Design and Simulation of a Time-Frame Integrate-and-Fire (TIF) Neuron Circuit Using eSim

eSim Research Migration Project

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Abstract

In this work, a Time Frame Integrate and Fire (TIF) neuron circuit is designed and simulated using the open source eSim platform in 180 nm CMOS technology. The objective is to reproduce the cardinal behavior of a neuron namely integration of input signals and generation of output spikes within a controlled time frame operation. The circuit integrates synaptic inputs on a capacitor, compares the resulting voltage with a threshold, and generates a spike when the threshold is exceeded. fugacious simulations distinctly demonstrate the expected behavior, including gradual voltage accumulation, threshold triggered switching, and periodic spike generation. Even with a comparatively big technology node, the results confirm that the essential operating principles of a TIF neuron can be efficaciously realized using open-source tools.

1 Introduction

With the growing demand for energy efficient computing, neuromorphic systems have emerged as a promising alternative to conventional digital architectures. alternatively of relying on continuous voltage processing, these systems encode and process information through separate events or spikes, related to biological neurons.

Among the various neuron models, the Integrate and Fire (IF) neuron is one of the simplest and near widely used. The Time Frame Integrate and Fire (TIF) neuron builds upon this concept by introducing controlled time windows for integration and reset, allowing better temporal control and stability.

The aim of this project is to design and simulate a TIF neuron using the eSim platform as part of the FOSSEE Research Migration initiative. The focus is not on technology scaling but on verifying whether the core functional behavior integration, threshold detection, and spike generation—can be reproduced accurately in a 180 nm CMOS environment.

2 Circuit Description and Working Principle

The implemented circuit follows a standard structure consisting of four key blocks: a synaptic input network, an integration stage, a comparator, and a spike generation unit.

The synaptic network converts input voltage pulses into currents, which are then accumulated on a capacitor in the integration stage. This accumulation results in a gradual rise of the membrane voltage, mimicking the behavior of a biological neuron.
Once the membrane voltage crosses a predefined threshold, the comparator switches its state. This transition activates the spike generation circuit, producing a crisp output pulse that represents a neuron firing event.
A pivotal feature of the TIF neuron is the use of time frame control signals. These signals regulate when the circuit integrates inputs, when it shares charge, and when it resets. As a result, the neuron operates in a cyclic manner—integrating inputs during one phase and resetting during another—ensuring stable and repeatable behavior.

3 Implementation in eSim

The implementation of the TIF neuron circuit in eSim was carried out through the following steps:

- **Technology Selection:** All MOSFETs were modeled using standard **180 nm CMOS libraries** available in eSim to ensure compatibility and realistic device behavior.
- **Schematic Design:** The complete TIF neuron circuit was designed in **KiCad**, including synaptic input networks, integrator, comparator, and spike generation blocks.
- **Device Sizing and Biasing:** Proper transistor sizing, bias voltages, and capacitor values were selected to achieve stable analog operation and correct integrate-and-fire behavior.
- **Input Signal Generation:** Pulse voltage sources were used to emulate **synaptic input signals**, while additional control signals such as **clock (CLK), reset (RST), and charge-sharing (CS)** were applied to implement time-frame operation.
- **Simulation Setup: Transient analysis** was configured in Ngspice to study the time-domain response of the circuit under dynamic input conditions.
- **Waveform Observation:** Key nodes such as **comparator output (Vcomp), and spike output (Vspike)** were monitored to verify correct circuit functionality.

4 Results and Discussion

The transient simulation results clearly demonstrate the correct operation of the Time-Frame Integrate-and-Fire (TIF) neuron, and the obtained waveforms show strong agreement with the expected behavior illustrated in the reference diagram.
The membrane voltage exhibits a repeated **integration–reset cycle**, where the voltage increases gradually due to the accumulation of synaptic input currents and then drops sharply after each firing event. This behavior confirms that the integrator stage is functioning correctly and continuously accumulating charge within each time frame.
When the membrane voltage reaches the effective threshold level, the comparator switches rapidly, resulting in the generation of output spikes. The spike waveform observed in the simulation consists of **periodic sharp pulses**, which are consistent with the expected firing behavior of a TIF neuron.
A key observation from the simulation is the presence of **multiple spikes within each time frame**, indicating that the neuron is operating in a rate-coded manner. This aligns well with

the reference waveform, where the number of spikes within a time frame represents the input strength.

The discharge mechanism is also clearly visible in the waveform. After each spike or time-frame transition, the membrane voltage drops due to controlled discharge, ensuring that the neuron resets properly before the next integration phase. Although the discharge in the simulated waveform shows slight variations and non-idealities, this can be attributed to device-level effects and the use of 180 nm technology.

Compared to the reference waveform, the overall behavior—including **integration slope, threshold crossing, spike generation, and reset operation**—matches qualitatively. Minor differences such as waveform distortion, noise-like variations, and slightly irregular spike amplitudes are observed, which are expected due to parasitic effects, finite transistor gain, and non-ideal switching characteristics in practical implementations.

Despite these differences, the simulation successfully reproduces the essential characteristics of a TIF neuron, including:

- controlled integration over time
- threshold-based switching
- spike generation
- time-frame dependent operation

These results confirm that the implemented circuit accurately captures the intended functionality and validates the correctness of the design in the eSim environment.

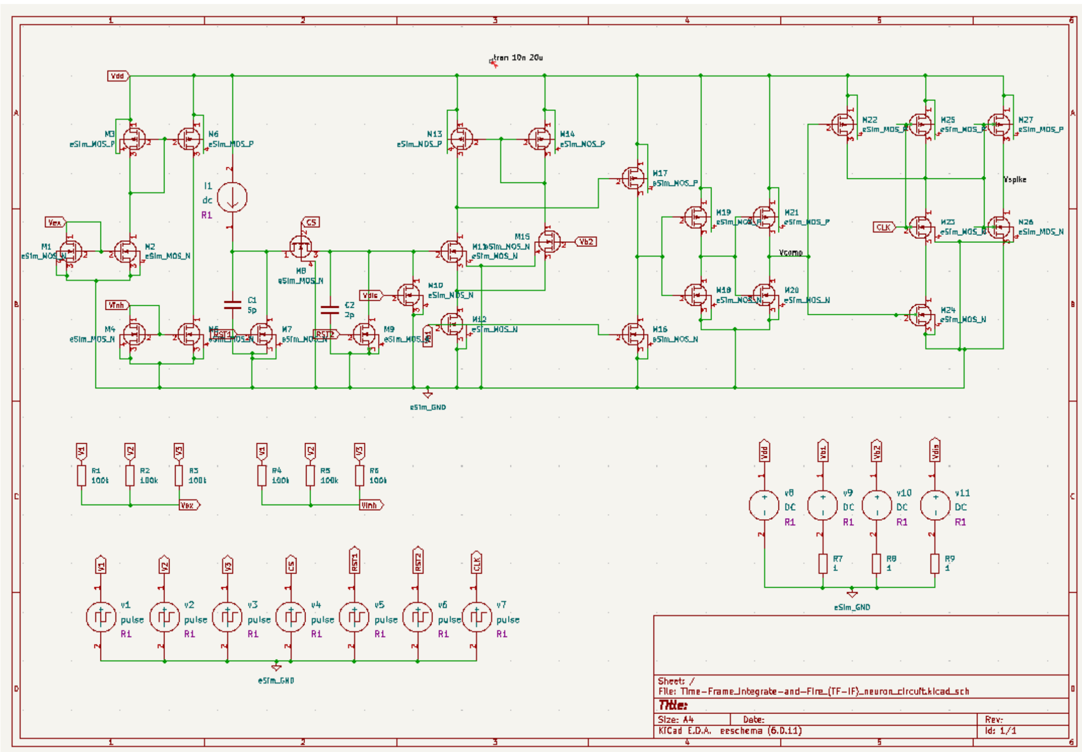

Figure 1: Schematic

Figure 2: Blue: VDD, Green: Clock (CLK), CS= 0V, Vb1(Vbias1) = 0V,
Yellow: Vb2(Vbias2) = 0.7V, Dark Green: RST1=RST2=0V

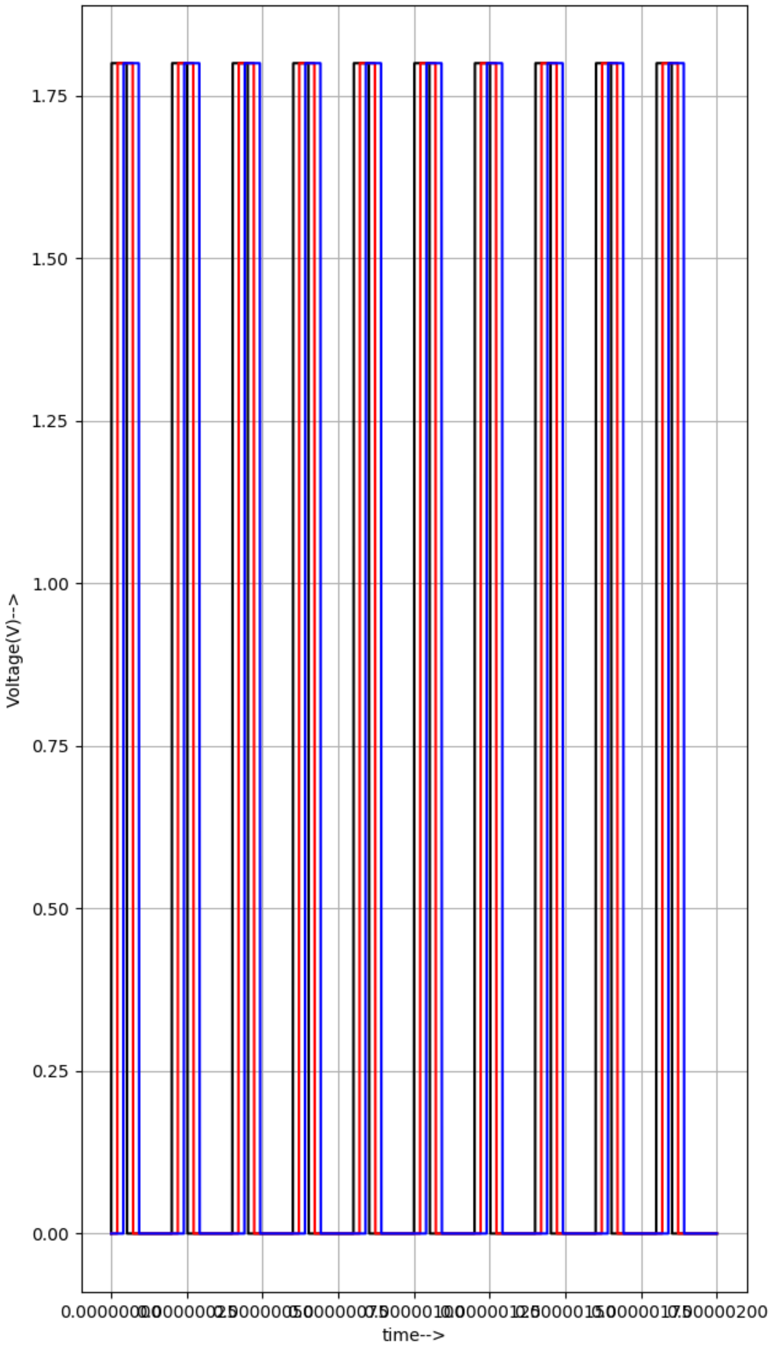

Figure 3: Black: V1, Red= V2, Blue V3

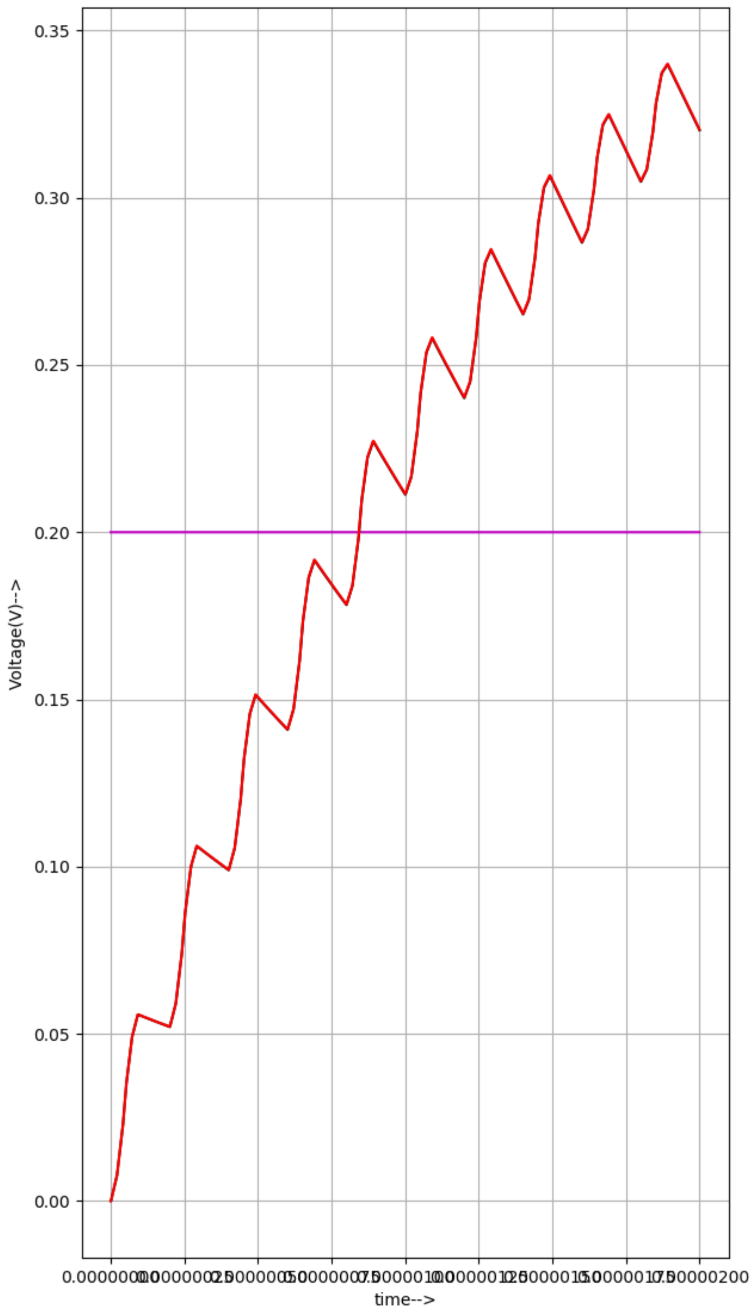

Figure 4: Vex, Vinh

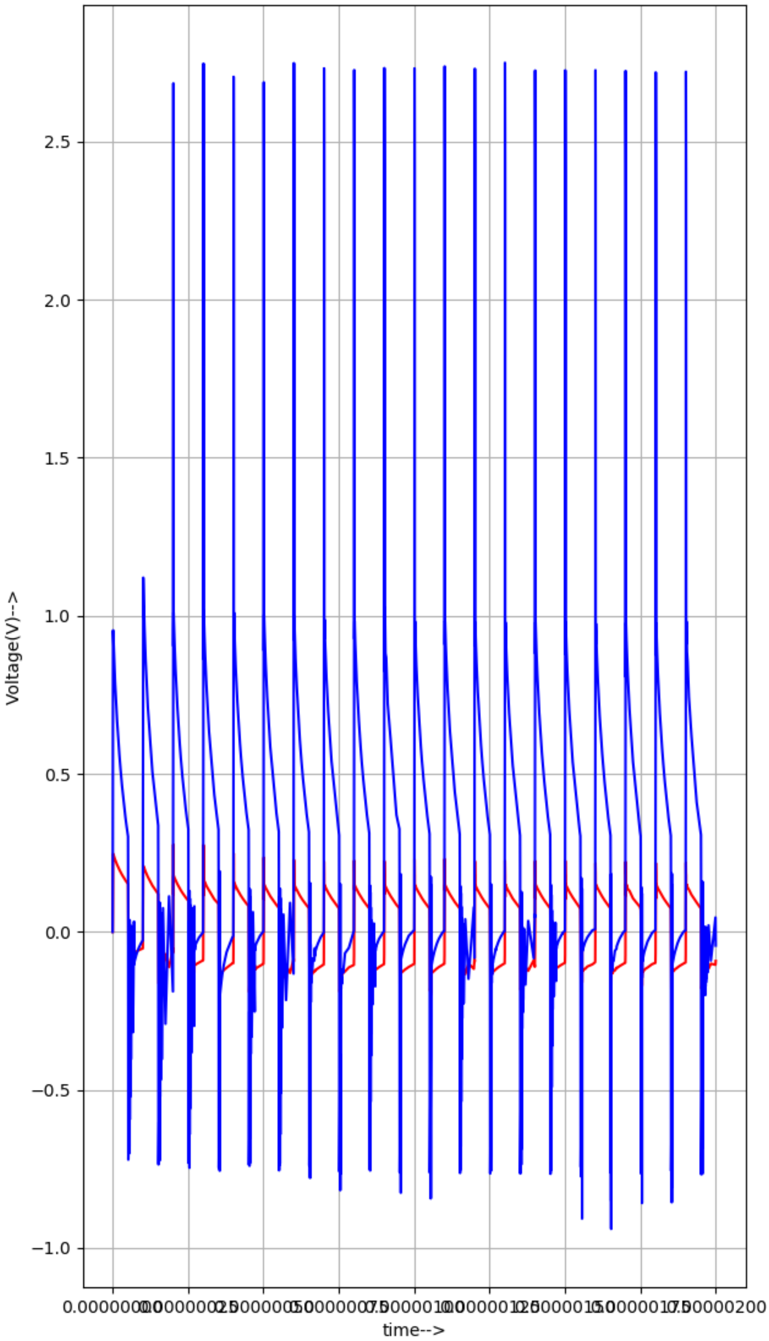

Figure 5(Output): Blue: Vspike, Red: Vcomp
Ibias= 200 nA

5 Conclusion

This project successfully demonstrates the design and simulation of a Time-Frame Integrate-and-Fire neuron using the eSim platform. The circuit effectively captures the essential characteristics of neuron behavior, including integration, threshold detection, and spike generation.

The results confirm that even with a larger technology node, it is possible to accurately reproduce neuromorphic circuit behavior using open-source tools. This highlights the potential of eSim as a valuable platform for studying and developing analog neuromorphic systems.

References

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