Direct Digital Wavelet Synthesis for Embedded Biomedical Microsystems
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Summary
This work presents a compact direct digital wavelet synthesizer for extracting phase and amplitude data from cortical recordings using a feed-forward recurrent digital oscillator. The proposed system dynamically controls oscillation to generate frequency selective quadrature wavelets.

Features
▶ Reconfigurable Digital Wavelet Synthesizer
▶ Time-Frequency analysis with global Φ reference
▶ Low Complexity (684 total elements at 16 bit)
▶ 4 Quadrature bit-stream outputs using ΔΣ²
▶ Time-Bandwidth Product of ≈ 0.6

Introduction
Spectrum analysis is an essential tool for many biomedical applications to provide electrode impedance characteristics [1, 2] and assist in signal decomposition for brain machine interfaces (BMI) [3, 4]. We propose using two digital recurrence oscillators to generate wavelets that analyse selected frequency bins for these applications.

Here, a) shows the block diagram of the Feed-forward digital oscillator and b) shows the z-domain pole-zero plot of the feedback loop varying k for a fixed frequency.

Implementation
In addition to the oscillators, this module uses amplitude tracking and ΔΣ² modulators to vary the oscillation dynamics according to the input parameters. The amplitude information proportionally adjusts the growing or receding oscillation in a way that each pulse envelope is overlapping by 50%.

Results
Using large (right) or small (left) values of cbw we can compare the transient output after decimation of the two quadrature bit-streams (top), the adaptive control of k (middle), and the frequency response of the generated wavelet (bottom).

These wavelets have exceptional time-frequency characteristics. The Time-Bandwidth-Product approaches the ideal value of 0.5 as the envelope approximates to the two-sided hyperbolic cotangent.

Summary
Using the Lattice Synthesis Engine and a LCMXO3LF FPGA target, the overall hardware complexity for this synthesizer is summarised below:

<table>
<thead>
<tr>
<th>FPGA Resource</th>
<th>LUT4</th>
<th>Register</th>
<th>SLICE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wavelet Gen</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dynamic Sys. Control</td>
<td>10</td>
<td>24</td>
<td>10</td>
</tr>
<tr>
<td>Oscillator Core (2x)</td>
<td>5</td>
<td>217</td>
<td>125</td>
</tr>
<tr>
<td>ΔΣ² Modulator (4x)</td>
<td>16</td>
<td>160</td>
<td>112</td>
</tr>
<tr>
<td>Total</td>
<td>31</td>
<td>401</td>
<td>252</td>
</tr>
<tr>
<td>Max. Clock Speed: 109.4 MHz with OSR 32 at 331 μW per MHz</td>
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References