Quantum Computing Emulation using Neuromorphic Artificial Spiking Neurons

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This paper presents a novel approach to quantum computing emulation using neuromorphic artificial spiking neurons. The work addresses the limitations of current quantum hardware, including noise, decoherence, and scalability, by utilizing energy-efficient analog and mixed-signal circuits operating at room temperature.

A modified Axon-Hillock spiking neuron is proposed and extended with control blocks, see the figure, for on/off activation, phase shifting, synchronization, and amplitude attenuation, enabling the emulation of a universal set of quantum gates, the Phase Shift, Hadamard, and CNOT quantum gates, with ultra-low power consumption.

In this framework, qubit states are mapped to pairs of spiking neurons, where output amplitude and spike timing represent the complex coefficients of the quantum state. The proposed architecture have been demonstrated through circuit simulations and layout in 180 nm CMOS for fundamental quantum operations, including the Hadamard gate, the three-qubit Greenberger-Horne-Zeilinger (GHZ) state, and the Quantum Fourier Transform (QFT). The simulations show that the neuron-based circuits can reproduce the expected superposition and entanglement behavior of these quantum states using precisely timed control signals.

Compared with previous digital FPGA-based [1] or oscillator-based [2, 3] approaches, the proposed spiking-neuron design offers lower power consumption and reduced circuit complexity, making it suitable for scalable hardware emulation of quantum algorithms. This work opens a pathway toward flexible, room-temperature, and mobile-ready quantum-inspired computation using standard semiconductor technology.

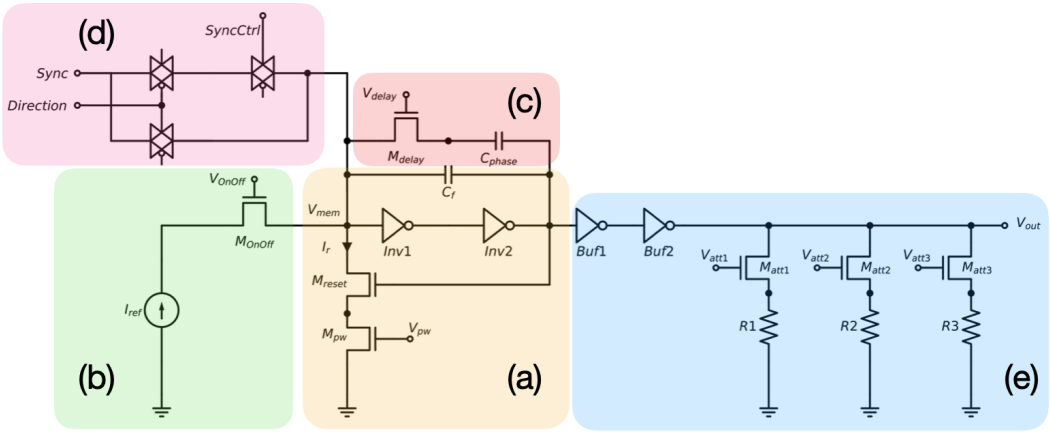

Figure 1: Extended AH-neuron for quantum-gate emulation: (a) The AH neuron, (b) input current and OnOff switch to active the neuron, (c) delay block for phase shifting, (d) synchronization to provide superposition, (e) output buffers and attenuator block.

[1] A. U. Kahlid and Z. Zilic, ICCD, p. 310, 2004.

[2] M. Ezawa, Phys. Rev. Res, 3(2), 023051, 2021.

[3] R. L. Smith and T. H. Lee, IEEE TCSII, 71(10), 4541, 2024.