A Dual-Band CMOS Receiver for IEEE 802.11n WLAN

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Motivation – IEEE 802.11n

- IEEE 802.11/Wi-Fi is the standard for fast wireless communication
- IEEE 802.11g
  - 54 Mbps theoretical bit rate
  - 2.4 GHz band
- IEEE 802.11n
  - 600 Mbps theoretical bit rate
  - 2.4 & 5 GHz bands
System Architecture

- Differential, Concurrent, Dual-band, & Image Rejection
- Antenna, filter, and LNA provide high attenuation at image frequency
- Decreased area and power
Architecture Image Rejection

- LO frequency is carefully selected such that the image frequency is in the region of attenuation for frequency selective components.
Dual Band LNA – Transistor Sizing

- Fixed $I_d$ and $V_{ds}$, so fixed $P_{DC}$

\[ I_d = \frac{1}{2} \mu C_{ox} \frac{W}{L} (V_{gs} - V_{th})^2 \]

\[ g_m = \mu C_{ox} \frac{W}{L} (V_{gs} - V_{th}) \]

\[ f_t = \frac{1}{2 \pi C_{gs}} \]

![Graph showing $g_m f_t$ vs. $W$]
# Dual Band LNA - Dual Band Matching

## Input Matching

\[
\text{Im}(Z_1(\omega)+Z_2(\omega)) = 0 \\
\text{Im}(Z_1(\omega_2)+Z_2(\omega_2)) = 0
\]

\[
\frac{g_m \cdot L}{C_{gs}} = 50\Omega
\]

## Output Matching

\[
\text{Im}(Y_1(\omega)+Y_2(\omega)) = 0 \\
\text{Im}(Y_1(\omega_2)+Y_2(\omega_2)) = 0
\]

## Final Design
LNA – Simulation Results

<table>
<thead>
<tr>
<th>LNA Parameters</th>
<th>2.4 GHz</th>
<th>5.2 GHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gain (dB)</td>
<td>17.3</td>
<td>13</td>
</tr>
<tr>
<td>NF (dB)</td>
<td>2.5</td>
<td>3</td>
</tr>
<tr>
<td>S11 (dB)</td>
<td>&lt;-9</td>
<td>&lt;-11</td>
</tr>
<tr>
<td>IIP3(dBm)</td>
<td>-6</td>
<td>-3</td>
</tr>
<tr>
<td>IP1dB (dBm)</td>
<td>-13.5</td>
<td>-12.9</td>
</tr>
<tr>
<td>Quiescent Power (mW)</td>
<td>10.1</td>
<td>10.1</td>
</tr>
</tbody>
</table>
Mixer Architecture

- Differential RF & LO inputs for improved linearity
- M4- M7
  - Multiplication function
- M2, M3, R_{load} carefully sized
  - Conversion gain, \( G_C = \frac{V_{IF}}{V_{RF}} = \frac{2}{\pi} g_{m2} R_{load} \)
  - Power Consumption
Mixer - Simulation Results

- Conversion gain vs. $P_{LO}$

- Noise figure and input referred noise vs. $P_{LO}$
  - indicates good noise performance.
Mixer - Results Summary

- 1dB Compression point and IIP3 vs. $P_{RF}$ demonstrates the mixer’s good linearity

<table>
<thead>
<tr>
<th>Mixer Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gain (dB)</td>
<td>13.59</td>
</tr>
<tr>
<td>Quiescent Power (mW)</td>
<td>2.40</td>
</tr>
<tr>
<td>THD (dB)</td>
<td>-62.17</td>
</tr>
<tr>
<td>SSB NF (dB)</td>
<td>10.70</td>
</tr>
<tr>
<td>Input Referred Noise (nV/$\sqrt{\text{Hz}}$)</td>
<td>2.43</td>
</tr>
<tr>
<td>Isolation RF to IF (dB)</td>
<td>91.80</td>
</tr>
<tr>
<td>Isolation RF to LO (dB)</td>
<td>100.0</td>
</tr>
<tr>
<td>Isolation LO to RF (dB)</td>
<td>87.70</td>
</tr>
<tr>
<td>Isolation LO to IF (dB)</td>
<td>91.90</td>
</tr>
<tr>
<td>IIP3 (dBm)</td>
<td>-5.89</td>
</tr>
<tr>
<td>P1dB (dBm)</td>
<td>-15.95</td>
</tr>
</tbody>
</table>
**Quadrature Voltage Controlled Oscillator**

- Provides differential quadrature outputs
- Composed of two super-harmonic coupled LC oscillators

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>$f_{LO}$</td>
<td>3.14 GHz</td>
</tr>
<tr>
<td>$V_{ppk}$</td>
<td>1.4 V</td>
</tr>
<tr>
<td>Power</td>
<td>5 mW</td>
</tr>
<tr>
<td>Tuning</td>
<td>16%</td>
</tr>
<tr>
<td>Phase Noise</td>
<td>105 dBC/Hz @ 1 MHz</td>
</tr>
</tbody>
</table>

![Oscillator Circuit Diagram](image)
QVCO Output Waveform

Transient Response

V (V)

Time (ns)

75.0 75.25 75.5 75.75 76.0
System Performance

- **RF**
- **LO**
- **IF**

### Parameters

<table>
<thead>
<tr>
<th>Parameters</th>
<th>2.4 GHz</th>
<th>5.2 GHz</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Frequency Band</strong></td>
<td>2.4 - 2.4835 GHz</td>
<td>5.15 – 5.35 GHz</td>
</tr>
<tr>
<td><strong>Gain (dB)</strong></td>
<td>26.1</td>
<td>31.91</td>
</tr>
<tr>
<td><strong>Quiescent Power (mW)</strong></td>
<td>17.44</td>
<td>17.44</td>
</tr>
</tbody>
</table>
Layout

2200 μm

1300 μm

LNA

Mixer

QVCO
Summary

- Designed the front end of an 802.11n receiver
- Differential & concurrent receiver architecture
- Performs image rejection through attenuation
- Designed a dual-band LNA, mixer, and QVCO
- Demonstrated a 2.4 & 5 GHz dual-band receiver front-end using the IBM 0.13 μm process with good results
- Design can be further improved for minimum power consumption or noise figure.
Acknowledgements

- Professor Wentzloff for his assistance with this project
- The students in the class for their collaboration in this course
Questions