



Neuromorphic Computing in CMOS: Digital, Analog or Mixed-Signal ?

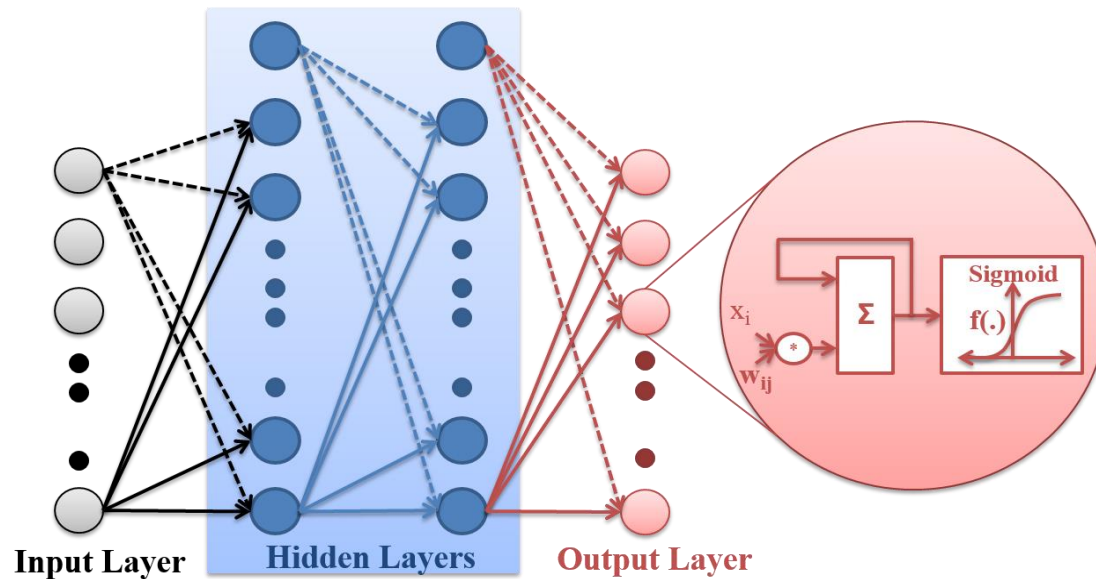
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Kaushik Roy
ECE, Purdue University

Sep 27, 2016

Neuromorphic – Fundamental Question

Neuron Architecture

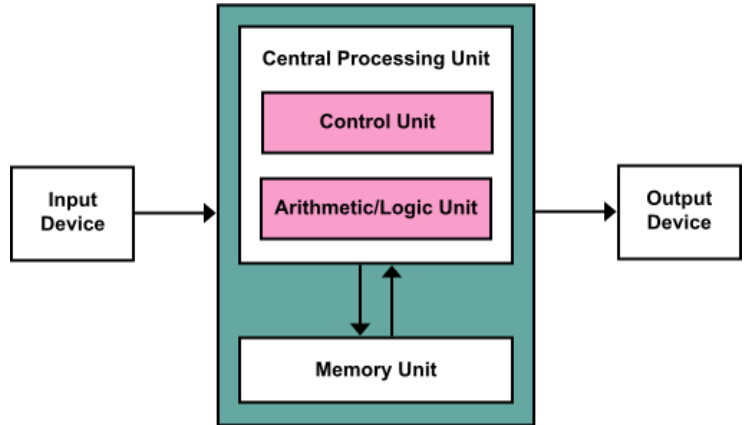
Error-Resiliency → Energy-efficiency



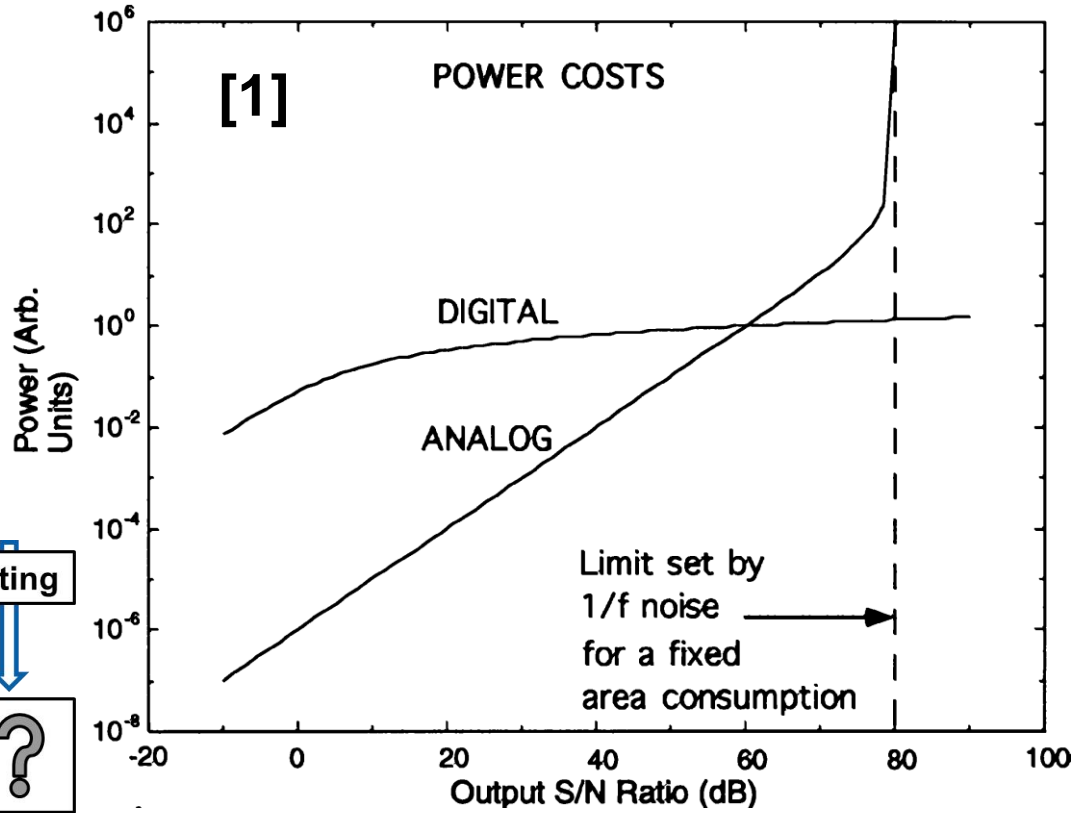
- Digital, Analog or Mixed-Signal?
- Approximate Neurons ?
- Noisy Neurons ?

Digital vs. Analog

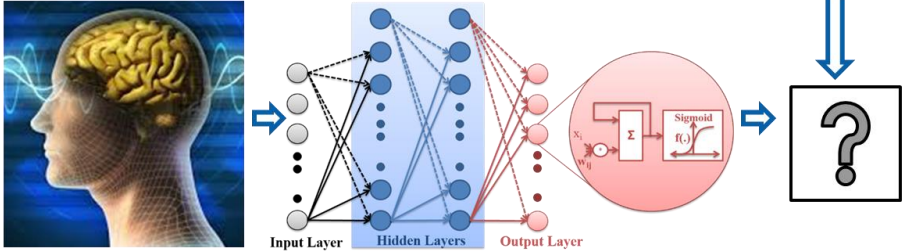
Von-Neumann Computing



Digital vs. Analog

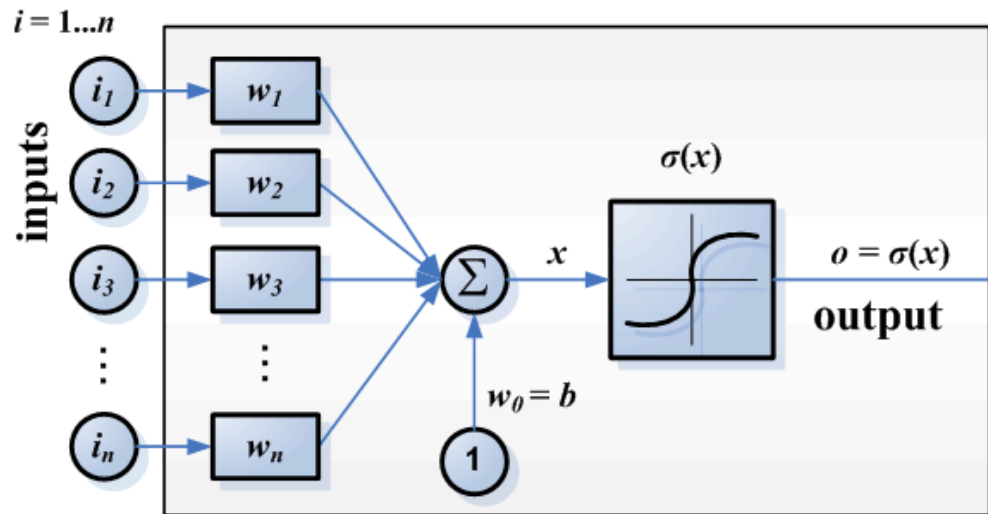


Brain-Inspired Error-Resilient Neuromorphic Computing



[1] Sarpeshkar, Rahul. "Analog versus digital: extrapolating from electronics to neurobiology." *Neural computation* 10.7 (1998): 1601-1638.

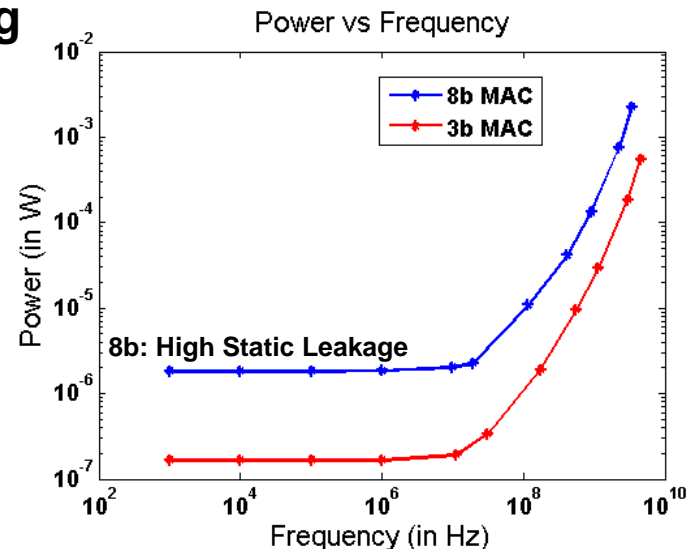
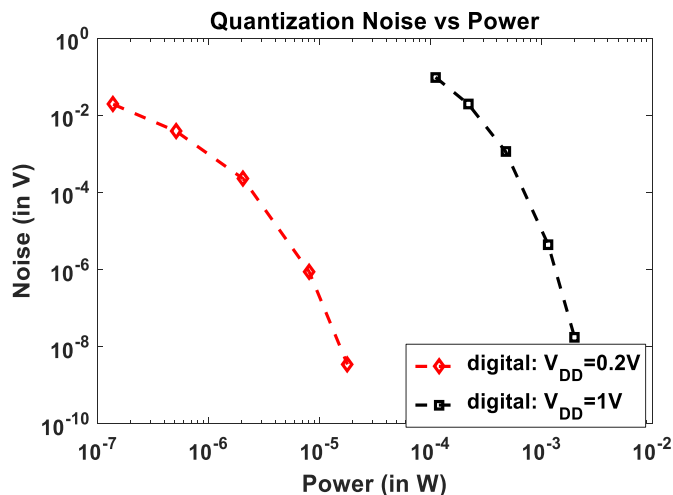
Neuron Architecture - Digital



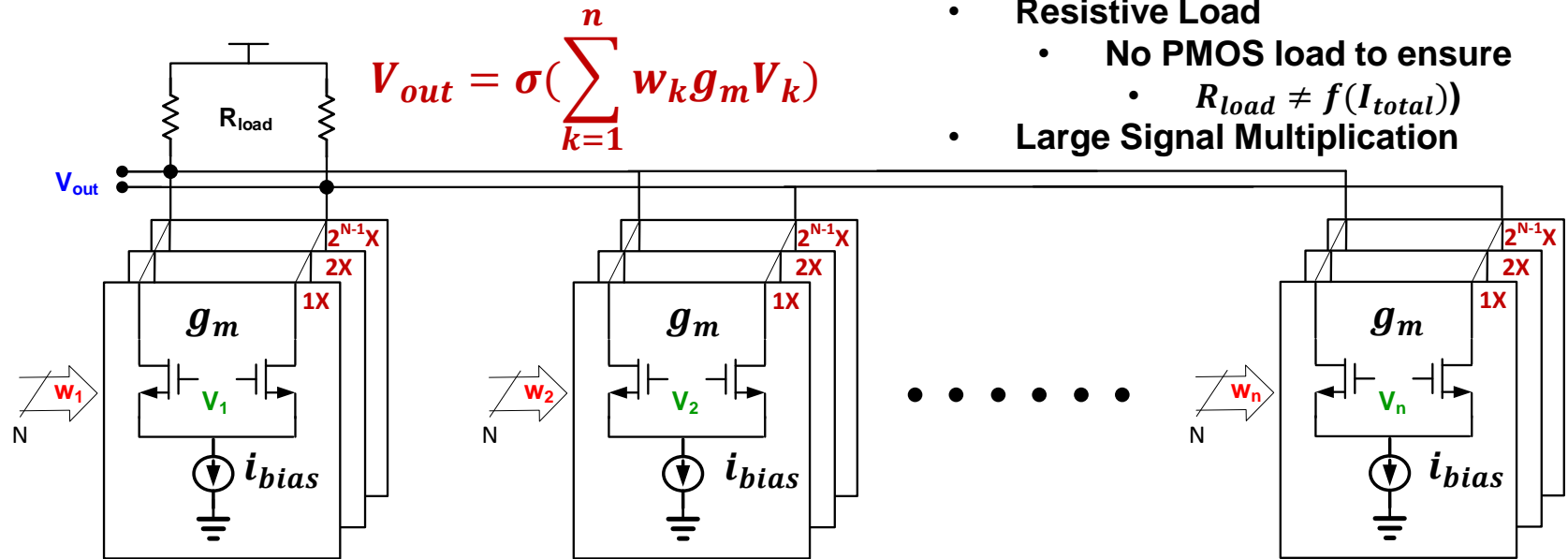
**Digital MAC (n=2)
Transistor Count**

b	MOSFETs
2	214
4	998
8	4422
16	18162
24	40858

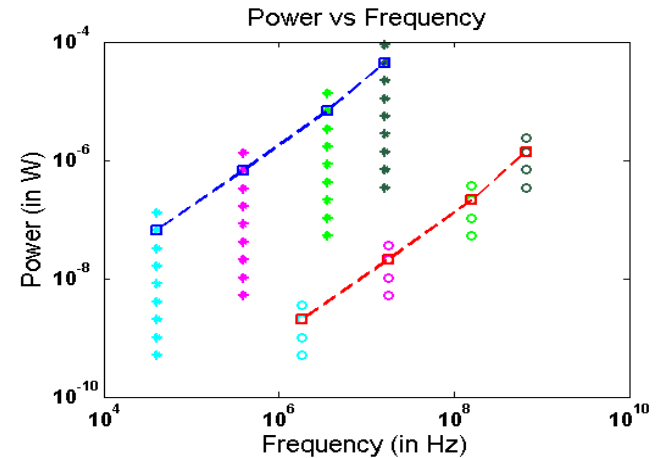
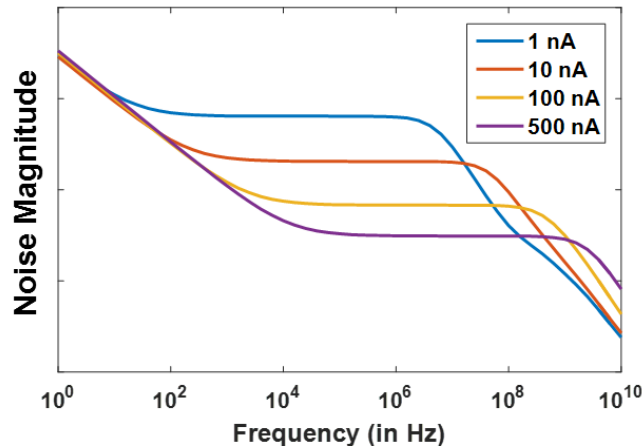
Multiplier Adder Thresholding



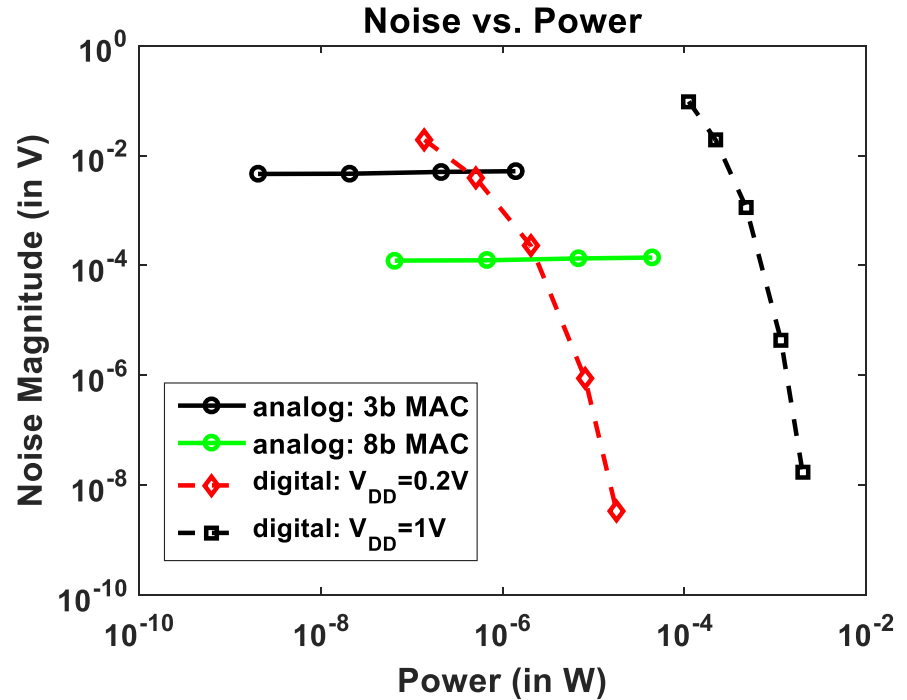
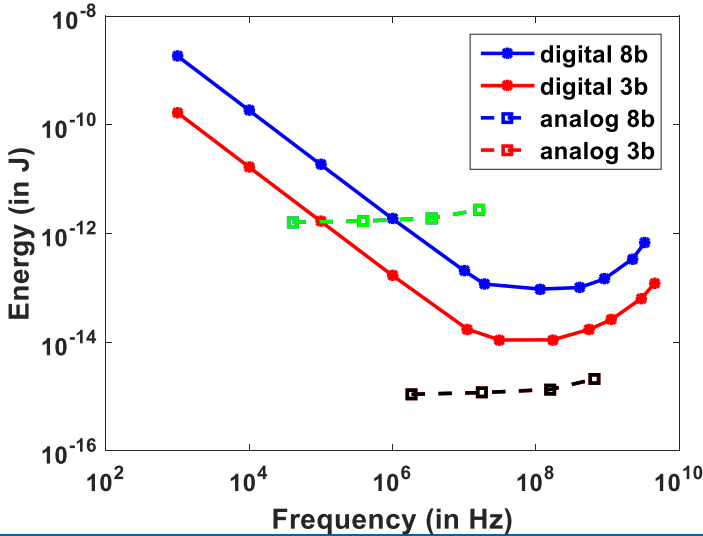
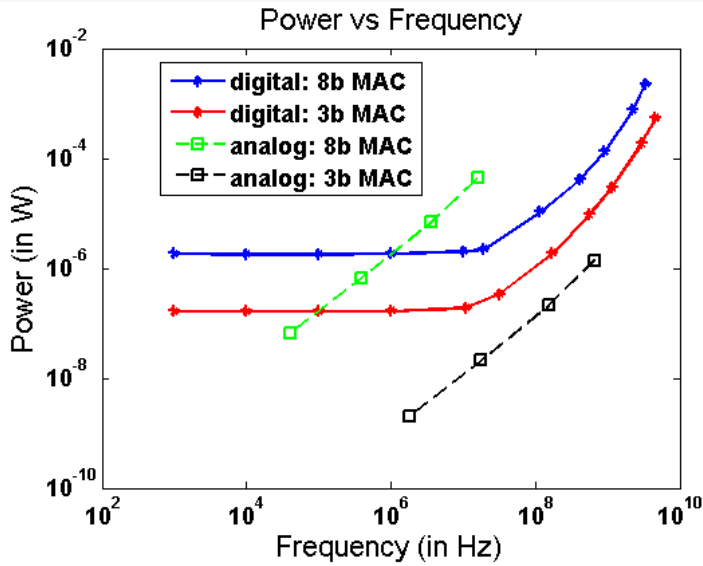
Neuron Architecture – Mixed-Signal



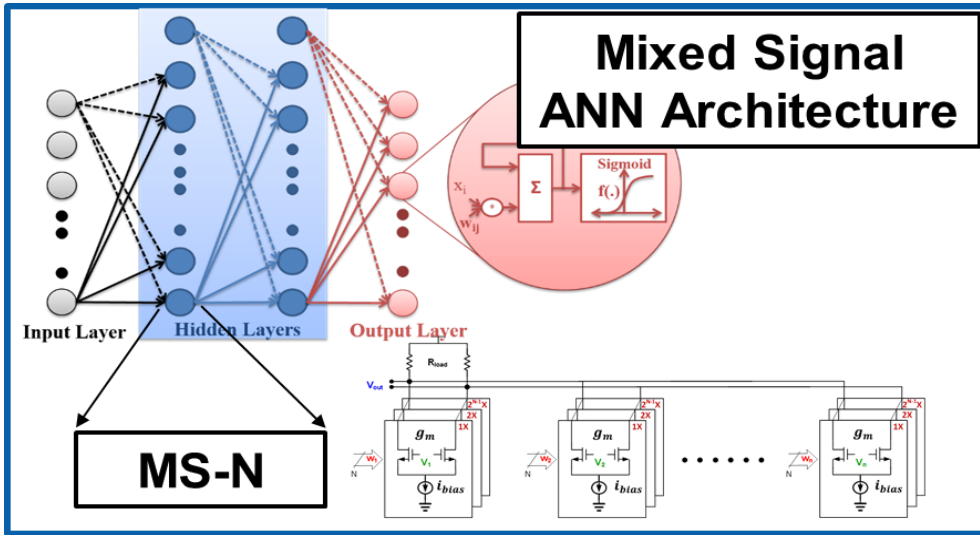
- Resistive Load
 - No PMOS load to ensure
 - $R_{load} \neq f(I_{total})$
- Large Signal Multiplication



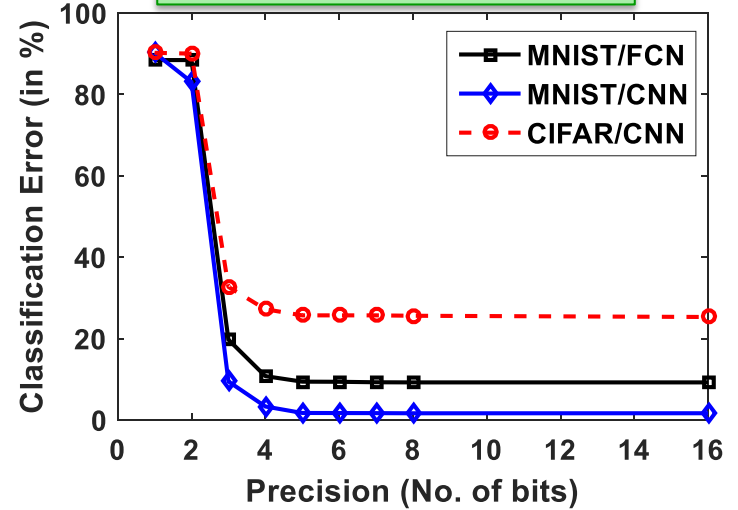
Comparison: Dig-N vs. MS-N



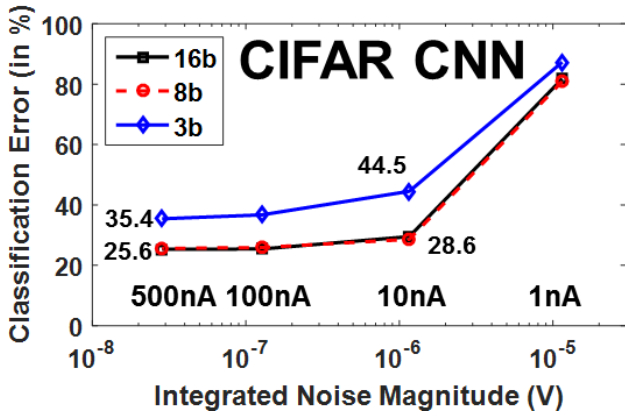
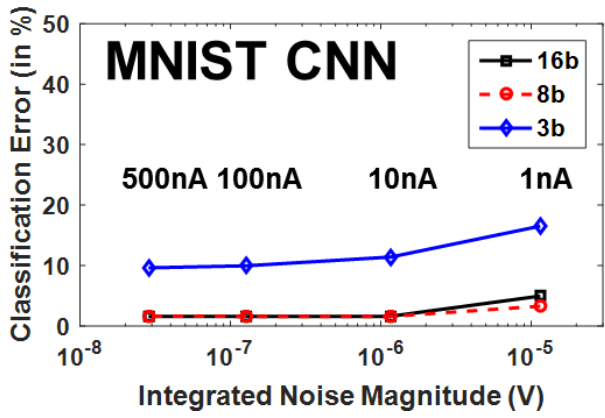
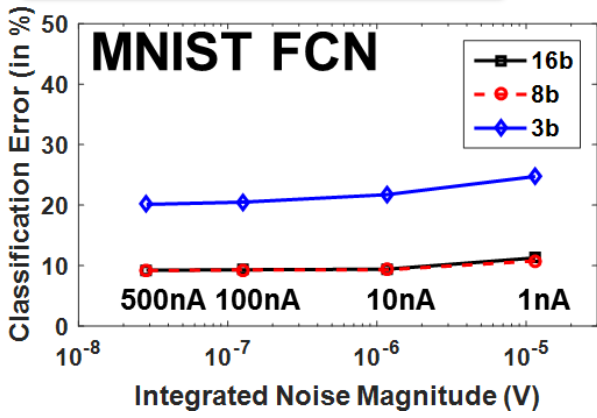
Error Resiliency vs. MS-N Noise



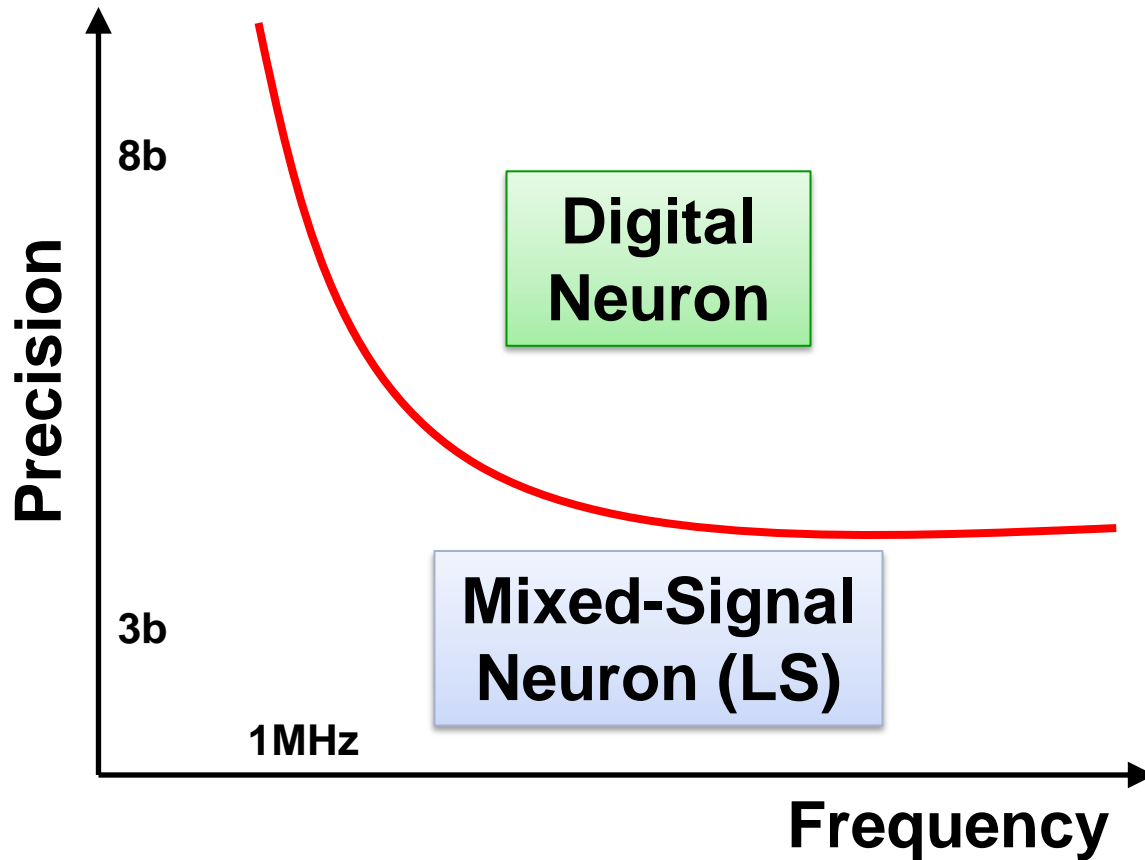
Quantization Noise



Thermal Noise



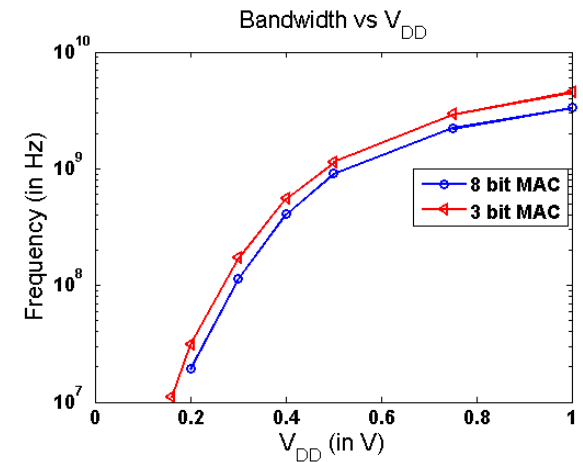
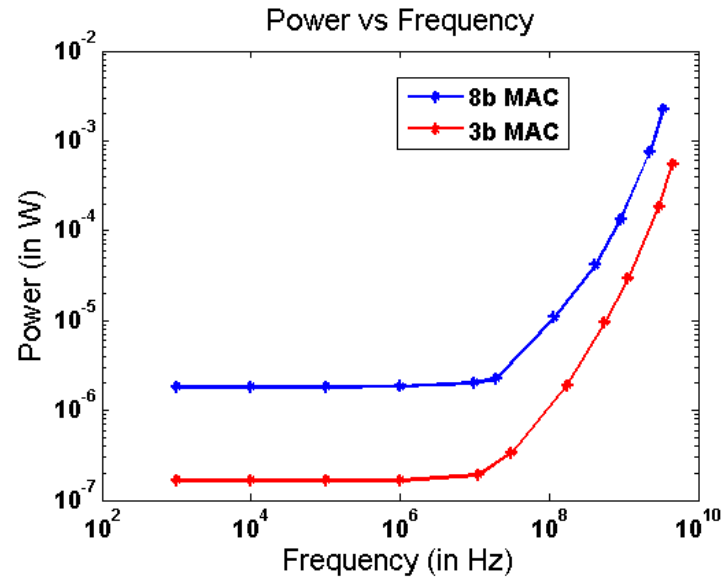
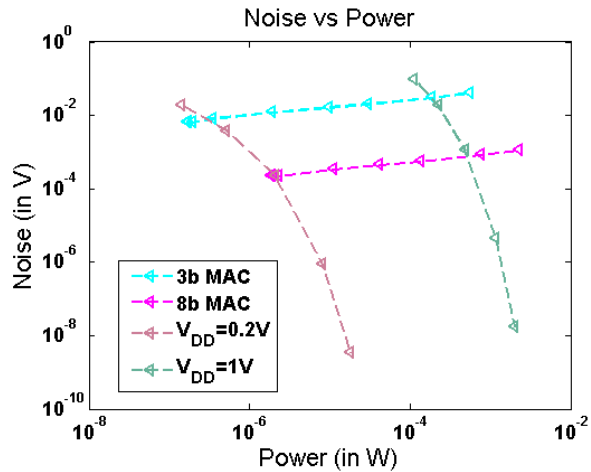
Conclusion



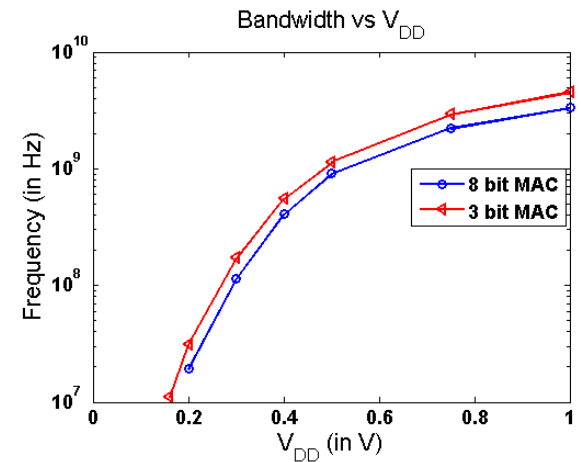
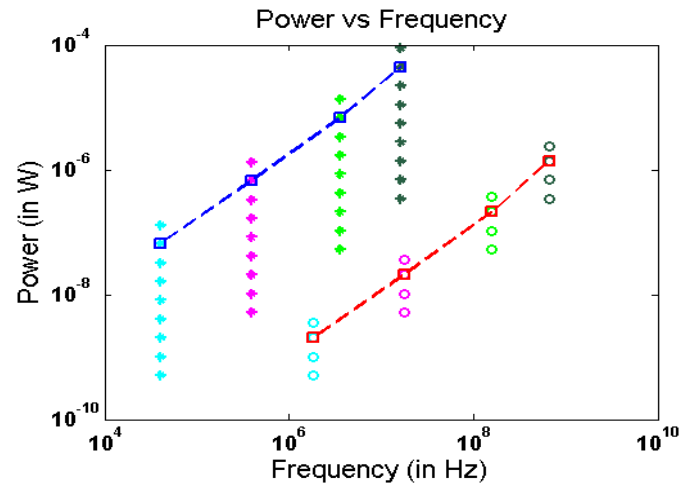
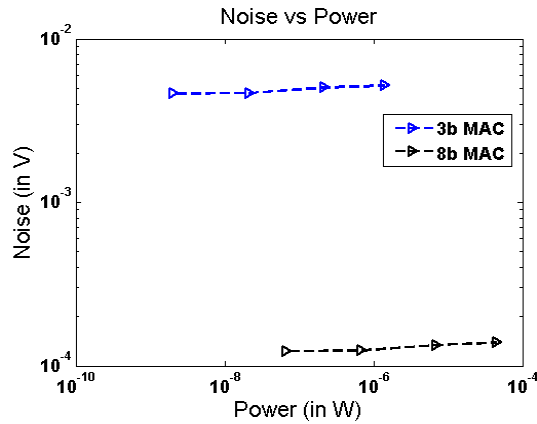


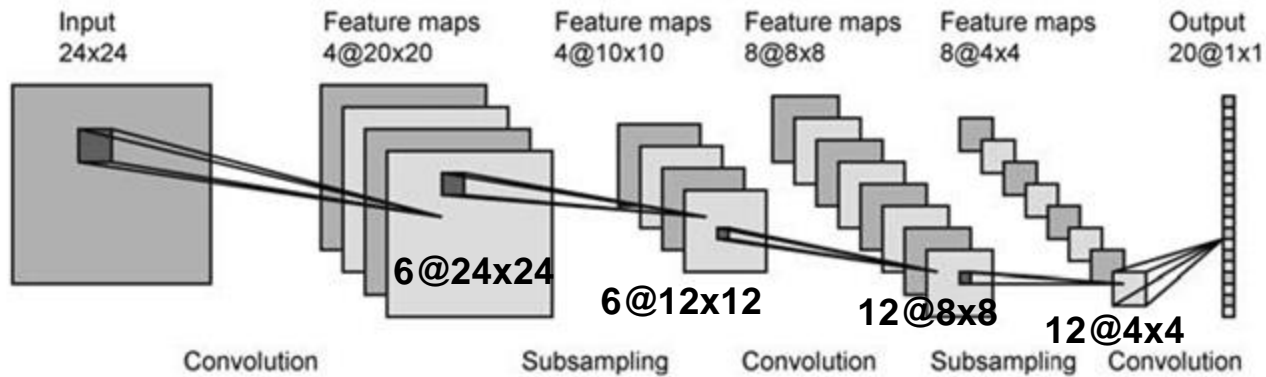
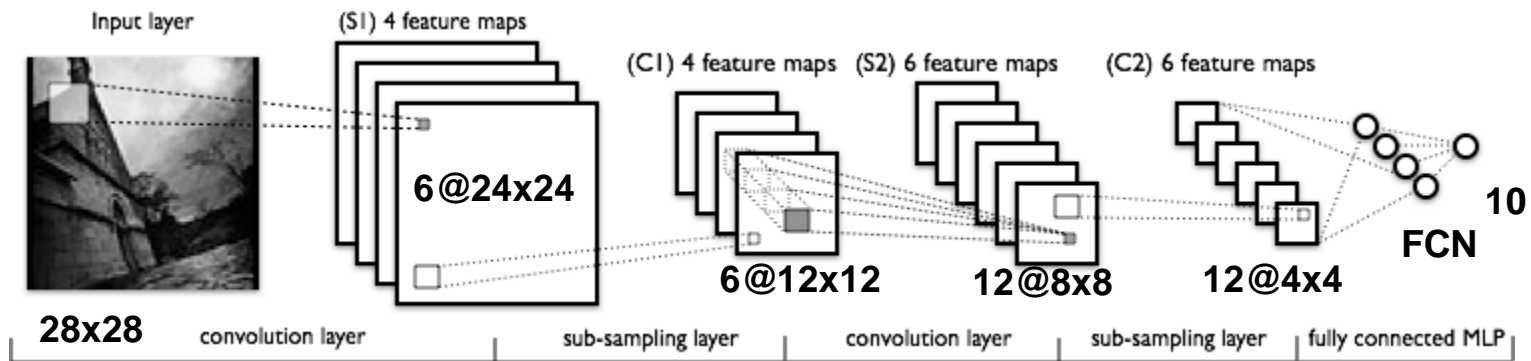
THANK YOU

Dig-N: Noise and BW vs. Power



Dig-N: Noise and BW vs. Power

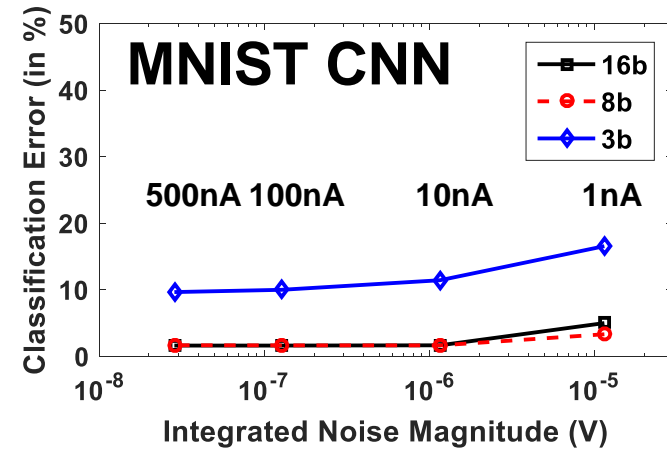
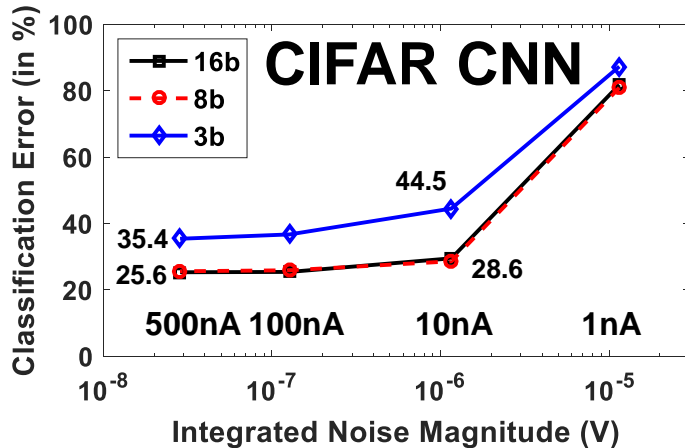
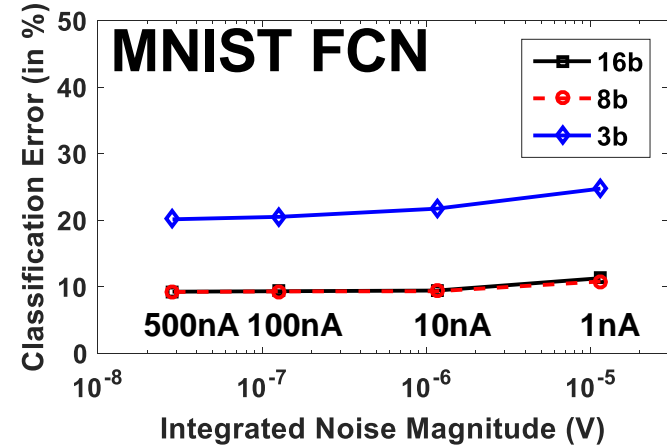
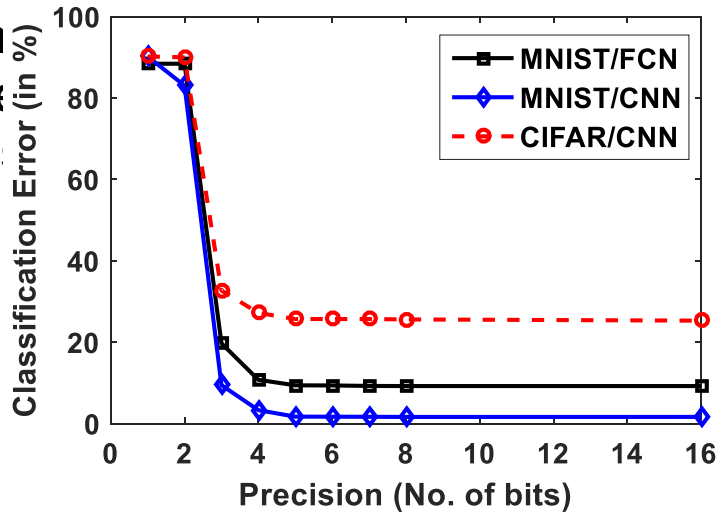




28x28

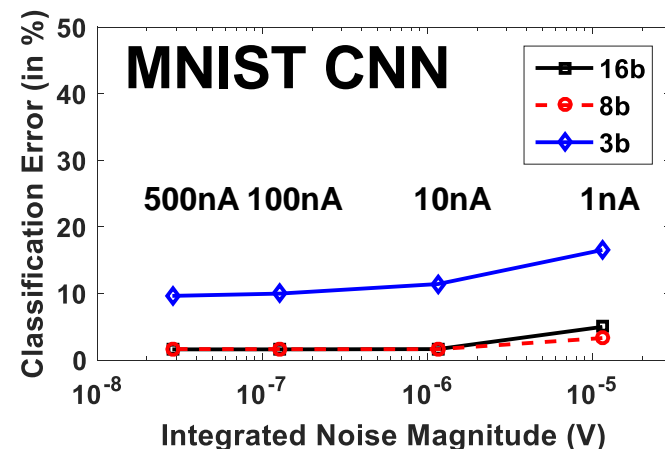
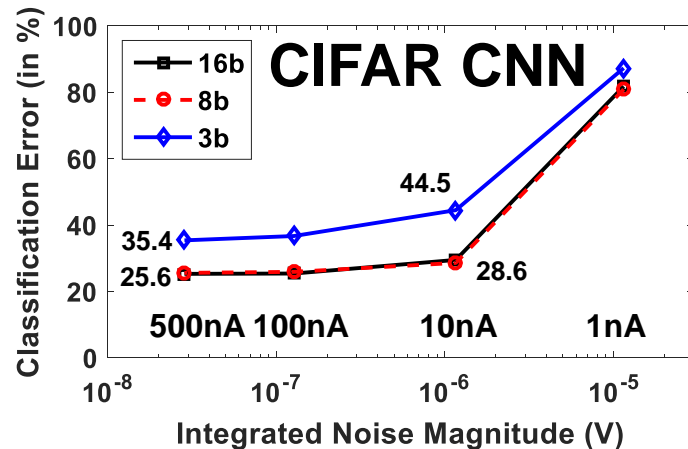
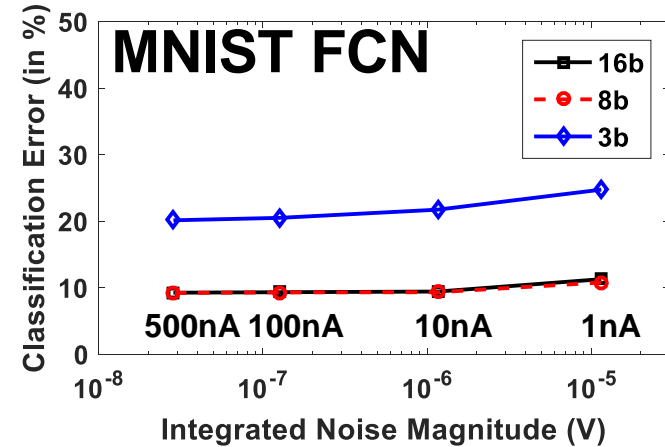
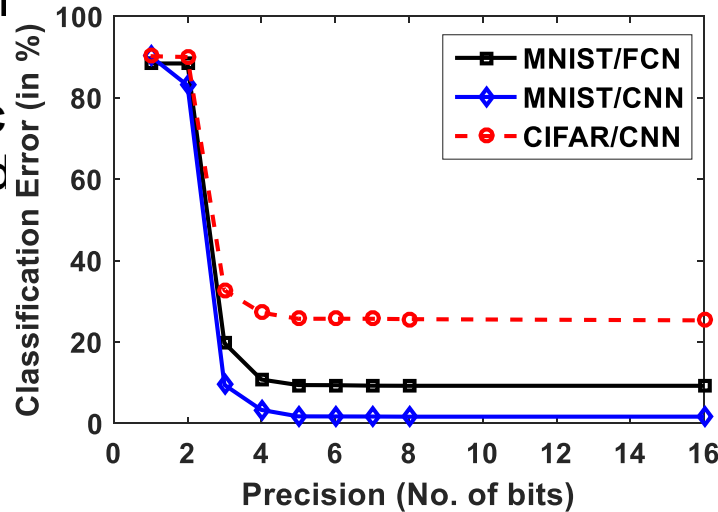
Prec vs error

Train Scale CE at 5 bits



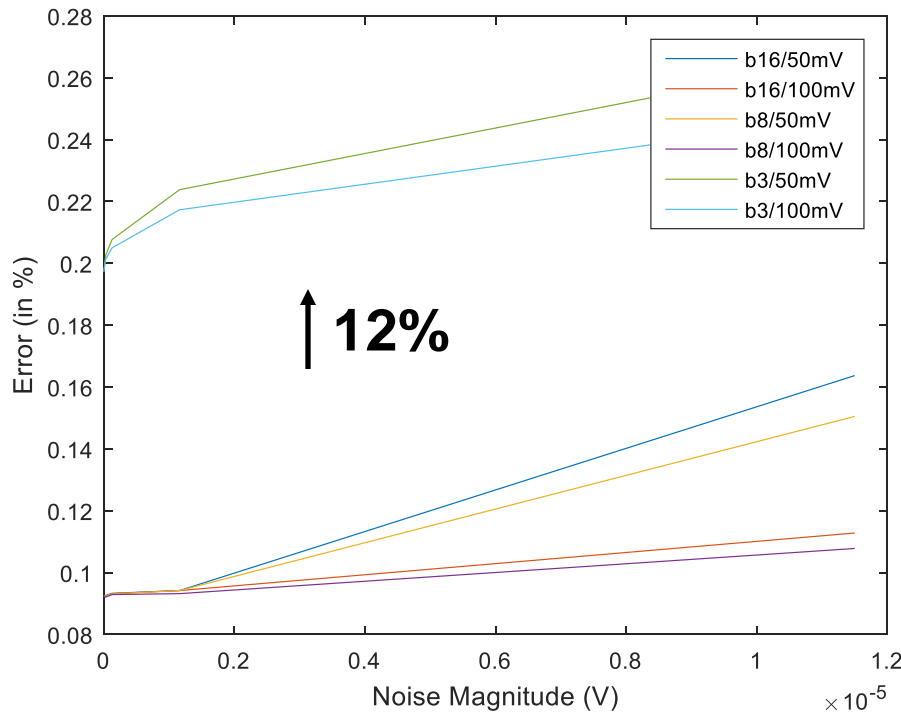
Prec vs error

Trained with I
Scaled down
CE as QN inc
5b it can hold



MNIST

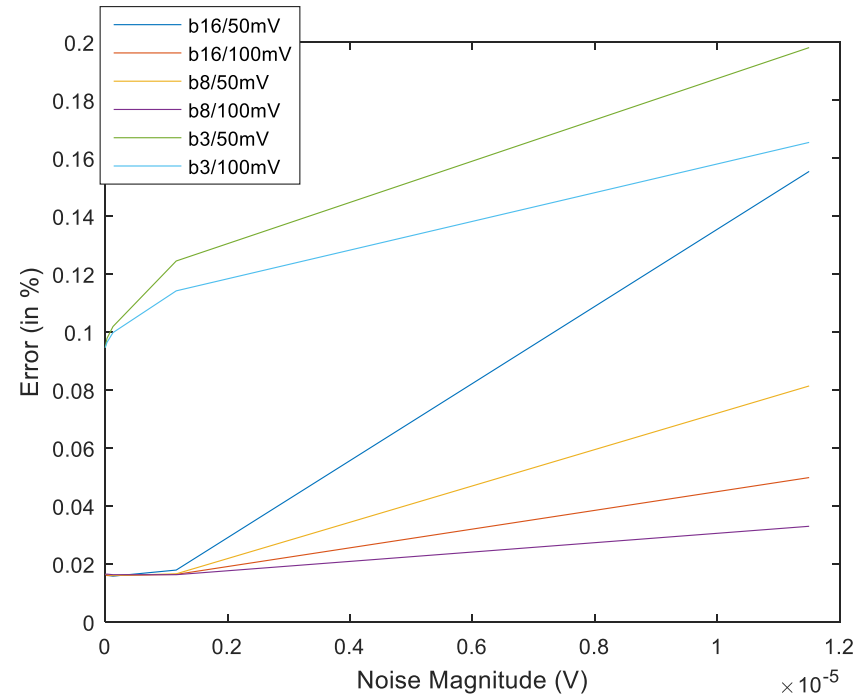
FCN (I784, 1H 50, 2H 100, O10)



Baseline error is low (good training)
Resilient to introduction of thermal noise
50mV (low SNR) diverges more

CNN

Includes retraining for 3b



CNN is better trained – Shared weight
More neuron, bigger network – more error averaging