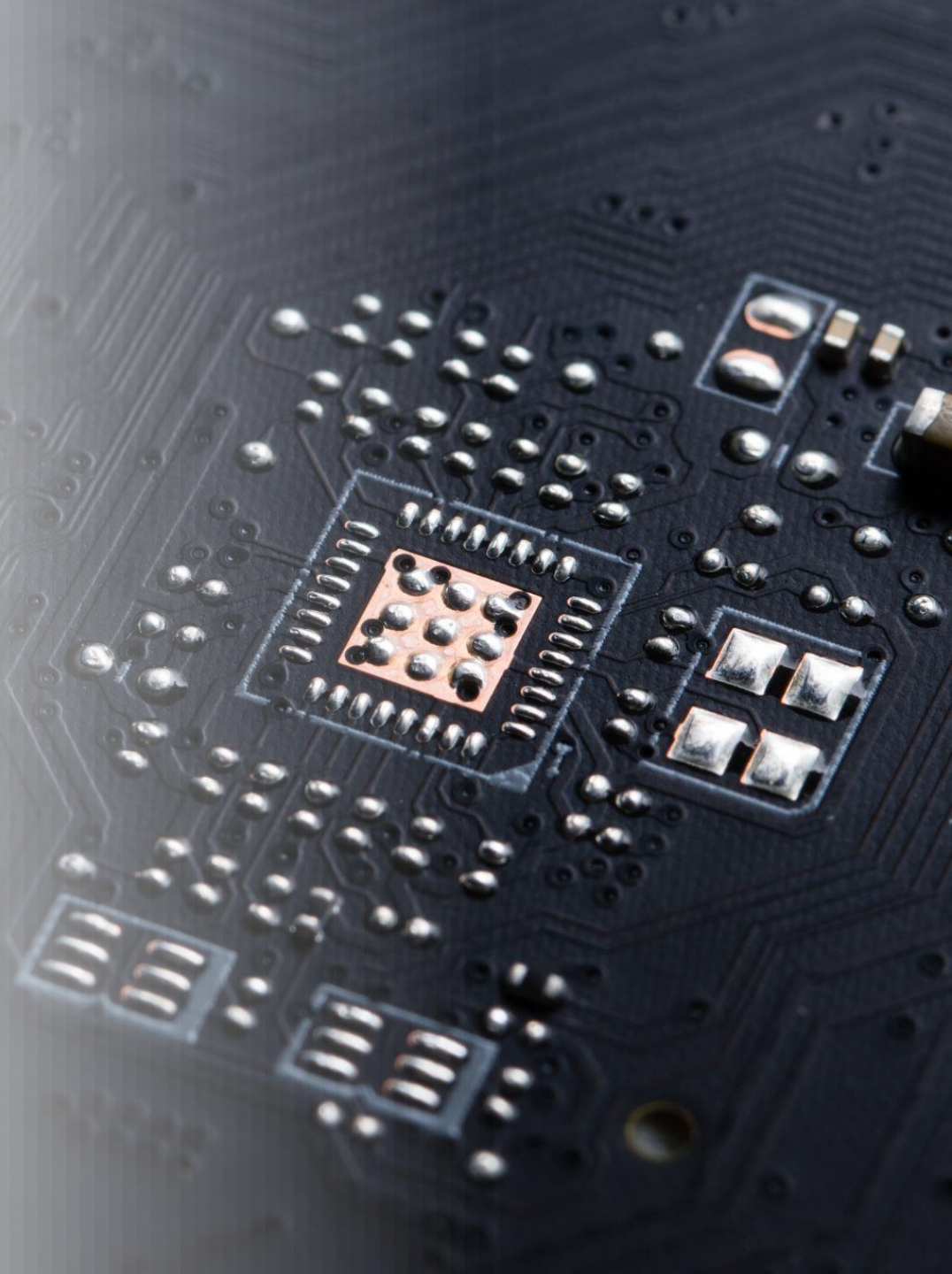
SOI Implementation of Spiking Equilibrium Propagation for Real-Time Learning

Amruta Parulekar (20d070009)

Anubhav Bhatla (200070008)

Tanmay Joshi (200070027)

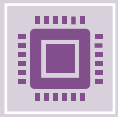


Introduction

Backpropagation is a neural network training method involving calculation of the gradients of the loss function while moving backwards through the layers.

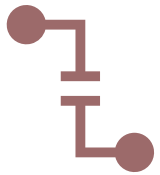
It is computationally intensive, requires labelled training data and treats artificial neural networks (ANNs) as static systems, disadvantages which are countered by Equilibrium propagation (EP)

EP finds stable equilibrium states of minimum energy by using feedback connections that iteratively update the network activations based on input data, current state and target state.



EP mimics the way neurons reach equilibrium while learning and spiking EP employs spiking neural networks (SNNs), using spike-based transmission, proving suitable for tasks requiring precise timing

Background

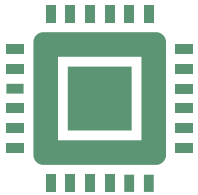


Energy-based models (EBMs)

Assign energy scores to different model configurations for the observed and generated data.

Training: Minimize energy function

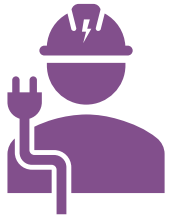
Testing: Find configuration with lowest energy function



45nm CMOS Technology

Widely used for integrated circuit design

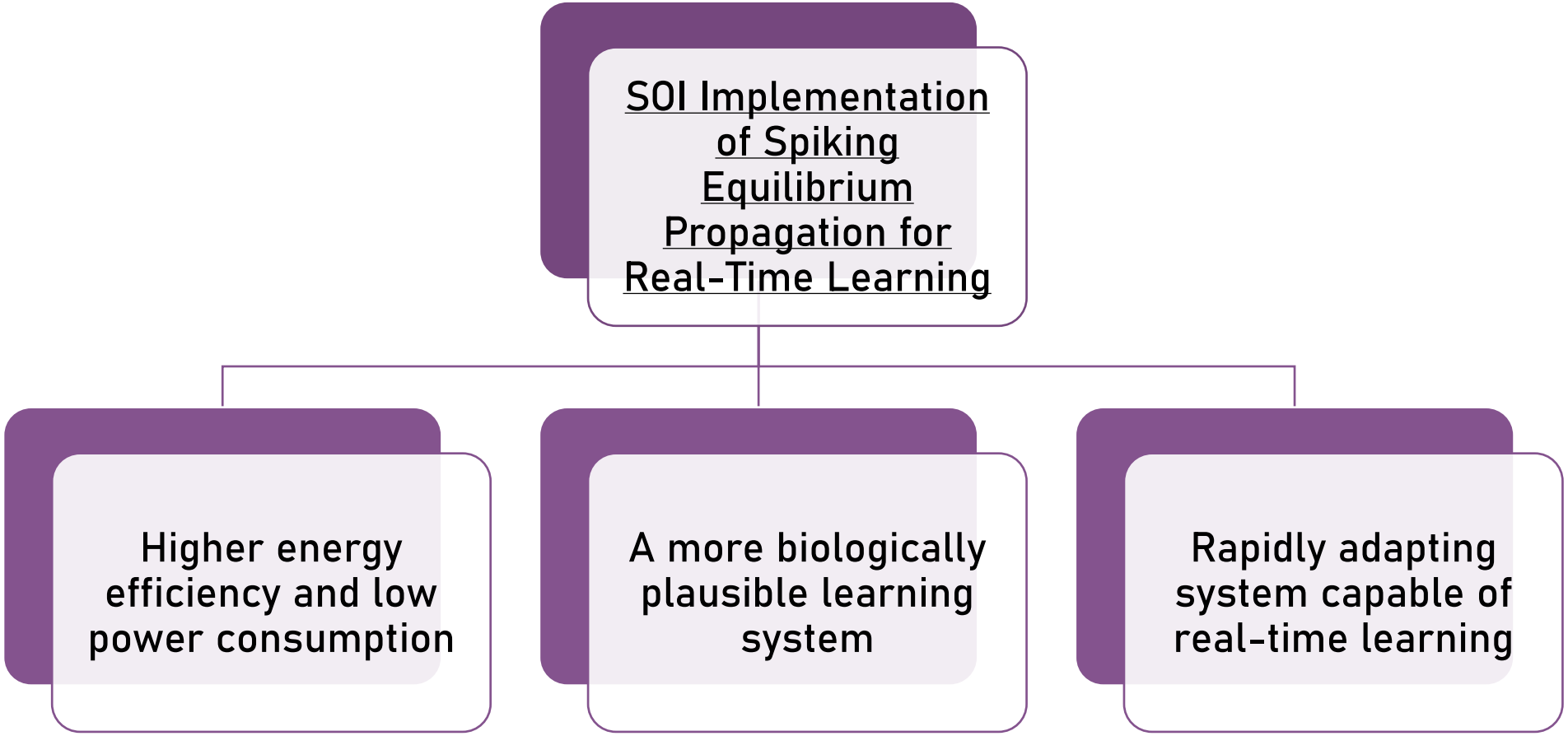
Is recognized for its energy efficiency, low power consumption, and high integration capabilities.



Real-time learning

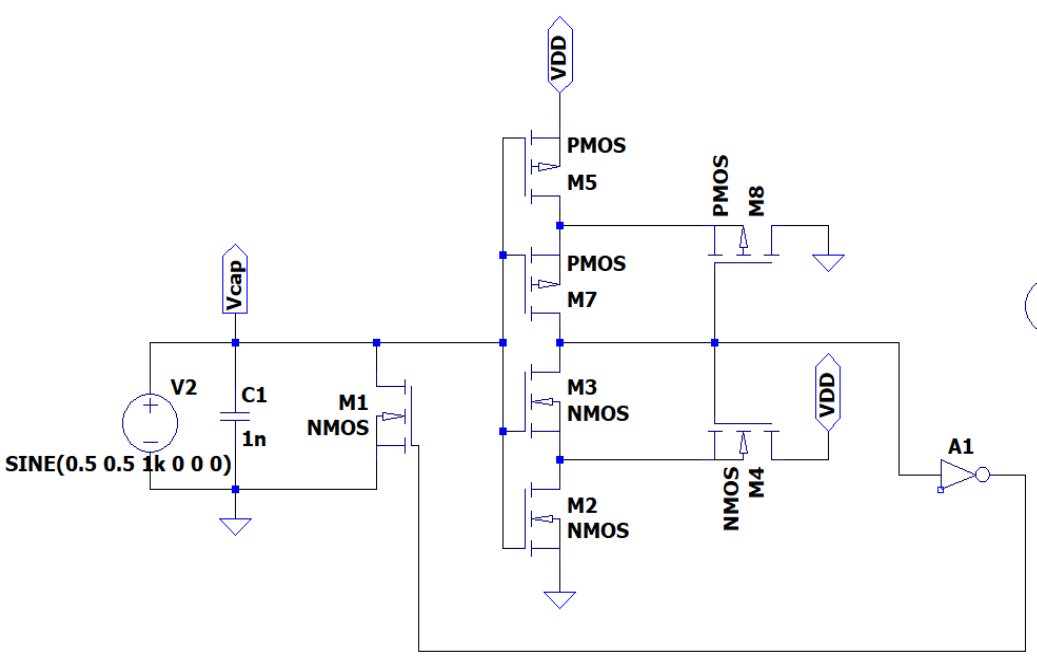
Involves a system that adapts its parameters instantaneously as input data changes with time

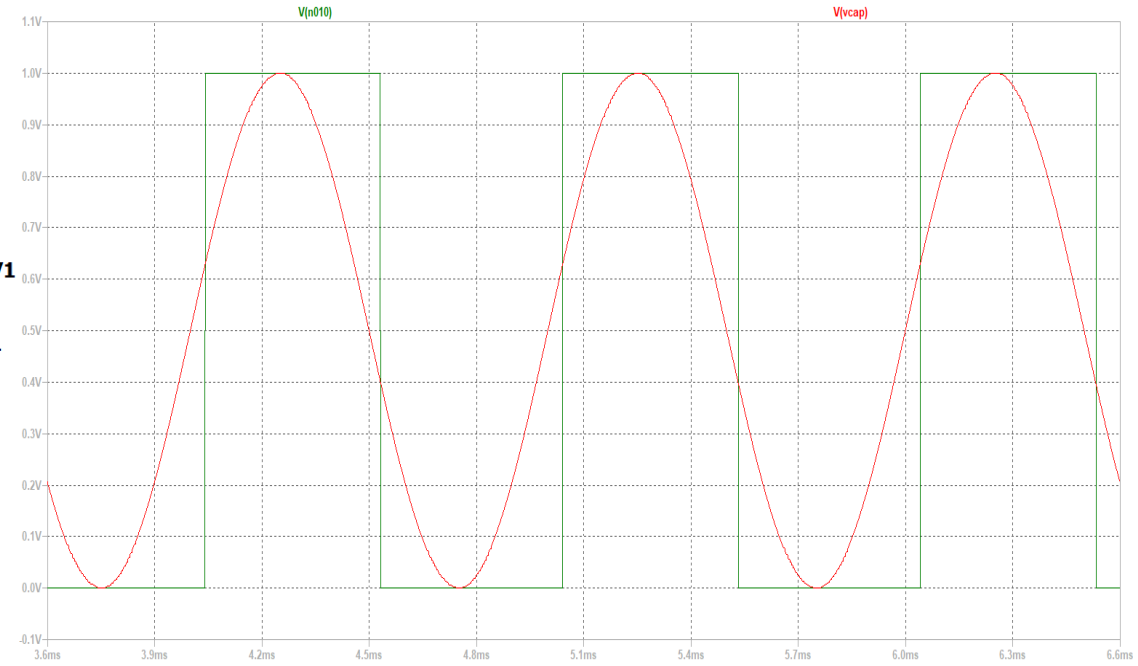
Objectives


SOI Implementation of Spiking Equilibrium Propagation for Real-Time Learning
Higher energy efficiency and low power consumption
A more biologically plausible learning system
Rapidly adapting system capable of real-time learning

Experimentation flow

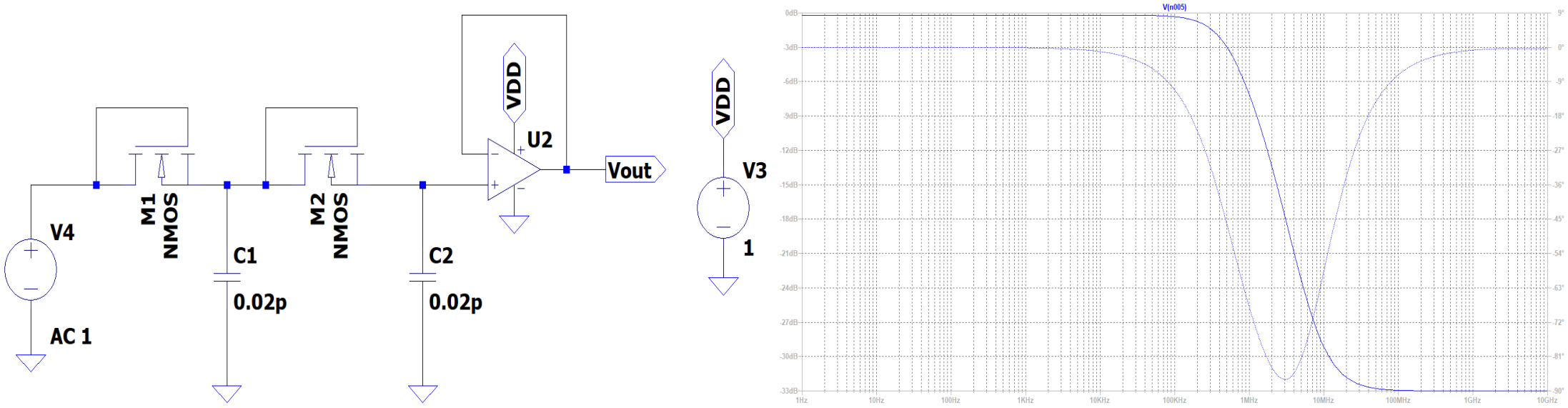
Integrate-and-Fire circuit





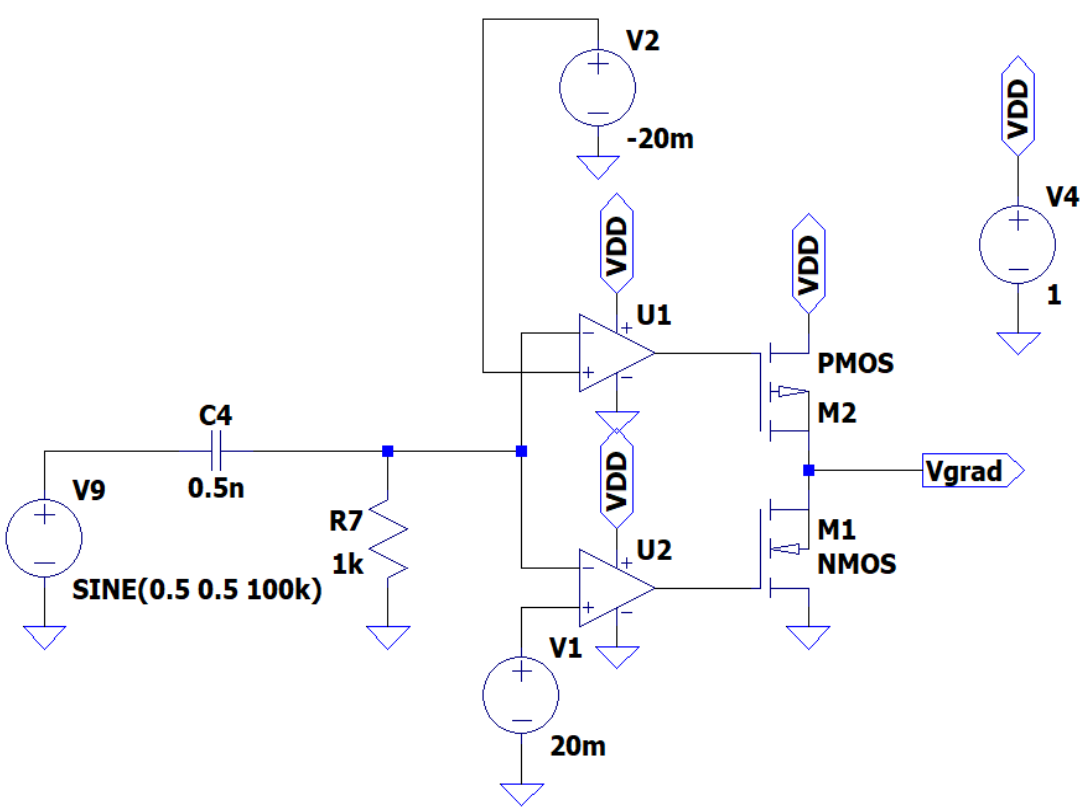
- This circuit simulates the spiking behavior of a LIF post-synaptic neuron
- It employs a Schmitt trigger generating spikes through rapid switching when the input voltage reaches a threshold

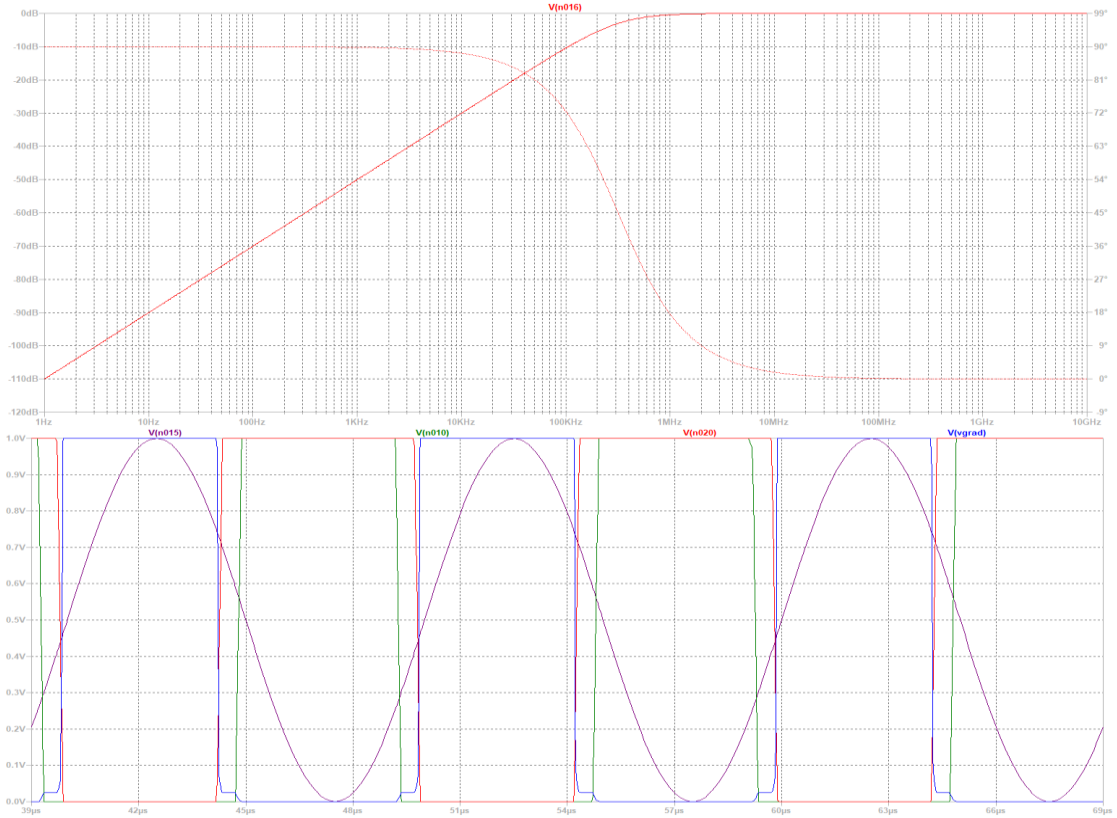
Two-stage Low-pass filter



- This circuit ensures rapid voltage increase with each spike and slow decay between spikes
- It uses two diode-connected nMOS devices in series with capacitors from each diode's output to ground to leaky-integrate the IFC output

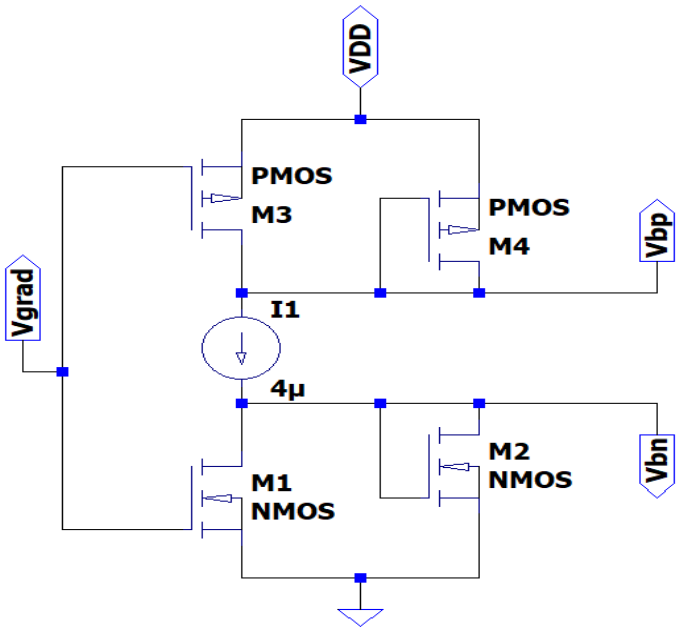
Derivative circuit

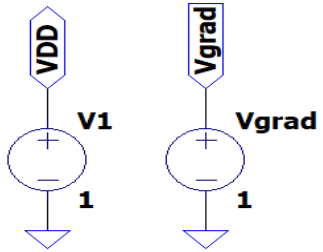


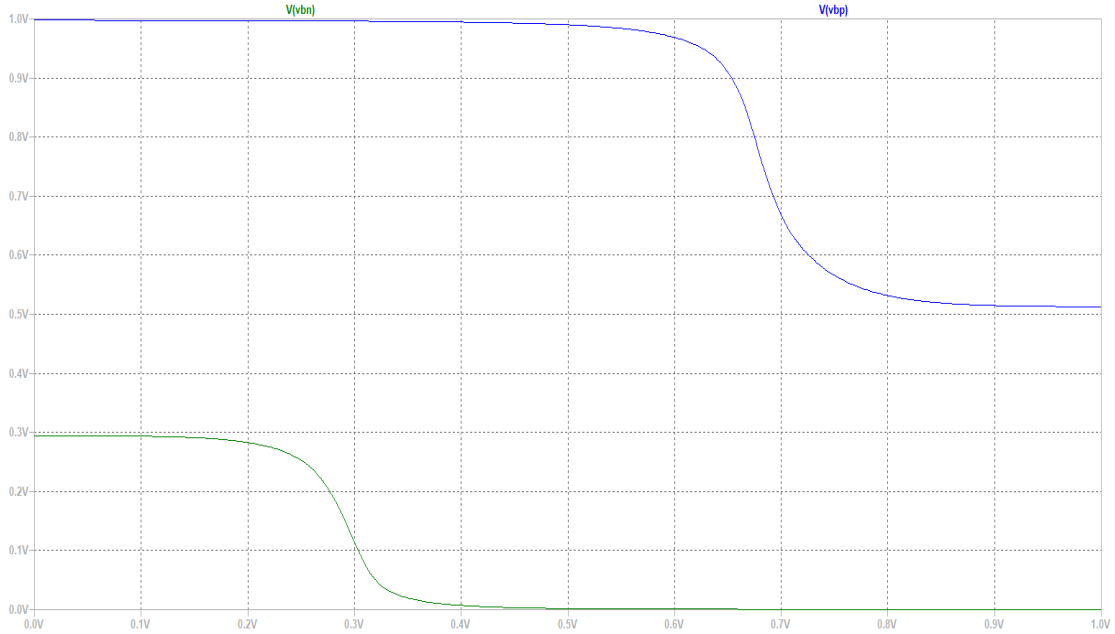


- This circuit produces an output signal proportional to the derivative of the input signal
- It is constructed using a differential amplifier connected in an RC feedback

Bias circuit

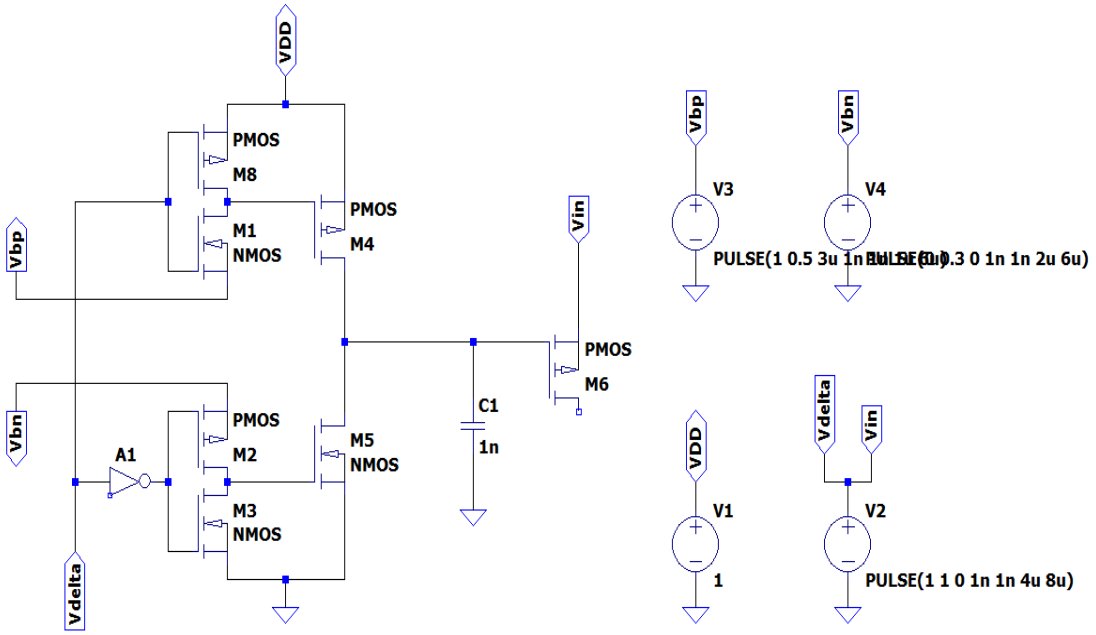


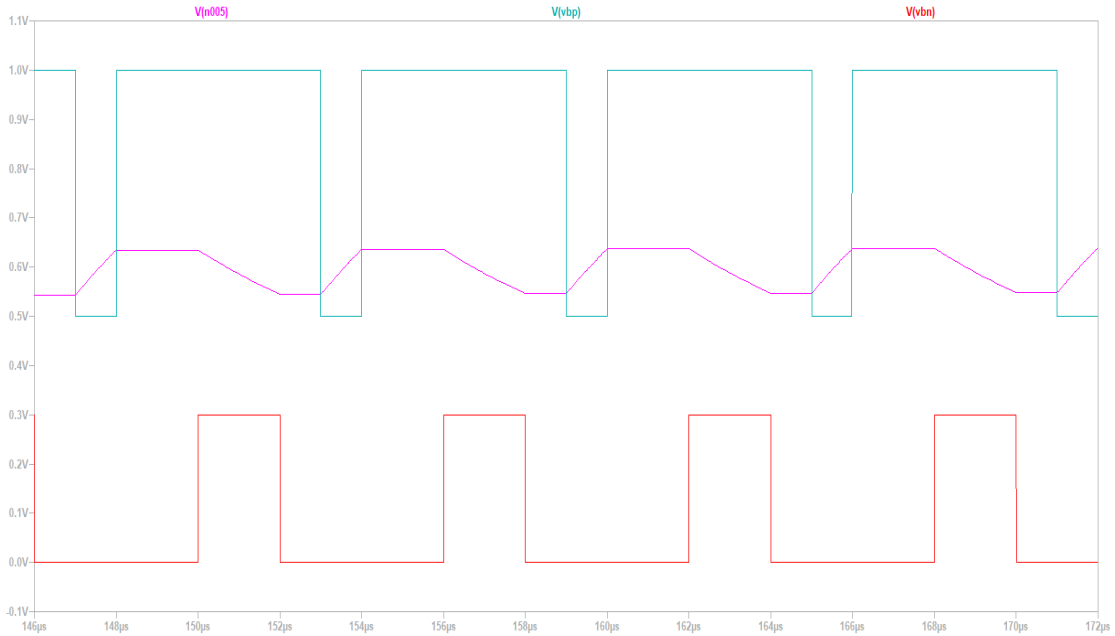




- This circuit takes the gradient of the spike rate as input and outputs bias voltages (Vbp and Vbn) to the synapse circuit.
- Based on the gradient values, M3 & M4 control Vbp and M2 & M1 control Vbn

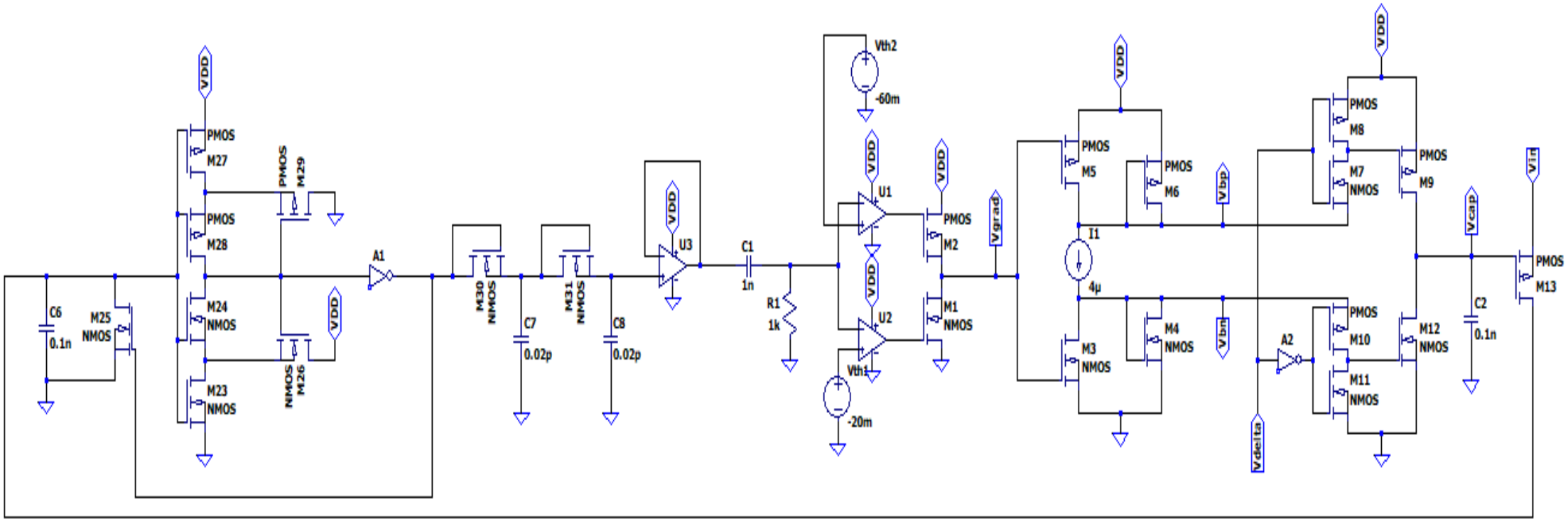
Synapse circuit



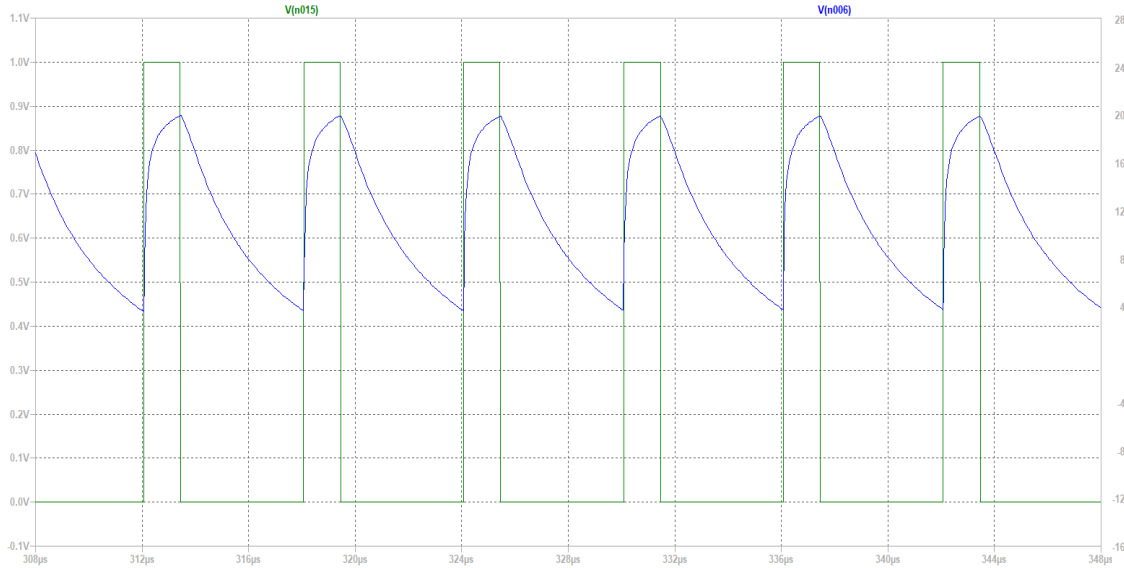


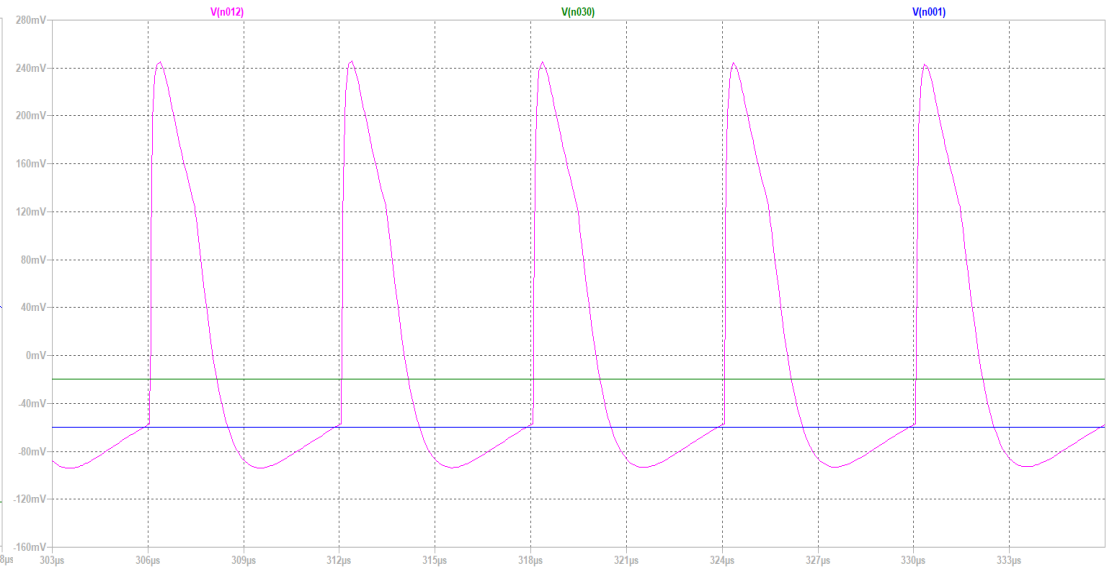
- This circuit processes inputs from the presynaptic and post-synaptic neurons to generate an output fed back to the post synaptic IFC.
- It involves a capacitor that charges, discharges or remains steady based on different input conditions

The complete circuit



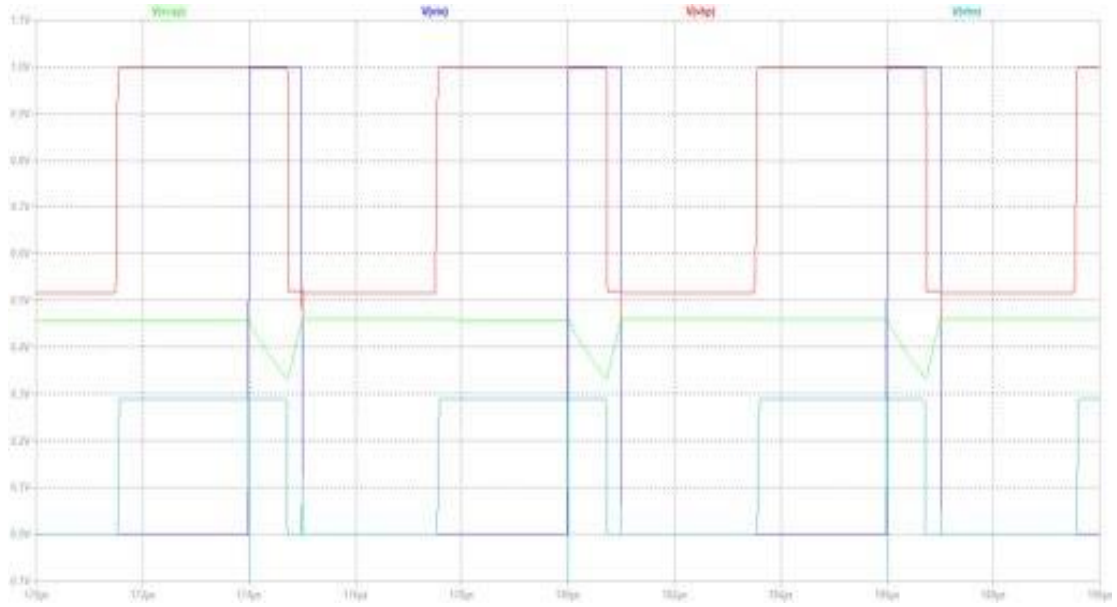
Results





- Post-synaptic neuron spikes
- Analog spike rate for post-synaptic neuron
- Threshold voltages
- Post-synaptic neuron Spike-rate derivative

Results



Output capacitor voltage

Presynaptic neuron spikes

Bias voltages

Power values:

Total power consumption=82.65uW

Power consumed by synapse circuit=8.79uW

Conclusion

WE HAVE SUCCESSFULLY SIMULATED THE NEURON AND SYNAPTIC CIRCUIT OF THE SPIKE EQUILIBRIUM PROPAGATION HARDWARE USING 45NM CMOS TECHNOLOGY.

WE HAVE CASCADED THE FIVE CIRCUIT BLOCKS SUCH THAT EACH OPERATES WITHIN ITS REQUIRED REGION OF OPERATION. THEY ARE WORKING AS INTENDED.

THIS COMBINED CIRCUIT GIVES US A LOW-POWER AND ENERGY EFFICIENT, BIOLOGICALLY INSPIRED ALGORITHM FOR REAL TIME LEARNING TASKS.

References

[1] B. Scellier and Y. Bengio, "Equilibrium propagation: Bridging the gap between energy-based models and backpropagation," Frontiers in Computational Neuroscience, vol. 11, 2017. [Online]. Available: https://www.frontiersin.org/articles/10.3389/fncom.2017.00024

[2] B. Taylor, N. Ramos, E. Yeats, and H. Li, "CMOS implementation of spiking equilibrium propagation for real-time learning," in 2022 IEEE 4th International Conference on Artificial Intelligence Circuits and Systems (AICAS), 2022, pp. 283–286.

THANK YOU