COLLECTIVE DYNAMICS OF FERROELECTRIC NEURONS

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SRC JUMP

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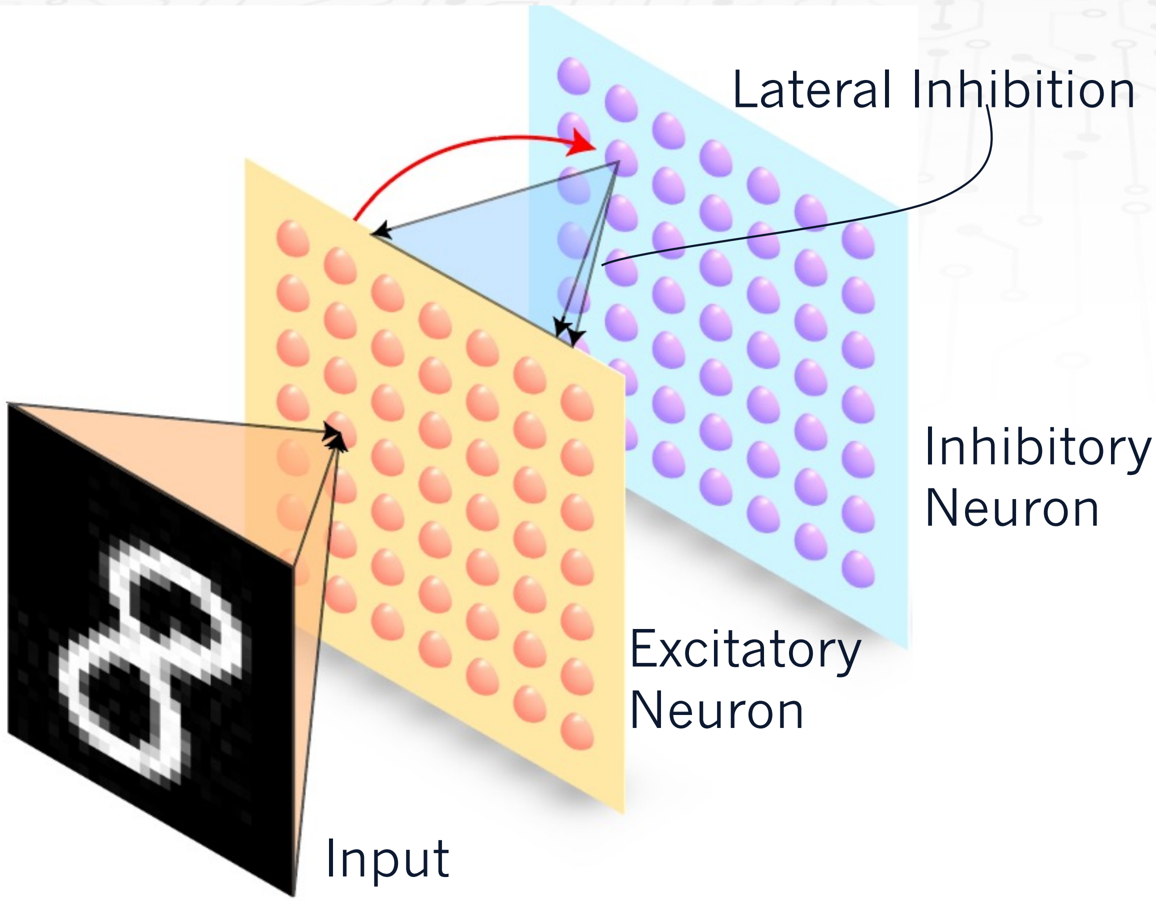
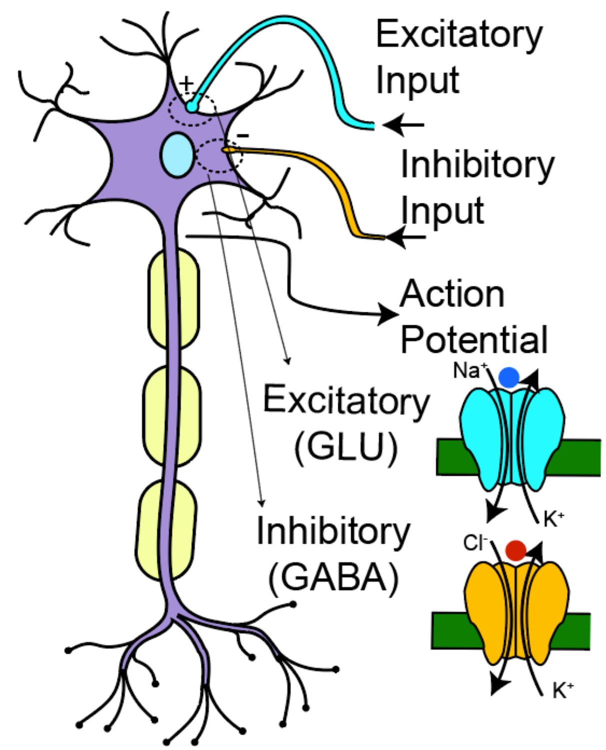
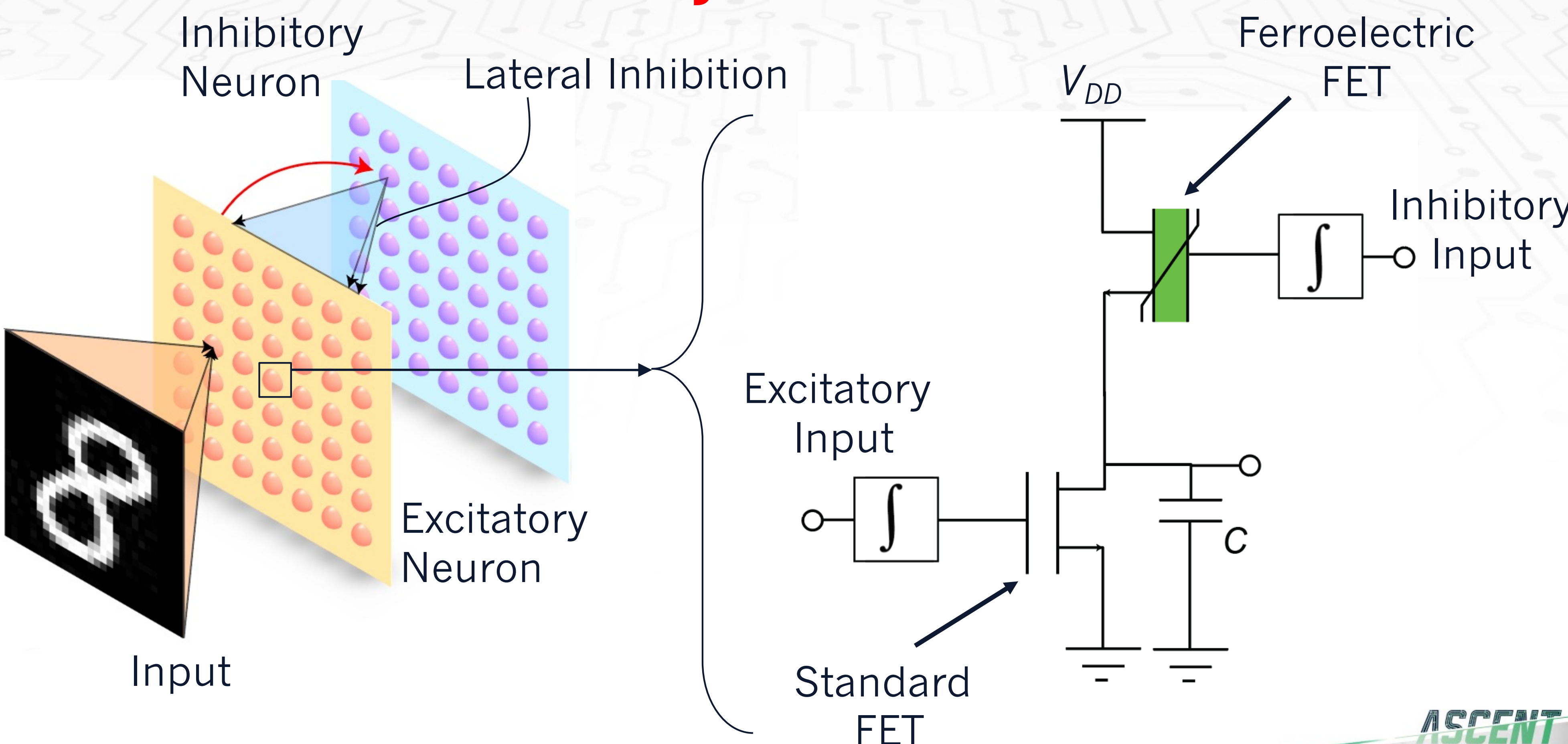
Spiking Neural Network: The Role of Inhibition





Deihl & Cook, Frontiers Comp. Neurosci. 9, 99 (2015)

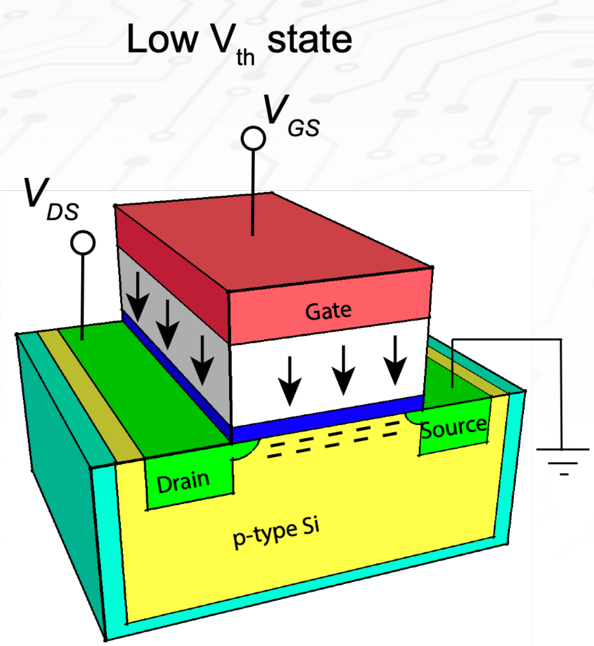
Ferroelectric Neuron with excitatory and **inhibitory** connection

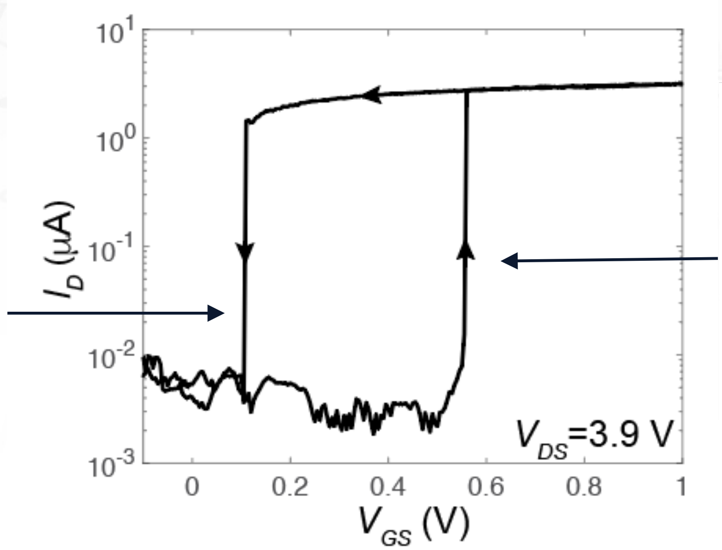


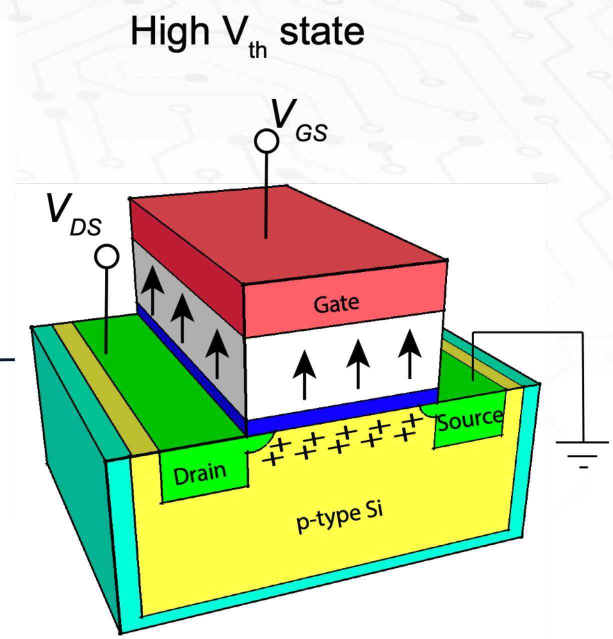
Wang et al. Int. Electron Dev. Meeting (IEDM) 2018.

Ferroelectric Field-Effect Transistors

Ferrroelectric Transistors (FEFET): Gate oxide stack includes a FE oxide

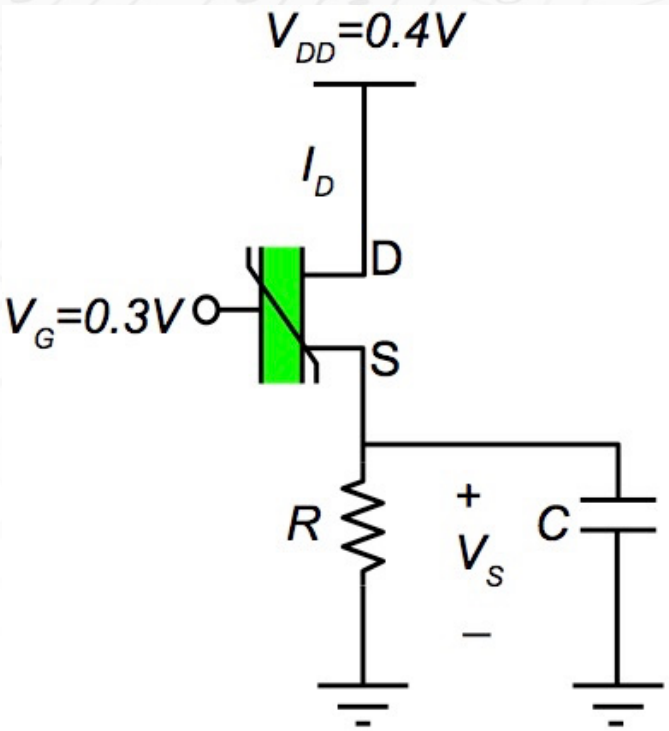


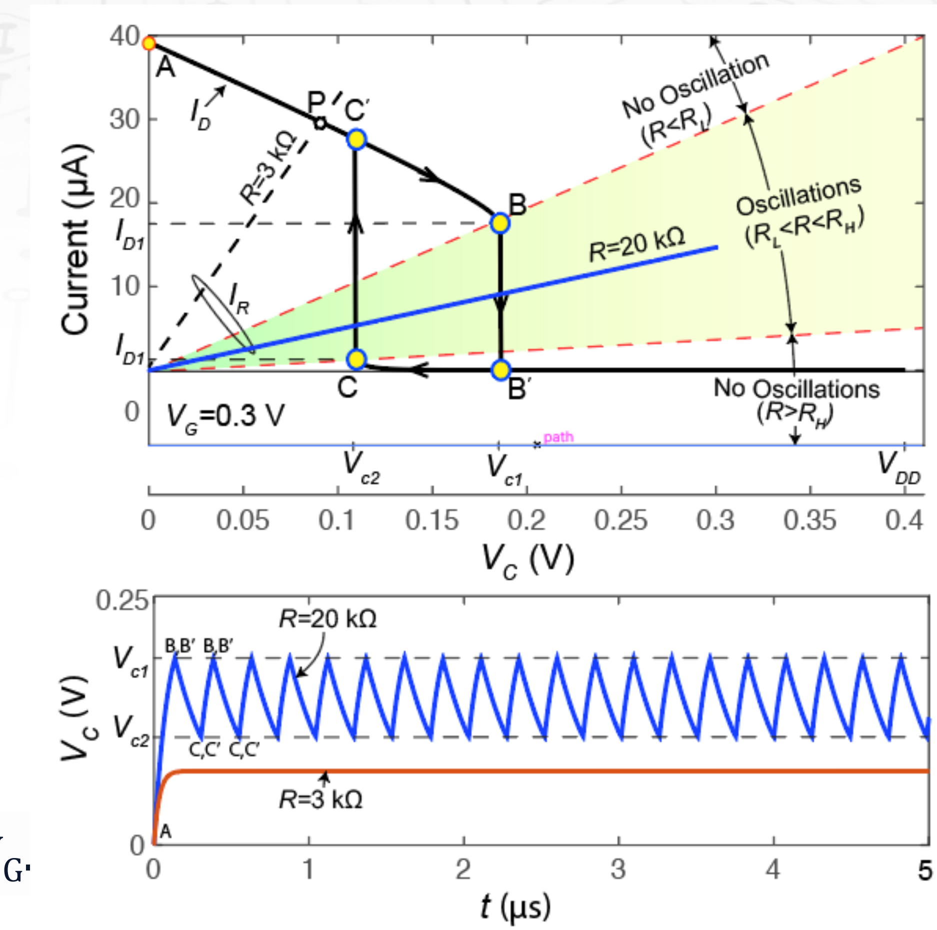




A ferroelectric transistor is a hysteretic device where the data is encoded in its threshold voltage.

A Ferroelectric Oscillator

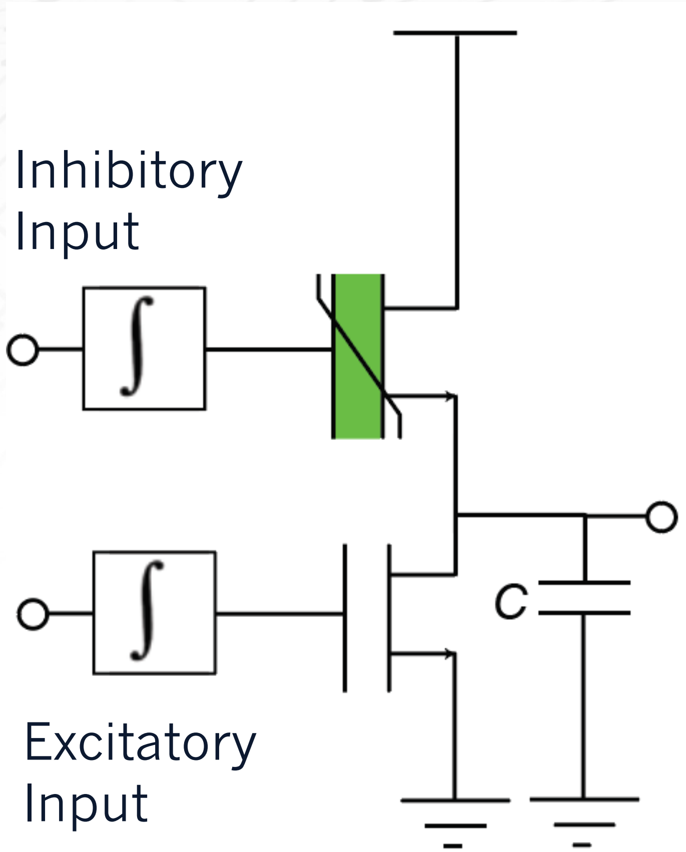




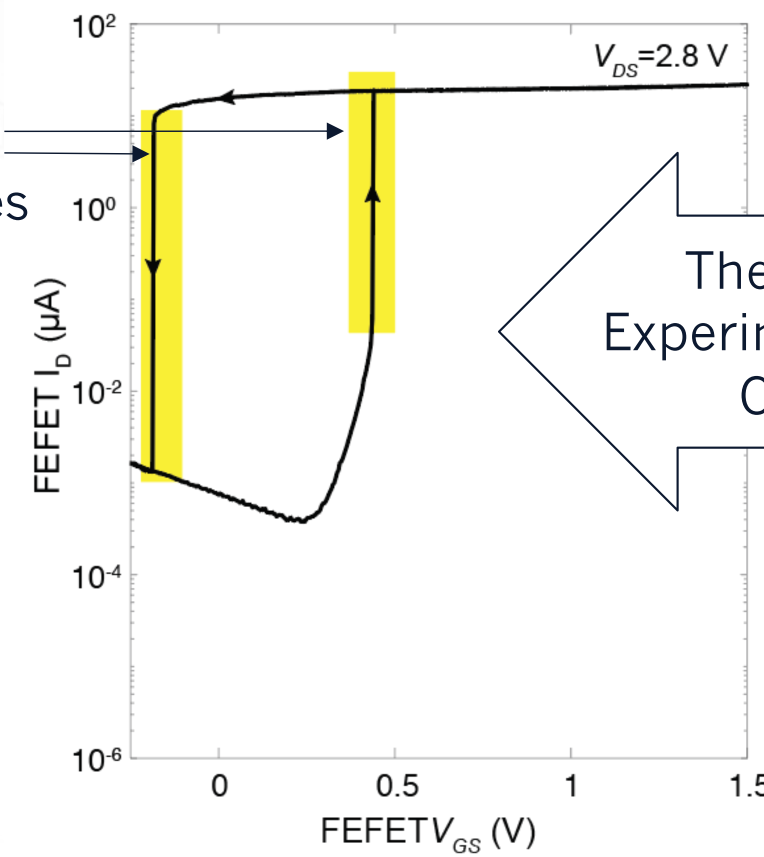
Oscillations can be controlled by the R or V_G.

Wang et al. IEEE Electron Device Lett. 38, 1614 (2017).

What Device Features enables the **Neuron and Inhibition** Functionality?



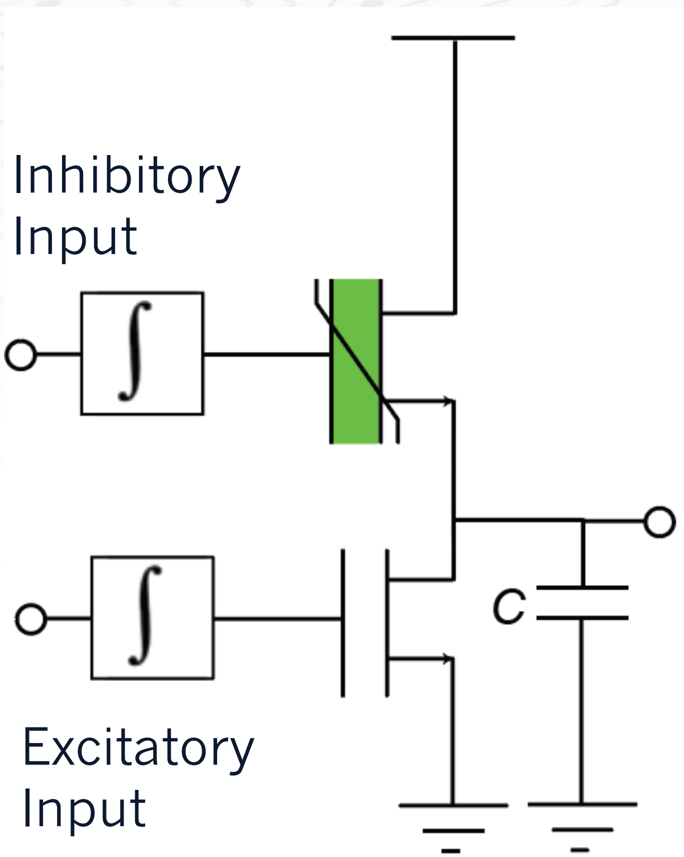
1. Abrupt Transitions, No stable states



These are Experimental Curves!

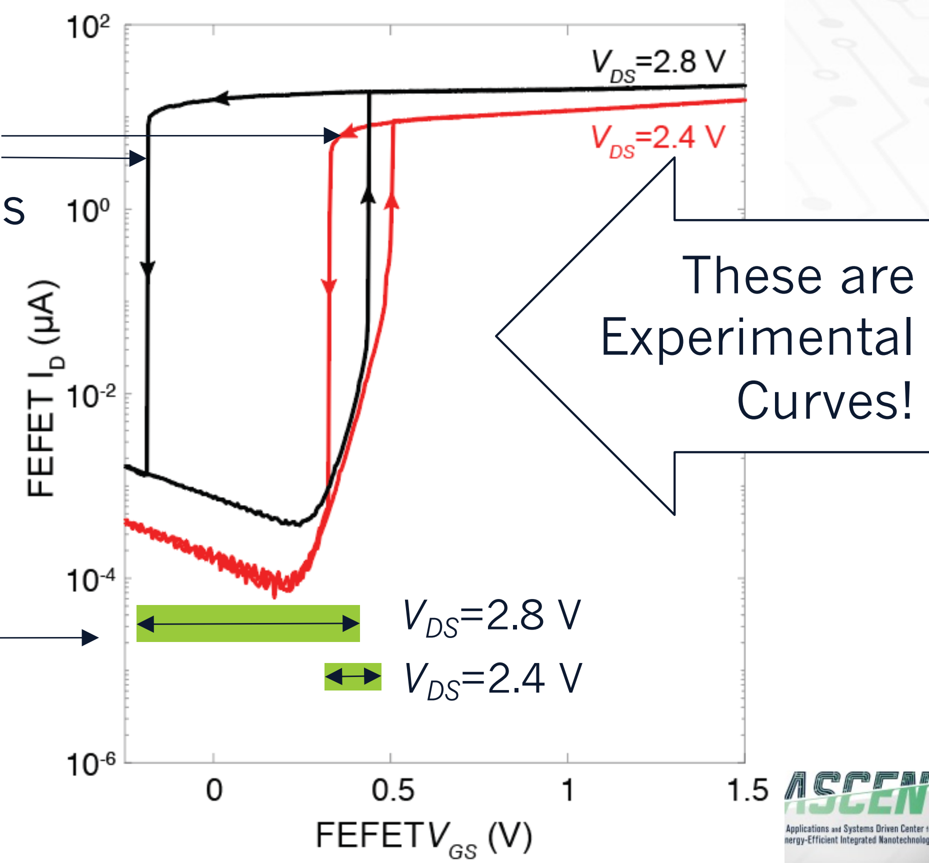
Wang et al. Int. Electron Dev. Meeting (IEDM) 2018.

What Device Features enable **Neuron and Inhibition** Functionality?



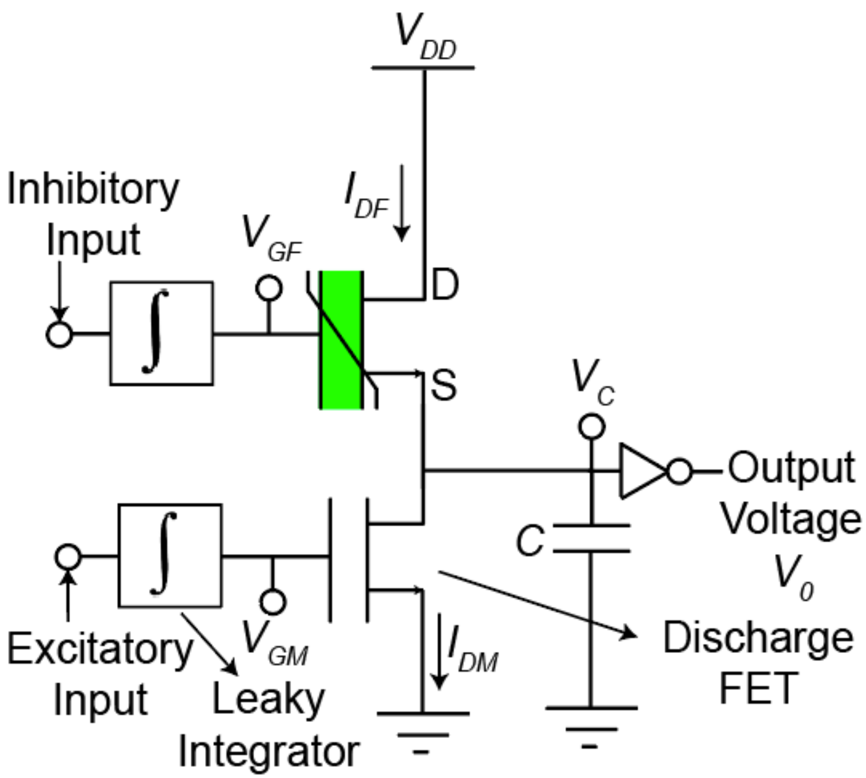
1. Abrupt Transitions, No stable states

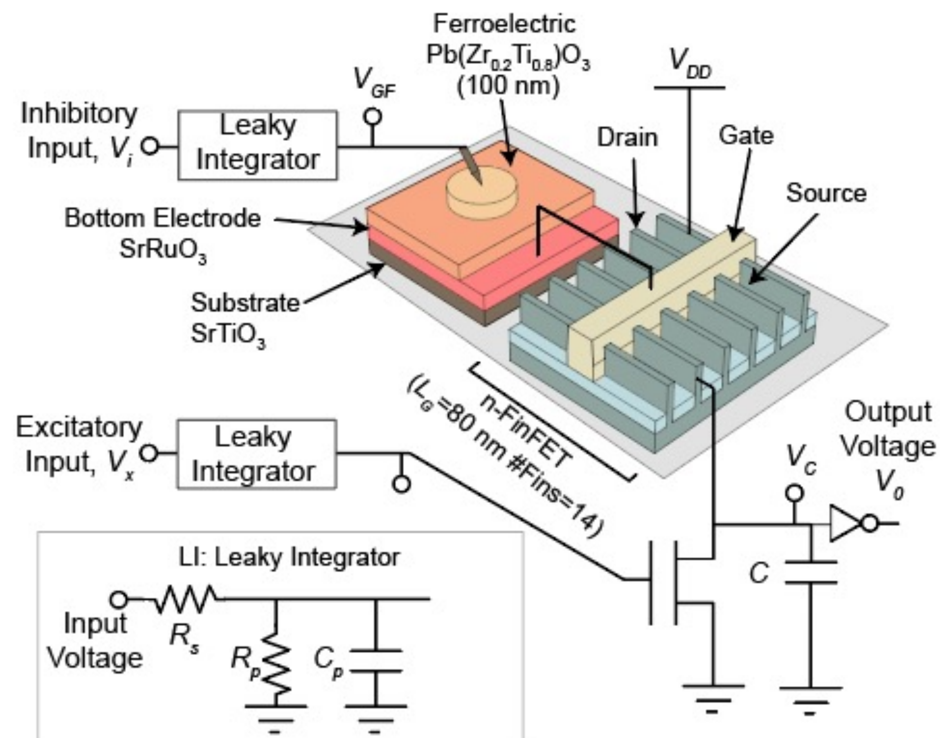
2. Hysteresis shift



Wang et al. Int. Electron Dev. Meeting (IEDM) 2018.

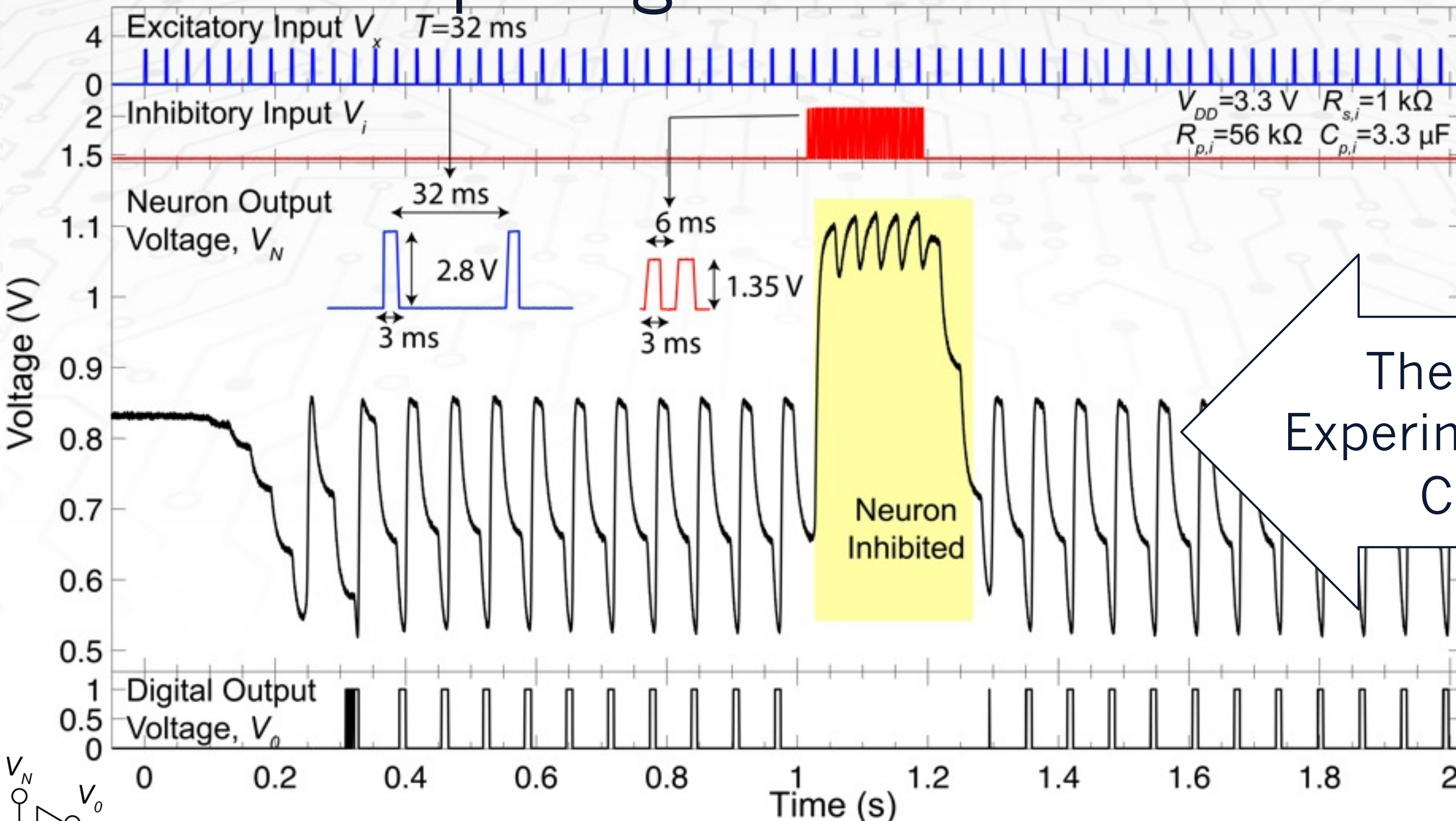
A Ferroelectric Spiking Neuron: Experimental setup

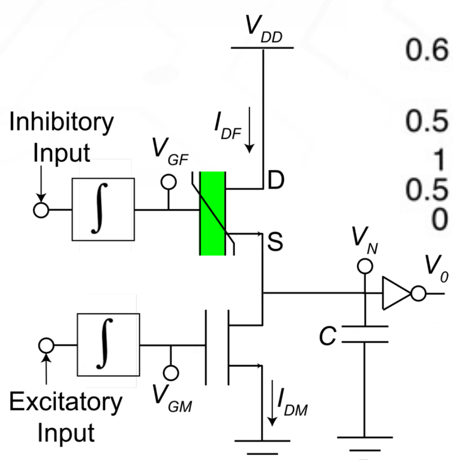




Wang et al. Int. Electron Dev. Meeting (IEDM) 2018.

Ferroelectric Spiking Neuron of Inhibition



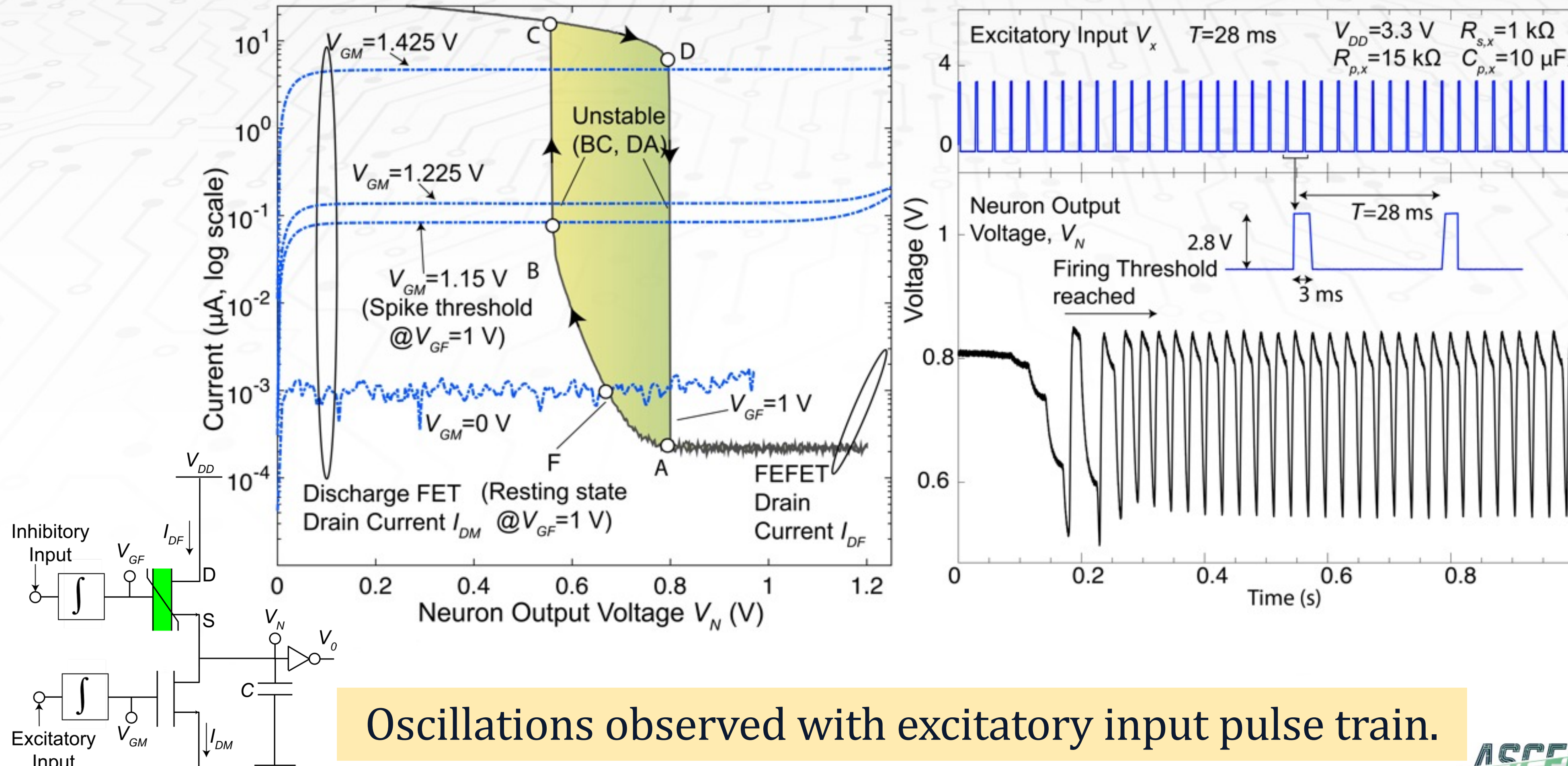


These are Experimental Curves!

The neuron is inhibited when inhibitory pulses arrive.

Wang et al. Int. Electron Dev. Meeting (IEDM) 2018.

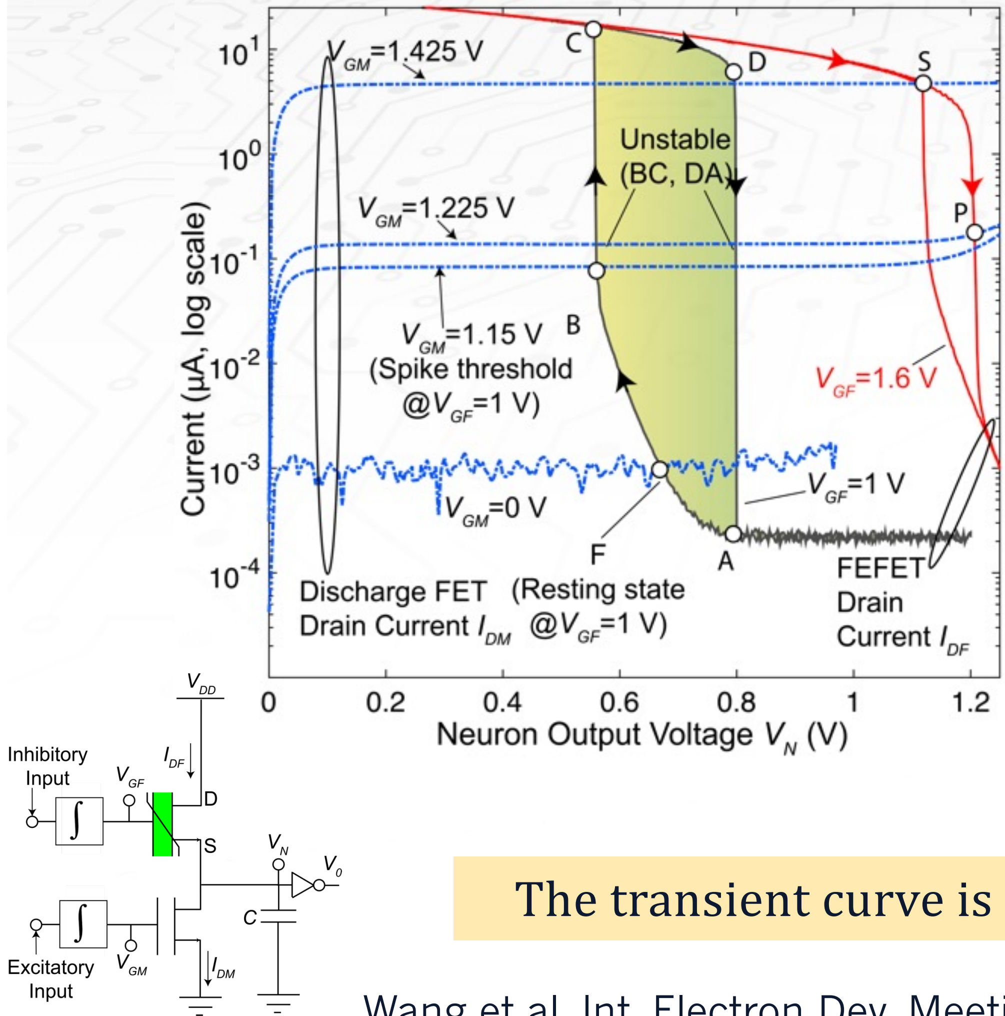
Demonstration of A Ferroelectric Spiking Neuron

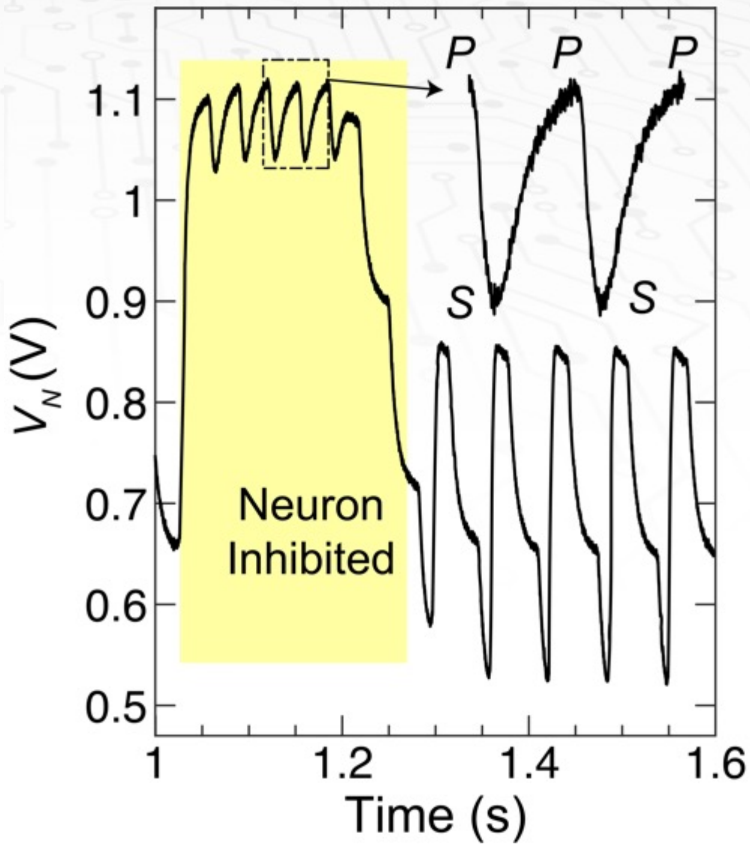


Oscillations observed with excitatory input pulse train.

Wang et al. Int. Electron Dev. Meeting (IEDM) 2018.

Demonstration of Inhibition

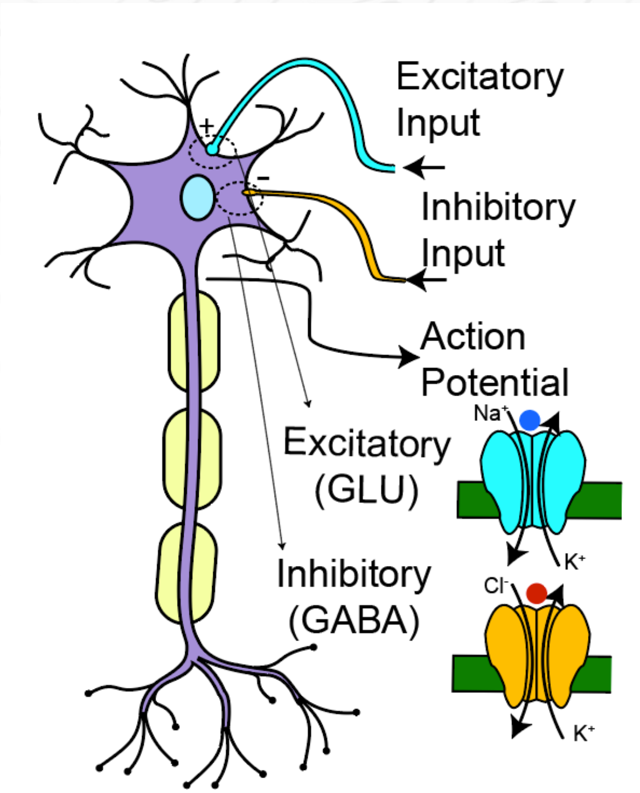


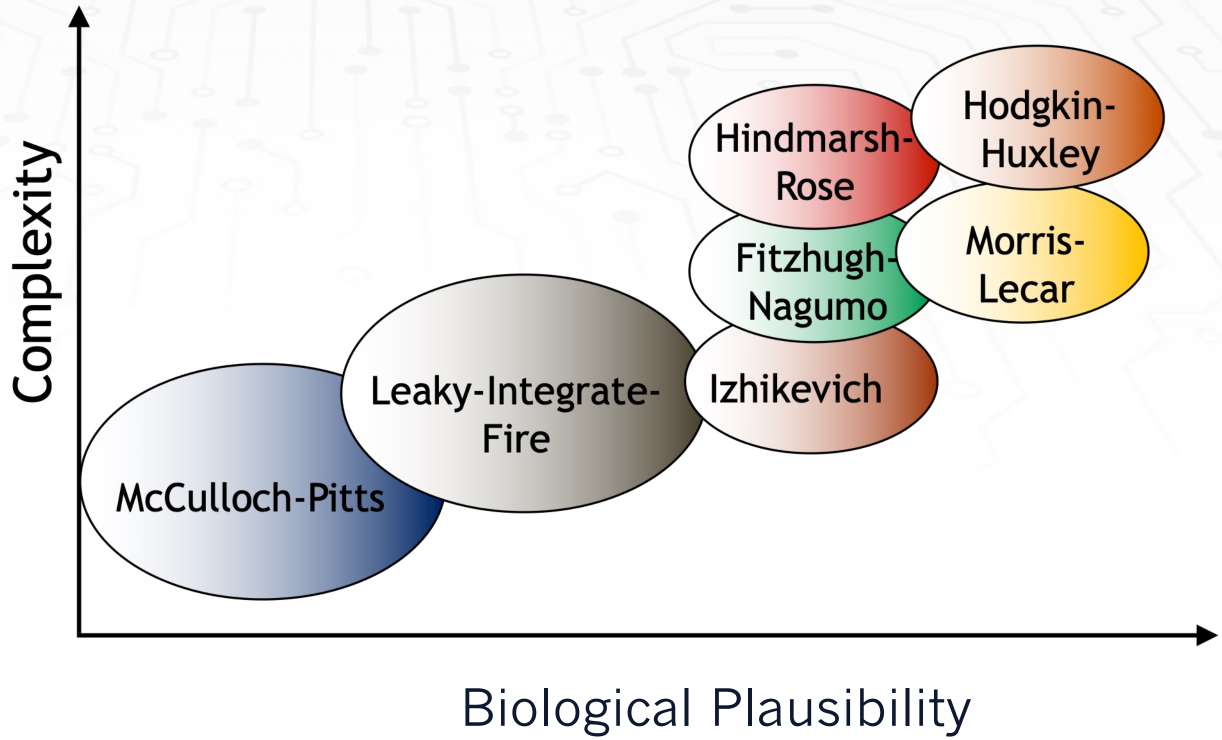


The transient curve is consistent with DC analysis.

Wang et al. Int. Electron Dev. Meeting (IEDM) 2018.

Landscape of Neuron Models

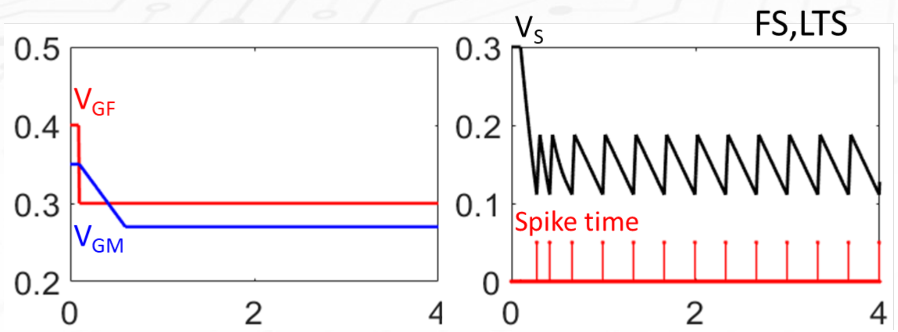




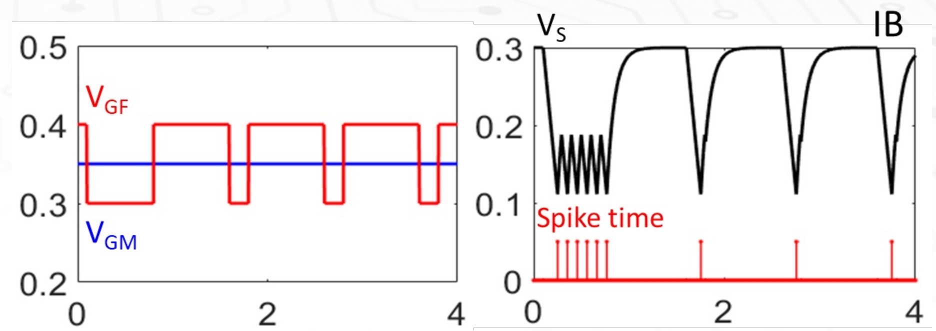
Schuman, Catherine D., et al. "A survey of neuromorphic computing and neural networks in hardware.", arXiv:1705.06963 (2017).

Biomimetic Spiking Patterns in Ferroelectric Neurons

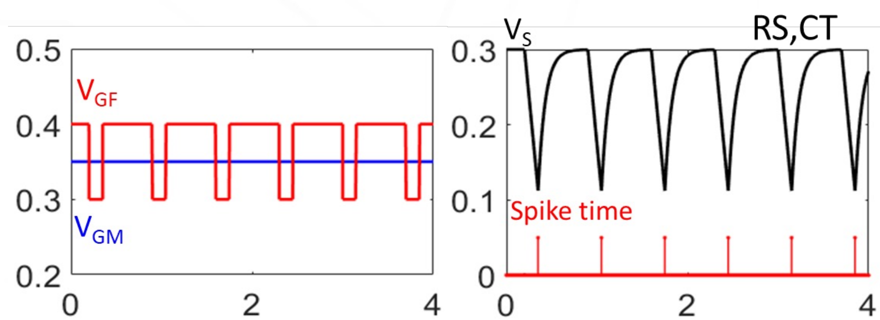
Apply excitatory and inhibitory inputs to mimic different spiking patterns of cortical neurons



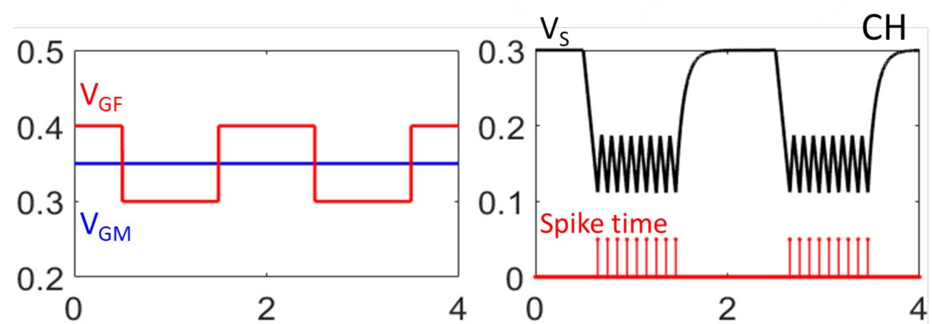
Fast Spiking (FS) and Low Threshold Spiking (LTS)



Regular Spiking (RS) and Thalamo-cortical (TC)



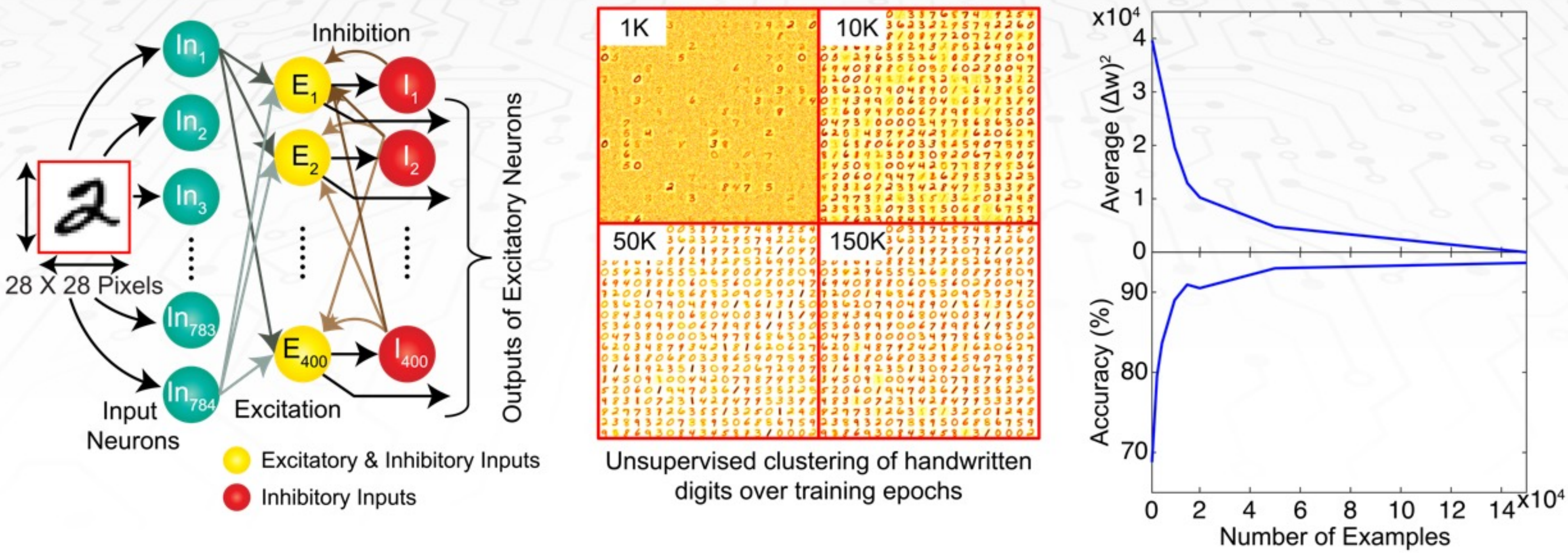
Intrinsically Bursting (IB)



Chattering (CH)

Fan et al. IEEE Electron Dev. Lett. 2019.

Ferroelectric SNN for Unsupervised Clustering



STDP for weight updates
Classification accuracy of 93% on MNIST dataset

Wang et al. Int. Electron Dev. Meeting (IEDM) 2018.

Benchmarking

	[5]	[6]	[7]	Current work
Technology	CMOS Analog, Mixed Signal		Emerging Technology	
Neuron Type	LIF	Multiply-Accumulate	LIF	LIF
Network Type	Spiking	Non-spiking	Spiking	Spiking
Data Encoding Architecture	Spike Timing	Multi-level perceptron	Spiking Rate	Spike Timing
Input Type	Excitatory	Excitatory	Excitatory	Excit. & Inhib.
Device Count	15 T	64 T	1T - 1 VO_2	1T - 1 FEFET
Synapse Weight	Pos. & Neg.	Pos. & Neg.	Pos. & Neg.	Pos.
Training & Classification	Unsupervised	Reinforcement	Supervised	Unsupervised
Power	10 nW	125 nW	Not reported	3.6 nW

[5] G. Indiveri. Proc. ISCAS 2003, 4, IV-IV. [6] A. Amravati et al. Proc. ISSCC 2018. [7] M. Jerry et al. Proc. 2017 Symp. on VLSI Tech., pp. T186-T187

Wang et al. Int. Electron Dev. Meeting (IEDM) 2018.

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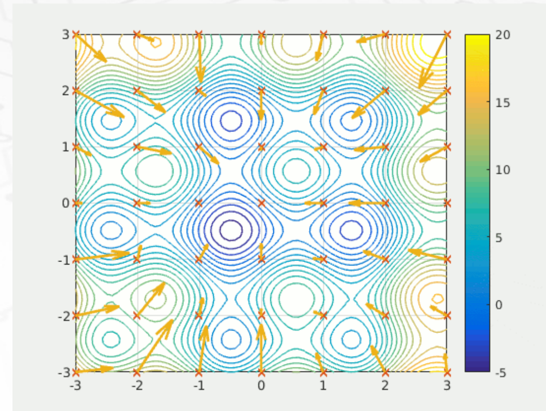
Collective Behavior and Swarm Intelligence

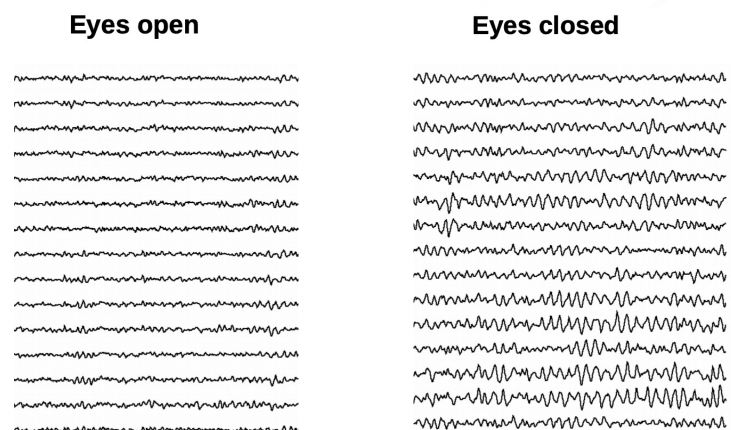
- Neuro-biology and natural swarm behaviors
- Large number of simple agents giving rise to intelligent behavior
- Computationally hard problems (graph coloring, traveling salesman problem etc.)

A school of fish and a shark

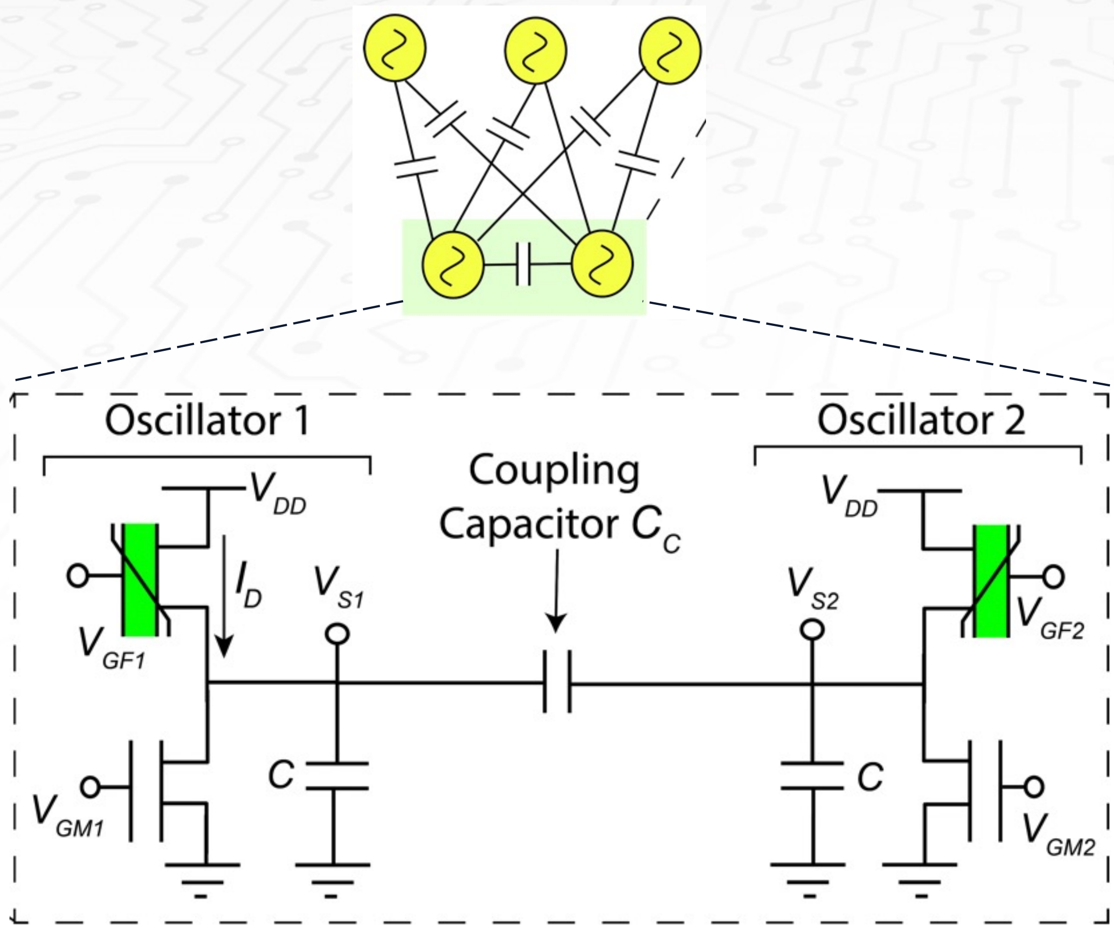
General Framework

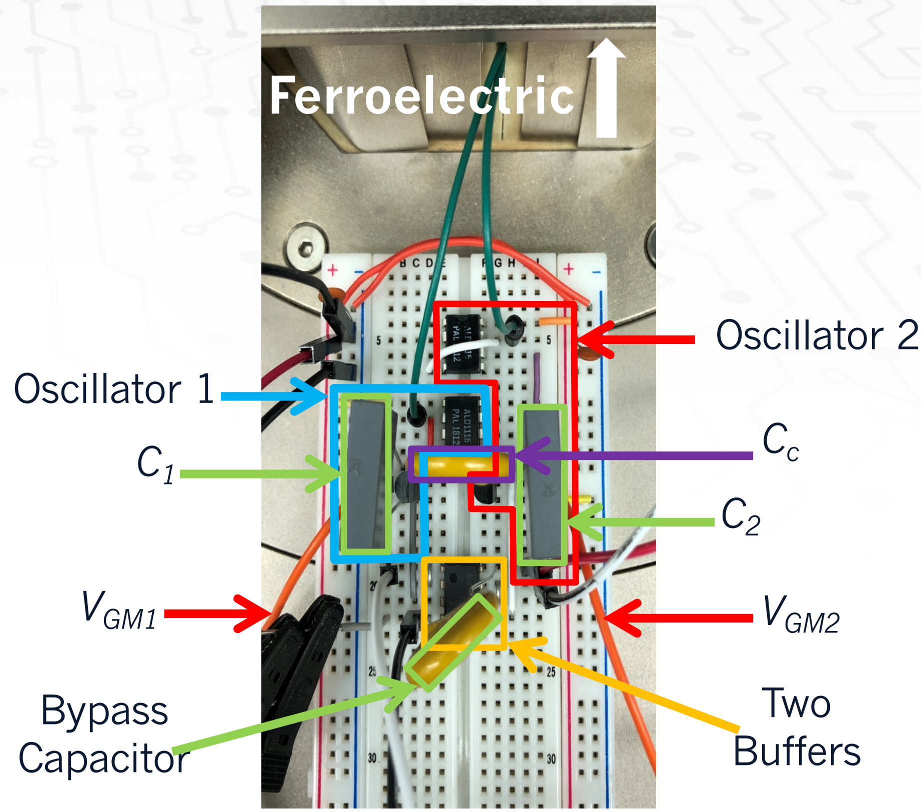


Collective Spatio-temporal oscillations in Primary Visual Cortex

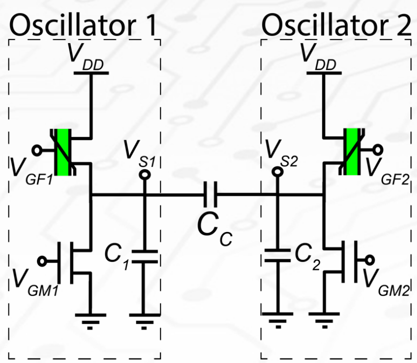


Coupled Ferroelectric Neurons (Experiments)

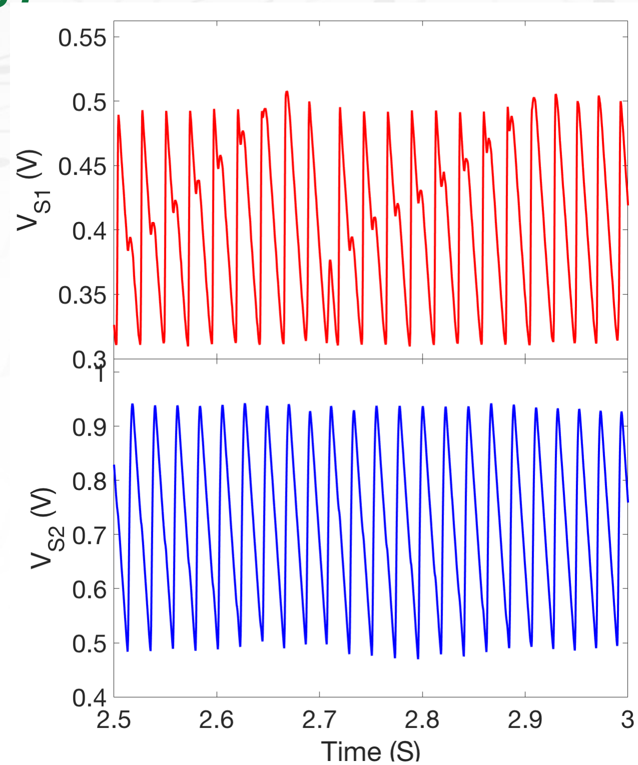


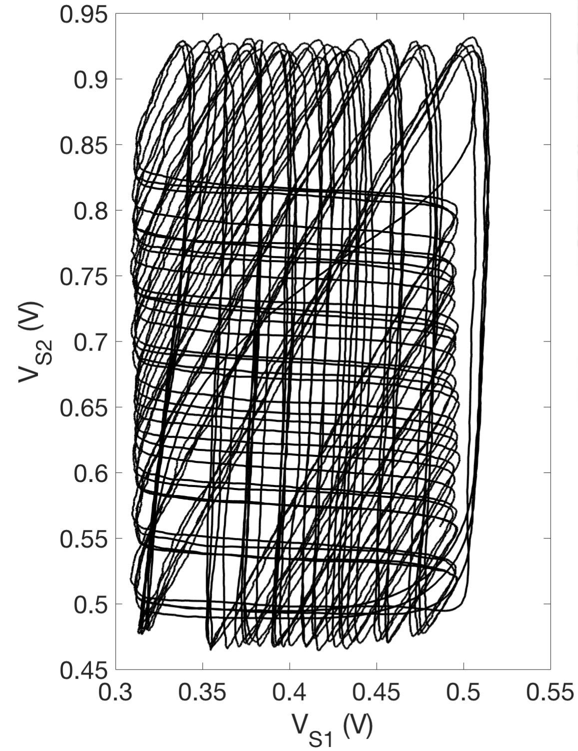


Synchronization Dynamics of Coupled FE Neurons (Experiments)



V_{GF1}=V_{GF2}=0.6 V
V_{GM1}=1.55 V
V_{GM2}=1.6 V
C_1=C_2=10 nF
C_c=1 nF

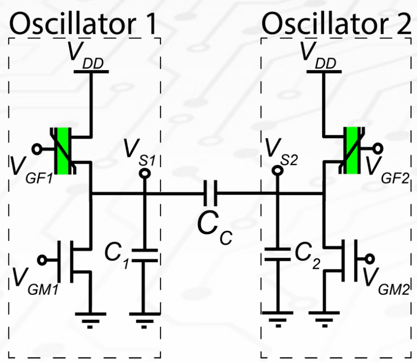




Two oscillators are weakly coupled, the coupled system is **not synchronized**, showing a non-repetitive crisscross pattern.

Wang et al. (unpublished).

Synchronization Dynamics of Coupled FE Neurons (Experiments)



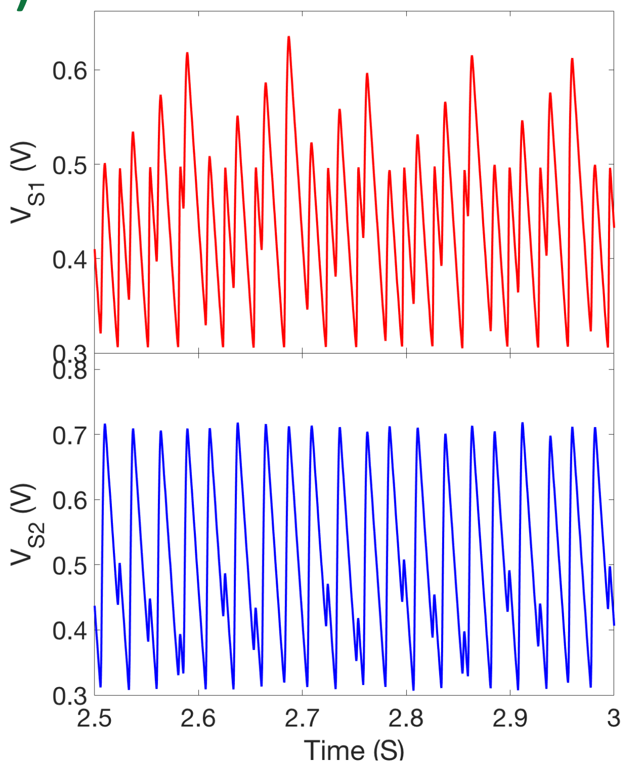
V_{GF1}=V_{GF2}=0.6 V

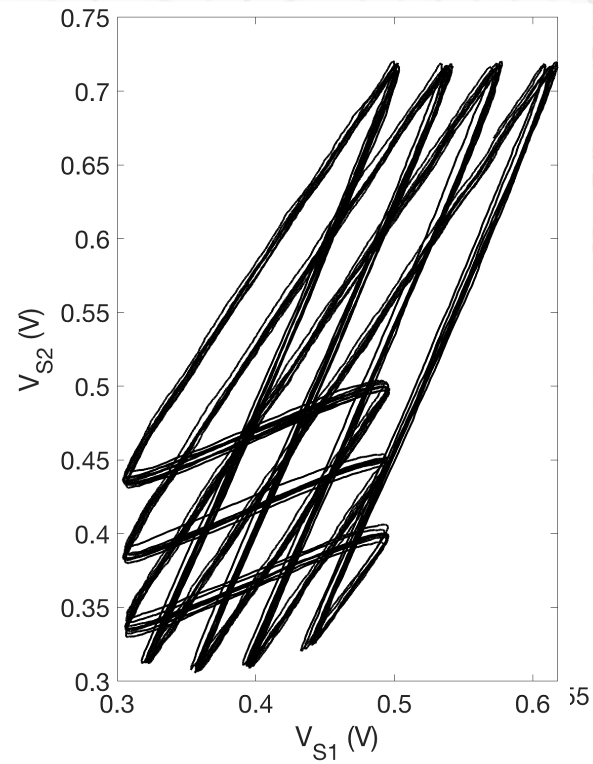
V_{GM1}=1.55 V

V_{GM2}=1.6 V

C_1=C_2=10 nF

C_c=10 nF





The coupled strength of two oscillators is increased, the coupled system is **synchronized**, showing a periodic pattern.

Wang et al. (unpublished).

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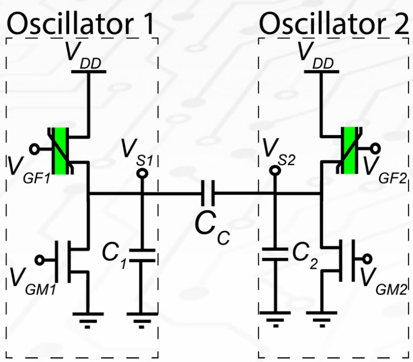
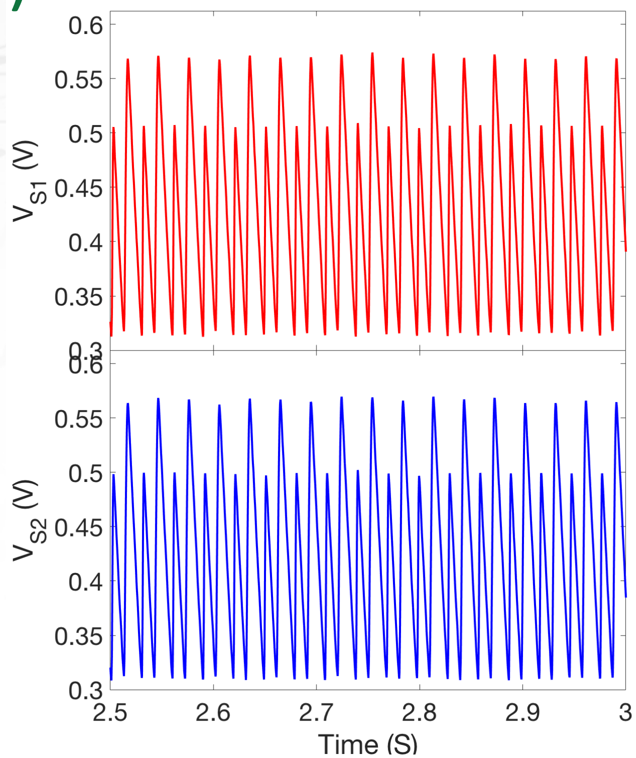
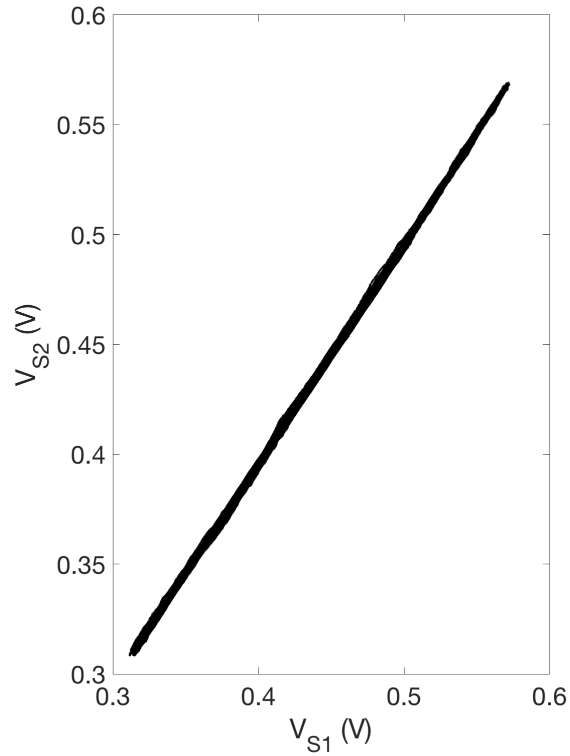
Synchronization Dynamics of Coupled FE Neurons (Experiments)





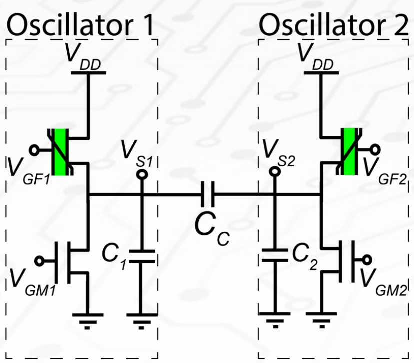


V_{GF1}=V_{GF2}=0.6 V
V_{GM1}=1.55 V
V_{GM2}=1.6 V
C_1=C_2=10 nF
C_c=1 uF

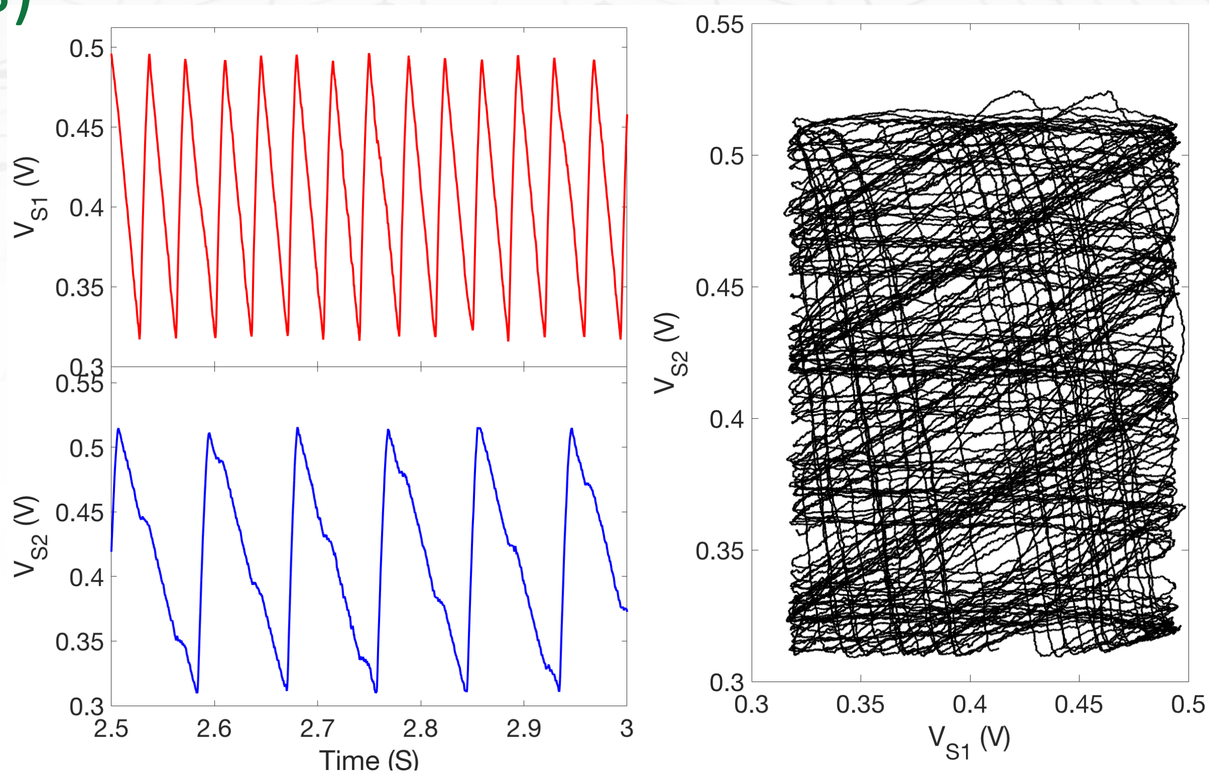
Two oscillators are strongly coupled, the coupled system is **synchronized**. In fact, two oscillators have identical waveforms.

Wang et al. (unpublished).

Synchronization Dynamics of Coupled FE Neurons (Experiments)



V_{GF1}=V_{GF2}=0.6 V
$\mathbf{V_{GM1}}$**=1.7 V**
$\mathbf{V_{GM2}}$**=1.6 V**
C_1=C_2=100 nF
C_c=10 nF

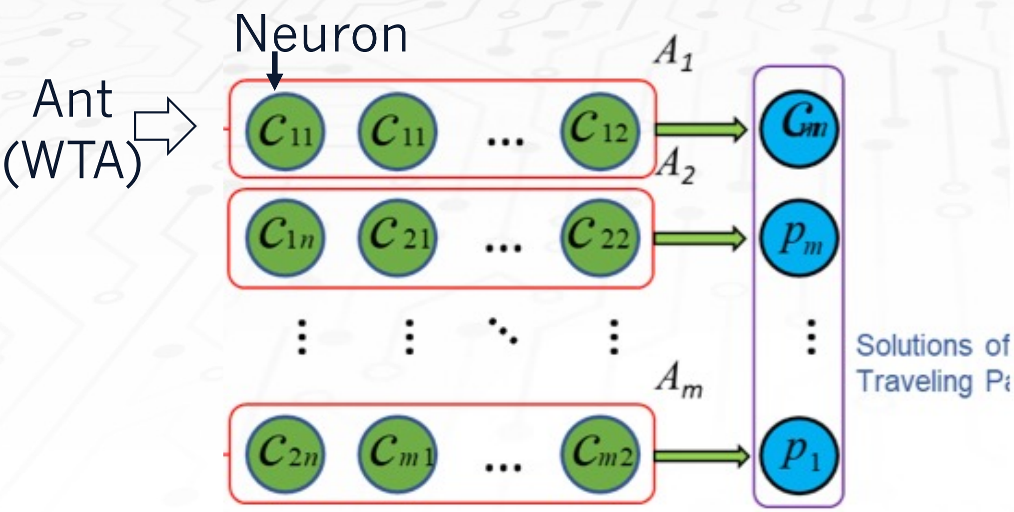


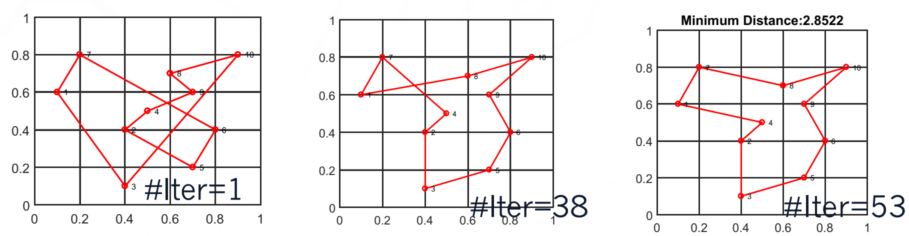
Increase the difference between V_{GM} *leading to larger frequency difference of two individual oscillators, as the result the system is* ***not synchronized*** *at C_c=10 nF.*

Wang et al. (unpublished).

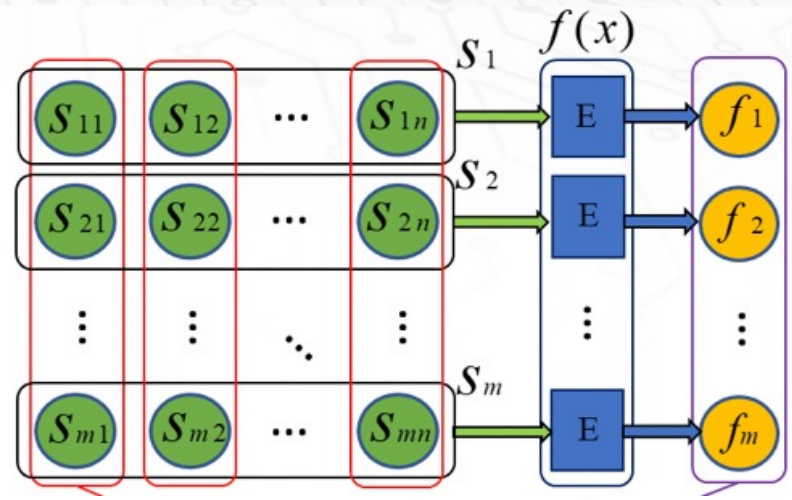
Ant Colony Algorithm for Traveling Salesman Problem

Optimization of Continuous Objective Function





FE Neuron: Regular Spiking (RS) mode.
Inhibition Needed.
Phase based Representation.



FE Neuron: Fast Spiking (FS) mode.
Inhibition disabled.
Rate-based Representation

Fan et al. Frontiers in Neuroscience 2019.

Thanks/Questions and Comments

JUMP

Joint University Microelectronics Program

www.src.org/program/jump

Semiconductor Research Corporation

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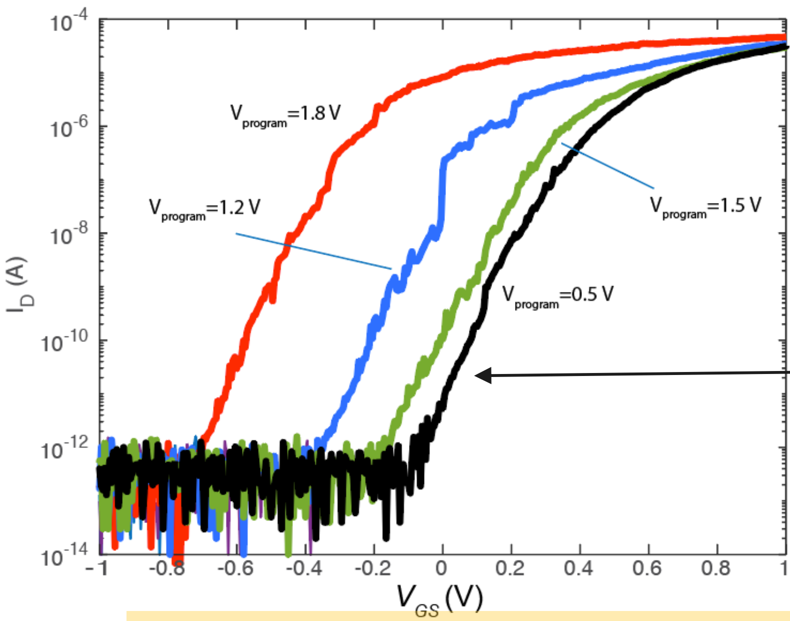
Device features needed

For embedded memory and analog synapse

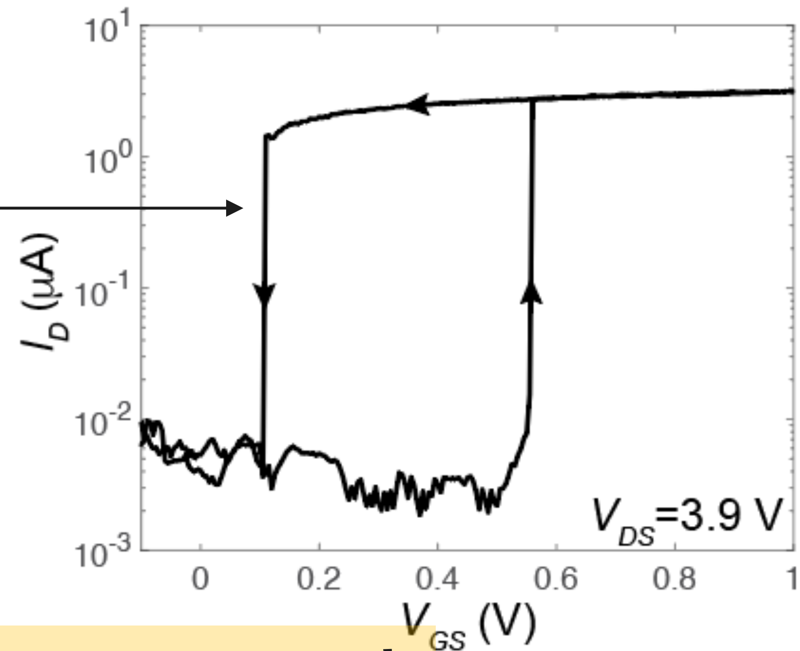


Switching Transitions

Abrupt
No stable states

Diffuse
Stable states

For oscillator and neuron



Abrupt transitions with no stable states therein are required for oscillators and neurons!