2020 Research Day

Neural Network Analog-to-Digital & Digital-to-Analog Converters using Floating-Gate Memristors

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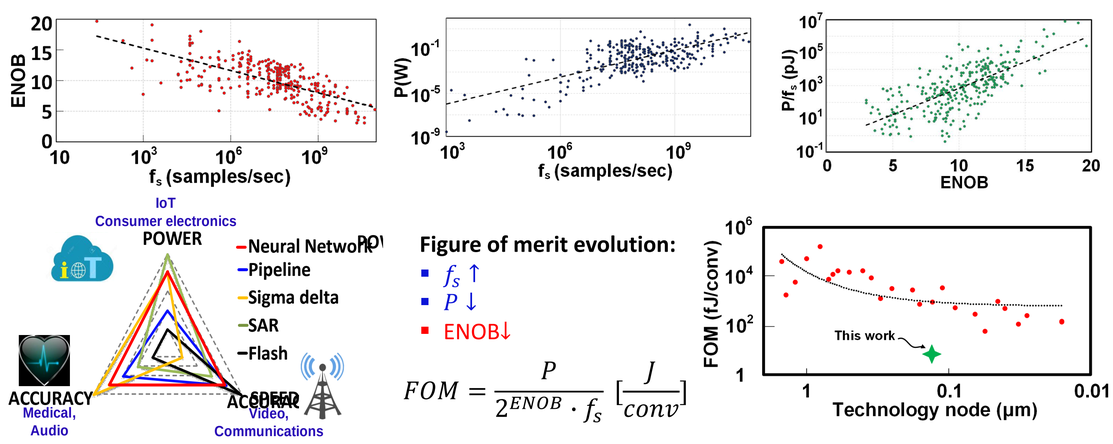
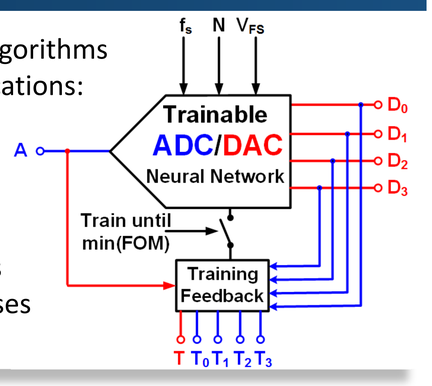
CMOS Data Converters Are Special Purpose Applications due to The Speed-Power-Accuracy Tradeoff

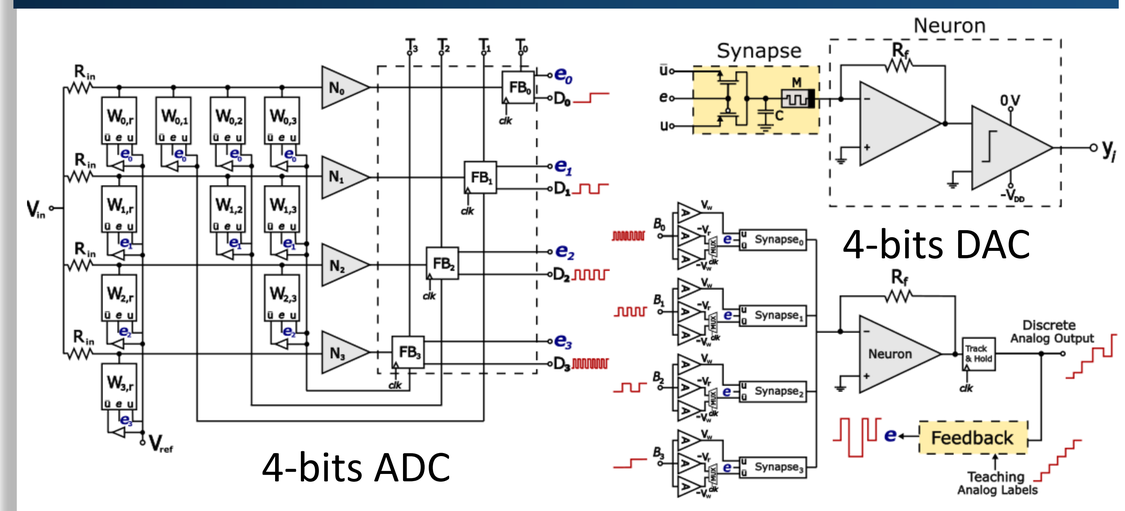


Solution: Real-Time Trainable Data Converters using Memristors[1]

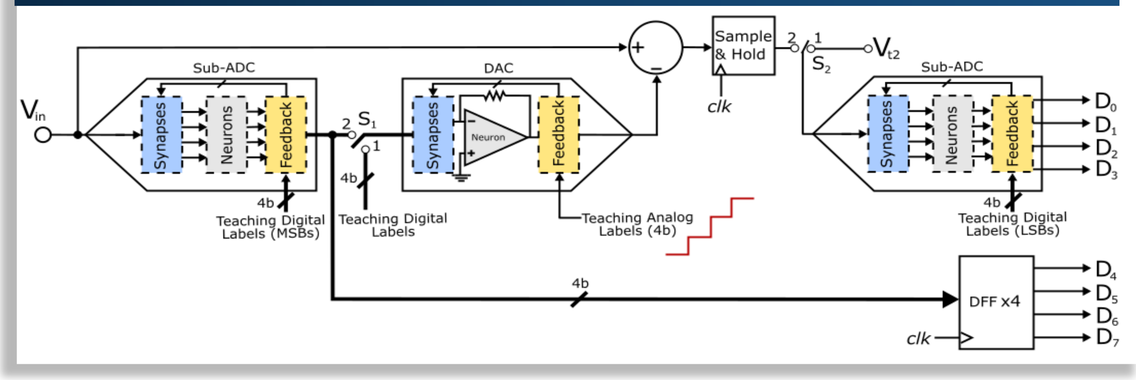
- Trainable data converters using supervised learning algorithms
- Data converter architecture for general purpose applications:
  - -Full-scale voltages V_{FS}
  - -Number of bits N
  - -Sampling frequencies f_s
  - -Logarithmic quantization
- Implemented as artificial neural network architectures
- Multi-level memristive devices used as artificial synapses



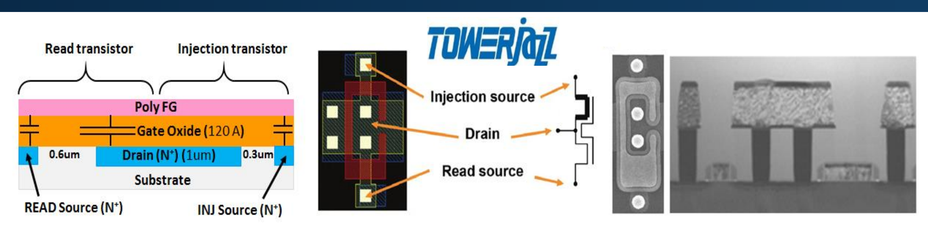
Neural Network ADC [2] & DAC [3]

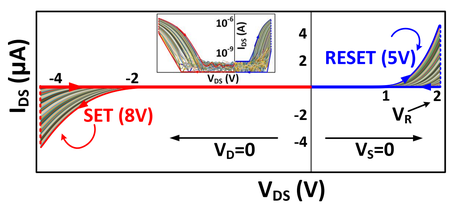


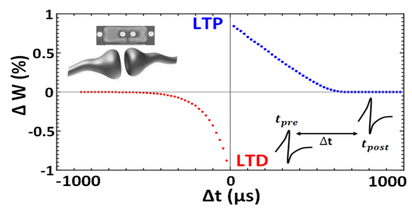
Pipelined Neural Network ADC for High-Resolution [4]

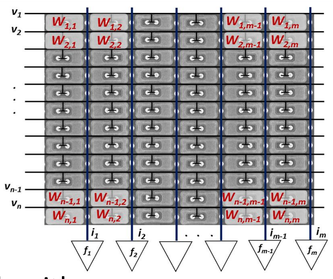


Methods: A Two-Terminal Floating-Gate Memristive Device for Analogue Neuromorphic Computing[5-6]





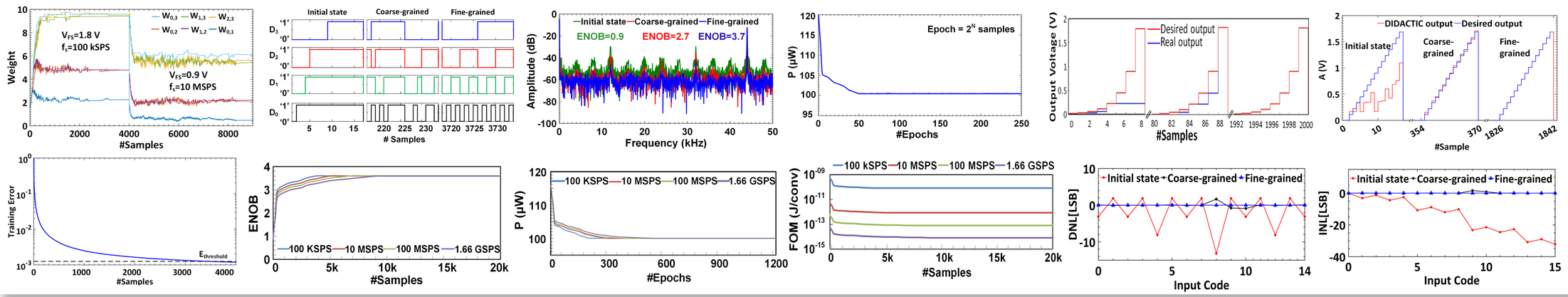




1. Experimental demonstration of trainable multiply-accumulate using:
   - i. A selector-free integrated array of two-terminal floating-gate memristive devices
   - ii. Sub-threshold mode operation, and gradual tuning (65 resistive levels)
   - iii. Standard 180nm CMOS process, ten-year data retention, and 100K endurance cycles

2. SPICE and software simulations:
   - i. Neuron activations and learning algorithms
   - ii. Model for floating-gate memristive device
   - iii. CAD framework: DRC, LVS, RC extraction

Preliminary Results: Breaking Through the Speed-Power-Accuracy Tradeoff



Conclusions and Ongoing Work

1. We propose neural network data converters:
   - i. Trained using machine learning algorithms
   - ii. Demonstrated using floating-gate memristive devices in standard 180nm CMOS
2. These results show a potential to:
   - i. break through the speed-power-accuracy tradeoff in conventional data converters
   - ii. enable a generic architecture for general purpose applications

3. Ongoing work investigates fabrication of large-scale data conversion architectures using deep neural networks and mixed-signal circuits [4][7-8]

Publications and Acknowledgements

[1] L. **Danial**, & S. Kvatinsky, "Real-Time Trainable Data Converters for General Purpose Applications," *NANOARCH,* 2018.
[2] L. **Danial** *et al.*, "Breaking Through the Speed-Power-Accuracy Tradeoff in ADCs Using a Memristive Neuromorphic Architecture," TETCI, 2018.
[3] L. **Danial** *et al.*, "DIDACTIC: A Data-Intelligent Digital-to-Analog Converter with a Trainable Integrated Circuit Using Memristors," *JETCAS,* 2018.
[4] L. **Danial** *et al.*, "A Pipelined Memristive Neural Network Analog-to-Digital Converter," *ISCAS,* 2020.
[5] L. **Danial** *et al.*, "A Low-Power Memristive Operation Mode of Two-Terminal Floating-Gate Transistors for Analogue Neuromorphic Computing," *Nature Elect.*, 2019.
[6] L. **Danial** *et al.*, "Modeling a Floating-Gate Memristive Device for Computer-Aided Design of Neuromorphic Computing," *DATE,* 2020.
[7] L. **Danial** *et al.*, "Delta-sigma modulation neurons for high-precision training of memristive synapses in deep neural networks," *ISCAS*, 2019.
[8] L. **Danial** *et al.*, "Logarithmic Neural Network Data Converters Using Memristors for Biomedical Applications," *BioCAS,* 2019.
*This work is done in collaboration with TowerJazz