

Reliability Analyses of Ultra-Low Voltage Analog Spiking Neurons

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EXTENDED ABSTRACT

In recent years, a lot of developments have been made in the field of neuromorphic engineering towards time-based architectures such as Spiking Neural Networks (SNN) to overcome the limitations reached by Moore's law [1]. The neurons, fundamental elements constituting these SNNs, must be optimized with regards to area, speed and most importantly energy consumption to accommodate for their large-scale integration or specific low-power applications. CMOS-based analog neurons approximating the Morris-Lecar (ML) mathematical model (Fig. 1.a) offer an interesting trade-off between energy efficiency and biophysical plausibility [2].

In this work, SPICE simulations of the compact circuit proposed in [3] are carried out to analyse its behaviour under ultra-low voltage. We observe a severe degradation of the typical spike characteristics (Fig. 1.b) that we try to quantify with the use of several metrics such as the peak-to-peak amplitude of the membrane voltage (V_m), its period and the spike rising/falling times.

These figures of merit allow us to determine, for different excitation currents, a minimum supply voltage ($V_{DD,min}$) below which the amplitude of V_m becomes lower than the neuron inverter switching voltages (V_{switch}), making the circuit unable to properly drive other devices. A severe degradation of the biophysically-plausible spike shape is also observed with the help of the two time-based metrics, negating one of the main advantages of ML-based neurons.

To estimate the functionality of a prospective SNN under ultra-low voltage, we perform variability analyses on the neuron circuit with Monte Carlo simulations. We present the simulated distribution of the normalized spike amplitude and observe significant shifts from the nominal values at lower supply voltages, demonstrating the high variability and instability of the analog neuron operating in deep subthreshold regime.

Using the previously defined minimum voltage limit $V_{DD,min}$, a neuronal failure probability is presented for supply voltage values between 100 and 200 mV and it shows the rapid decrease in functioning neurons under voltages lower than 200 mV, which can prove to be a problem with regards to SNN classifying accuracy [4]. These findings highlight the importance of carrying out thorough stability and robustness analyses for analog neurons operating in subthreshold regimes.

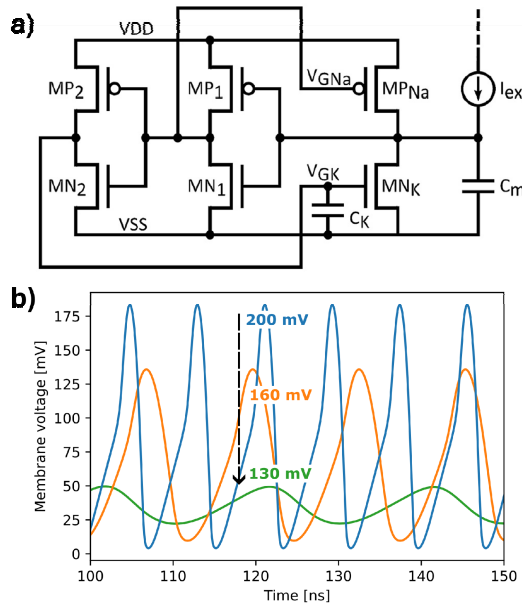


Fig. 1. a) Compact analog neuron design based on the Morris-Lecar model, from [3]. b) Membrane voltage of a simplified ML analog neuron under different ultra-low supply voltages.

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