{1}{1 + C_c / C_{gs}} \approx 1 $$

So the NF of the LNA which adopts capacitor cross-coupled is [5]:

$$ F = 1 + \frac{\gamma}{2\alpha} $$
It can be seen that the second part of the equation is decreased by half. Meanwhile, capacitor cross-coupled can reduce power consumption. The reason is given in the next section.

1.2 Impedance matching

Fig. 3 shows the small signal representation of the proposed LNA.
Ignoring $C_{gs}$ of the MOSFETs, the input impedance can be expressed as:

$$Z_{in} = \frac{1}{2g_{m1}} \frac{1}{\frac{-1}{g_{m3}} = \frac{1}{2g_{m1} - g_{m3}}}$$

But this formulation only expresses the real part of the input impedance. There exists pathways through the capacitance to the ground. So the imaginary part of the input impedance is large. By adjusting the capacitance and the W or L of the MOSFETs, we can decrease the imaginary part to accomplish impedance matching.

If the capacitor cross-coupled were not adopted, the input impedance is:

$$Z_{in} = \frac{1}{g_{m1} - \frac{1}{g_{m3}}} = \frac{1}{g_{m1} - g_{m3}}$$

It can be seen that for the same $Z_{in}$, capacitor cross-coupled decreases $g_{m1}$. So current consumption is also reduced. This is the reason that capacitor cross-coupled can reduce the power consumption.

### 1.3 Noise analysis

The main noise of MOSFET is the drain noise. So we only consider the drain noise, neglecting the other noise.

When the source is matched, the total transconductance is $^{(4)}$:

$$G = \frac{1}{2} \left( g_{m1} + g_{m3}/2 \right)$$

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(841)
So the output noise current due to the source resistor is:

\[ i_{n,Rs} = \frac{1}{2} V_{n,Rs} \left( g_{m1} + g_{m5} / 2 \right) \]  

(7)

The noise contribution due to the M_{1,2} comes from two mechanisms that add to the output.

The first mechanism is due to part of \( i_{n1} \) entering into M_{1,2} and producing an output current equal to:

\[ i_{n1,d} = i_{n1} \left( \frac{g_{m1}}{2 (2 g_{m1} - g_{m3})} - \frac{1}{2} \right) = i_{n1} \left( \frac{g_{m1} R_{S}}{4} - \frac{1}{2} \right) \]  

(8)

The second one is due to part of \( i_{n1} \) flowing through \( R_{S} \) and producing a voltage \( V_{43} \) that is converted into a differential output current. We can get a voltage \( V_{43} \) by using a Thevenin equivalent circuit:

\[ V_{43} = \frac{i_{n1} R_{S}}{2 (2 g_{m1} - g_{m3})} = \frac{i_{n1} R_{S}}{4} \]  

(9)

So the total noise current due to M_{1,2} is:

\[ i_{n1,d} = \frac{i_{n1}}{2} \left( \frac{g_{m1} R_{S}}{4} - \frac{1}{2} \right) + i_{n1} \frac{g_{m5} R_{S}}{8} = i_{n1} \left( \frac{R_{S}}{2} \left( g_{m1} + \frac{g_{m5}}{2} \right) - 1 \right) \]  

(10)

When the equation (11) is satisfied, the noise of the input M_{1,2} can be cancelled.

\[ g_{m5} = 2 \left( \frac{2 - g_{m1} R_{S}}{R_{S}} \right) \]  

(11)

The differential noise current from M_{3,4} is:

\[ i_{n3,d} = i_{n3} \frac{g_{m1} R_{S}}{4} + i_{n3} \frac{g_{m5} R_{S}}{8} = i_{n3} \frac{R_{S}}{4} \left( g_{m1} + \frac{g_{m5}}{2} \right) \]  

(12)

The noise current from M_{5,6} is:

\[ i_{n5,d} = i_{n5} / 2 \]  

(13)

So the total NF of the LNA is:

\[ F_{LNA} = 1 + \gamma \frac{g_{m1} (R_{S} G - 1)^2}{2 R_{S} G^2} + \gamma (g_{m1} R_{S} - 1) + \frac{\gamma g_{m5}}{2 R_{S} G^2} \]  

(14)

Where \( \gamma \) is the MOSFET thermal noise coefficient. When (11) is applied, the NF of the LNA becomes:

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\[ F_{\text{in}} = 1 + \gamma (g_{m}R_{g} - 1) + \gamma (2 - g_{m}R_{g}) = 1 + \gamma \]  \hspace{1cm} (15)

2. **The simulation results**

This paper presents a low voltage low noise amplifier for 700–900MHz WSN applications in 0.18µm RF CMOS process. It consumes about 900µA current from 1V power supply. The layout of the LNA is shown in Fig. 4. All the post-simulation is done with a buffer. The post-simulation result of NF is shown in Fig. 5. The NF equals to 3.0dB at 800MHz. The post-simulation of S11 is shown in Fig. 6. During 700–900MHz, S11 is -12.82–12.7dB; Fig. 7 shows the post-simulation of S21. During 700–900MHz, S21 is 11.88–14dB; The post-simulation of S22 is shown in Fig. 8. During 700–900MHz, S22 is -16.52–16.59dB. At low gain mode, IP_{1dB} is -15dBm (as shown in Fig. 9), and the IIP3 is 1dBm (as shown in Fig. 10). The load of the LNA is down-conversion mixer. We set the input impedance of down-conversion mixer as 2K ohm. The voltage gain is 22dB. The post-simulation results are concluded in Table I.
Table I. Summary of the LNA post-simulation results

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply voltage (V)</td>
<td>1</td>
</tr>
<tr>
<td>Power consumption (mW)</td>
<td>0.9</td>
</tr>
<tr>
<td>S11 (dB)</td>
<td>-12.82~12.7</td>
</tr>
<tr>
<td>S21 (dB)</td>
<td>11.88~14</td>
</tr>
<tr>
<td>S12 (dB)</td>
<td>-55.12~53.64</td>
</tr>
<tr>
<td>NF at high gain mode (dB)</td>
<td>2.82</td>
</tr>
<tr>
<td>IP1dB at low gain mode (dBm)</td>
<td>-15</td>
</tr>
<tr>
<td>IIP3 at low gain mode (dBm)</td>
<td>1</td>
</tr>
</tbody>
</table>

3. Summary

This paper presents a low noise amplifier for 700~900MHz WSN applications in 0.18μm RF CMOS process. The power supply is 1V. The LNA adopts capacity cross-coupled, current-reuse and noise cancellation to decrease the NF and power consumption. Post-simulation results show that LNA can be fully adapted to WSN system applications.

References