Research on Low Power VLSI Implementation of a Neuromorphic System for Pattern Recognition Using Spike-Based Learning

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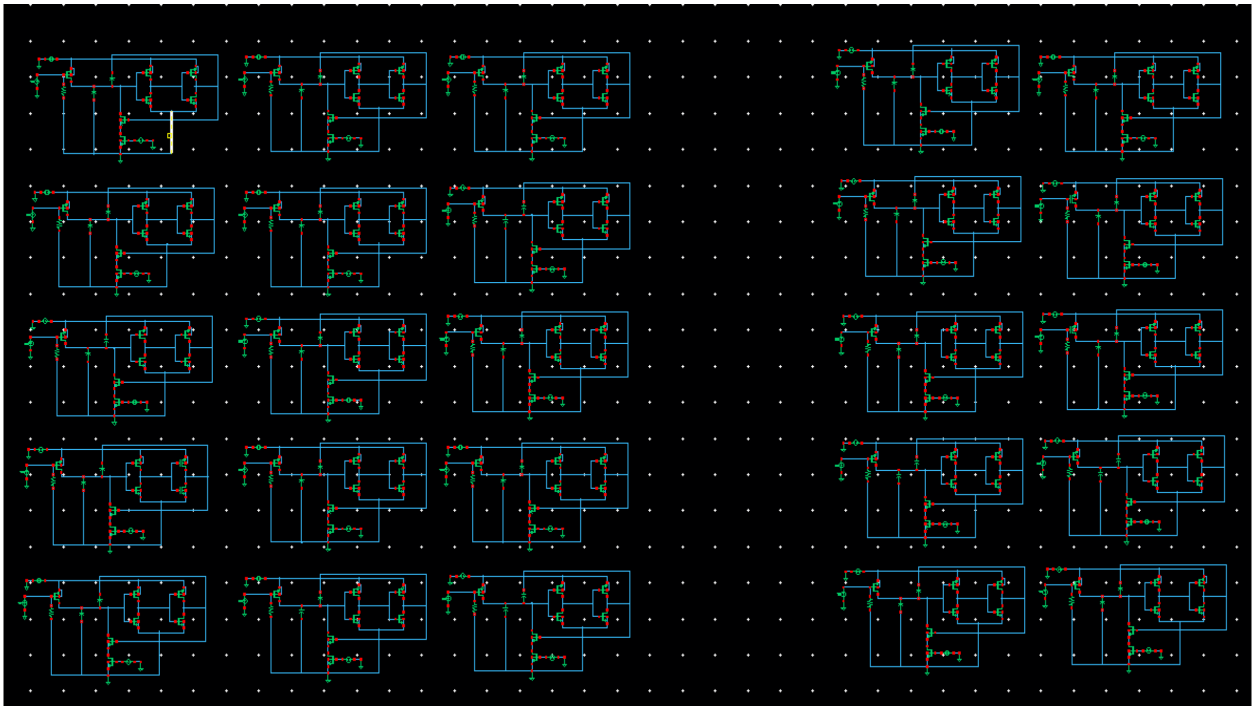

Figure 1: 5×3 and 5×2 Neuron Matrix Architectures

Description: On the left side, the resistance is relatively low, set at 12 megaohms, which results in the generation of noticeable spikes. This behavior is attributed to the reduced opposition to electrical flow, allowing transient signals or noise to manifest more prominently. In contrast, the right side features a higher resistance of 20 megaohms, which significantly dampens such spikes by offering greater opposition to electrical current. This difference highlights how varying resistance levels influence the behavior of electrical signals within a system.

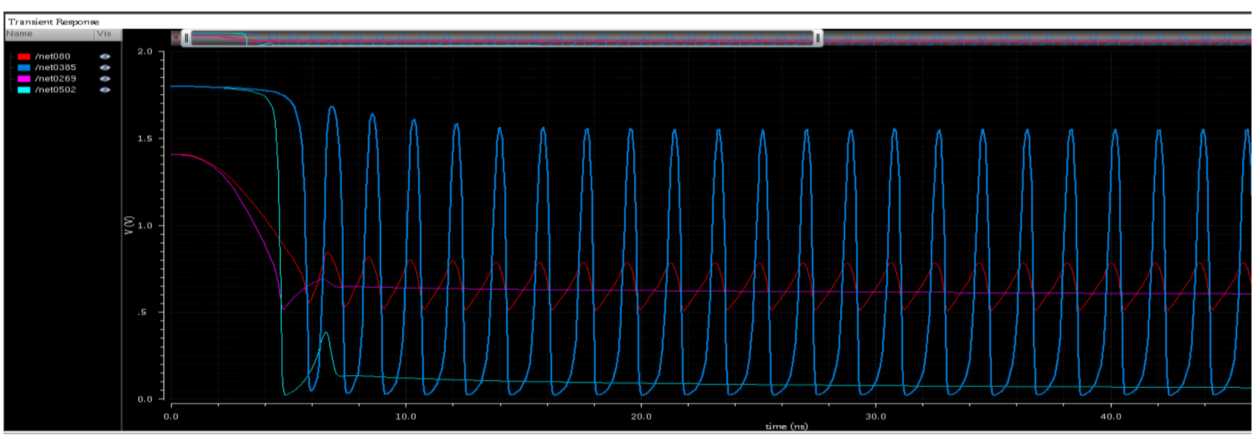

Figure 2: Effect of Resistance on Neuronal Firing

Description: This graph demonstrates the transient response of a neuron-like system under varying resistance and voltage conditions. The **blue line** represents low resistance (12 megaohms), showing frequent spikes due to rapid current flow, enabling the membrane voltage to repeatedly cross the firing threshold of **0.7 V**. The **red line** highlights this threshold, where spiking occurs. The **pink line** represents a high, stable membrane voltage without fluctuations, while the **cyan line** corresponds to high resistance (20 megaohms), where no spikes are observed because the restricted current prevents the membrane voltage from reaching the threshold. This emphasizes the critical role of resistance in regulating neuronal firing behavior.

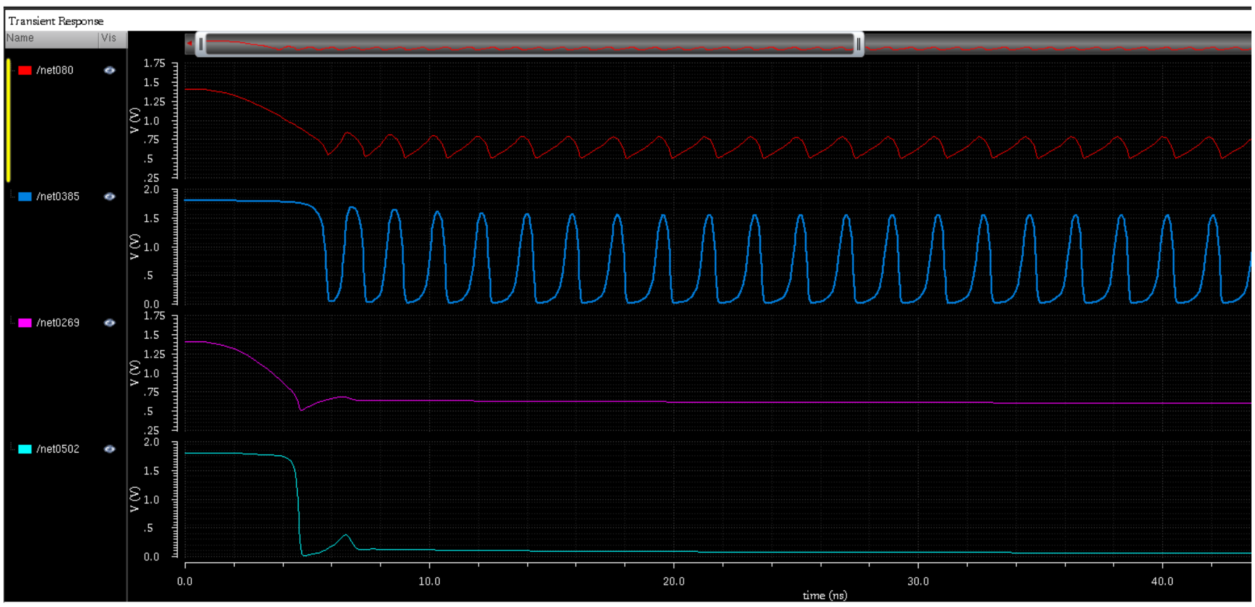

Figure 3: Effect of Resistance on Neuronal Firing (separately)

In our system, the input is a voltage signal, so a direct current signal cannot be supplied. To overcome this limitation, we used a pulse current source connected in series with a resistor. The voltage across this resistor was then fed into the system as the input. For a single neuron, the supply voltage must remain within a specific range relative to the supply voltage (**Vdd = 1.8V**) to ensure proper operation.

If the input voltage exceeds **Vdd**, the neuron stops firing because it disrupts the system's functionality. Conversely, if the input voltage is too low, such as **0.8V**, it cannot reach the firing threshold, resulting in a constant output voltage instead of the desired spike-like behavior. This highlights the importance of maintaining an appropriate input voltage range to ensure the generation of spiking activity within the system.

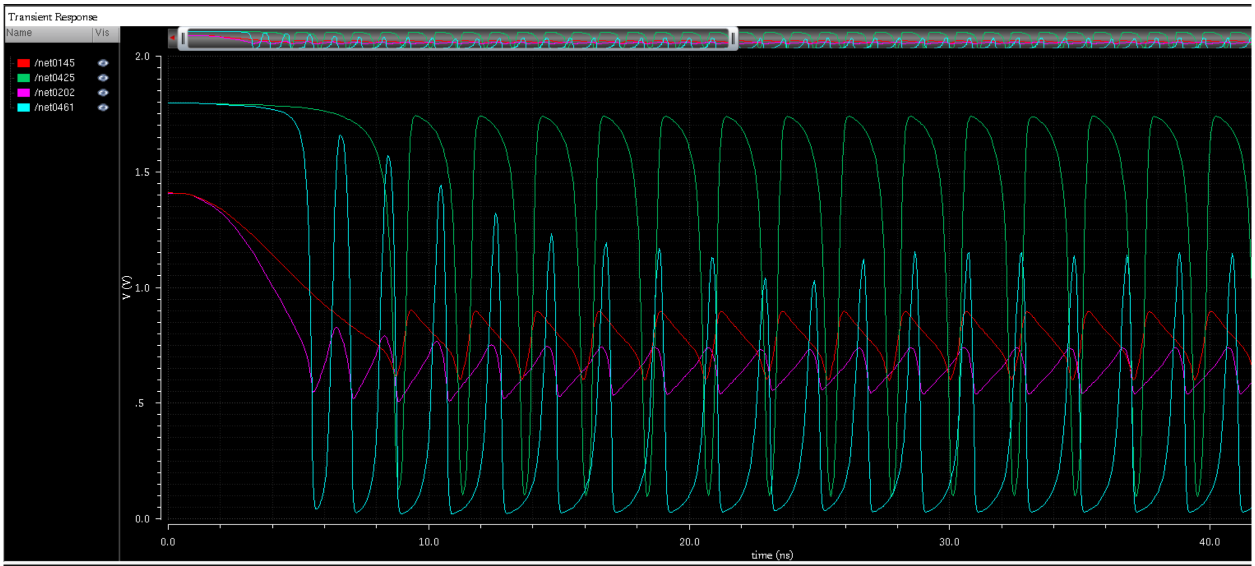

Figure 4: Resistance-Dependent Neuronal Firing

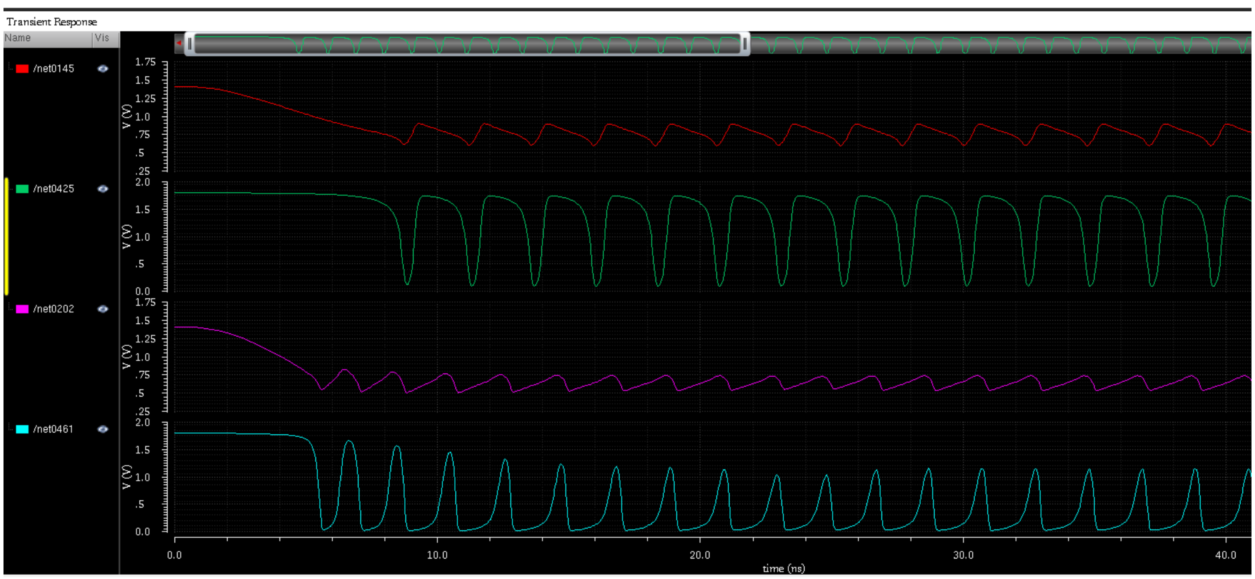

Figure 5: Resistance-Dependent Neuronal Firing separately

The graph displays the transient response of a neuron-like system under varying resistance conditions. The **red line** represents the membrane voltage at 8.5 megaohms, while the **pink line** represents the membrane voltage at 13 megaohms. The **green line** denotes the spike activity for the 8.5 megaohm resistance, and the **cyan line** indicates the spike activity for the 13 megaohm resistance. The resistance range used in this simulation is 100 nanoamperes, and the values were obtained using Ohm's Law.

Ohm's Law: V = IR, where V is the voltage, I is the current, and R is the resistance.

Steps:

1. **Simulation Setup:** The neuron-like system was simulated with varying resistance values, specifically 8.5 megaohms and 13 megaohms. A constant current of 100 nanoamperes was applied to the system.
2. **Membrane Voltage Dynamics:** The membrane voltage was recorded for both resistance values. The 8.5 megaohm resistance exhibited a lower membrane voltage compared to the 13 megaohm resistance.
3. **Spike Activity:** The spike activity, characterized by rapid changes in membrane voltage, was observed for both resistance values. The 8.5 megaohm resistance showed more frequent and higher amplitude spikes compared to the 13 megaohm resistance.
4. **Resistance-Dependent Spiking:** The results demonstrate that the resistance value significantly influences the spiking behavior of the neuron-like system. Lower resistance values lead to increased excitability and higher spike frequencies.

In essence, the graph illustrates the impact of resistance on the membrane voltage dynamics and spiking behavior of a neuron-like system.

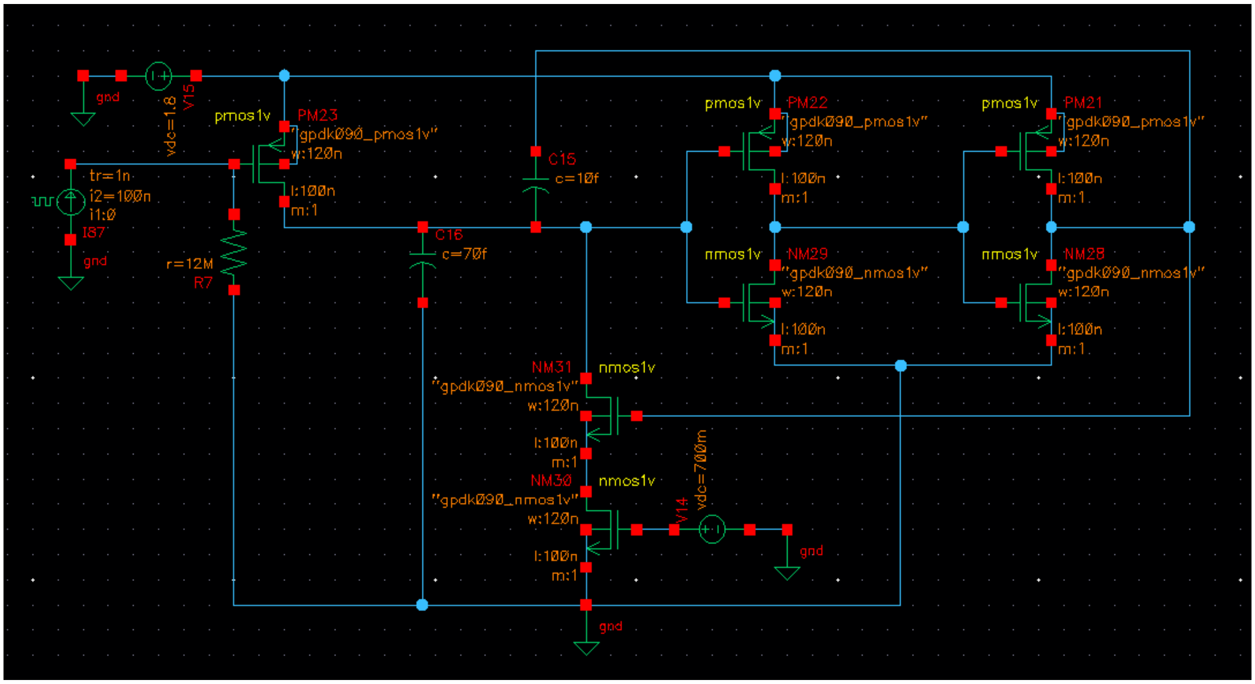

Figure 6: Neuromorphic Neuron Circuit Schematic for Threshold-Dependent Spiking

This schematic depicts a neuron circuit, an electronic model mimicking biological neuronal behavior using MOSFETs, resistors, and capacitors. A pulse generator on the left provides input stimulus, simulating synaptic input or current injection. The resistor (R7 = 12MΩ) and capacitor (C16 = 70fF) regulate the membrane potential, determining the charging and discharging time constant. PMOS and NMOS transistors form the thresholding mechanism, activating when the input voltage exceeds a certain threshold, leading to sharp voltage spikes. The interconnected transistors create a positive feedback loop, generating all-or-nothing spiking behavior, replicating neuronal firing. Capacitors also induce a refractory period by requiring reset time after each spike. The circuit's output, representing neuronal spiking, is taken from the feedback loop. This system effectively emulates neuronal dynamics like spiking, resting states, and threshold-dependent firing, making it useful in neuromorphic computing and AI hardware.