A Pulse-Driven LC-VCO with a Figure-of-Merit of -192dBc/Hz

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Motivation

Low power TRx is required for next gen portable devices

VCO – A major power consumer in TRx.

VCO for next generation wireless devices

- High purity
- High efficiency
- Small area

Tackling Efficiency: Class-C VCO

➢ High current efficiency

Efficiency and MOS sizing

For high efficiency
- Large $A_{\text{max}}$
- Small $V_{\text{GS}}$
- Small conduction angle

$A_{\text{max}} = \frac{V_{DD} - (V_{GS} - V_{TH})}{2}$

Large MOS required for better efficiency

Effects of Large MOS

- Tank capacitance is susceptible to $V_{GS}$ variations.

$$C_{gs} = \begin{cases} \frac{2}{3}WLCOX \text{ (saturation)} \\ WL_{OV}COX \text{ (cut-off)} \end{cases}$$
Variations in $C_{GS}$ translates to phase noise.
AM-PM conversion - Contd.

\[
\text{Phase Noise [dBc/Hz]} \\
\begin{array}{c|c|c|c}
\text{V_{gbias}[V]} & -0.3 & 0.0 & 0.3 \\
\hline
\text{Simulation} & \bullet & \bullet & \bullet \\
\text{With AM-PM} & \text{---} & \text{---} & \text{---} \\
\text{Without AM-PM} & \text{---} & \text{---} & \text{---} \\
\end{array}
\]

\[\text{Large AM-PM} \quad \text{Small } \Phi\]

\[
\text{Smaller } \Phi \text{ with smaller transistor size.}
\]

\[
\text{PN} = 10 \log_{10} \left\{ \frac{2Fk_B T}{P_{sig}} \left( \frac{\omega_0}{2Q_\omega_{offset}} \right)^2 \right\} + \left\{ \frac{V_M K_{V_{gbias}}}{2\omega_{offset}} \right\}^2
\]

\[
K_{V_{gbias}} = \frac{\partial \omega}{\partial V_{gs}} \approx \frac{1}{4\sqrt{LC}} \frac{WC_{OX}}{\pi} \left( \frac{2}{3} L - L_{OV} \right) + \frac{1}{KA_t \sin \phi}
\]
Issue of Class-C VCO

\[ V_{GS} - V_{TH} \] must be small for small \( \Phi \)
Large MOS is required for larger current

\[ \Phi \] with smaller transistor size.
Proposed Pulse-Driven VCO

Conduction angle is independent of MOS size.
Analysis: AM-PM Conversion

Time Domain Analysis

AM-PM translation is minimized.
Proposed Circuit Schematic

conduction angle control

VDD

IB

Rb

Cb

Amplitude regenerator

VP

VN

Vbp

Vbn

M1

M2

VTail

MTail

CTail

VDD

IB

Rb

Cb
Pulse Drive: Startup

Cond. Angle Control

Amplitude Regeneration

High robustness
Pulse Drive: Startup Contd.

Cond. Angle Control

Amplitude Regeneration

Class-AB

Class-B

Induced Class-C
Pulse Drive: Steady State

Cond. Angle Control

Amplitude Regeneration

High Efficiency
Noise from the additional MOS

Delay introduced by the inverter is within safe ISF region.

Delay becomes trivial in advanced processes.
Noise introduced by the driver circuitry is small.
Chip Micrograph

Reference VCO

Proposed

VDD

V_gbias

VDD

VDD

M1

M2

M1

M2

V_Tail

C_Tail

V_Tail

C_Tail

Pulse Drive

Pulse Drive

Pulse Drive
Measurement Results

Reference VCO
\[ P_{dc} = 2.54\text{mW} \]
\[ \text{FoM} = -190\text{dBc/Hz} \]

This work
\[ P_{dc} = 2.05\text{mW} \]
\[ \text{FoM} = -192\text{dBc/Hz} \]
# Performance Comparison

<table>
<thead>
<tr>
<th>CMOS Process</th>
<th>Frequency [GHz]</th>
<th>Phase Noise [dBc/Hz]</th>
<th>Pdc [mW]</th>
<th>FoM [dBc/Hz]</th>
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<tbody>
<tr>
<td>[1] JSSC2008</td>
<td>130nm</td>
<td>4.9</td>
<td>-130@1MHz</td>
<td>1.30</td>
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<tr>
<td>[2] VLSI2009</td>
<td>180nm</td>
<td>4.5</td>
<td>-109@1MHz</td>
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<tr>
<td>[3] JSSC2013</td>
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<td>4.84</td>
<td>-125@1MHz</td>
<td>3.40</td>
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<td>[4] ESSCIRC2011</td>
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<td>5.1</td>
<td>-120@1MHz</td>
<td>0.86</td>
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<td>[5] JSSC2013</td>
<td>65nm</td>
<td>3.7</td>
<td>-142@3MHz</td>
<td>15.0</td>
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<tr>
<td>[6] JSSC2013</td>
<td>65nm</td>
<td>4.8</td>
<td>-144@10MHz</td>
<td>4.00</td>
</tr>
<tr>
<td>This Work</td>
<td>180nm</td>
<td>3.6</td>
<td>-124@1MHz</td>
<td>2.05</td>
</tr>
</tbody>
</table>

Conclusion

- A phenomenon in class-C VCO due to which AM noise is up-converted to PN is identified.
- A new technique namely “pulse-drive” is proposed to alleviate AM-PM conversion issue.
- The proposed pulse-drive technique avoids AM-PM conversion without sacrificing efficiency.
- A VCO is implemented using the proposed pulse-drive technique and tested to verify the claims.
- The proposed circuit is however process dependent and has limited frequency of operation.
Simulated Waveforms (2)