UNIVERSITY OF WISCONSIN–MADISON

End-to-End Stochastic Computing

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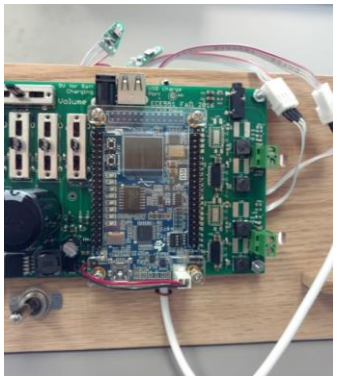


Executive Summary

- In systems with sigma-delta modulated sensors, increase performance by operating directly on data instead of converting (End-to-end)
- Stochastic computing has advantages in end-to-end systems while it has challenges that prevent it from being used in other applications
- We implement a prototype audio mixer system

Background

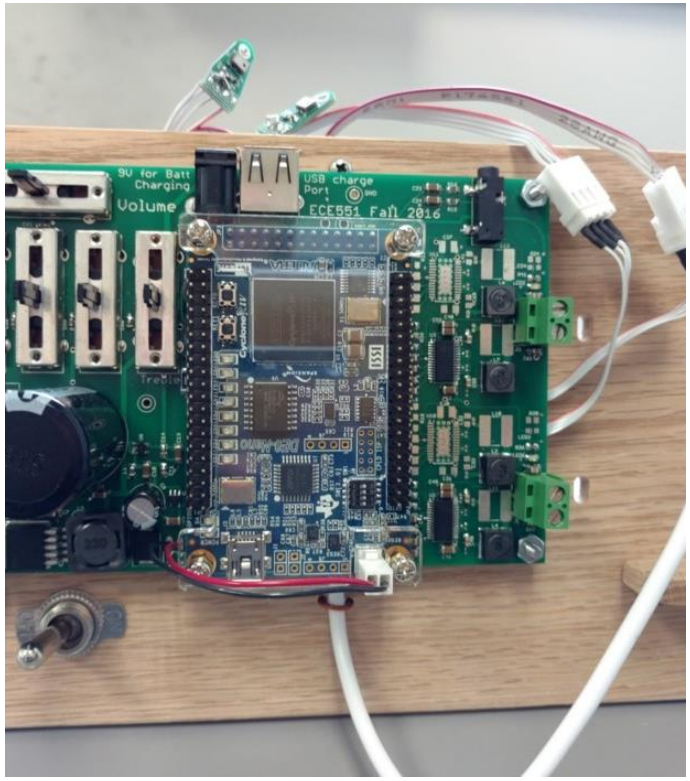
- Stochastic representation
    - Represent the number, n, you are trying to send by sending a 1 with probability n for a set bit stream
    - 0011011001 would be a representation of 5
- Probabilistic Calculus introduced in 1960s by Von Neumann
    - Trivial implementation of multiplication using AND gates
    - Bernstein polynomials – any finite interval function that maps to another finite interval
    - Can implement the polynomials with a series of adders and multiplexers

Advantages of Stochastic Computing

- Error Tolerant
    - Soft errors (bit flips) are tolerated well, no bit is more important than another
- Smaller circuit size
    - Simple logic makes the gate cost low
- Shorter critical paths
    - Simpler logic allows higher clock frequencies

Traditional Challenges

- Representation costs in terms of bits due to precision requirements
- Generating the stochastic numbers has high energy costs
- Possible increases in length of computation due to length of bit stream, gate invocations are higher
- Function mapping errors because the Bernstein Polynomial is an approximation



Implementation

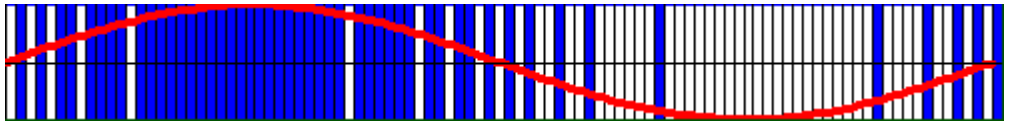
Audio system using pulse-density modulated representation.

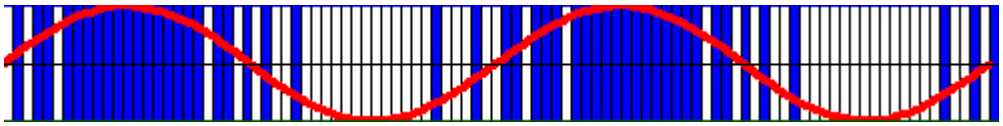
Altera Cyclone IV FPGA

Pulse Density Modulated (PDM) Signals

Sample PDM encoded sine waves.

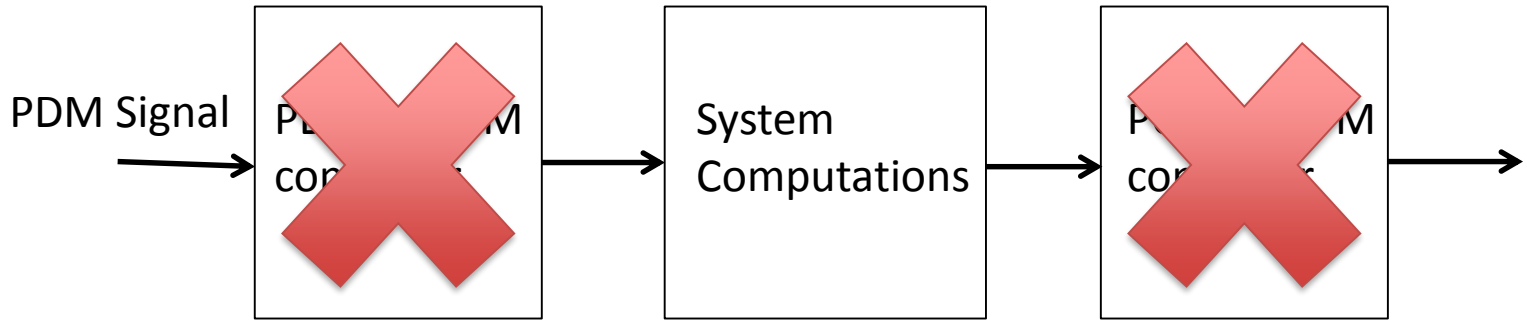
Blue represents a 1 while the white represents a 0.



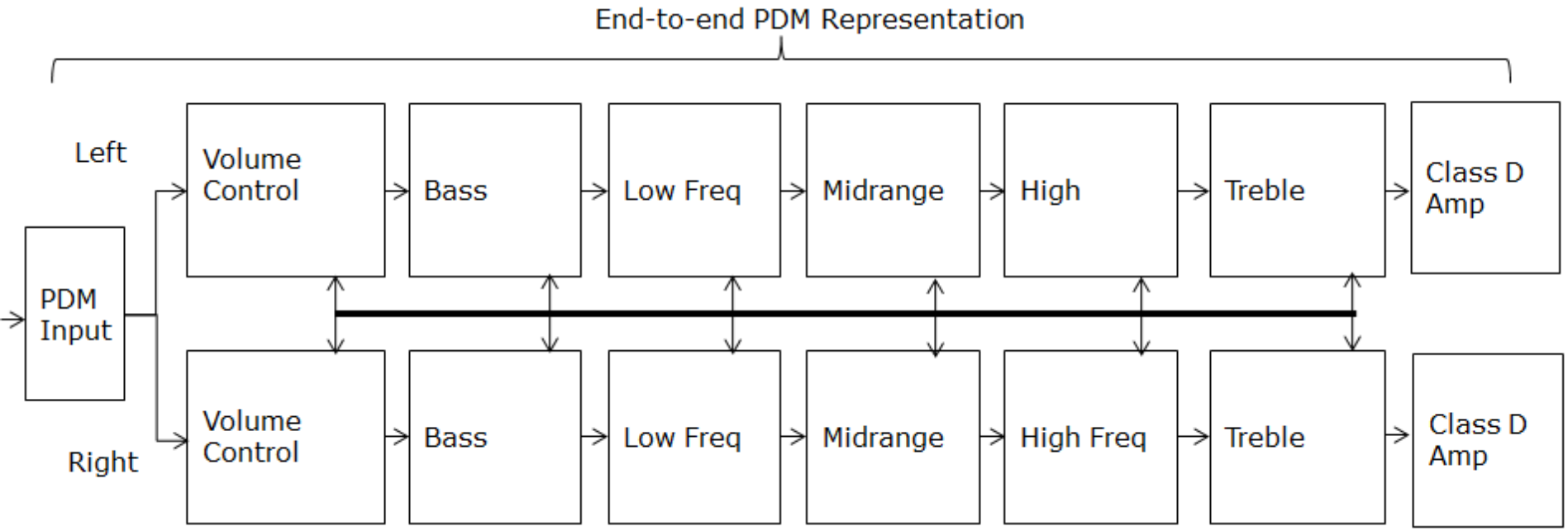


Images from https://en.wikipedia.org/wiki/File:Pulse-density_modulation_1_period.gif
https://en.wikipedia.org/wiki/File:Pulse-density_modulation_2_periods.gif

Traditional Implementation Block Diagram



PDM Block Diagram



Prototype’s Advantages

- Does not have any conversion costs
- Simplified datapath
- More energy efficient (estimated)

Evaluation

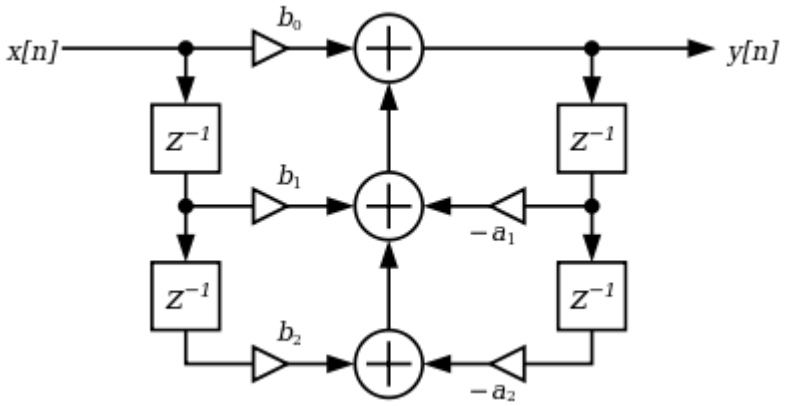
Synthesized PDM design on board and also created a pulse-code modulated (PCM) based design that is synthesizable on the same board.

PCM Model

- Downsample signal from 3 MHz to 24 KHz
- Filtering is performed on the PCM data
- Converts back to PDM through sigma-delta modulation

Evaluation

- PDM to PCM conversion – Cascaded integrator-comb
- Biquad filters – PDM integrates and delays through RAM for 128 steps, PCM keeps conventional implementation
- PCM to PDM conversion – 128x interpolation with 3stage filter cascade of 3rd order CIC to a second order sigma-delta modulator

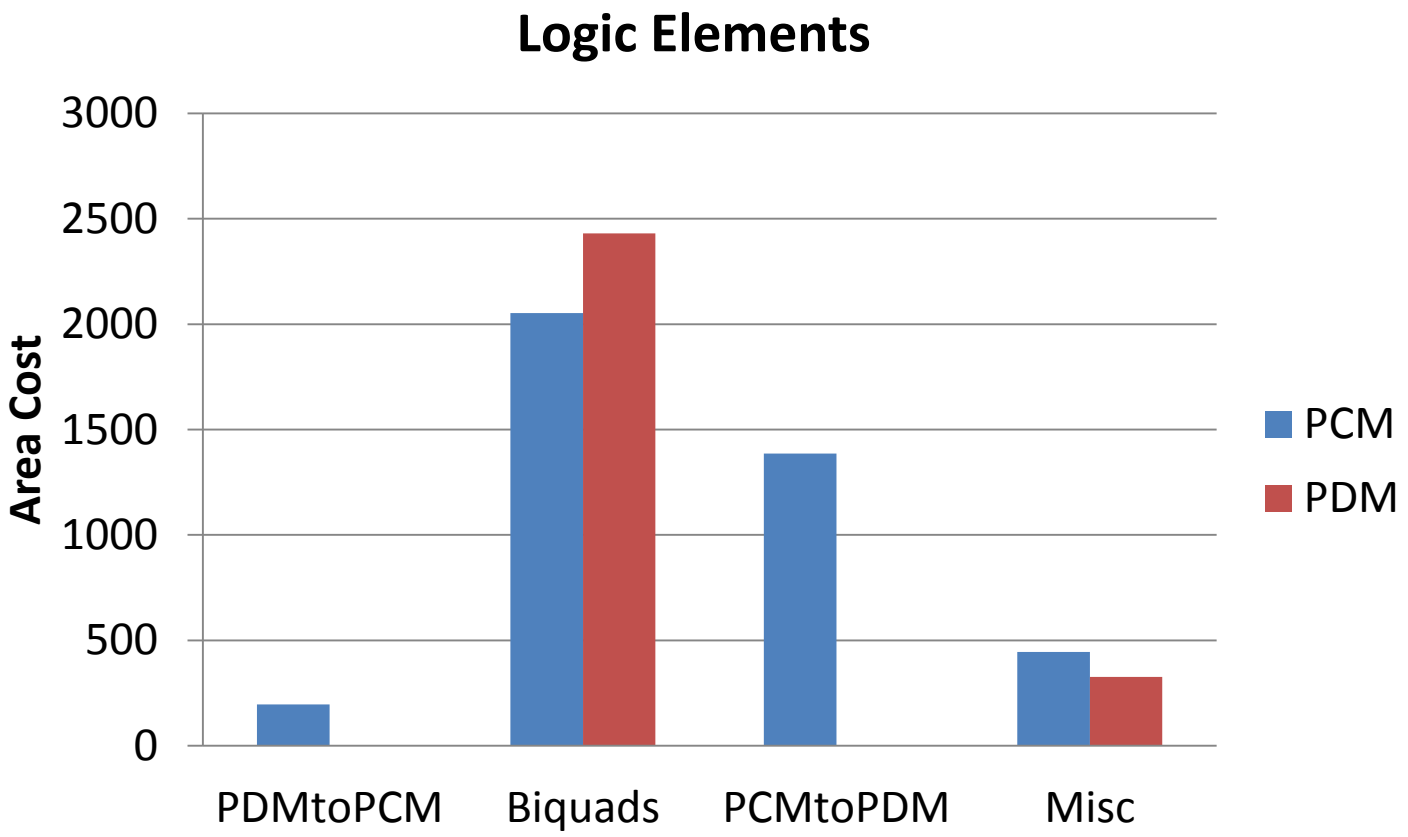


Biquad Filter

- In the PDM implementation, there is a 128 bit buffer in the filter to match the sampling rate

Image from: https://en.wikipedia.org/wiki/File:Biquad_filter_DF-I.svg

Area Comparison



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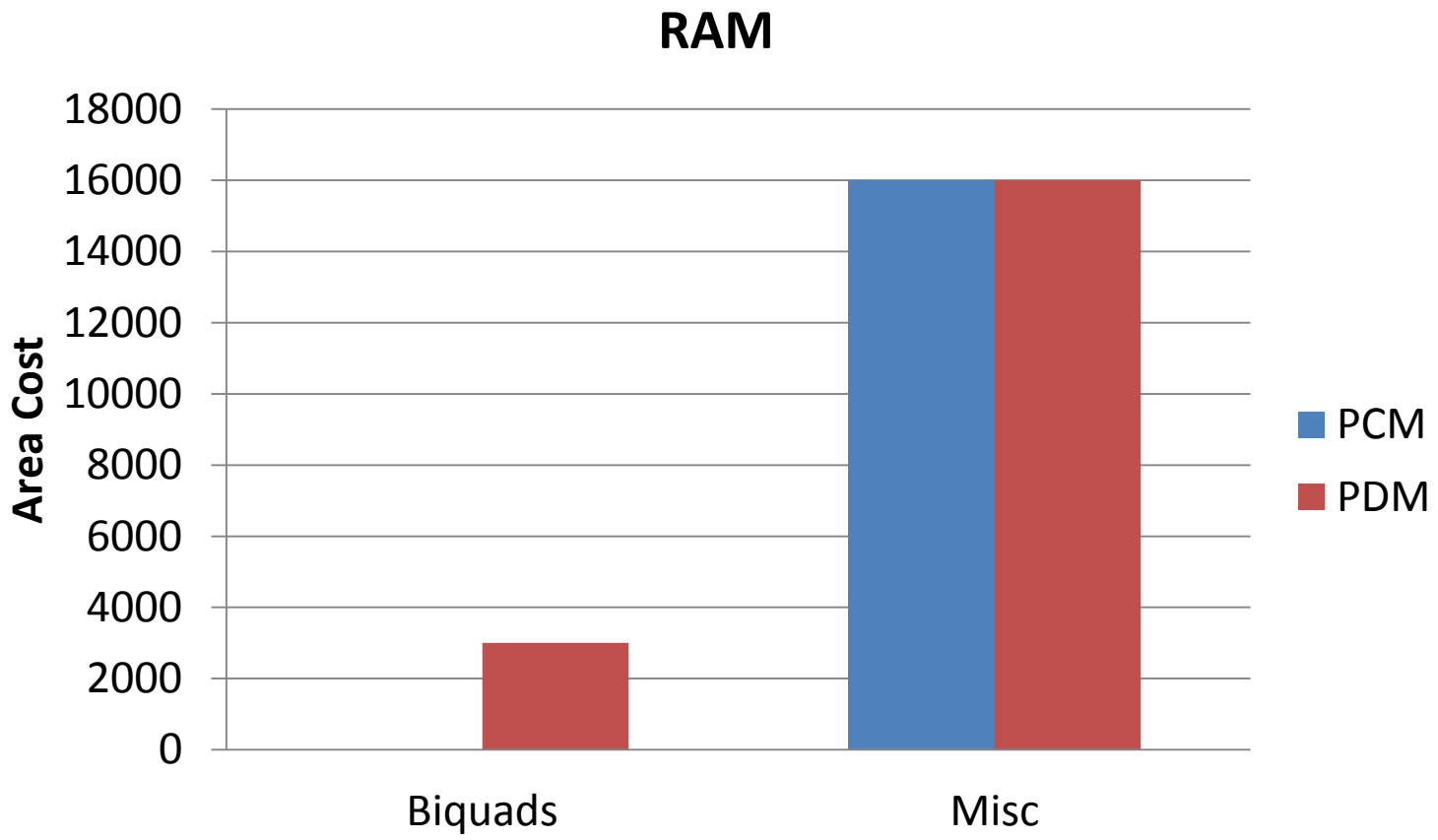

Conclusion

Stochastic computing can work well for single-bit stream inputs and outputs

There are two other prototypes in our lab that this would make sense in practice:

- Drone with an onboard homing program
- Robotic arm using visual input to calculate kinematics equations

Acknowledgements

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Questions?

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