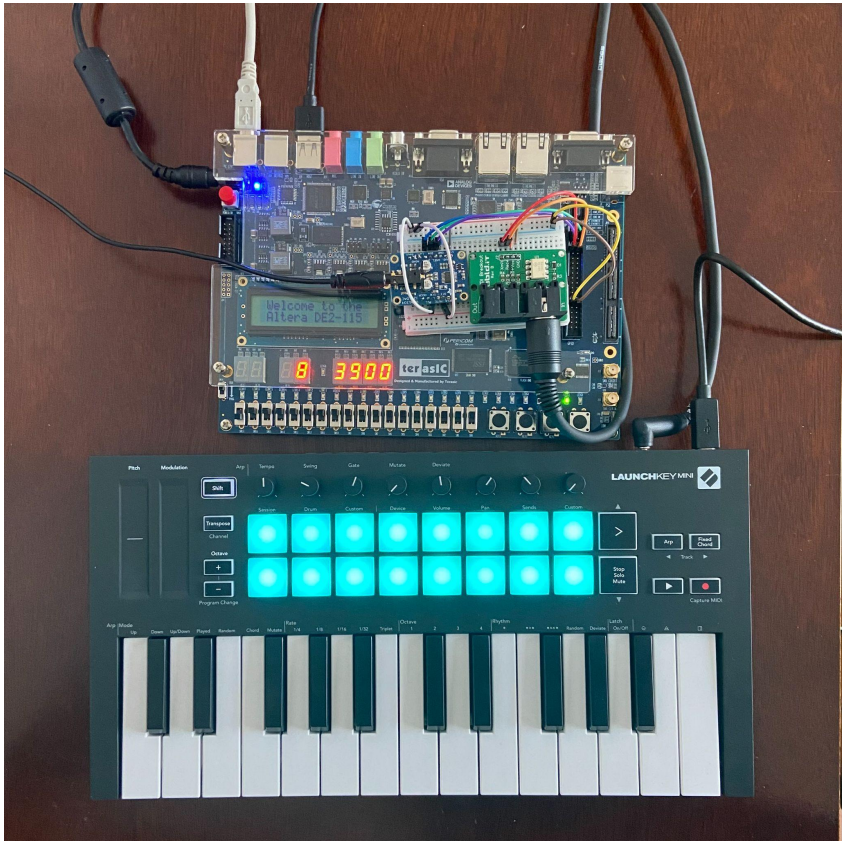
conFFTi - FPGA music synthesizer

Team D8 - Michelle Chang, Hongrun Zhou, Jiuling Zhou

Application Area

- Accepts real-time input from a MIDI keyboard
- Easy user control over sound generation and mixing on FPGA
  - Sine, Pulse, Triangle
    - **Pulse Width Modulation**
  - ADSR Envelope
  - Unison Detune
- Effects that aid music composition
  - **Record and cycle**
    - Up to 4 notes
    - Variable spacing between notes
  - Arpeggiator (implemented by keyboard)
    - Fixed spacing between notes

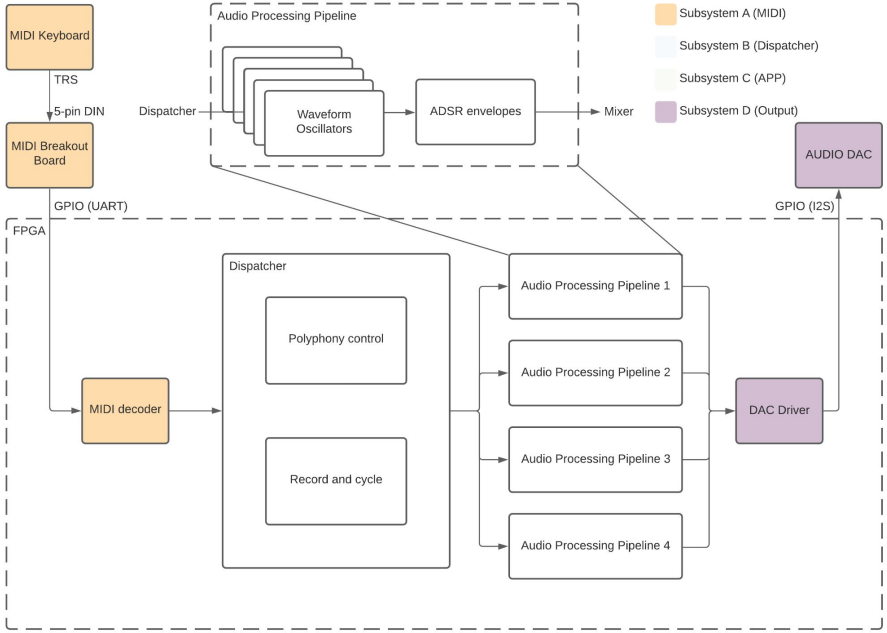


Solution Approach

- DE2-115 Cyclone IV FPGA
  - Large number of logic elements and RAM
- Launchkey Novation MINI MkIII
  - Intuitive knobs and pads
  - MIDI output
- ubld.it MIDI breakout board
  - Converts 5-pin MIDI signal to single pin MIDI bitstream at 3.3V
- UDA1334 I2S DAC
  - 44.1kHz, 24 bit, 2-channel output
  - Converts I2S signal to audio through an standard 3.5mm audio socket

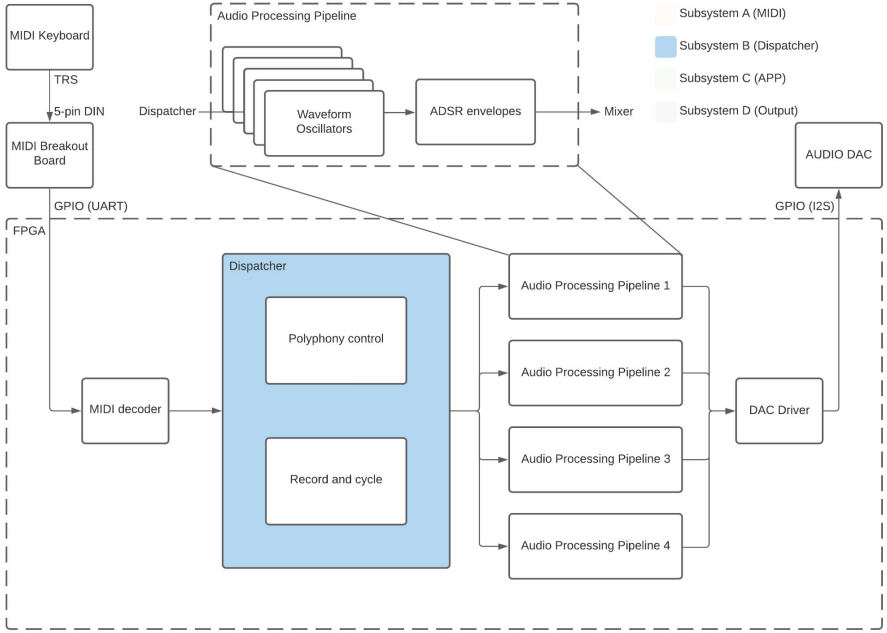
Complete Solution - Device I/O

- FPGA Interface: GPIO
- Input:
  - Deserialize UART 8+2 signals into bytes
  - Decode byte sequence into MIDI message
- Output:
  - Mixer averages the audios from all pipelines
  - Sample audio at 44.1kHz
  - Serialize audio into I2S format



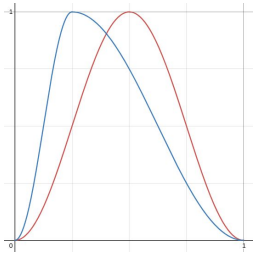
Complete Solution - Dispatcher

- Polyphony
  - Keeps track of the occupancy status of each pipeline
  - Upon receiving NOTE ON message, find an empty pipeline for it
- Record and cycle
  - Records the length of notes and number of ticks in between
  - Send the notes to a pipeline with the same length and ticks in between

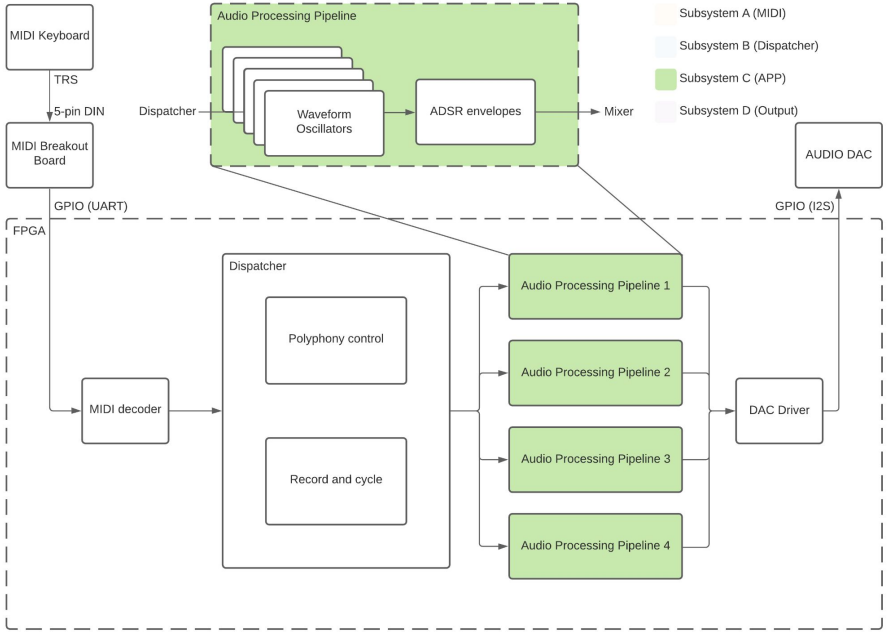


Complete Solution - Pipeline

- Sound Generation
  - 1 main oscillator
  - Configurable “duty cycle” with all waveforms



  - Division: convert divisor to reciprocal, then multiply
- Unison Detune
  - 4 auxiliary oscillators
- ADSR
  - multiplicative envelopes



Metrics

Item	Testing Method	Requirement	Result	Pass?
Correctness	Unit Testbench	Pass ModelSim simulation tests	Passed	Y
Latency (including DAC)	Oscilloscope	10ms	3.30 ms (Fig.A)	Y
Latency (except DAC)	Oscilloscope	1ms	940 us (Fig.B)	Y
Frequency deviation	Oscilloscope	< 10 cent for all octaves	Lower octaves have less distortion and higher octaves have more (Table.A)	< C6 Y; >= C6 N
Signal shape distortion	Compare data points in simulation results to Matlab plots	Average deviation taken from data points is < 5%	Passed for all three waveforms (Fig.C, Table.B)	Y

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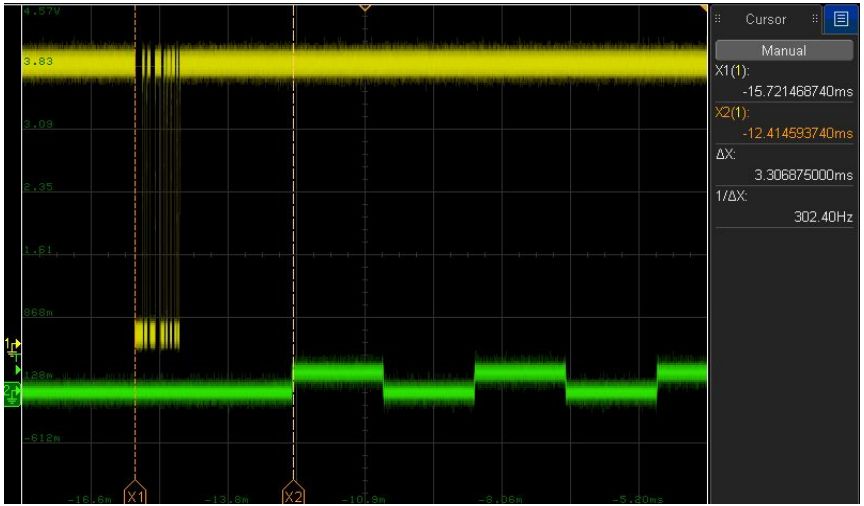

Fig.A. latency from MIDI interface to DAC **output** is 3.31ms

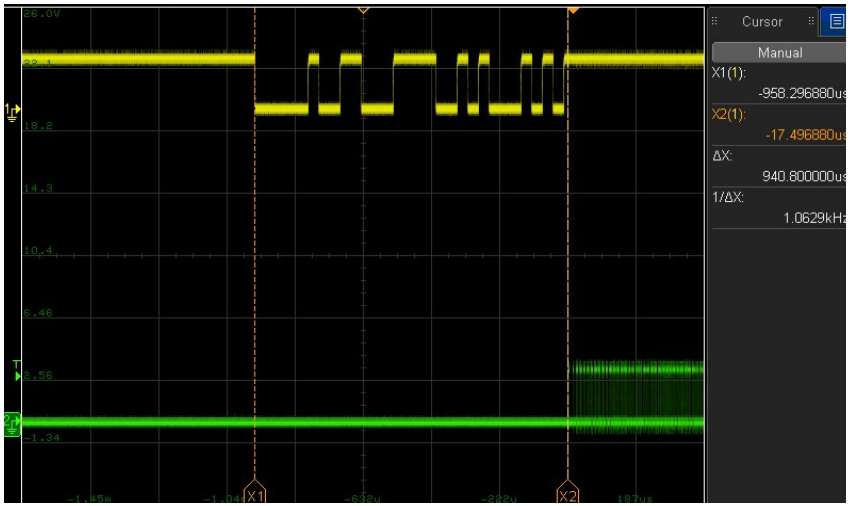

Fig.B. latency from MIDI interface to DAC **input** is 940us

Metrics - Frequency distortion

Frequency deviation	Oscilloscope	< 10 cent for all octaves	Lower octaves have less distortion and higher octaves have more (table.A)	< C6 Y; >= C6 N

$$¢ = 1200 \frac{\ln\left[\frac{f_2}{f_1}\right]}{\ln 2}$$

Note	C0	C1	C2	C3	C4	C5	C6	C7	C8
wavelength (us)	60935	30625	15300	7631	3843	1903	962	469	232
frequency (Hz)	16.41	32.65	95.36	131.04	260.16	525.37	1039.00	2129.10	4309.80
target frequency (Hz)	16.35	32.70	95.41	130.81	261.63	523.25	1046.50	2093.00	4186.01
deviation (cents)	-6.34	2.65	0.91	-3.04	9.75	-7.00	12.45	-29.61	-50.45

Table.A. frequency deviation in cents (humans can distinguish as little as 5 cents of pitch difference)

Metrics - Shape distortion

Signal shape distortion	Compare data points in simulation results to Matlab plots	Average deviation < 5%	Passed for all three waveforms (Fig.C, Table.B)	Y

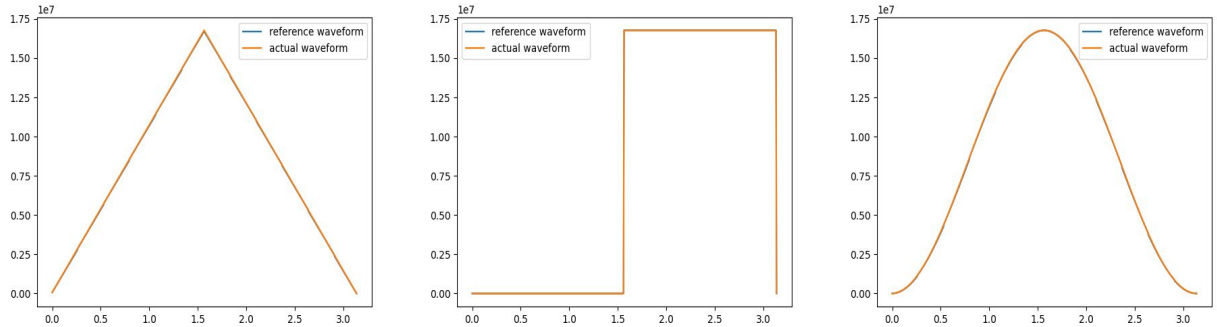

Fig.C. comparison of actual waveform (period = 500 data points) to reference waveform generated by software

period (#data points)	50	500	5000
sin	0.20%	0.20%	0.42%
triangle	0.20%	0.20%	0.43%
square	0%	0%	0%

Table.B. deviation calculated in percentage of waveforms of different types and different period lengths

Trade-offs

- GPIO + DAC vs. FPGA CODEC
  - Pro: Easier to synthesize on another FPGA without using the CODEC on FPGA
  - Con: More circuit components
- GPIO + MIDI Breakout board vs. FPGA USB
  - Pro: Easier to synthesize on another FPGA without using the USB on FPGA
  - Con: More circuit components

Project Management and Division of Labor