SPIKING NEURAL NETWORKS WITH EXCITATORY AND INHIBITORY CONNECTIONS AND BEYOND

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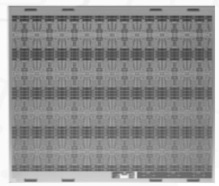
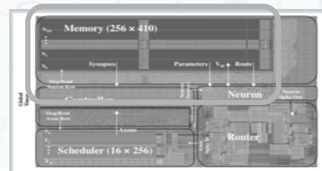
Technology Roadmap for SNN

CMOS

Intel's Loihi

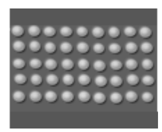


IBM's TrueNorth

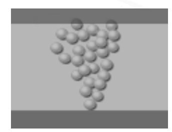


CMOS + emerging non-volatile memory

PCM

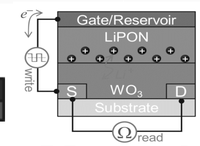


RRAM



FeFET

ECRAM



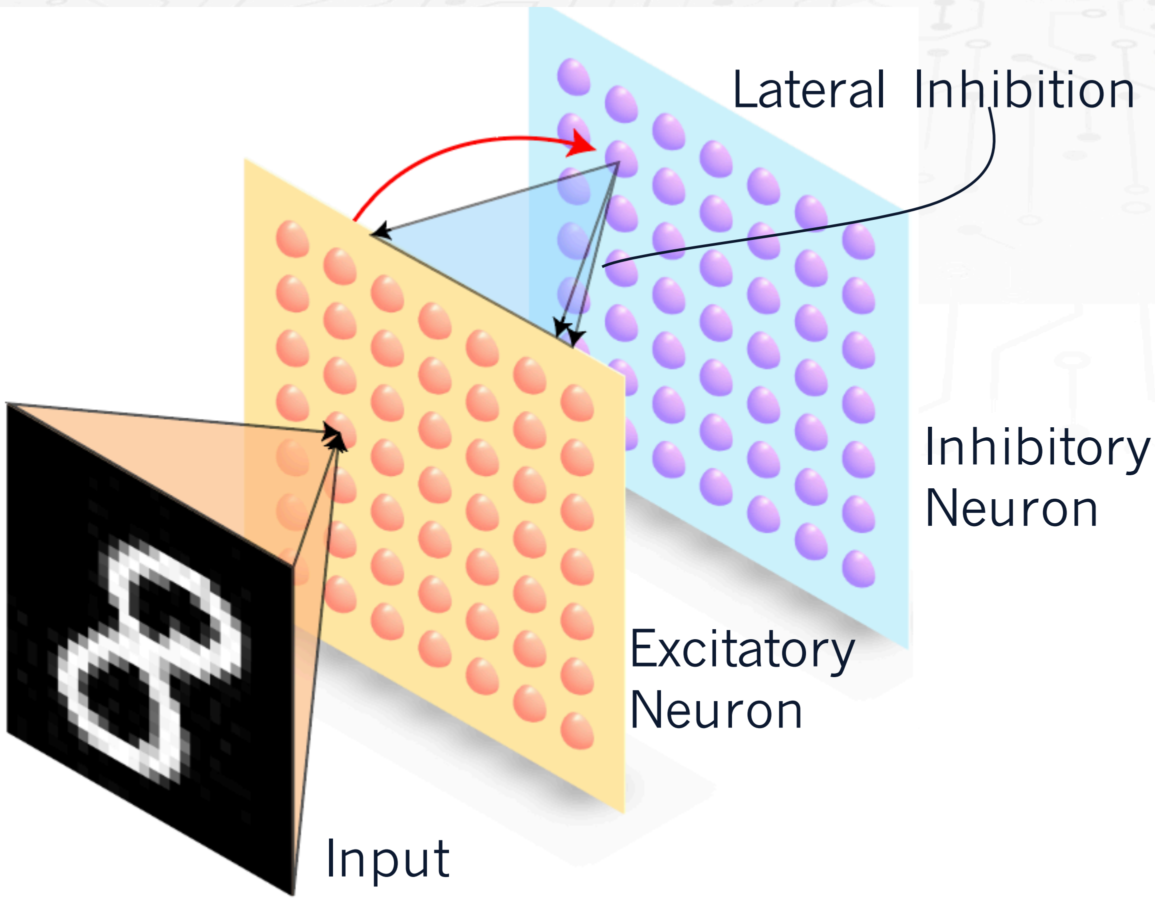
New features provides by novel devices

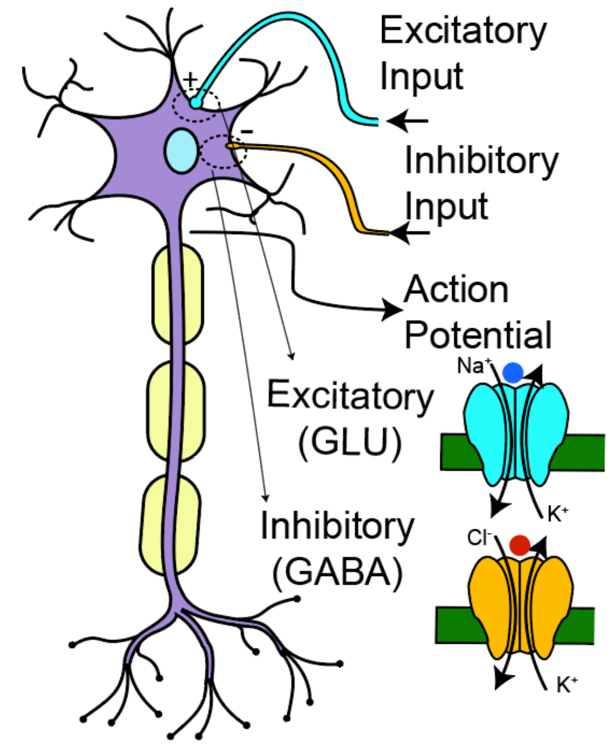
- Always-on stochasticity
- FeFET based neuron
- Continuous-time dynamical system

Algorithms supporting device/circuit innovations

- Perception
- Decision-making
- Action

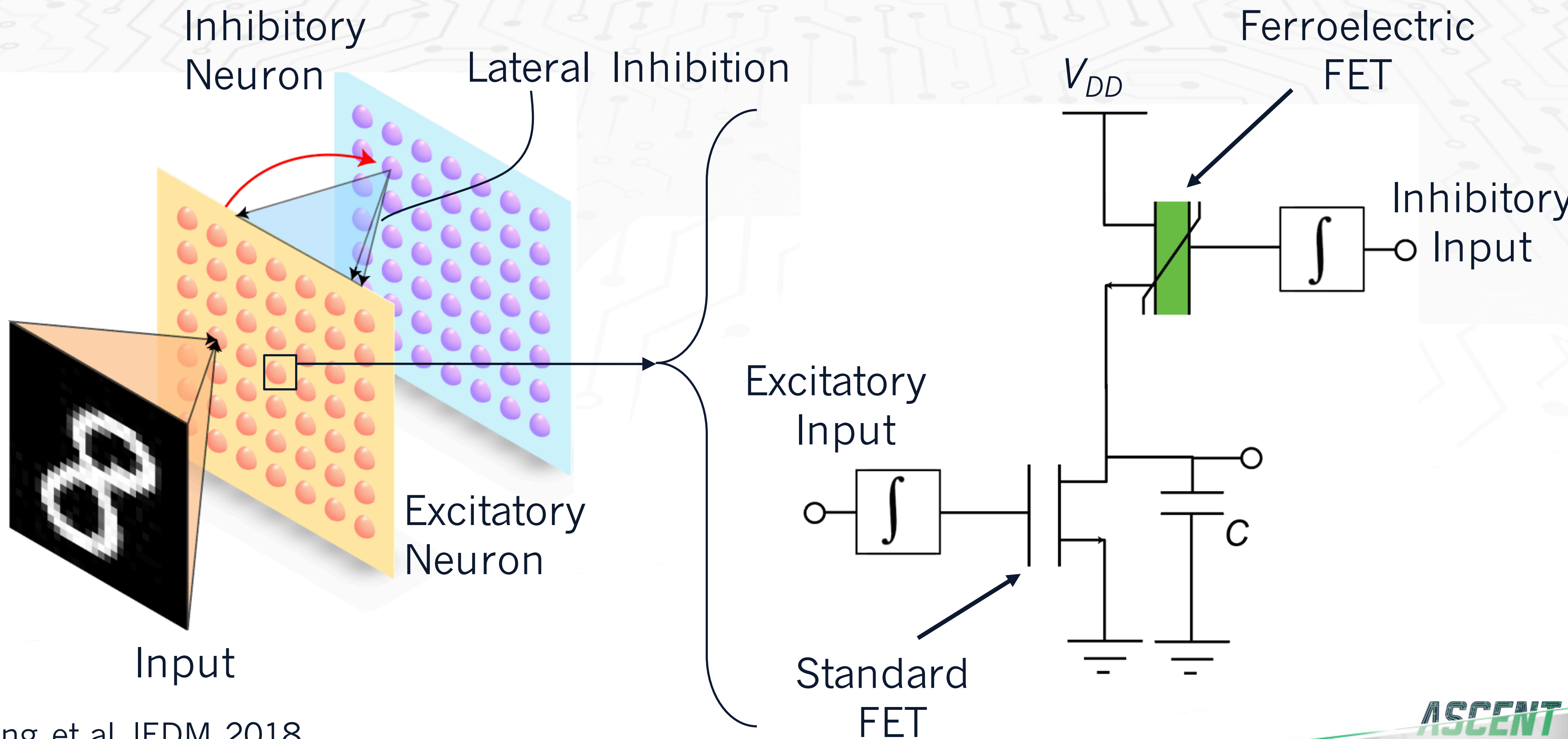
Spiking Neural Network: The Role of Inhibition





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

Ferroelectric Neuron with excitatory and **<u>inhibitory</u>** connection



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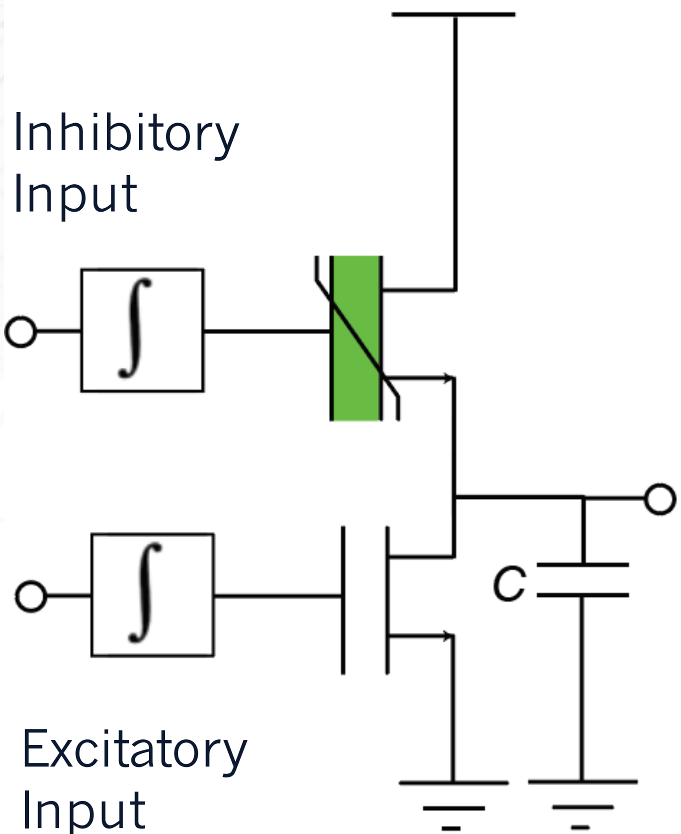
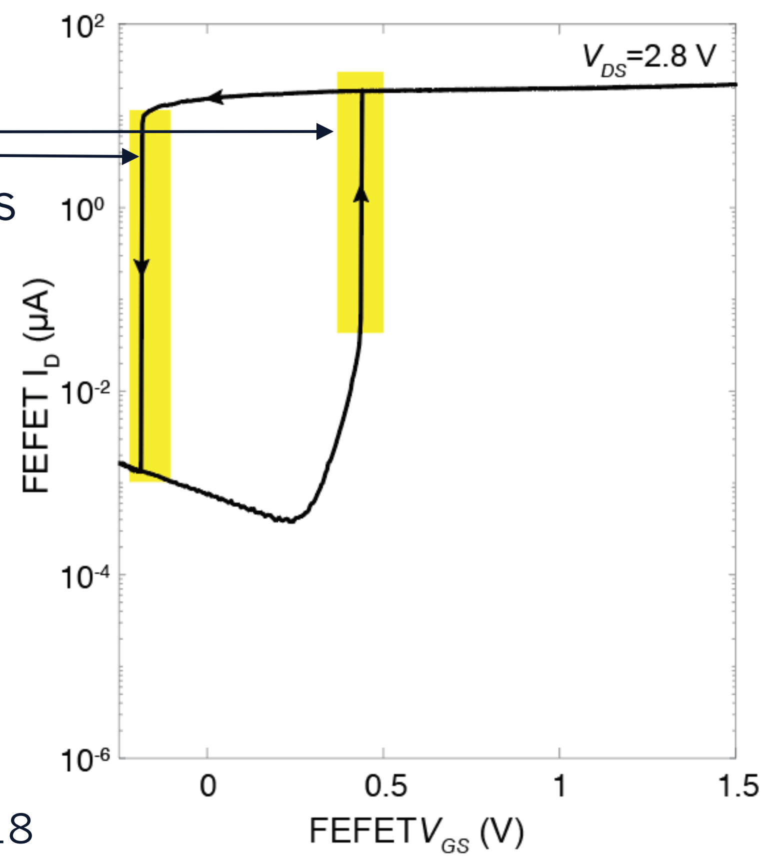
What Device Features enables the **Neuron and Inhibition** Functionality?



1. Abrupt Transitions, No stable states



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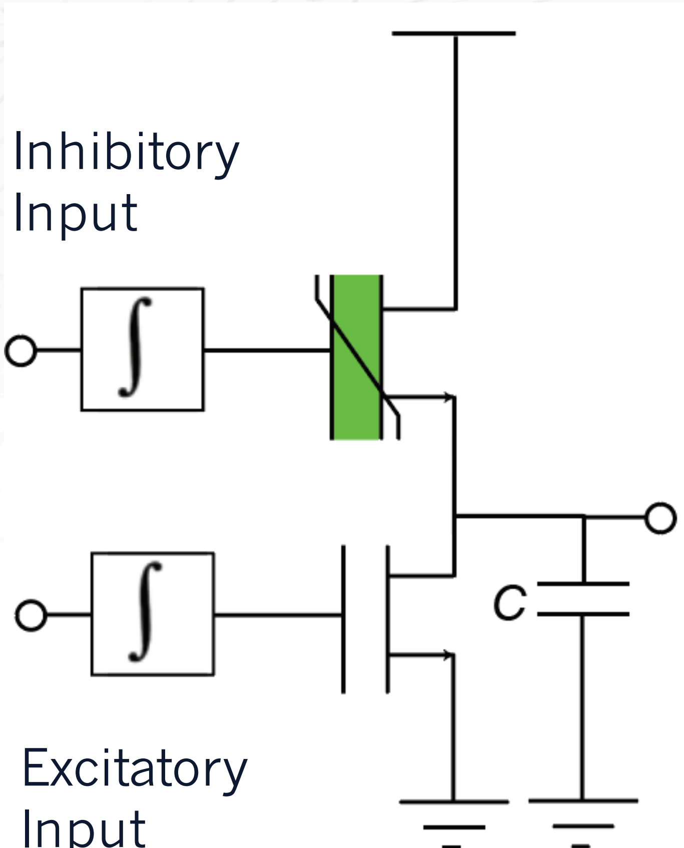

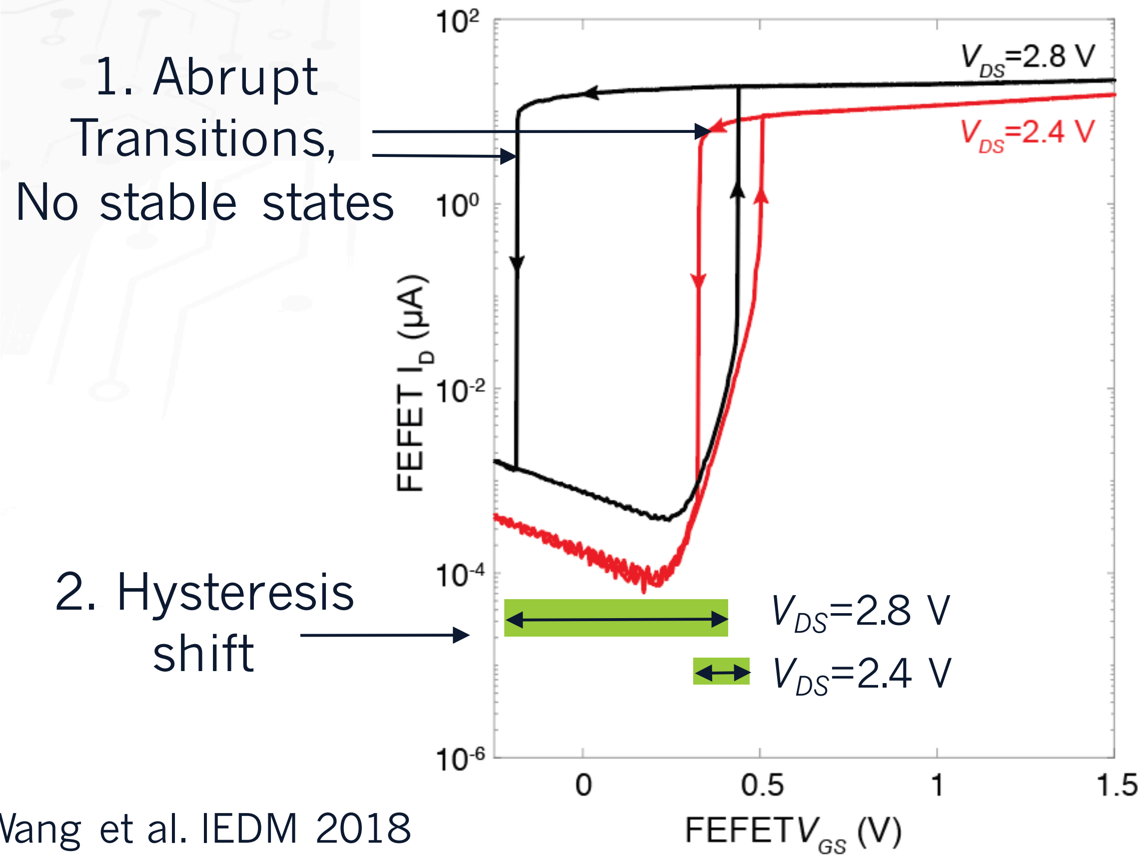

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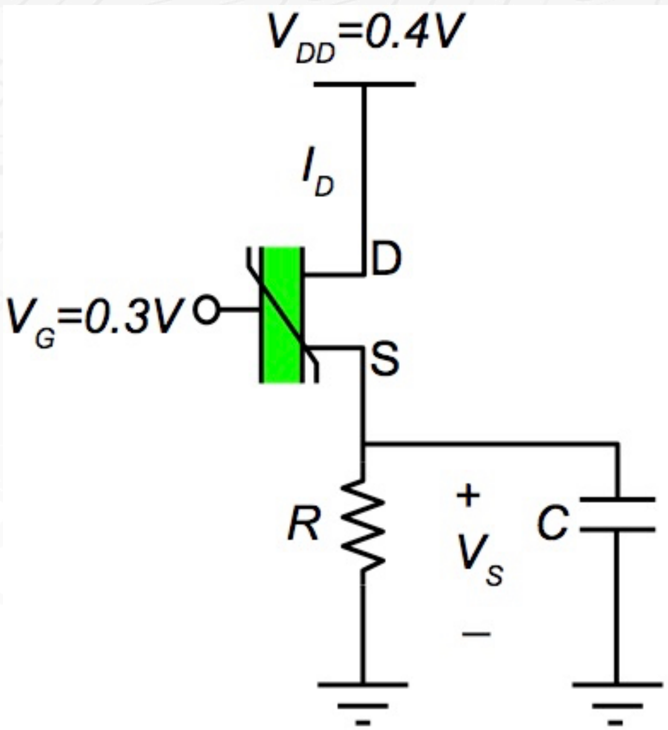
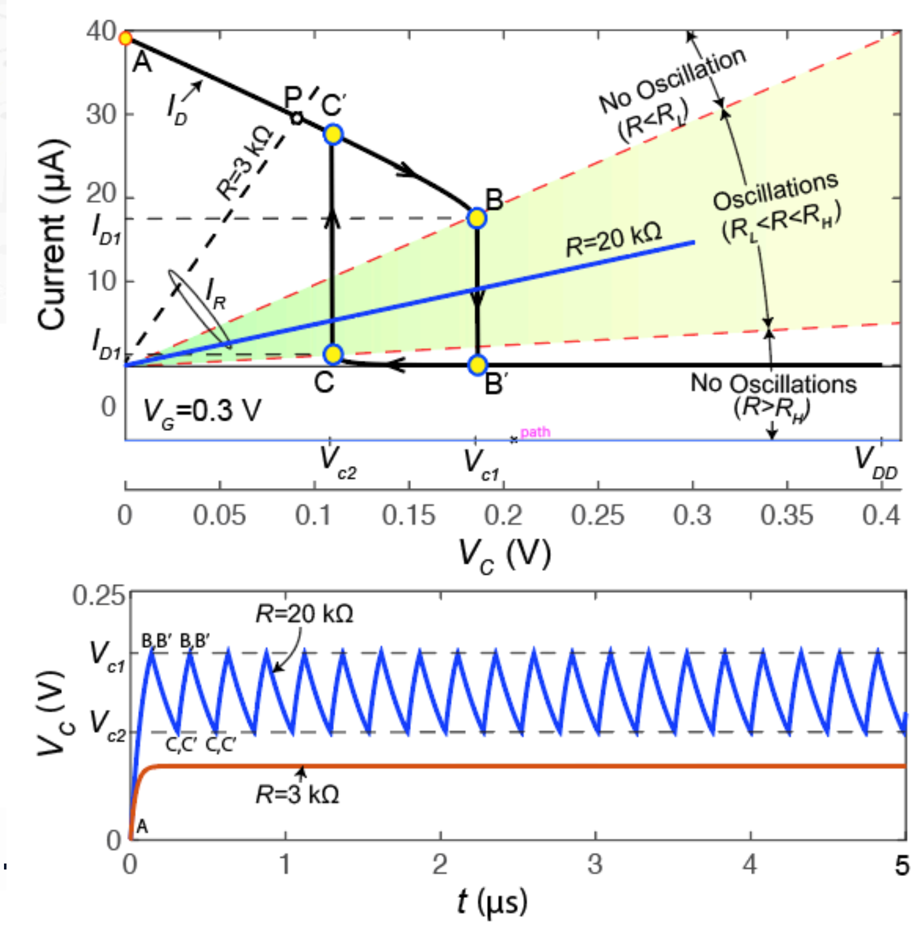
A Ferroelectric Oscillator

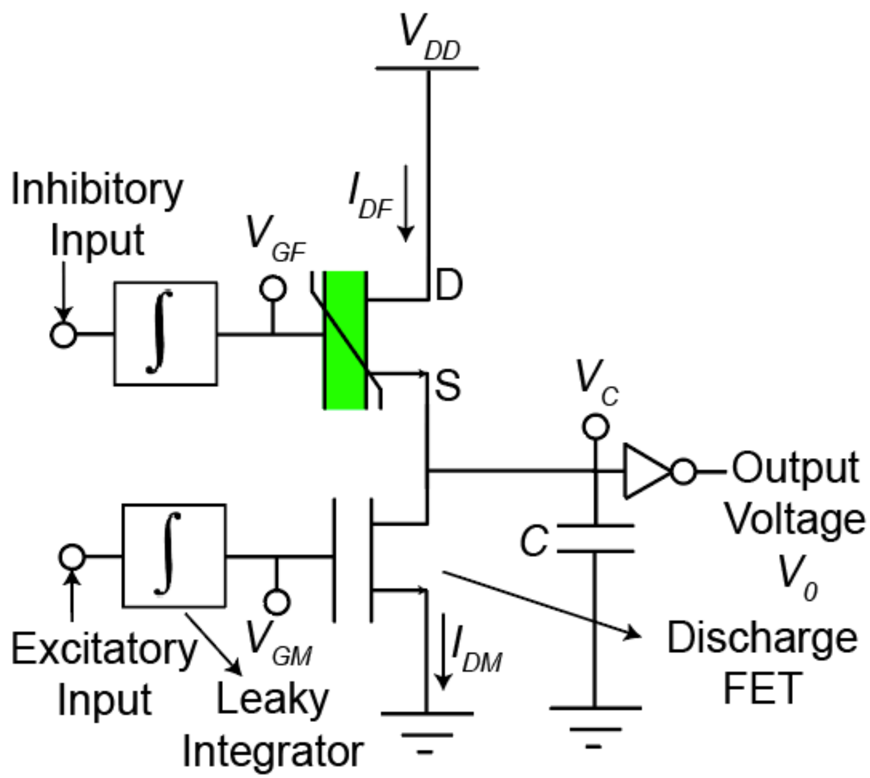


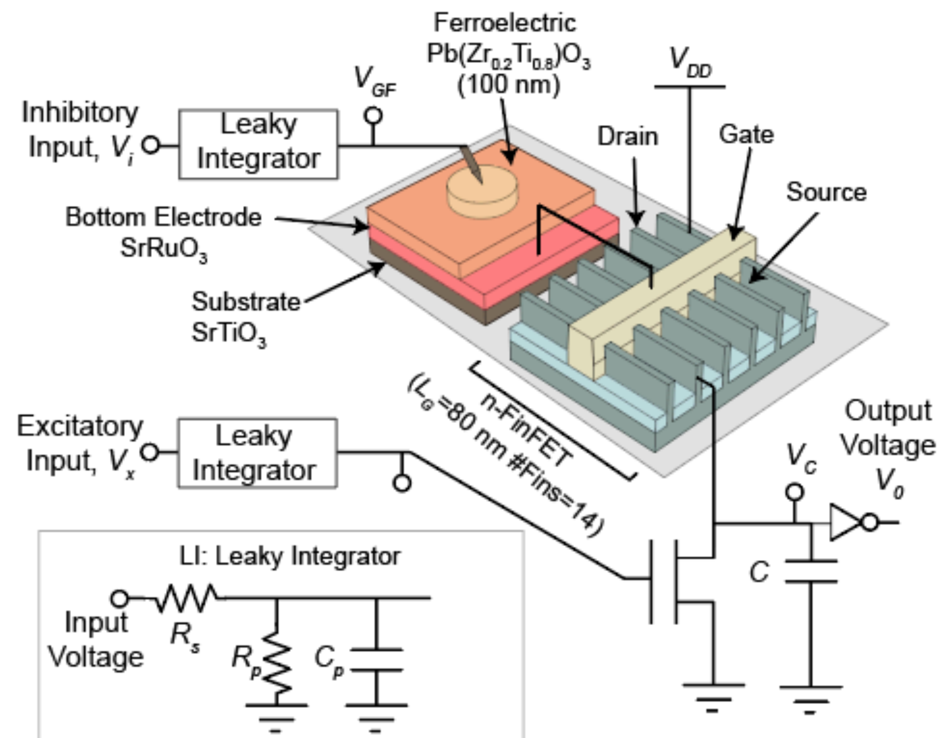


Oscillations can be controlled by the R or V_G.

Z. Wang et al. *IEEE Electron Device Lett.* vol. 38, no. 11, pp. 1614–1617, 2017.

A Ferroelectric Spiking Neuron: Experimental setup





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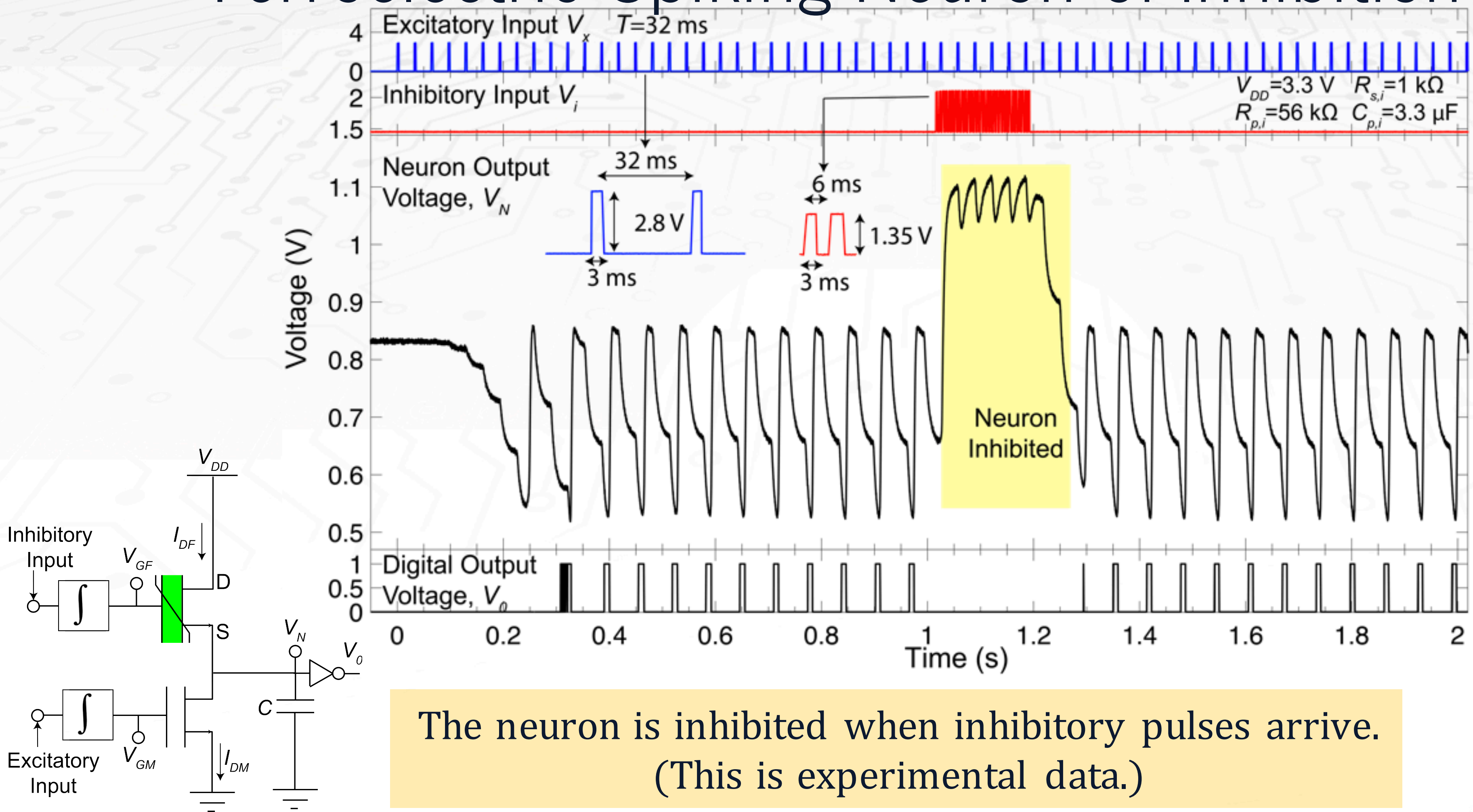
Ferroelectric Spiking Neuron of Inhibition



The neuron is inhibited when inhibitory pulses arrive.
(This is experimental data.)

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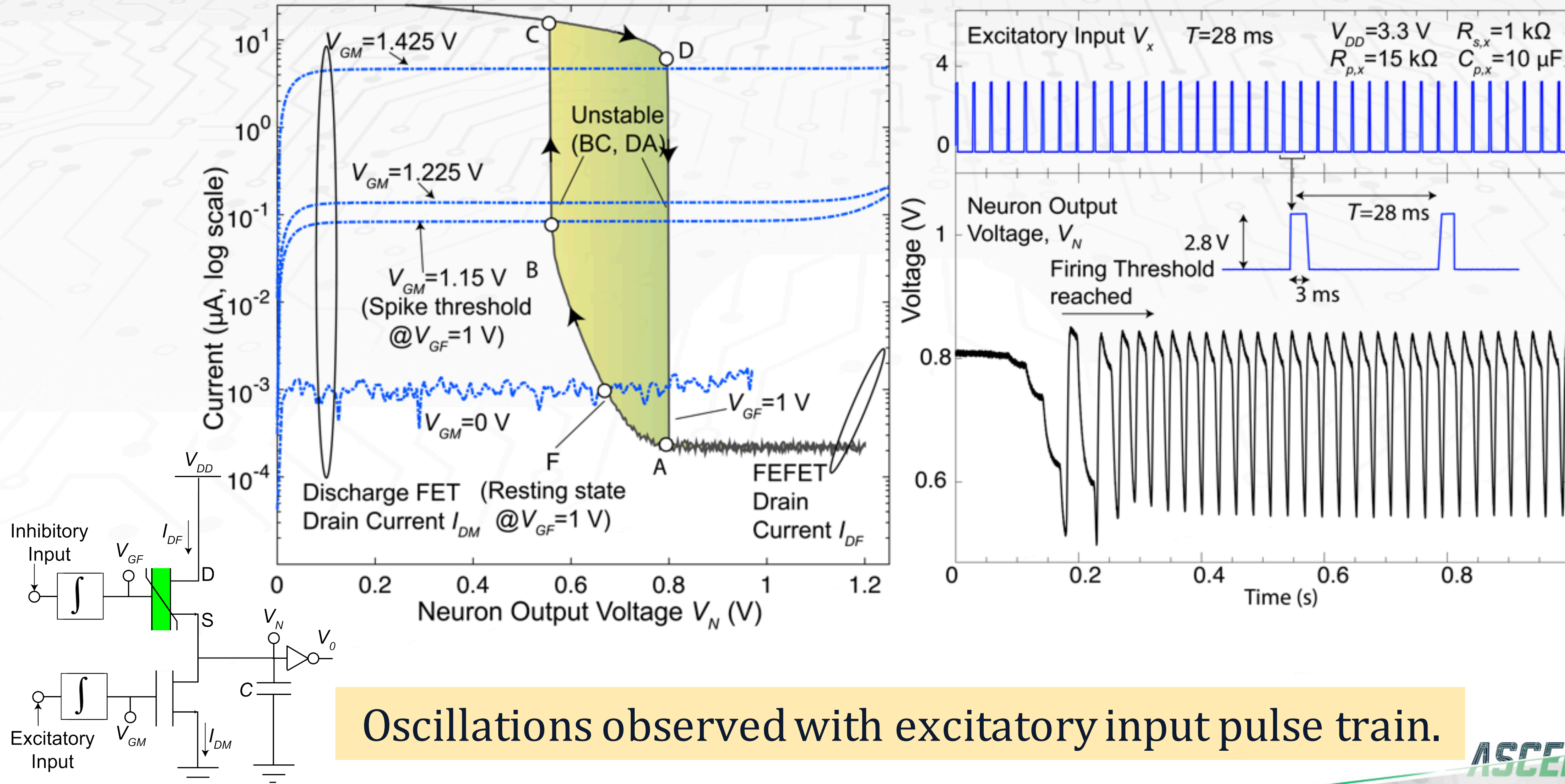
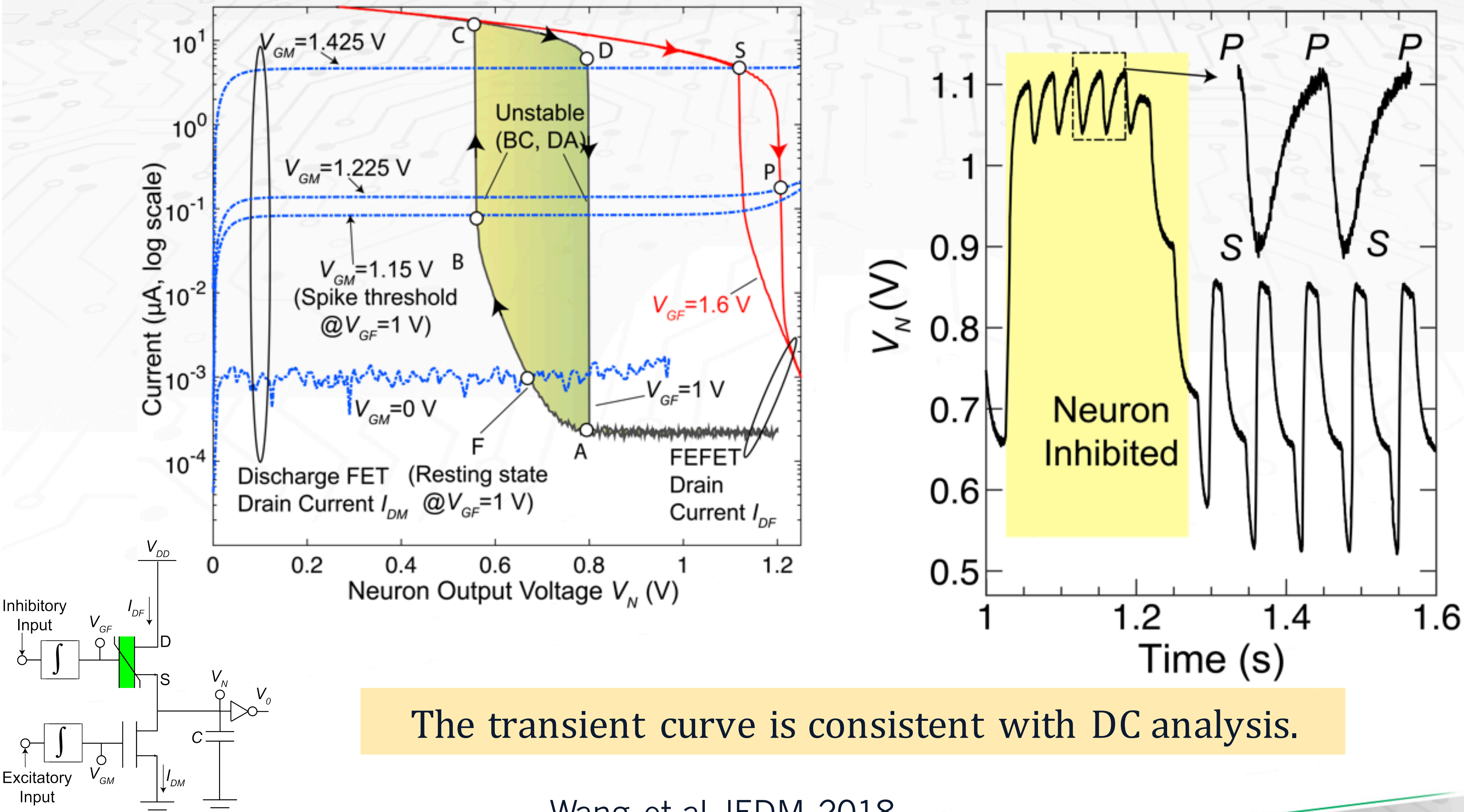
Demonstration of A Ferroelectric Spiking Neuron



Oscillations observed with excitatory input pulse train.

Demonstration of Inhibition



The transient curve is consistent with DC analysis.

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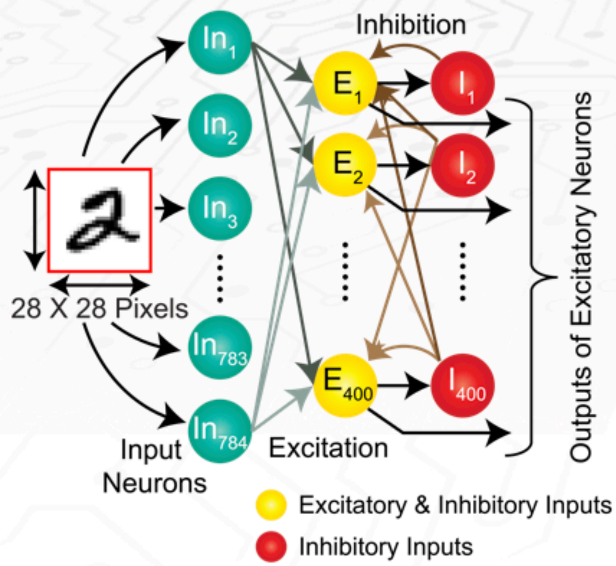
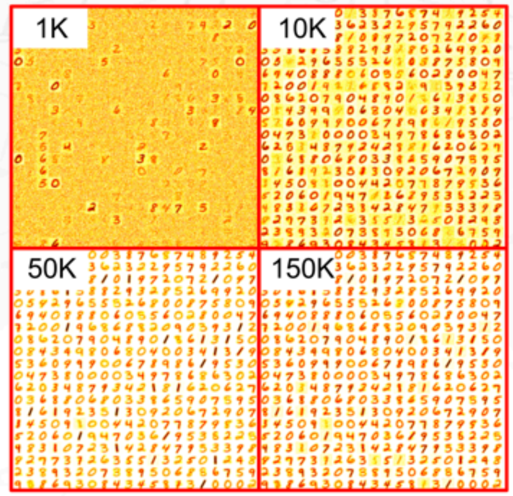
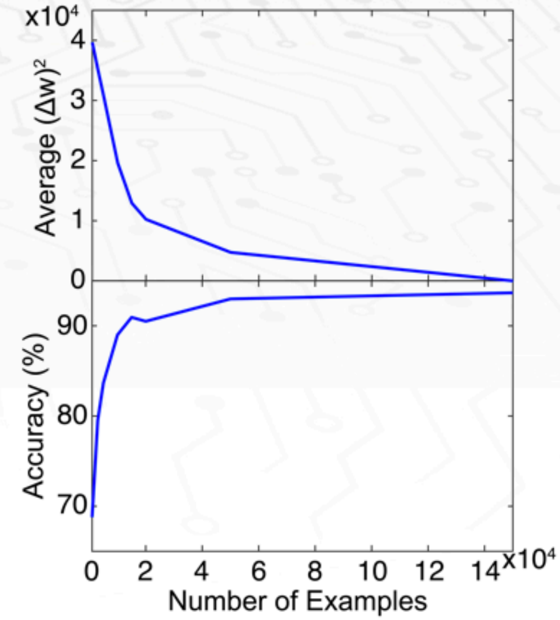
Ferroelectric SNN for Unsupervised Clustering





Unsupervised clustering of handwritten digits over training epochs



STDP for weight updates

Classification accuracy of 93% on MNIST dataset

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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

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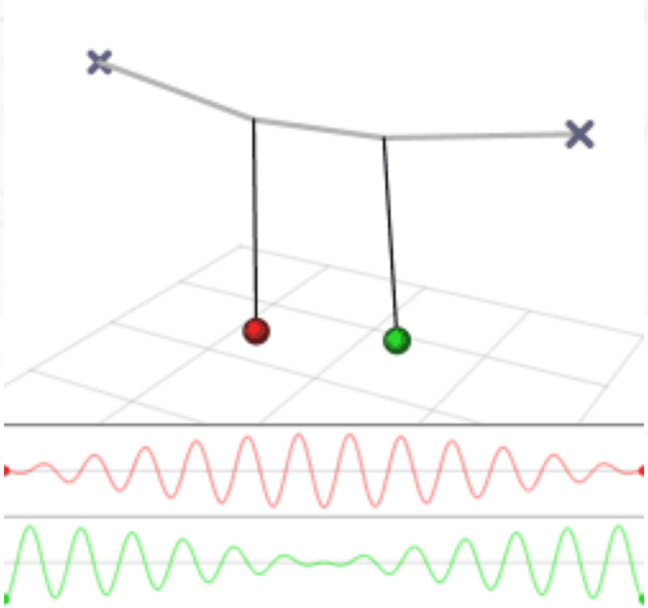
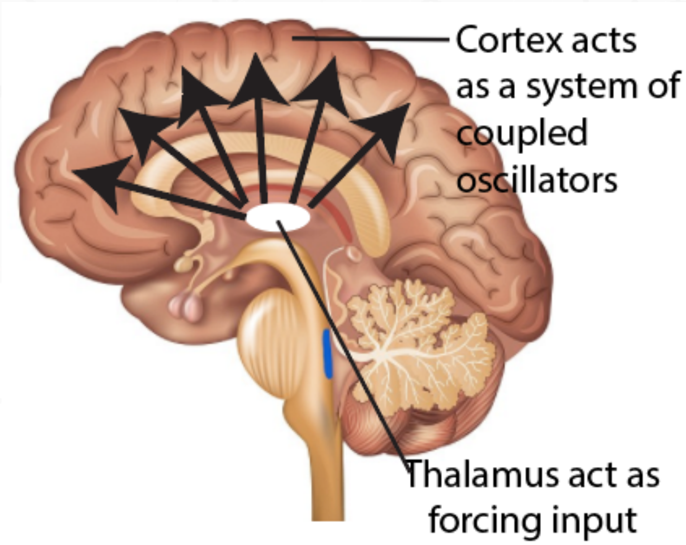
Beyond SNNs: Continuous Time Dynamical Systems-Coupled Oscillators

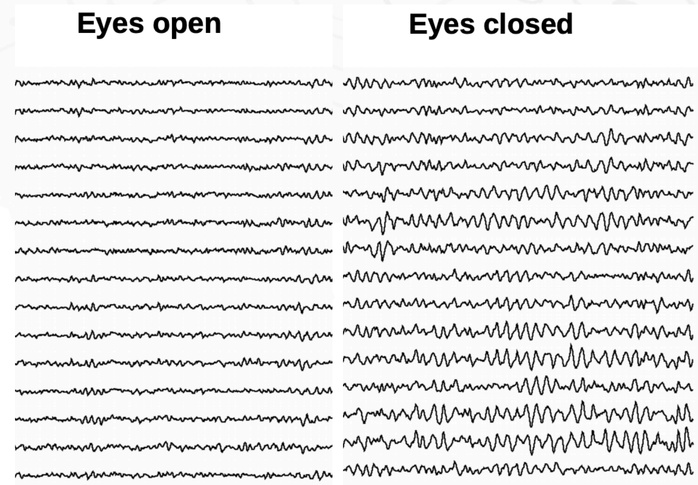
A Physics Example: Coupled Pendulums



A Biological Example: Primary Visual Cortex



Collective Spatio-temporal oscillations



https://www.uni-potsdam.de/cosmos-itn/wp-content/uploads/2018/06/Aberdeen_Lectures_Montbrio1.pdf

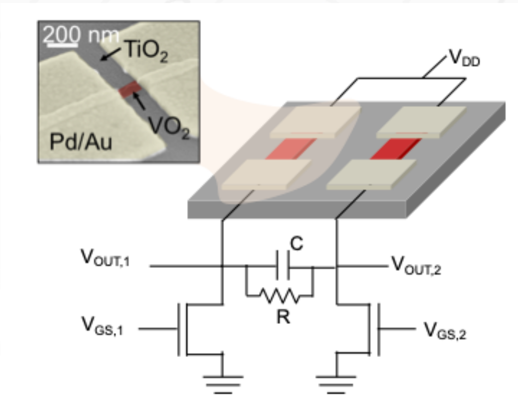
(More to come Arijit Raychowdhury')

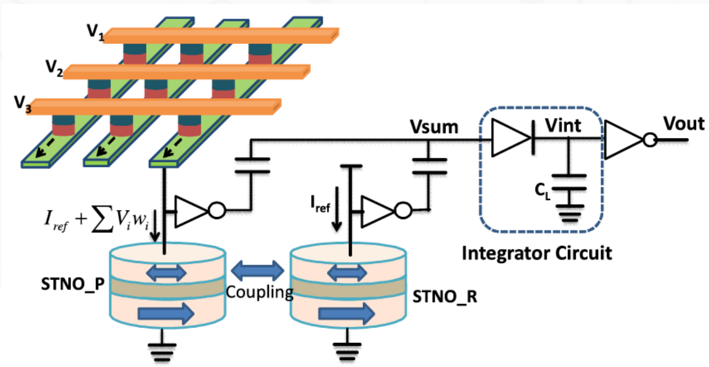
Continuous Time Dynamical Systems With **Emerging Devices**

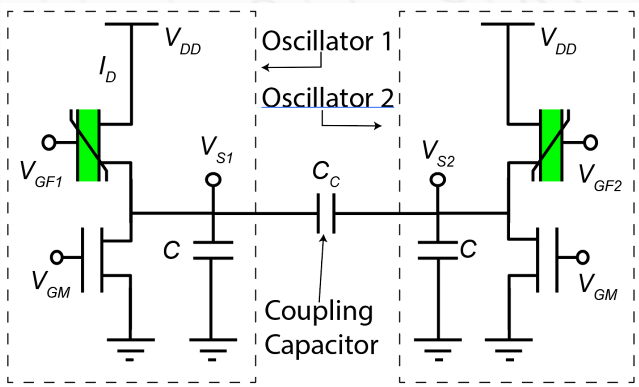
Metal→Insulator Transition Material based Oscillators

Spintronic Oscillators

Ferroelectric Oscillators





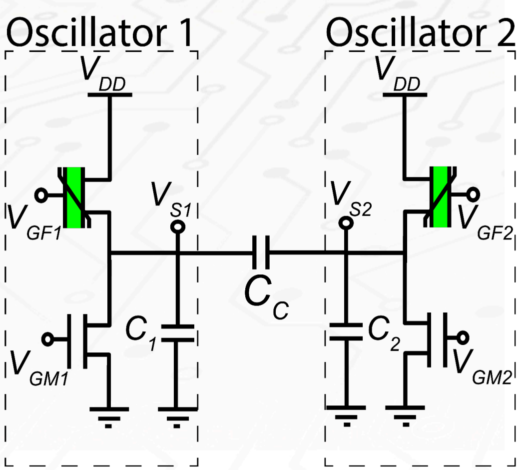


Shukla et al. Sci. Rep. 2014. IEDM 2014
Chen et al. APL 2018

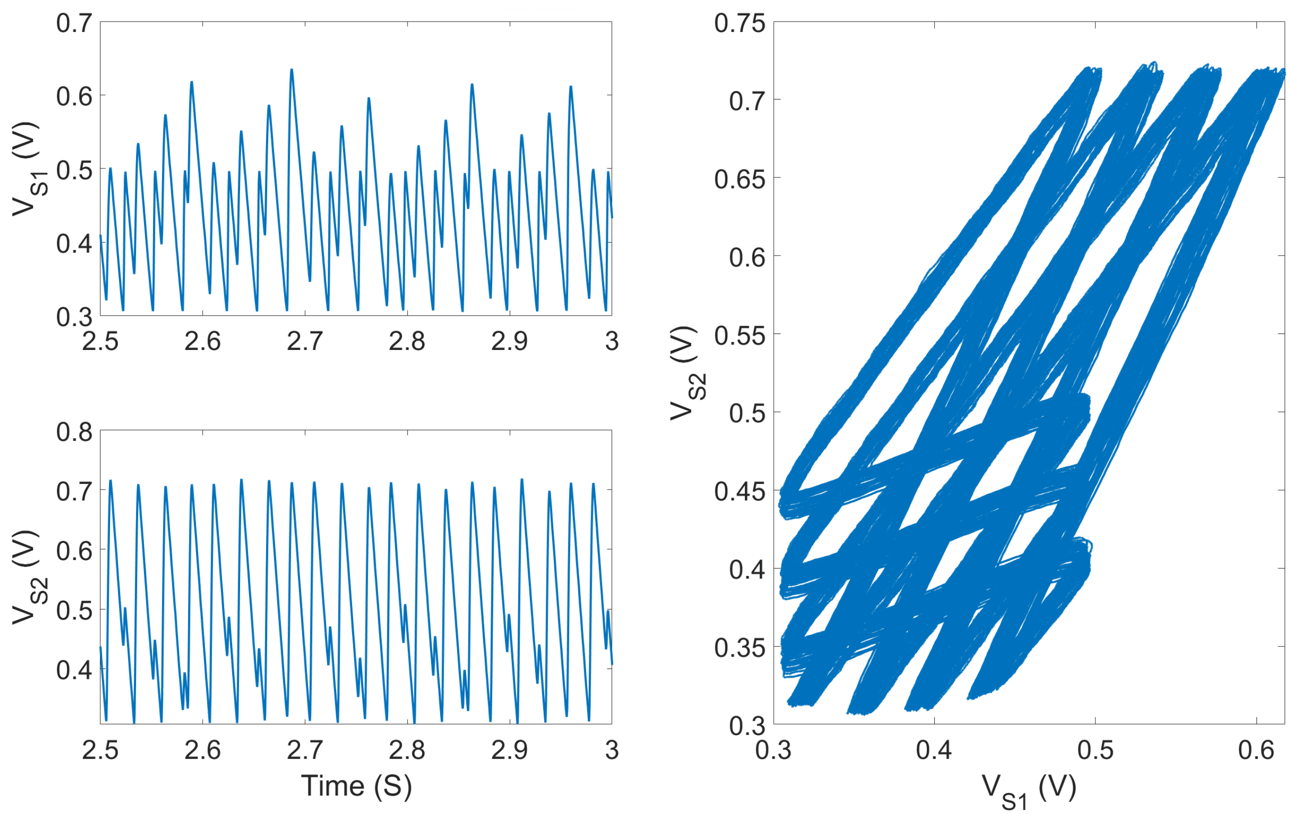
Yogendra et al. IEEE Trans. Magnetics, 2015
Nikonov et al. JXCDC 2015.

Wang et al. IEEE EDL 2017

Coupled FE Oscillators: Synchronized



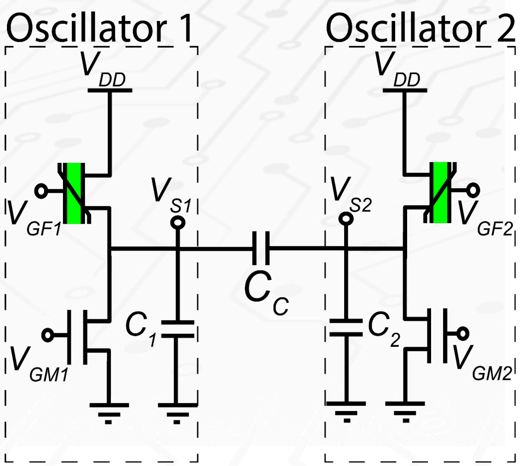
$V_{GF1}=V_{GF2}=0.6$ V
$V_{GM1}=1.55$ V
$V_{GM2}=1.6$ V

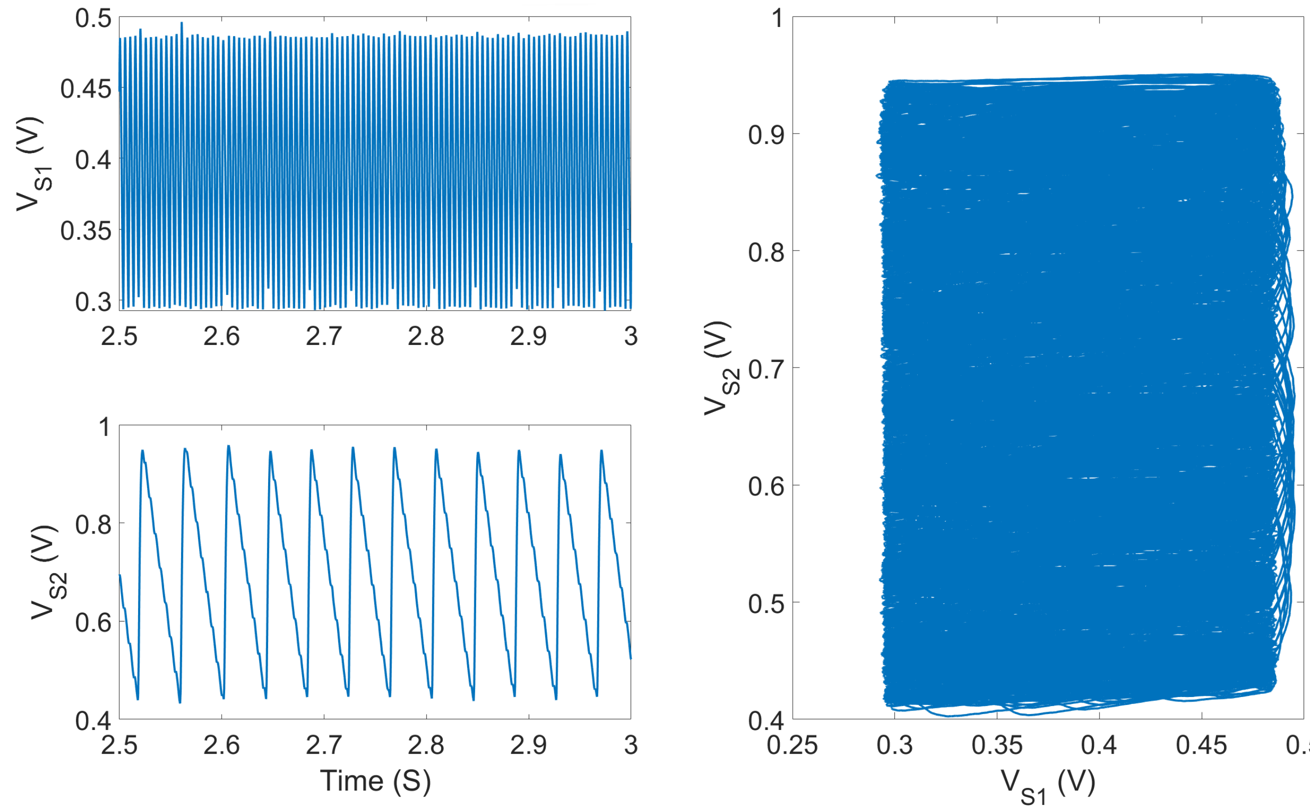


"Stable" orbits—i.e., synchronized—when V_{GM1} and V_{GM2} are close.

Wang et al. (unpublished)

Coupled FE Oscillators: Unsynchronized





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

$V_{GM1}=1.7$ V

$V_{GM2}=1.55$ V

No stable orbits—i.e., unsynchronized—when V_{GM1} and V_{GM2} are far apart.

Wang et al. (unpublished)

Thanks/Questions and Comments

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