A Millimeter Wave Quadrature VCO Based on Magnetically Coupled Resonators

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60GHz QVCO

- **Wireless Applications:**
  - Enable direct conversion receiver architectures
  - Provide phase rotators drivers in phased-arrays system

- **Wire-line Applications:**
  - Clock recovery
Outline

• Limits of classical transistor coupled QVCOs at mm-waves
• Ring of VCOs with passive coupling
• Design of a QVCO based on magnetic inter-stages
• Experiments
• Conclusions
Classical Transistor Coupled VCOs

$$f_0 = \frac{1}{2\pi\sqrt{LC}} \left( 1 \pm \frac{1}{2Q} \frac{I_q}{I_i} \right)$$

$f_0$ depends on $I_q$ and $I_i$

Amplitude noise in $I_q$ and $I_i$ directly translates into oscillator phase noise.
Ring Oscillator with Passive Coupling

If the trans-impedance \( Z(\omega) \) is a filter of order higher than two, 90° shift can be provided by passive components only.

Improved phase noise performances
Passive Coupled Parallel Resonators

- Optimum $kQ$ value exists (0.75)
- For a typical $Q$ of 5, $k$ is 0.15
Phase Noise Comparison

• Oscillators drawing 22 mA, employing LC tank with Q of 5
• No varactor included
• 2 decades 1/f noise improvement vs transistor coupled
**Coupled Resonators Design**

**CAPACITIVE COUPLING**
- Four inductors are needed

**MAGNETIC COUPLING**
- Area reduced by a factor of 2
- Simplified Signal routing
Low-k Transformer

Shield produces reduction of:
- equivalent coupling $k_{eq}$
- $L_{ext}$
- $Q$ of $L_{ext}$
QVCO Schematic

- A-MOS varactors for tuning
- No active biasing device for minimum 1/f noise
- Rcm to prevent common mode oscillations
Chip Micrograph

Technology: 65nm CMOS

Power Consumption: 22mW

Core Area: 0.075mm²

Supply Voltage: 1V

Test Chip fabricated by STMicroelectronics
Chip Micrograph

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Test Chip fabricated by STMicroelectronics
Measurements

- Buffer H Mixer L: Testing @ 60GHz
- Buffer L Mixer H: Down-conversion

Reconfigurable Gilbert cell

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Phase Noise

Corner Frequency: < 1MHz

-117 dBc/Hz
Phase Accuracy

Frequency: 200MHz

Phase Error < 1.5°  Amplitude Mismatch < 1dB
## State of the art mm-W QVCOs

<table>
<thead>
<tr>
<th>Ref</th>
<th>Process</th>
<th>Frequency (GHz)</th>
<th>T.R. (GHz)</th>
<th>P.N. @ 1MHz (dBc/Hz)</th>
<th>FOM (dBc/Hz)</th>
<th>Phase Error</th>
<th>Area (mm²)</th>
<th>Power (mW)</th>
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<td>Laskin TMTT Dec. 2009</td>
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<td><strong>Process</strong></td>
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<td><strong>4</strong></td>
<td><strong>-85</strong></td>
<td><strong>-165</strong></td>
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<td><strong>22</strong></td>
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<td><strong>4</strong></td>
<td><strong>9</strong></td>
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<td><strong>P.N. @ 1MHz (dBc/Hz)</strong></td>
<td><strong>-85</strong></td>
<td><strong>-90</strong></td>
<td><strong>-75</strong></td>
<td><strong>-95 / -97</strong></td>
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<tr>
<td><strong>FOM (dBc/Hz)</strong></td>
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<td><strong>-172.7</strong></td>
<td><strong>-156</strong></td>
<td><strong>-177 / -179</strong></td>
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<tr>
<td><strong>Phase Error</strong></td>
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<td>n.a.</td>
<td>&lt; 1.5°</td>
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<td><strong>Area (mm²)</strong></td>
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<td><strong>Power (mW)</strong></td>
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<td>43.2</td>
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Conclusions

• A new circuit topology of quadrature VCO, based on magnetically coupled resonators has been presented

• A low-k transformer has been realized to implement the coupled resonators and optimize the oscillator area

• Very good performances in terms of phase noise and phase accuracy have been demonstrated

• The realized VCO lends itself to be used in direct conversion receivers or to implement phased array solutions