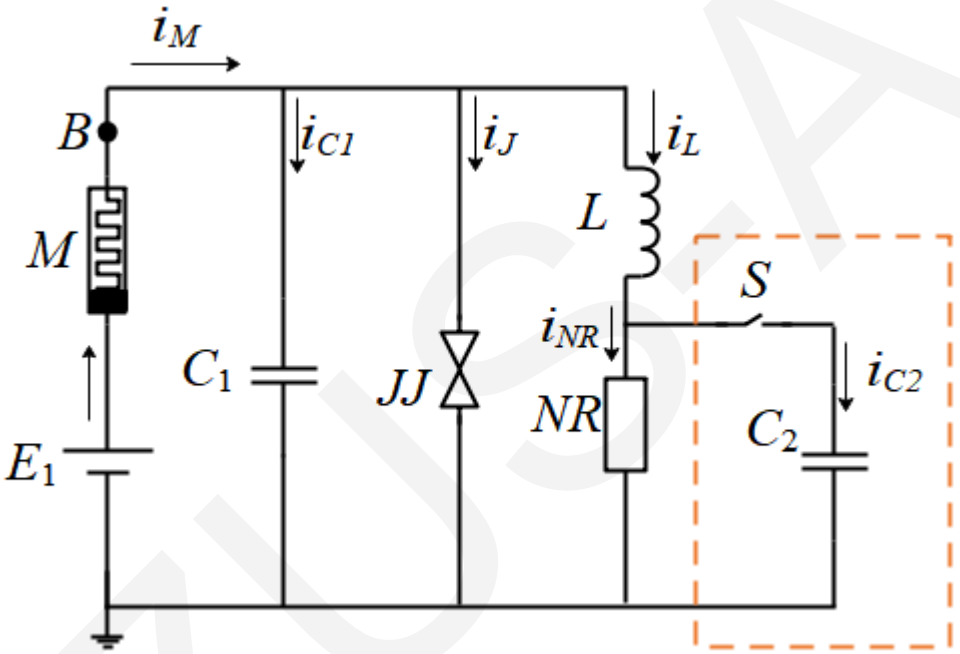
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Subbranch circuit approach for controlling neuronal dynamics in a memristive Josephson system

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Modeling and Methods



The proposed controllable neuron circuit, which consists of two interconnected sections: the core neuron circuit and an external shunt-control branch highlighted by a dashed box. The external capacitor C2 is nonpolarized because the voltage across the nonlinear resistor NR may reverse during dynamics. Therefore, no polarity symbol is indicated in the diagram.

Case 1: Switch open

$$\begin{cases} C_1 \dfrac{\mathrm{d}V_B}{\mathrm{d}t} = \left(\alpha + 3\beta\varphi^2\right)\left(E_1 - V_B\right) - I_c \sin\left(\phi\right) - i_L, \\ \dfrac{\mathrm{d}i_L}{\mathrm{d}t} = \dfrac{1}{L}\left(V_B - V_{NR}\right), \\ \dfrac{\mathrm{d}\phi}{\mathrm{d}t} = \dfrac{2e}{\hbar} V_B, \\ \dfrac{\mathrm{d}\varphi}{\mathrm{d}t} = k_1\left(E_1 - V_B\right) + k_0\varphi, \\ i_L = -\dfrac{1}{\rho}\left(V_{NR} - \dfrac{1}{3}\dfrac{V_{NR}^3}{V_0^2}\right). \end{cases}$$

Energy formulation

$$W_{\text{off}} = \frac{1}{2} C_1 V_B + \frac{1}{2}\left(\alpha\varphi + \beta\varphi^3\right)\left(E_1 - V_B\right)$$

$$+ \frac{1}{2} L i_L^2.$$

Case 2: Switch close

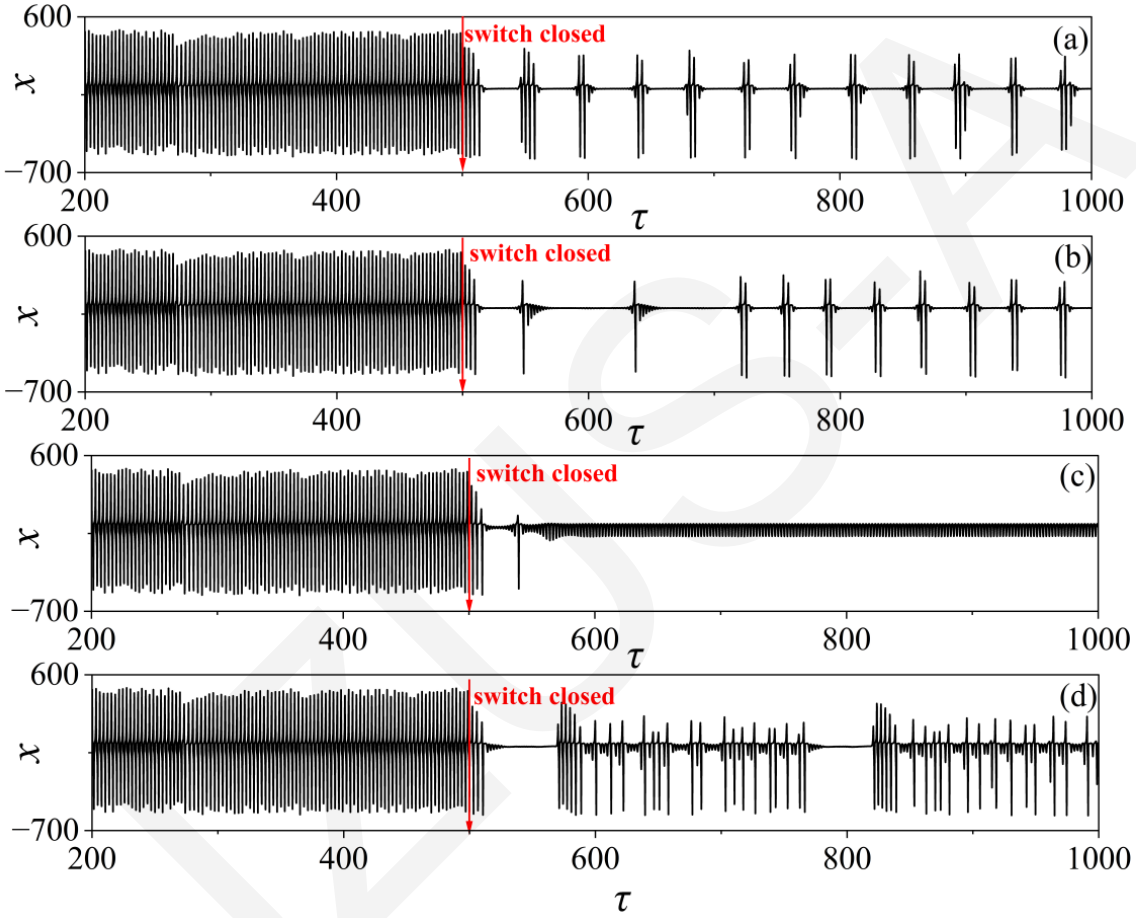
$$\begin{cases} C_1 \dfrac{\mathrm{d}V_B}{\mathrm{d}t} = \left(\alpha + 3\beta\varphi^2\right)\left(E_1 - V_B\right) - I_c \sin\left(\phi\right) - i_L, \\ \dfrac{\mathrm{d}i_L}{\mathrm{d}t} = \dfrac{1}{L}\left(V_B - V_{NR}\right), \\ \dfrac{\mathrm{d}\phi}{\mathrm{d}t} = \dfrac{2e}{\hbar} V_B, \\ \dfrac{\mathrm{d}\varphi}{\mathrm{d}t} = k_1\left(E_1 - V_B\right) + k_0\varphi, \\ C_2 \dfrac{\mathrm{d}V_{NR}}{\mathrm{d}t} = i_L + \dfrac{1}{\rho}\left(V_{NR} - \dfrac{1}{3}\dfrac{V_{NR}^3}{V_0^2}\right). \end{cases}$$

$$W_{\text{on}} = \frac{1}{2} C_1 V_B + \frac{1}{2} C_2 V_{NR} + \frac{1}{2} L i_L^2$$

$$+ \frac{1}{2}\left(\alpha\varphi + \beta\varphi^3\right)\left(E_1 - V_B\right).$$

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Numerical results and discussion



The switch closes at τ=500. The final firing mode depends on the external capacitance μ. Subfigures correspond to (a) μ =15.5→bursting; (b) μ =10.5→bursting (different spike count); (c) μ =5.5→regular periodic; (d) μ = 0.5→chaotic.

Conclusions

This study validates a dual-dimensional “mode-energy” control strategy for memristive Josephson neuronal circuits using an external capacitive branch. By adjusting the capacitance parameter μ, the system achieves controllable switching among periodic firing, bursting, and chaos. Simultaneously, varying the stimulus amplitude A reshapes the internal energy distribution, determining the dominant roles of energy storage components. The regulatory mechanism originates from the asynchronous energy evolution of the external capacitor C_2, which perturbs the global energy balance via local shunting. This work provides a physical pathway for reconfigurable neuromorphic circuits.