Imperial College London

NGNI Next Generation Neural Interfaces

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Direct Digital Wavelet Synthesis for Embedded Biomedical Microsystems

Lieuwe B. Leene, Timothy G. Constandinou

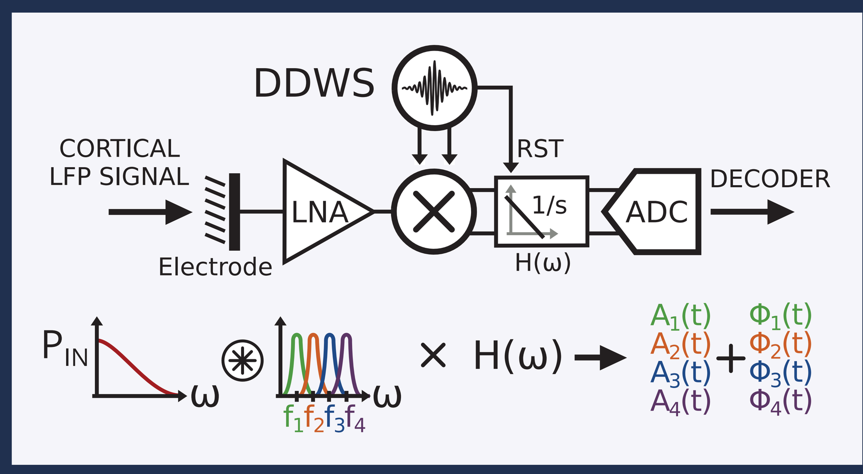
Centre for Bio-Inspired Technology, Institute of Biomedical Engineering, Imperial College London, UK

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 $\Delta\Sigma^2$
- Time-Bandwidth Product of ≈ 0.6

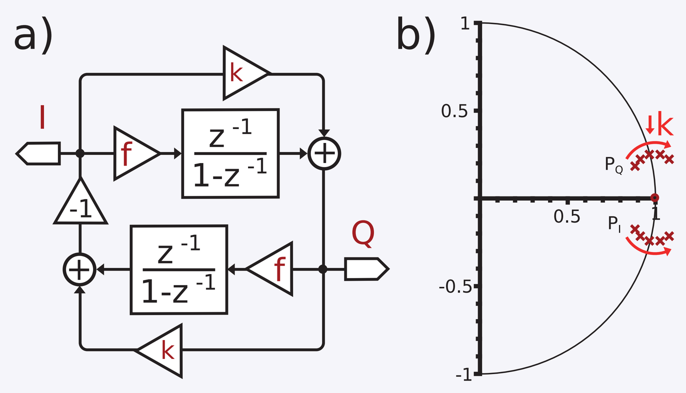


LFP-based decoding system that uses amplitude and phase information of precise frequency bins.

► Introduction

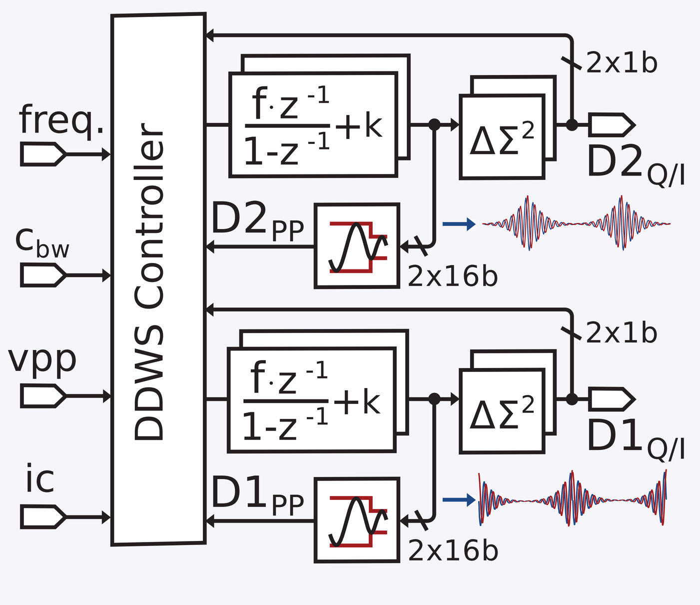
Spectrum analysis is an essential tool for many biomedical applications to provide electrode impedance characteristics [1, 2] and assist in signal decomposition for brain machine interfaces (BMI) [3, 4]. We propose using two digital recurrence oscillators to generate wavelets that analyse selected frequency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

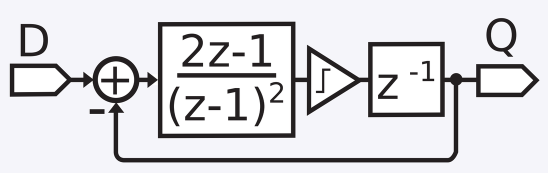
Here, a) shows the block diagram of the Feed-forward digital oscillator and b) shows the z-domain pole-zero plot of the feedback loop varying k for a fixed frequency.



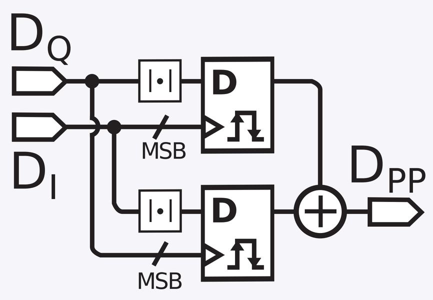
► Implementation

In addition to the oscillators, this module uses amplitude tracking and $\Delta\Sigma^2$ 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%.





ΔΣ Encoding Block



Amplitude tracking logic

Control Algorithm:

begin

$\mathbf{x1}_{Q/I}[n] = \mathbf{R}(k1,f) \cdot \mathbf{x1}_{Q/I}[n-1]$

$\mathbf{x2}_{Q/I}[n] = \mathbf{R}(k2,f) \cdot \mathbf{x2}_{Q/I}[n-1]$

if $D1_{PP} > vpp$ ***or*** $|k1| < c_{bw}/2$ **then**

$k1 = 0.5 - c_{bw}$

else if $D1_{PP} < ic$ ***and*** $s2<0$ **then**

$k1 = 0.5 + c_{bw}$

if $D2_{PP} > vpp$ ***or*** $|k2| < c_{bw}/2$ **then**

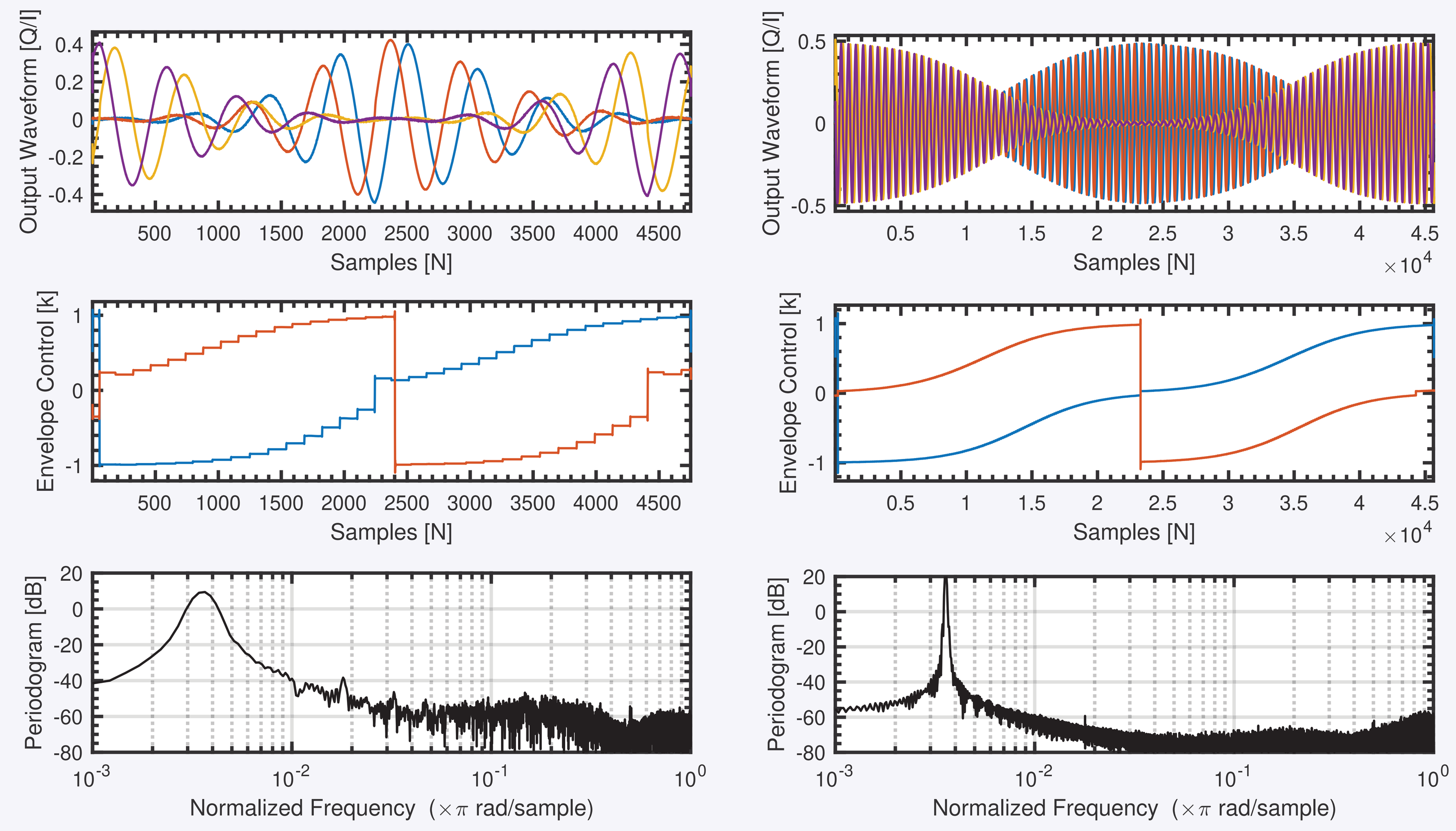
$k2 = 0.5 - c_{bw}$

else if $D2_{PP} < ic$ ***and*** $s1<0$ **then**

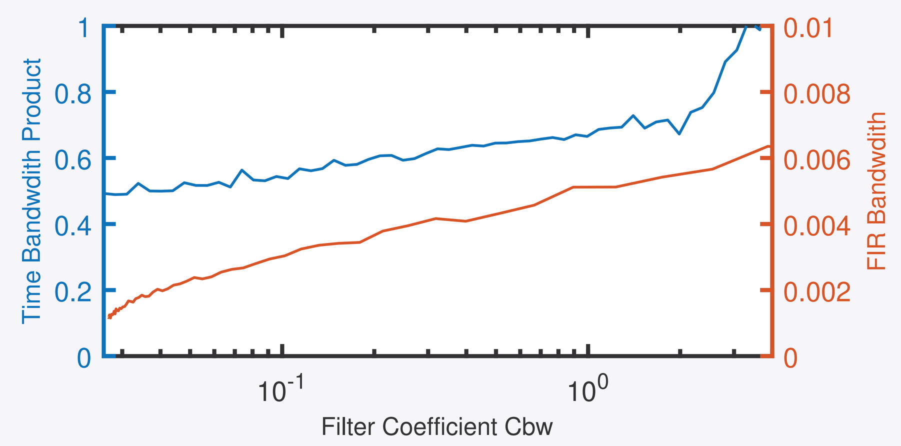
$k2 = 0.5 + c_{bw}$

► Results

Using large (right) or small (left) values of c_{bw} 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:

FPGA Resource	LUT4	Register	SLICE
Wavelet Gen			
Dynamic Sys. Control	10	24	10
Oscillator Core (2x)	5	217	125
$\Delta\Sigma^2$ Modulator (4x)	16	160	112
Total	31	401	252

Max. Clock Speed: 109.4 MHz with OSR 32 at 331 μW per MHz

References

[1] W. Franks *et al.*, "Impedance characterization and modeling of electrodes for biomedical applications," *IEEE Rev. Biomed. Eng.*, vol. 52, no. 7, pp. 1295–1302, July 2005.

[2] A. Sun *et al.*, "A multi-technique reconfigurable electrochemical biosensor: Enabling personal health monitoring in mobile devices," *IEEE Trans. Biomed. Circuits Syst.*, vol. 10, no. 5, pp. 945–954, Oct 2016.

[3] S. R. Sridhara *et al.*, "Microwatt embedded processor platform for medical system-on-chip applications," *IEEE J. Solid-State Circuits*, vol. 46, no. 4, pp. 721–730, April 2011.

[4] Z. Zhang *et al.*, "Low-complexity seizure prediction from iEEG/sEEG using spectral power and ratios of spectral power," *IEEE Trans. Biomed. Circuits Syst.*, vol. 10, no. 3, pp. 693–706, June 2016.

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