A Double-Balanced Injection-Locked Frequency Divider for Tunable Dual-Phase Signal Generation

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Outline

• Introduction
• Injection Locking
• Phase Tuning by Injection Locking
• Dual Phase Signal Generation
• Circuit Prototype
• Measurement Results
• Conclusion
Motivation

• Arbitrary Phased LO Frequencies Generation

Tunable Phased LOs => Adaptive Maximal Ratio Combining
Motivation

- Accurate Quadrature Generation

Input

\[ 2\omega,0^\circ \]

Frequency Divider I

\[ \omega,0^\circ \]

\[ 2\omega,180^\circ \]

Frequency Divider Q

\[ \omega,90^\circ \]

Quadrature

Process Variation \(\Rightarrow\) Mismatch in I&Q \(\Rightarrow\) Quadrature Error

Up to now, no active compensation techniques
Injection-Locked Frequency Divider

Divide-by-2 Injection-Locked Frequency Divider

Mixer Model for ILFD

\[ \Delta i = i_1 - i_2 \quad \Delta \omega = \omega - \omega_0 \]

\[ \varphi = \frac{1}{2} \left( \sin^{-1} \left[ \frac{3/\eta}{1 + (\omega_0/Q\Delta \omega)^2} \right] + \sin^{-1} \left[ \frac{1}{1 + (\omega_0/Q\Delta \omega)^2} \right] \right) \]

Phase Tuning by ILFD

Normalized frequency offset \( \frac{Q\Delta \omega}{\omega_0} \) (%)

Injection ratio \( \eta = \frac{I_{inj}}{I_{osc}} \)
Phase Tuning for Dual Phase Signal Generation

Input

\[ 2\omega, 0^\circ \]

\[ + \]

\[ 2\omega, 180^\circ \]

Output 1

\[ \omega, \phi_1 \]

\[ \phi_1 = 0^\circ + \phi_1 \]

\[ \Delta \phi = \phi_2 - \phi_1 \]

Output 2

\[ \omega, \phi_2 \]

\[ \phi_2 = 90^\circ + \phi_2 \]
Circuit Prototype

\[ \text{ILFD} \]
Die Photo of Circuit Prototype

0.18um Digital CMOS  

1.0mm × 1.1mm

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Single Ended Phase Tuning

50° phase tuning range and 50°/V gain.
Differential Phase Tuning

Phase Difference (degree)

100° phase tuning range.

$V_{t1} - V_{t2}$ (Volt)
Locking range is 2.31GHz when input amplitude is 0.33V.
Phase Noise Performance

ILO output phase noise tracks input by 12dB (divide by 4).
# Performance Summary

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Phase Tuning</th>
<th>Locking Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.8-6 GHz</td>
<td>55° single-ended</td>
<td>15%</td>
</tr>
<tr>
<td></td>
<td>100° differential</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Vdd</th>
<th>Power Consumption</th>
<th>Phase Noise</th>
</tr>
</thead>
<tbody>
<tr>
<td>Core: 1.8V</td>
<td>Core: 8mA</td>
<td>12dB down</td>
</tr>
<tr>
<td>Balun ILFD: 1.4V</td>
<td>Balun ILFD: 4mA</td>
<td></td>
</tr>
<tr>
<td>Buffer: 1.8V</td>
<td>Buffer: 18mA</td>
<td></td>
</tr>
</tbody>
</table>

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Conclusion

• Phase tuning by injection locking demonstrated.
• Application include robust, accurate quadrature generation and MIMO systems.
• Linear phase tuning characteristics from ILFD.
• Differential tuning employed to extend the tuning range.
• Circuit prototype achieved tunable dual-phase signal generation with large locking range and good phase noise performance.
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