THE NEUROSPIKE CIRCUIT

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Abstract

This abstract presents a novel and effective analog circuit for the Leaky Integrate-and-Fire (LIF) model, which is a key part of Spiking Neural Networks (SNNs). The LIF model imitates how a biological neuron behaves. It works by gathering incoming charge, which represents excitatory and inhibitory post-synaptic currents. At the same time, a leakage component causes the stored potential to gradually decrease back to a resting state, simulating the ion leakage across the cell membrane. When the membrane potential goes beyond a set threshold voltage, the neuron produces an output spike, and its potential resets immediately.

Our circuit design, built using the 180nm CMOS process, aims to improve this process for low power and high efficiency. We created a design that lowers the number of components, making the circuit smaller and easier to scale for integration into bigger neural systems. This method enables the development of cascaded neural systems, where one neuron's output can directly drive the input of another, creating a complete and functional SNN. The simulation results confirm the circuit's effectiveness and show its promise for real hardware-based SNN applications.

1. Theoretical Background

1.1 The Leaky Integrate-and-Fire (LIF) Neuron Model

The LIF neuron is a simplified yet powerful model of a biological neuron. Its behavior is mathematically described by a differential equation(1)

$$cm\frac{dvm}{dt} = -gm1(vm - vreset) + cm\,\partial v \sum i(t) \quad (1)$$

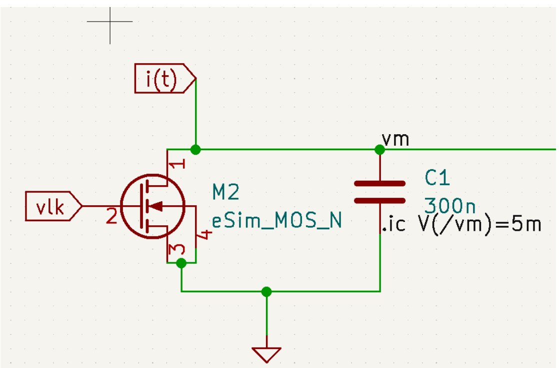


FIG1.1.0 : **LIF MODEL**

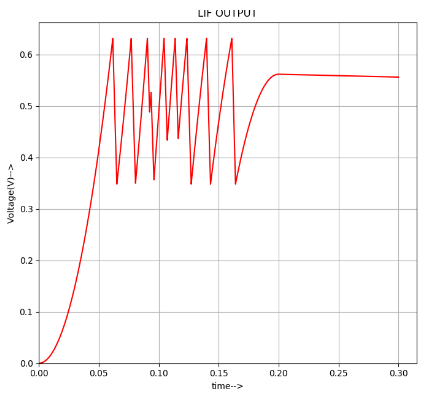


FIG 1.1.1 :**V_m v/s Time(s)**

FIG 1.1.0 shows LIF neuron model. Here, the input current Iin charges the membrane capacitor $\mathbf{C_m}$, which increases the membrane voltage $\mathbf{V_m}$. The leak transistor $\mathbf{M_2}$,controlled by $\mathbf{V_{lk}}$, represents the ongoing leakage of the membrane potential. When $\mathbf{V_m}$ reaches a certain threshold, the Schmitt trigger produces the output spike $\mathbf{V_{spike}}$. The Schmitt trigger also offers feedback to rapidly discharge Cm, resetting $\mathbf{V_m}$ to $\mathbf{V_{reset}}$.

1.2 The Sub-threshold CMOS Schmitt Trigger

In the context of a neuron, this circuit is ideal for comparing the membrane potential against a threshold to generate a spike.

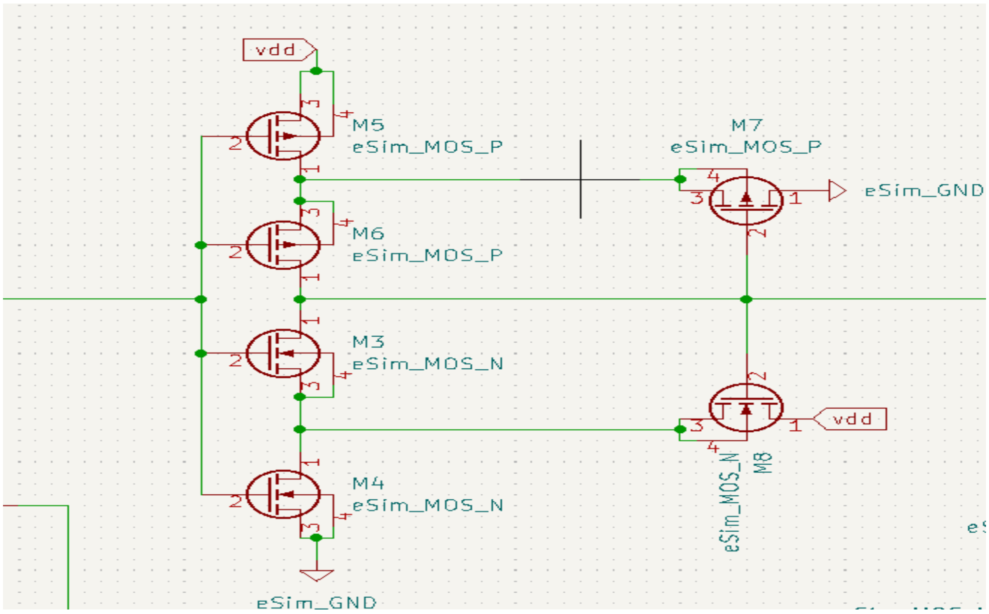


FIG 1.2.0:**Sub-threshold CMOS Schmitt Trigger**

A key feature of this design is its operation in the subthreshold region, where the gate-to-source voltage of the MOSFETs is below their threshold voltage. In this region, the transistor current is dominated by diffusion and shows an exponential dependence on gate voltage. This mode of operation leads to drastically reduced power consumption, making it a highly attractive choice for energy-efficient SNN hardware. This subthreshold design approach allows for the implementation of the LIF neuron's thresholding function with minimal power overhead, contributing to the overall efficiency of the neural system.

2. Design and Simulation

2.1 Design

Our proposed analog circuit design for the LIF model utilizes the 180nm CMOS process with a supply voltage of VDD=1V. The circuit is designed to function with low power, taking advantage of the subthreshold region of operation. The NMOS and PMOS transistors are designed with the same width and length, a common practice to simplify layout and ensure matched characteristics. The leaky current is established using a voltage Vlk=222mV, which biases the transistor into the subthreshold region. The neuron's integration capacitance is implemented with a 300nF capacitor.

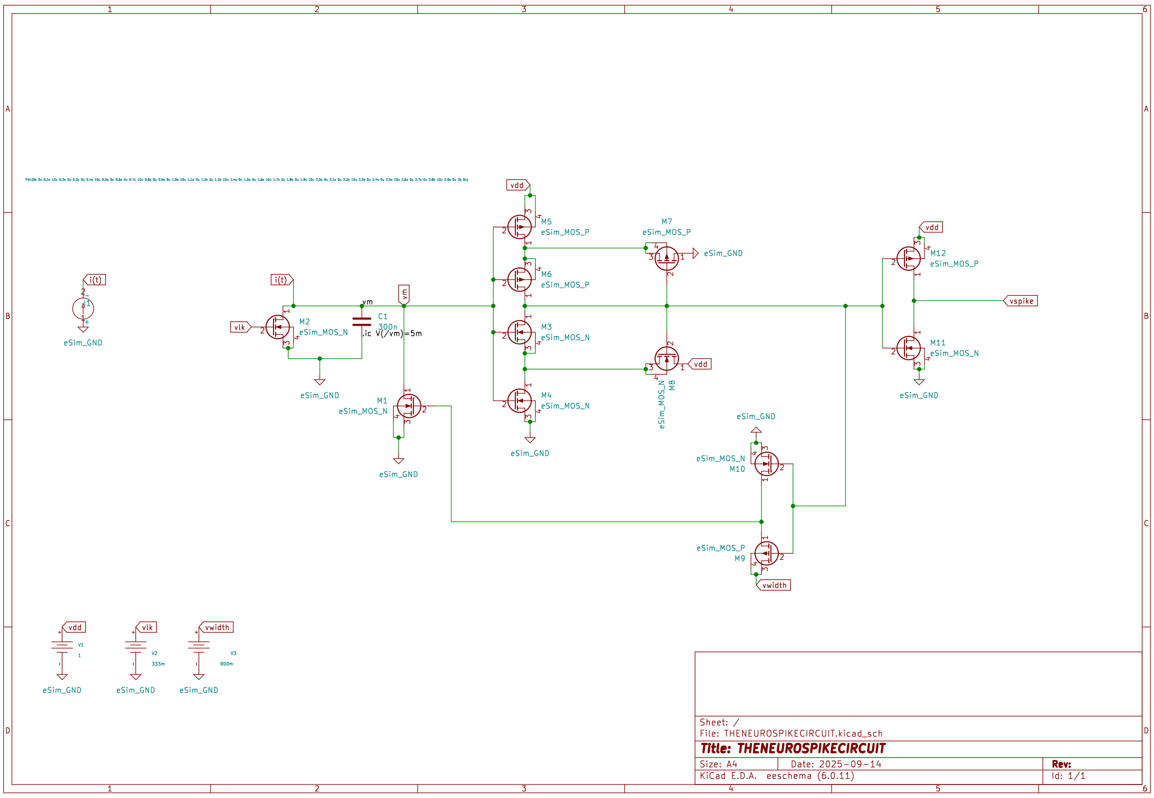


FIG 2.1.0:**THE NEUROSPIKE CITCUIT (TNC)**

This **TNC** circuit provides the necessary hysteresis to ensure stable switching and a clean output spike when the membrane potential crosses the threshold. This hysteresis comes from a positive feedback loop around an inverter, which acts as the center of the Schmitt trigger. The inverter's high gain in the transition region ensures a quick and clear change in the output voltage, which is key for producing a sharp, clean spike. The design aims to minimize the number of components for a compact and scalable implementation. This allows for easy cascading of multiple neurons to create larger, more complex SNN systems. We verified the functionality and performance of our circuit through thorough simulations.

2.2 Simulation

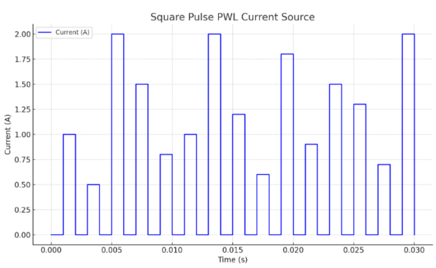


FIG 2.2.0 **i(t) vs T**

The input to the circuit is a current source, which charges the neuron's membrane capacitance to mimic the influx of ions in a biological neuron. This incoming current directly controls the rate at which the membrane potential rises.

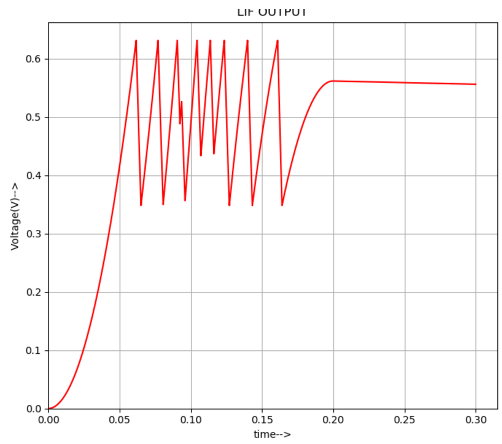


FIG 2.2.1 : **V_M VS T**

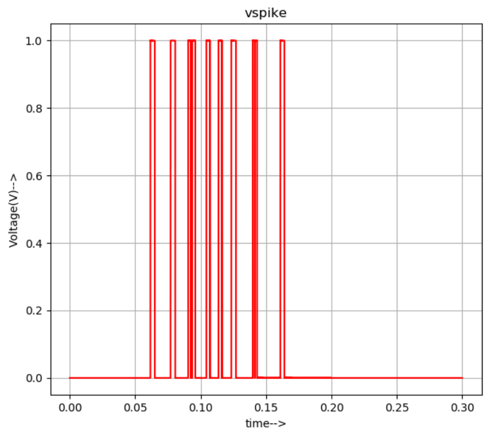
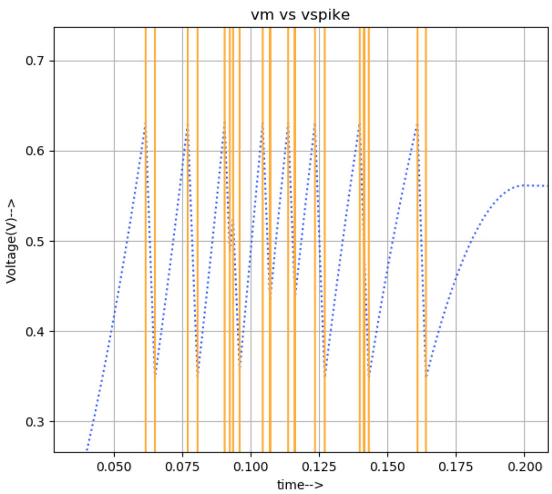


FIG 2.2.2 : **V_{SPIKE} VS T**



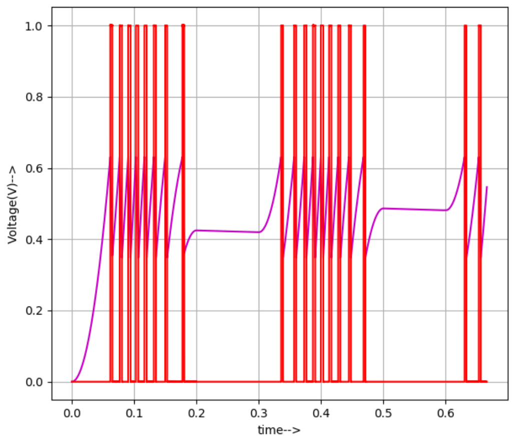


FIG 2.2.3 : **V_M & V_{SPIKE} (V_M >V_{TH})**

FIG 2.2.4:**V_M & V_{SPIKE} (V_M>V_{TH} & (V_M >V_{TH})**

FIG 2.2.3 shows When the membrane potential (V_m) reaches the threshold voltage (V_{th}), the neuron fires a spike(V_{spike}), and its potential is reset. such as in the time window from 0.2s to 0.3s, the Schmitt trigger remains in its stable low state, and no output spike is generated FIG 2.2.4.

3. References

[1] Zhitao Yang and Jianghan Zhu Analog Circuit Implementation of LIF and STDP Models for Spiking Neural Networks

[2] Luiz Alberto Pasini Melek, Anselmo Luís da Silva, Márcio Cherem Schneider, and Carlos Galup-Montoro. Analysis and Design of the Classical CMOS Schmitt Trigger in Subthreshold Operation