conFFTi - FPGA music synthesizer

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Use Case

- Synthetic musical instrument for electronic music production
- Fast, configurable and portable solution
  - **Software synthesizer**: cheap, configurable, but high latency
  - **Hardware synthesizer**: fast, but expensive, with limited configurability
  - **FPGA synthesizer**: (potentially) best of both worlds

Serum by Xfer Records - Advanced Wavetable Synthesizer for Mac/Windows

$189.00

ADSR

Free shipping, no tax

Software Synthesizer

Korg Opsix Altered FM Synthesizer

$799.99

Sweetwater

Free shipping

For most items: 30-day return policy

Hardware Synthesizer

Moog One Polyphonic Analog Synthesizer 16 Voice

$8,499.00

Guitar Center

Free shipping

For most items: 45-day return policy

State-of-the-art Hardware Synthesizer

conFFTi

- Accepts real-time input from a MIDI keyboard
- Generates audio output with subtractive, wavetable and frequency modulation synthesis on FPGA
  - Waveform generation (tri, sin, sqr, saw, wavetable)
  - Filter - Finite impulse response, Infinite Impulse response
  - Distortion - Compression, overdrive
  - Frequency Modulation
  - ADSR Envelope
  - Arpeggiator

Requirements

- 44.1kHz, 16-bit, single channel audio output
- 4-note polyphony
- Low latency (< 10 ms)
- UI for parameter manipulation utilizing keyboard faders and knobs

Technical Challenges

- Memory requirement
  - Arpeggiator is RAM heavy
  - 4-notes polyphony x 4-note arpeggiation x 44.1k sample/s x 16 bit/sample x 2 s/note x ⅛ byte/bit = 2.8MB
- Fix point division
  - unsupported by SystemVerilog
- Random Number Generation for Arpeggiator
  - Needs a low latency yet good (pseudo-)random generator

Solution Approach

- Memory requirement
  - FPGA with large RAM (brings more logical elements as well)
  - External RAM (cheaper)
- Fix point division
  - Look up tables
- Random Number Generation
  - Linear-feedback shift register
  - CRC generator

Solution Approach

- MIDI keyboard
  - DIN port for interfacing with the FPGA
  - Have a good number of knobs and faders (~8) for parameter control
- FPGA
  - Large RAM and Large number of logic element
  - 4 audio processing pipelines for 4 note polyphony
  - Use RAM to store high fidelity wavetables for 44.1kHz, 16-bit audio output
- Audio Output Unit
  - Microphone for realtime audio output

Testing, Verification and Metrics

- Waveform Comparison
  - For each effect, compare reference waveform generated by Matlab scripts to that of the waveform generated by the FPGA measured by an oscilloscope
- Metrics
  - Aim for high FPGA logic unit and memory utilization
  - Lowest possible latency

ECE Areas

- Software (Embedded Systems)
- Hardware (FPGA, SystemVerilog)
- Signals (Filter Design, Fourier Transform, Sampling)

Tasks and Division of Labor

- Michelle
  - Waveform generation
  - Filter design
  - Distortion
  - ADSR
  - Mixer
- Hongrun
  - MIDI keyboard interface
  - Audio output
  - Frequency Modulation
  - Arpeggiator
  - Waveform verification with Oscilloscope output
- Jiuling
  - Polyphony control
  - Random number generation
  - Delay
  - Echo

Schedule


Feb 26 - Feb 28 3 d Matlab scripts - waveform, filters
Mar 1 - Mar 2 2 d Matlab scripts - distortions, ADSR
Mar 3 - Mar 7 5 d Matlab scripts - Mixing notes
Mar 8 - Mar 15 8 d Simulation - Waveform Generation
Mar 16 - Mar 23 8 d Simulation - Filter (finite/infinite impulse response)
Mar 24 - Mar 31 8 d Simulation - Distortion (compression, overdrive)
Apr 1 - Apr 7 7 d Simulation - ADSR envelope
Apr 7 - Apr 12 6 d Simulation - Mixing notes
Apr 13 - Apr 15 3 d Synthesis & integration - waveform, filters
Apr 15 - Apr 17 3 d Synthesis & integration - distortions, ADSR
Apr 17 - Apr 19 3 d Synthesis & integration - mixing notes
Feb 24 - Mar 1 6 d Simulation environment set up
Feb 24 - Feb 25 2 d Matlab scripts - random number generation
Feb 26 - Feb 28 3 d Simulation - random number generation
Mar 2 - Mar 8 7 d Block diagram - polyphony control
Mar 9 - Mar 11 3 d Block diagram - delay
Mar 12 - Mar 14 3 d Block diagram - echo
Mar 15 - Mar 18 4 d Simulation - delay
Mar 19 - Mar 23 5 d Simulation - echo
Mar 24 - Mar 30 7 d Simulation - polyphony control
Mar 31 - Apr 6 7 d Synthesis & integration - polyphony control
Apr 6 - Apr 15 10 d Synthesis & integration - echo, delay & random number generation
Apr 16 - Apr 18 3 d Synthesis & integration - all
Feb 27 - Mar 1 3 d Matlab scripts - frequency modulation
Mar 2 - Mar 4 3 d Matlab scripts - arpeggiator
Mar 6 - Mar 14 9 d MIDI interface - note input
Mar 15 - Mar 17 3 d MIDI interface - Fader and knob control
Mar 18 - Mar 21 4 d Audio interface - DAC to FPGA interface
Mar 22 - Mar 27 6 d Simulation - frequency modulation
Mar 28 - Mar 30 3 d Synthesis & Integration - frequency modulation
Mar 31 - Apr 5 6 d Simulation - arpeggiator
Apr 6 - Apr 8 3 d Synthesis & Integration - arpeggiator
Apr 9 - Apr 15 7 d Verification - Oscilloscope & waveform comparison
Apr 16 - Apr 18 3 d Synthesis & integration - all
Apr 19 - May 2 14 d Slack time
Implementation Finished
4/12/2021
Integration Finished
4/19/2021
2021
02/22
03/01
03/08
03/15
03/22
03/29
04/05
04/12
04/19
04/26
05/03
05/10
2021
2/22/2021
Proposal Presentation
3/8/2021
Design Presentation
3/17/2021
Design Report
4/12/2021
Interim Demo
5/3/2021
Final Presentation
5/15/2021
Final Report