Quadrature Generation Techniques in CMOS Relaxation Oscillators

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ISCAS 2012
Outline

● Introduction & Motivation

● Quadrature Relaxation Oscillators (QRXO)
  – Shunt-coupled QRXO
  – Series-coupled QRXO

● Design and Simulation Results

● Summary
Introduction

- RF oscillator: key block in wireless & wireline communication systems [1,2]
- LC VCOs are commonly used
  - Low phase noise (high-Q)
  - Large area (spiral inductors)
  - Tuning range limited by device parasitics
- Quadrature LO signals
  - Recovery of IQ signal
  - Image-rejection
IQ LO Generation – 1

- **VCO ($f_0$) + polyphase filter**
  - High frequencies: capacitive parasitics become comparable to filter C
  - Buffers required to drive low impedances = high power consumption
  - Quadrature error $\subseteq$ R & C matching

- **VCO (2$f_0$) + Divide-by-2**
  - LC oscillator potentially has higher Q at 2$f_0$
  - Divider power becomes significant
  - Quadrature error $\subseteq$ device matching
IQ LO Generation – 2

- Four-stage ring oscillator ($f_0$)
  - Tuning range set by stage delays
  - Quadrature error $\Leftrightarrow$ delay matching
- Quadrature VCO ($f_0$) [1,3,4]
  - Power efficient at higher frequencies
  - Quadrature error $\Leftrightarrow$ coupling strength
Relaxation Oscillator

- Schmitt Trigger: Cross-coupled NMOS + R loads
- Integrator: Capacitor C
- Tune frequency using $I_0$
Quadrature Generation

- Quadrature Relaxation Oscillator [5,6]
  - $V_C$ and $V_{OUT}$ are 90° out of phase
  - Integrator of each oscillator triggers the other

- Quadrature LC VCO
  - Inhibit negative resistance generation for 0° or 180° modes
  - Shunt & series injection

- Quadrature Relaxation Oscillator (this work)
  - Suppress Schmitt-trigger operation for 0°/180°
  - Shunt & Series coupling
Shunt Coupled QRXO

- $I=Q$ (in-phase) $\Rightarrow$ $M_{5-6}$ oppose $M_{1-2}$
  - QRXO$_{I}$ dies out $\Rightarrow$ QRXO$_{Q}$ too ceases to oscillate

- $I=\overline{Q}$ (out-of-phase) $\Rightarrow$ $M_{7-8}$ oppose $M_{3-4}$
  - QRXO$_{Q}$ dies out $\Rightarrow$ QRXO$_{I}$ too ceases to oscillate
Series Coupled QRXO

- Series injection through $M_{5-8}$
- Coupling devices in triode region
Circuit Design & Simulation

- Quadrature relaxation oscillators designed and simulated using Spectre (Cadence)
  - $f_0 = 2.4\text{GHz}$
  - UMC 0.18µm CMOS process ($V_{DD} = 1.8\text{V}$)

- Reference 2.4GHz relaxation oscillator
  - Total bias current = 6mA
  - $M_{1-2} = 100\mu\text{m} \times 0.25\mu\text{m}$
  - Load resistance $R = 100\Omega$
  - Integrator capacitance $C = 460\text{fF}$
Shunt-coupled QRXO

- Quadrature coupling validated in simulation
- Primary design parameter: size of quadrature coupling devices
  - Large W/L $\Rightarrow$ strong coupling, larger parasitics
  - Small W/L $\Rightarrow$ weak coupling, more flicker noise
  - Larger L $\Rightarrow$ less flicker noise, more parasitics
  - $M_{5-8} = 36\mu m \times 0.65\mu m$
- Total QRXO current = 12mA
- 1% I-Q mismatch $\Rightarrow$ 0.25° quadrature error
Shunt QRXO – Startup
Shunt QRXO – Phase Noise

-99.4 dBc/Hz @ 1MHz offset

R = 24%; M_{5-8} (flicker) = 21%; M_{1-4} (thermal) = 18%
Shunt QRXO – Phase Error

![Graph showing the relationship between Coupling Device width (um) and Quadrature Phase Error (deg.), Oscillation Frequency (Ghz). The graph indicates a decrease in Quadrature Phase Error and an increase in Oscillation Frequency as the Coupling Device width increases.]
Series-coupled QRXO

- Quadrature coupling validated in simulation
- Coupling devices
  - Operate in triode region
  - Weaken cross-coupled NMOS operation (degeneration)
    - Large W/L ($M_{5-8} = 200\mu m \times 0.18\mu m$)
  - Flicker noise less of a concern
- Total QRXO current = 16mA
- 1% I-Q mismatch $\Rightarrow 0.1^\circ$ quadrature error
Series QRXO – Startup
Series QRXO – Phase Noise

-98.3 dBc/Hz @ 1MHz offset

$M_{1-4}$ (flicker) = 70%
Series QRXO – Phase Error

![Graph showing the relationship between Coupling Device width (um) and Quad. Phase Error (deg.), Oscillation Frequency (GHz)]
## Comparison

<table>
<thead>
<tr>
<th>Coupling Devices</th>
<th>Shunt coupled QRXO</th>
<th>Series coupled QRXO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saturation (smaller)</td>
<td>×</td>
<td>✓</td>
</tr>
<tr>
<td>Triode (larger)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quadrature Error</td>
<td>×</td>
<td>✓</td>
</tr>
<tr>
<td>Phase Noise</td>
<td>✓</td>
<td>×</td>
</tr>
<tr>
<td>Current Consumption</td>
<td>✓</td>
<td>×</td>
</tr>
</tbody>
</table>
Summary

- Two topologies for quadrature coupling of relaxation oscillators were presented.
- 2.4GHz quadrature oscillators were designed and simulated in a UMC 0.18µm CMOS process.
  - Shunt-coupled $\Rightarrow$ lower current, larger quadrature error.
  - Series-coupled $\Rightarrow$ larger current, lower quadrature error.
References


Thank you