Performance Analysis of Narrowband and Wideband LNA’s for Bluetooth and IR-UWB

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I. INTRODUCTION

Any receiver performance is highly depends on the LNA, because it is the first building block of any wireless receiver to amplify the upcoming signal from the antenna without adding much noise and distortion. The design of LNA has many challenges: such as to obtain high Gain, Low noise figure and Linearity requirement at required DC power consumption. Besides all these, the Design Goal is to obtain high Gain, Low noise figure and Linearity requirement at required DC power consumption. The Design Procedure is given as follows:-

Starting with value of degeneration Inductor (Ls) i.e. the value of Ls is fairly arbitrary but its maximum limit is 10 nH \([8]\). Here we will pick Ls= 0.5 nH

1) Cut off frequency \(\omega_c\)

\[\omega_c = \frac{f_m}{2\pi} = \frac{g_m}{\lambda g} = \frac{g_s}{\lambda s} \]

…..(1)

2) Quality Factor of Inductor \((Q_L)\)

\[Q_L = \sqrt{1 + \frac{1}{\rho}} \]

…..(2)

\[\rho = \frac{50.5}{5} = 0.162 \] 

…..(3)

from calculating using above equation no. (3)

\[Q_L = 2.67 \]

3) Centre Frequency \((\omega_0)\)

\[\omega_0 = 2\pi f = 1.665 \times 10^{10}\ \text{rad/second} \]

…..(4)

4) Evaluation of Lg

\[L_g = \frac{g_s}{\omega_0} - L_s = 7.51\ \text{nH} \]

…..(5)

5) Gate to Source Capacitance \((C_{gs})\)

\[C_{gs} = \frac{1}{\omega^2(L_g + L_s)} = 0.45\ \text{pF} \]

…..(6)

6) Width of Transistor \(W\)

\[C_{gs} = \frac{\pi}{2} C_{ox}, W, L_{min} \]

…..(7)

Here we are using CMOS14 0.5 μm process, which allow a minimum gate length of 0.6 μm.

Assuming-

\[L_{min} = 0.6, C_{ox} = \frac{\varepsilon_{ox}}{\tau_{ox}} = \frac{8.854}{10^{-14}} \text{F/cm} \]

\[C_{ox} = 3.419 \times 10^{-3}\ \text{pF/um}^2 \]

Abstract— LNA is the first element of building blocks of any Wireless receiver. It amplifies the upcoming signal without adding much noise and distortion. In this paper, design and analysis of four different LNA (Low noise amplifier) is presented using Agilent CMOS14 .5μm and .4μm process. Here, C-S degeneration, Current Mirror, Cascade, Cascade and Feedback technique are used for LNA design. The performance evaluation is carried out for first three Narrowband LNA having frequency band 2.45 GHz to 2.85GHz for Bluetooth application and fourth LNA having frequency band 3.1 GHz to 10.6 GHz for IR-UWB receiver application i.e. Wideband LNA. The simulation is done on software ADS2010. The analysis results- the best gain S21 between first three LNA is 21.10dB , input reflection coefficient S11 is -23.71dB, output reflection coefficient S22 is -9.10dB and noise figure is 2.03dB with 2.5V supply are unconditionally stable with stability factor 7.11at 2.85GHz. The fourth LNA having gain of 12.4dB, S11 is -15.5dB, S22 is -10.64dB and noise figure is 2.6dB with 2.5V supply is unconditionally stable with stability factor 7.11at 2.85GHz.

Keywords: Low noise amplifier (LNA), Common source (C-S), Impulse Radio Ultra Wide Band (IR-UWB), Advanced Design System (ADS)
\[ W = \frac{3}{2} C_{gs} \frac{c_{gs}}{c_{ox} - \min} = 330 \, \mu m \] 
\[ g_m = \frac{\omega_f}{C_{gs}} = 0.045 \, \text{A/V} \] 
\[ V_{e} = (V_{gs} - V_T) = \frac{g_m - \min}{\mu_n C_{ox} W} \] 
\[ \mu_n = \text{device mobility} = 433 \, \text{cm/V} \] 
\[ V_{e} = 0.5 \, \text{V} \]

Therefore we need to apply 
\[ V_{gs} = 0.5 + 0.67 = 1.17 \, \text{V to the gate} \] (For LNA circuit A)

9) Bias Current - \( I_d \)
\[ I_d = \frac{1}{2} g_m V_{e} = 11 \, \text{mA} \]

10) Estimated optimum noise figure - \( F_{opt} \)
\[ F_{opt} = 1 + \frac{2 \gamma}{\alpha} \left( \frac{\omega_f}{\omega_T} \right) \sqrt{\frac{\rho}{\rho + \sqrt{1 + \rho}}} = 3.26 \, \text{dB} \]

### III. CIRCUIT DESIGN

The design of three Narrowband LNAs is shown with brief details-

**A. Narrowband LNA**

It is configured as C-S Inductive degeneration topology. The schematic diagram of LNA shown below in fig. (1) Using the value calculated in previous section II for operating Bluetooth frequency band 2.45GHz-2.85GHz. Agilent CMOS14 .5μm process transistor is used. [5] The current mirror is used to avoid extra voltage source in circuits. MOSFET M2 forms a current mirror with MOSFET M1. The width of MOSFET M2 is some small fraction of MOSFET M1’s width to minimize power overhead of the bias current.

The resistance R1 is chosen large enough that its equivalent noise current is small enough to be ignored. In 50 ohm system its range is several hundred ohms to 1 kilo ohm. It isolates the current mirror from the RF input. Capacitor C1 and C2 is DC blocking coupling capacitor.

**B. Narrowband LNA**

It is configured as Cascade Common Source Inductive Degeneration Topology. LNA gives a very low noise figure because zero loss inductors have been used on the source and gate which is used in Narrowband LNA (A) circuit, but it is off chip. We need to determine that sort of loaded Q’s. We might get with the current technology at a frequency of 2.4GHz., but of course we could always use high Q ‘off-chip’ inductors but in the quest for systems on a chip we are restricted to gold bond wires (with a typical inductance of 1nH per 1mm of length) and spiral printed inductors. Schematic of LNA shown below in fig. (2) Using the value calculated in previous section. Its operating Bluetooth frequency band is 2.45GHz-2.85GHz using Agilent CMOS14 .5μm process transistor. [5]

**C. Narrowband LNA**

It is configured as Cascade C-S Inductive Degeneration LNA with simple C-S stage added to the Cascade output to increase the power gain of LNA. Schematic of LNA shown below in fig. (3) Using the value calculated in previous section for operating Bluetooth frequency band 2.45GHz-2.85GHz. Agilent CMOS14 .5μm process transistor is used. [5].

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*Fig. 1: Schematic of Narrowband LNA*

*Fig. 2: Schematic of Narrowband LNA*

*Fig. 3: Schematic of Narrowband LNA*
D. Wideband LNA

A schematic of wideband LNA using Cascade C-S inductive degeneration technique is shown in fig. (4). this design use Agilent CMOS14 .4μm process with different (W) value [9]. In this design the value of Ls is fairly arbitrary but is ultimately limited on the maximum size of inductance allowed by the technology, which is typically about 10 nH. [6].

The gate-source Capacitance is evaluated as

$$C_{gs} = \frac{1}{R_{sa0Q}}$$

where $f_0$ is the center frequency, $R_s$ is source resistance.

The degeneration inductor $L_s$ is calculated with the help of $C_{gs}$ as

$$L_s = \frac{R_s C_{gs}}{g_m}$$

The value of gate inductance $L_g$ is calculated using

$$C_{gs} = \frac{1}{\omega^2 (\mu_s + L_g)}$$

The peaking inductance LG3 helps to increase the forward Gain (S21) but does not keep the gain flat over the band of interest. However the combination of peaking inductance LG3 and feedback resistor RF3 keeps the gain constant over the band of interest.

IV. SIMULATION RESULTS

All the simulation is done on ADS 2010 software. The simulation is done for Scattering parameter analysis, Noise analysis, DC analysis and stability factor analysis. The simulation results of circuits given previously shown below-

Narrowband LNA results (A) (B) (C)

A. Narrowband LNA

Table. 1: DC analysis for drain current and gate voltage

<table>
<thead>
<tr>
<th>freq (GHz)</th>
<th>Vg (V)</th>
<th>ID (mA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0000</td>
<td>1.078</td>
<td>11.91</td>
</tr>
</tbody>
</table>

Fig. 5: Measured S-Parameter, Noise Figure vs. Frequency

Fig. 6: Measured S-Parameter, Noise Figure vs. Frequency

Fig. 7: Measured Stability Factor vs. Frequency

Table. 2: DC analysis for drain current and gate voltage
C. Narrowband LNA

![Measurement of S-Parameter, Noise Figure vs. Frequency](image)

![Stability Factor vs. Frequency](image)

Table 3: DC analysis for drain current and gate voltage

<table>
<thead>
<tr>
<th>freq (Hz)</th>
<th>ID (mA)</th>
<th>vg (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0000</td>
<td>10.92</td>
<td>1.078</td>
</tr>
</tbody>
</table>

D. Wideband LNA

![Measurement of S-Parameter, Noise Figure vs. Frequency](image)

Fig. 11: Measured Stability Factor vs. Frequency

The table shown below a result summarize of all four LNA:

Table 4: Analysis of all four LNAs in terms of Reflection coefficients (S_{11}, S_{22}), Gain (S_{21}), Noise figure and Power Consumption.

<table>
<thead>
<tr>
<th>Reference</th>
<th>Gate length (µm)</th>
<th>Frequency (GHz)</th>
<th>S_{11} (dB)</th>
<th>S_{22} (dB)</th>
<th>Gain (S_{21})</th>
<th>S_{12}</th>
<th>Noise Figure (dB)</th>
<th>Vdd/Id (V/mA)</th>
<th>Power (mW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LNA CKT A</td>
<td>0.6</td>
<td>2.45 - 2.85</td>
<td>- 11.67</td>
<td>- 3.19</td>
<td>- 13.21</td>
<td>- 13.55</td>
<td>0.57</td>
<td>1.51/1.03</td>
<td>16.54</td>
</tr>
<tr>
<td>LNA CKT B</td>
<td>0.6</td>
<td>2.45 - 2.85</td>
<td>- 17.93</td>
<td>- 0.20</td>
<td>- 11.62</td>
<td>- 44.76</td>
<td>2.04</td>
<td>2.31/0.92</td>
<td>25.11</td>
</tr>
<tr>
<td>LNA CKT C</td>
<td>0.6</td>
<td>2.45 - 2.85</td>
<td>- 23.71</td>
<td>- 9.97</td>
<td>- 21.10</td>
<td>- 45.41</td>
<td>2.03</td>
<td>2.51/1.08</td>
<td>NA</td>
</tr>
<tr>
<td>LNA CKT D</td>
<td>0.4</td>
<td>3.1 - 10.6</td>
<td>- 12.8</td>
<td>- 4.2</td>
<td>- 12.42</td>
<td>- 23</td>
<td>2.69</td>
<td>2.5N/NA</td>
<td>NA</td>
</tr>
</tbody>
</table>

V. Conclusion

Both type of LNA i.e. Narrowband is for Bluetooth and Wideband is for IR-UWB System is presented. We found that Cascade Inductive Source Degeneration C-S topology fulfill all the major requirements like a good tradeoff between input impedance matching, Gain, input/output reflection coefficient with suitable noise figure. CMOS transistor helps us to reduce the power consumption. Among the Narrowband LNAs the third LNA has a good gain of 21dB with noise figure of 2.03 dB is unconditionally stable. These results agree that Narrowband LNA is suitable for Bluetooth application and the Wideband LNA has good input matching and noise figure simultaneously. Inductive source degeneration technique helps to achieved high and flat gain (S_{21}) all over frequency band. This LNA is unconditionally stable with stability factor >1. These results demonstrate that Wideband LNA shown here is suitable for UWB impulse radio system applications.
REFERENCES