A GSM Band Low-Power LNA

1. LNA Schematic

![Schematic of the Designed LNA](image)

Fig1.1 Schematic of the Designed LNA
## 2. Design Summary

<table>
<thead>
<tr>
<th>Specification</th>
<th>Required</th>
<th>Simulation Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak S21 (Gain)</td>
<td>&gt; 10dB</td>
<td>&gt;11 dB</td>
</tr>
<tr>
<td>3dB Bandwidth</td>
<td>&gt; 200MHz (&lt;300MHz)</td>
<td>574 MHz</td>
</tr>
<tr>
<td>Center Frequency</td>
<td>900MHz</td>
<td>893.5 MHz</td>
</tr>
<tr>
<td>Noise Figure</td>
<td>&lt; 1.7dB (800-1000MHz)</td>
<td>1.275dB (800MHz)</td>
</tr>
<tr>
<td>S11</td>
<td>&lt; -10dB (800-1000MHz)</td>
<td>-10.45dB (800MHz)</td>
</tr>
<tr>
<td>P1dB</td>
<td>&gt; -30dBm (input referred)</td>
<td>-3.68dBm</td>
</tr>
<tr>
<td>IIP3</td>
<td>&gt; -15dBm (input referred)</td>
<td>7.586dBm</td>
</tr>
<tr>
<td>Power Consumption</td>
<td>&lt; 4mW (total)</td>
<td>3.846mW</td>
</tr>
</tbody>
</table>
3. Simulation Results

![Simulation Result for S21](image1)

**Fig 1.2 Simulation Result for S21**

![Simulation Result for S11](image2)

**Fig 1.3 Simulation Result for S11**
Fig 1.4 Simulation Result for Noise Figure

Fig 1.5 Simulation Result for P1dB
Fig 1.6 Simulation Result for IIP3 (Start point = -10dBm)

Fig 1.6 Simulation Result for IIP3 (Start point = -28dBm)
CAD II: Low-Noise Amplifier Design

I. Device parameter summary

**Inductors**

<table>
<thead>
<tr>
<th>Locations</th>
<th>Value</th>
<th>Outer diameter</th>
<th># of Turns</th>
</tr>
</thead>
<tbody>
<tr>
<td>gate inductance</td>
<td>16.407 nH</td>
<td>1.64 mm</td>
<td>2</td>
</tr>
<tr>
<td>source degen.</td>
<td>2.498 nH</td>
<td>410 um</td>
<td>2</td>
</tr>
<tr>
<td>load inductance</td>
<td>171.22 nH</td>
<td>10 mm</td>
<td>2</td>
</tr>
</tbody>
</table>

**Capacitor (for C_{GS} compensation)**

<table>
<thead>
<tr>
<th>Location</th>
<th>Value</th>
<th>X dimension</th>
<th>Y dimension</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cgs compensation</td>
<td>16.407 nH</td>
<td>1.64 mm</td>
<td>2</td>
</tr>
</tbody>
</table>

**MOSFET**

<table>
<thead>
<tr>
<th>Location</th>
<th>Width</th>
<th>Length</th>
<th>#r of fingers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input</td>
<td>200 um</td>
<td>0.14 um</td>
<td>1</td>
</tr>
</tbody>
</table>

II. Simulation Results

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak S21 (Gain)</td>
<td>10.26 dB</td>
</tr>
<tr>
<td>3 dB BW</td>
<td>797 MHz</td>
</tr>
<tr>
<td>Center Freq.</td>
<td>674.5 MHz</td>
</tr>
<tr>
<td>S11</td>
<td>-10.01 dB</td>
</tr>
<tr>
<td>Noise Figure</td>
<td>&lt; 1.576 dB</td>
</tr>
<tr>
<td>P1 dB</td>
<td>- 12.79 dBm</td>
</tr>
<tr>
<td>IIP3</td>
<td>- 7.52 dB</td>
</tr>
<tr>
<td>Power Consumption</td>
<td>3.66 mW</td>
</tr>
</tbody>
</table>
S21 (PSS)
P1dB

1st Order

M3(-12.79dBm)

Part = "PORTS"

1st Order Freq = 500M
Figure 1. NF, S11, S21
Figure 2. 1dB Compression point.
Figure 3. 3dB Compression point.
<table>
<thead>
<tr>
<th>Specification</th>
<th>Desired</th>
<th>Achieved</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak S21 Gain</td>
<td>&gt;10dB</td>
<td>15dB</td>
</tr>
<tr>
<td>3dB Bandwidth</td>
<td>200MHz - 300MHz</td>
<td>500MHz to 1.028GHz</td>
</tr>
<tr>
<td>Center Frequency</td>
<td>900MHz</td>
<td>763MHz (for peak Gain) ~900MHz (for NF)</td>
</tr>
<tr>
<td>Noise Figure</td>
<td>&lt;1.7dB</td>
<td>1.25dB - 1.31dB</td>
</tr>
<tr>
<td>S11</td>
<td>&lt;10dB</td>
<td>-10.2dB</td>
</tr>
<tr>
<td>P1dB</td>
<td>&gt;-30dB</td>
<td>-8.04dB</td>
</tr>
<tr>
<td>IIP3</td>
<td>&gt;-15dB</td>
<td>-1.113dB</td>
</tr>
<tr>
<td>Power Consumption</td>
<td>&lt; 4mW</td>
<td>3.8mW</td>
</tr>
</tbody>
</table>

Table 1. Desired vs. Achieved values
1. Schematic of the LNA

- **V\textsubscript{bias} = 325 mV**
- **W/L = 510µm / 320nm**
- **V\textsubscript{dd} = 1.2V**
- **V\textsubscript{dd} = 1.2V**
- **17pF 60µm x 60.59µm**
- **1µF**
- **50fF**
- **Input port**
- **Output port**
- **12pF 50µm x 49.99µm**
- **10KΩ**

*Dimensions and other components as indicated in the schematic.*
2. Summary Table

<table>
<thead>
<tr>
<th>Specification</th>
<th>LNA Design</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak S21</td>
<td>&gt; 10 dB</td>
</tr>
<tr>
<td>3dB Bandwidth</td>
<td>200 MHz ~ 300 MHz</td>
</tr>
<tr>
<td>Center Frequency</td>
<td>900 MHz</td>
</tr>
<tr>
<td>Noise Figure</td>
<td>&lt; 1.7 dB from 800 MHz to 1 GHz</td>
</tr>
<tr>
<td>S11</td>
<td>&lt; -10 dB from 800 MHz to 1 GHz</td>
</tr>
<tr>
<td>P1dB</td>
<td>&gt; -30 dBm</td>
</tr>
<tr>
<td>IIP3</td>
<td>&gt; -15 dBm</td>
</tr>
<tr>
<td>Power</td>
<td>&lt; 4 mW</td>
</tr>
</tbody>
</table>

Path: /afs/umich.edu/user/k/k/kkhuang/eecs522/CAD/CAD_LNA

3. Plots of S11 S21 P1dB IIP3 and Noise Figure
TABLE OF MEASURED VALUES AND SPECIFICATIONS

<table>
<thead>
<tr>
<th>Specification</th>
<th>Required</th>
<th>This LNA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak S21 (Gain)</td>
<td>&gt; 10 dB</td>
<td>13.99 dB</td>
</tr>
<tr>
<td>3dB Bandwidth</td>
<td>200 MHz &lt; BW &lt; 300 MHz</td>
<td>299.5 MHz</td>
</tr>
<tr>
<td>Center Frequency</td>
<td>900 MHz</td>
<td>895.7 MHz</td>
</tr>
<tr>
<td>Noise Figure</td>
<td>&lt; 1.7 dB between 800 MHz and 1 GHz</td>
<td>1.682 dB max</td>
</tr>
<tr>
<td>S11</td>
<td>&lt; -10 dB between 800 MHz and 1 GHz</td>
<td>-10.32 dB max</td>
</tr>
<tr>
<td>P1dB</td>
<td>&gt; -30 dBm (input referred)</td>
<td>-7.15861 dB</td>
</tr>
<tr>
<td>IIP3</td>
<td>&gt; -15 dBm (input referred)</td>
<td>14 dBm</td>
</tr>
<tr>
<td>Power Consumption</td>
<td>&lt; 4mW (including bias circuits)</td>
<td>3.972 mW*</td>
</tr>
</tbody>
</table>

* 3.31 mA is drawn from the 1.2 V supply by the transistors, the bias resistor contribution is negligible (~5 pW)

Attached (in order):
- Illustration of the schematic
- Plots
  - S11
  - S21
  - P1dB
  - IIP3
  - Noise Figure
S-Parameter Response

M0 (800 MHz, -10.32 dB)

M1 (999.5 MHz, -10.06 dB)
Input Referred 1dB Compression = -7.15861

1st Order

Port = "PORT0"

1st Order freq = 900M
<table>
<thead>
<tr>
<th>Specification</th>
<th>Goal</th>
<th>Simulation Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>S21 (Gain)</td>
<td>&gt;10 dB</td>
<td>&gt;13 dB</td>
</tr>
<tr>
<td>3dB Bandwidth</td>
<td>200 MHz &lt; BW &lt; 300 MHz</td>
<td>283 MHz</td>
</tr>
<tr>
<td>Center Frequency</td>
<td>900 MHz</td>
<td>900 MHz</td>
</tr>
<tr>
<td>Noise Figure</td>
<td>&lt;1.7 dB between 800 MHz &amp; 1 GHz</td>
<td>&lt;1.6 dB between 800 MHz &amp; 1 GHz</td>
</tr>
<tr>
<td>S11</td>
<td>&lt;-10 dB between 800 MHz &amp; 1 GHz</td>
<td>&lt;-10 dB between 800 MHz &amp; 1 GHz</td>
</tr>
<tr>
<td>P1dB</td>
<td>&gt;-30 dBm input referred</td>
<td>-8.3 dBm</td>
</tr>
<tr>
<td>IIP3</td>
<td>&gt;-15 dBm input referred</td>
<td>-4.4 dBm</td>
</tr>
<tr>
<td>Power Consumption</td>
<td>&lt;4mW</td>
<td>3.87 mW</td>
</tr>
</tbody>
</table>
The bias voltage was set to 0.370 VDC.
Summary

<table>
<thead>
<tr>
<th></th>
<th>Peak S21</th>
<th>3dB BW</th>
<th>IIP3</th>
<th>1 dB Compression</th>
<th>Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design</td>
<td>13.548 dB</td>
<td>225.4 MHz</td>
<td>-5.58</td>
<td>-5.75 dBm</td>
<td>3.953 mW</td>
</tr>
<tr>
<td>Goal</td>
<td>&gt; 10 dB</td>
<td>200 MHz &lt; BW &lt; 300 MHz</td>
<td>&gt; -15 dBm</td>
<td>&gt; -30 dBm</td>
<td>&lt; 4 mW</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Frequency</th>
<th>S21</th>
<th>NF</th>
<th>S11</th>
</tr>
</thead>
<tbody>
<tr>
<td>800 MHz</td>
<td>12.211 dB</td>
<td>1.3421 dB</td>
<td>-10.982 dB</td>
</tr>
<tr>
<td>900 MHz</td>
<td>13.518 dB</td>
<td>1.3518 dB</td>
<td>-29.761 dB</td>
</tr>
<tr>
<td>1 GHz</td>
<td>12.785 dB</td>
<td>1.5043 dB</td>
<td>-11.326 dB</td>
</tr>
</tbody>
</table>

Plots

![S-Parameter Response](image-url)
Table 1 - Specification List

<table>
<thead>
<tr>
<th>Specification</th>
<th>Target Value</th>
<th>Actual Value</th>
<th>Actual Value</th>
<th>Actual Value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Lower Corner</td>
<td>900MHz</td>
<td>Upper Corner</td>
</tr>
<tr>
<td>Peak S21</td>
<td>&gt; 10dB</td>
<td>13.05 dB</td>
<td>13.66 dB</td>
<td>12.79 dB</td>
</tr>
<tr>
<td>3dB BW</td>
<td>200MHz &lt; BW &lt; 300MHz</td>
<td>N/A</td>
<td>450 MHz</td>
<td>N/A</td>
</tr>
<tr>
<td>Center Frequency</td>
<td>900MHz</td>
<td>N/A</td>
<td>900 MHz</td>
<td>N/A</td>
</tr>
<tr>
<td>Noise Figure</td>
<td>&lt; 1.7dB between 800MHz and 1GHz</td>
<td>1.343 dB</td>
<td>1.343 dB</td>
<td>1.675 dB</td>
</tr>
<tr>
<td>S11</td>
<td>&lt; 10dB between 800MHz and 1GHz</td>
<td>-10.62 dB</td>
<td>-22.32 dB</td>
<td>-10.14 dB</td>
</tr>
<tr>
<td>P1dB</td>
<td>&gt; -30dBm</td>
<td>N/A</td>
<td>-4.63 dBm</td>
<td>N/A</td>
</tr>
<tr>
<td>IIP3</td>
<td>&gt; -15dBm</td>
<td>N/A</td>
<td>-4.23 dBm</td>
<td>N/A</td>
</tr>
<tr>
<td>Power Consumption</td>
<td>&lt; 4mW</td>
<td>N/A</td>
<td>3.994 mW</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Table 2 - Component List

<table>
<thead>
<tr>
<th>Component</th>
<th>Parameters</th>
<th>Capacitance</th>
<th>Length</th>
<th>Width</th>
</tr>
</thead>
<tbody>
<tr>
<td>CM2</td>
<td>Capacitor</td>
<td>830.6277fF</td>
<td>8.5um</td>
<td>11.05um</td>
</tr>
<tr>
<td>CM1</td>
<td>Capacitor</td>
<td>4.999709fF</td>
<td>8.5um</td>
<td>81.71um</td>
</tr>
<tr>
<td>I3</td>
<td>Inductor</td>
<td>28.043nH</td>
<td>400um</td>
<td>8</td>
</tr>
<tr>
<td>I4</td>
<td>Inductor</td>
<td>1.609nH</td>
<td>150um</td>
<td>3</td>
</tr>
<tr>
<td>I5</td>
<td>Inductor</td>
<td>4.673nH</td>
<td>300um</td>
<td>3</td>
</tr>
<tr>
<td>T1</td>
<td>NFET</td>
<td>200um</td>
<td>150nm</td>
<td>8</td>
</tr>
<tr>
<td>T6</td>
<td>NFET</td>
<td>200um</td>
<td>150nm</td>
<td>8</td>
</tr>
</tbody>
</table>
1dB Compression

1dB Compression point = -4.63413 dB
figure 4 designed circuit
Figure 5: S-parameter analysis results (S11)
figure 6 s parameter analysis results (s21)
figure 7 s parameter analysis results (Noise Factor)
figure 6 1 dB compression point
figure 7  IIP3 Point (it is -3.9 dBm, red line is 3th harmonic blue is fundamental)
Device Values and Sizes:

Given Devices:

- $R_S = 50 \, \Omega$
- $R_{\text{bias}} = 10 \, k\, \Omega$
- $C_C = 12 \, \text{pF}$
- $C_L = 50 \, \text{fF}$
- $V_{\text{DD}} = 1.2 \, \text{V}$
- $V_{\text{bias}} = 397 \, \text{mV}$
### Inductors:

<table>
<thead>
<tr>
<th></th>
<th>Inductance</th>
<th>Outer Diameter</th>
<th>Metal Width</th>
<th>Number of Turns</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lg</td>
<td>23.075 nH</td>
<td>470 µm</td>
<td>11 µm</td>
<td>7.5</td>
</tr>
<tr>
<td>Ls</td>
<td>1.025 nH</td>
<td>400 µm</td>
<td>10 µm</td>
<td>1</td>
</tr>
<tr>
<td>Ld</td>
<td>2.266 nH</td>
<td>290 µm</td>
<td>15 µm</td>
<td>2.5</td>
</tr>
</tbody>
</table>

### Capacitors:

<table>
<thead>
<tr>
<th></th>
<th>Capacitance</th>
<th>X-Dimension</th>
<th>Y-Dimension</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cx</td>
<td>709.6945 fF</td>
<td>50 µm</td>
<td>6.75 µm</td>
</tr>
<tr>
<td>Cd</td>
<td>11.60083 pF</td>
<td>200 µm</td>
<td>28.12 µm</td>
</tr>
</tbody>
</table>

### Transistors:

<table>
<thead>
<tr>
<th></th>
<th>Width of Single Finger</th>
<th>Width of All Fingers</th>
<th>Length</th>
<th>Number of Fingers</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1</td>
<td>15.21 µm</td>
<td>380.25 µm</td>
<td>160 nm</td>
<td>25</td>
</tr>
<tr>
<td>M2</td>
<td>15.21 µm</td>
<td>380.25 µm</td>
<td>160 nm</td>
<td>25</td>
</tr>
</tbody>
</table>

### Summary Table:

<table>
<thead>
<tr>
<th>Specification</th>
<th>Desired Value</th>
<th>Measured Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak S21 (Gain)</td>
<td>&gt;10 dB</td>
<td>13.378 dB</td>
</tr>
<tr>
<td>3dB Bandwidth</td>
<td>200 MHz &lt; BW &lt; 300 MHz</td>
<td>297.14 MHz</td>
</tr>
<tr>
<td>Center Frequency</td>
<td>900 MHz</td>
<td>900 MHz</td>
</tr>
<tr>
<td>Noise Figure</td>
<td>&lt;1.7 dB between 800 MHz and 1 GHz</td>
<td>&lt;1.637 dB between 800 MHz and 1 GHz</td>
</tr>
<tr>
<td>S11</td>
<td>&lt;-10 dB between 800 MHz and 1 GHz</td>
<td>&lt;-10.17 dB between 800 MHz and 1 GHz</td>
</tr>
<tr>
<td>P1dB</td>
<td>&gt;-30 dBm (input referred)</td>
<td>-2.525 dBm</td>
</tr>
<tr>
<td>IIP3</td>
<td>&gt;-15 dBm (input referred)</td>
<td>-7.037 dBm</td>
</tr>
<tr>
<td>Power Consumption</td>
<td>&lt;4 mW</td>
<td>3.913 mW</td>
</tr>
</tbody>
</table>
Plots:

Figure 2. Plot of $S_{11}$

Figure 3. Plot of $S_{21}$
Periodic Steady State Response

Figure 4. Plot of P1dB

Figure 5. Plot of IIP3
Figure 6. Plot of Noise Figure