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Bio-inspired Superconducting Neuron and Synapse

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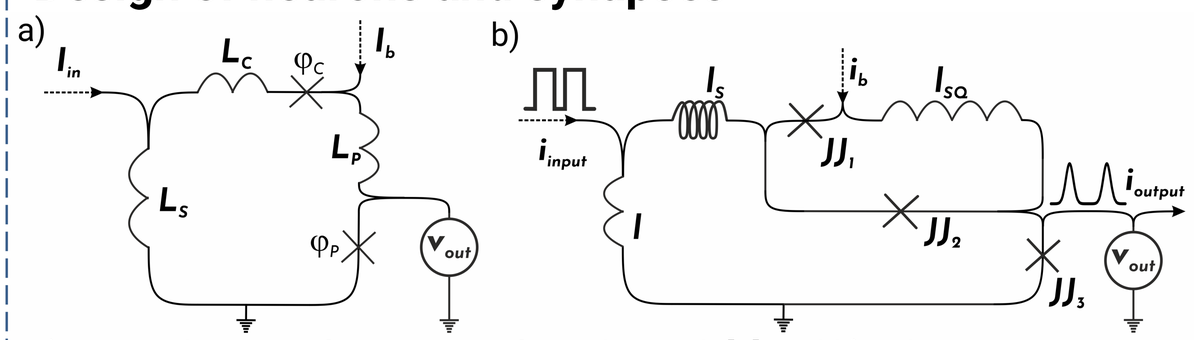
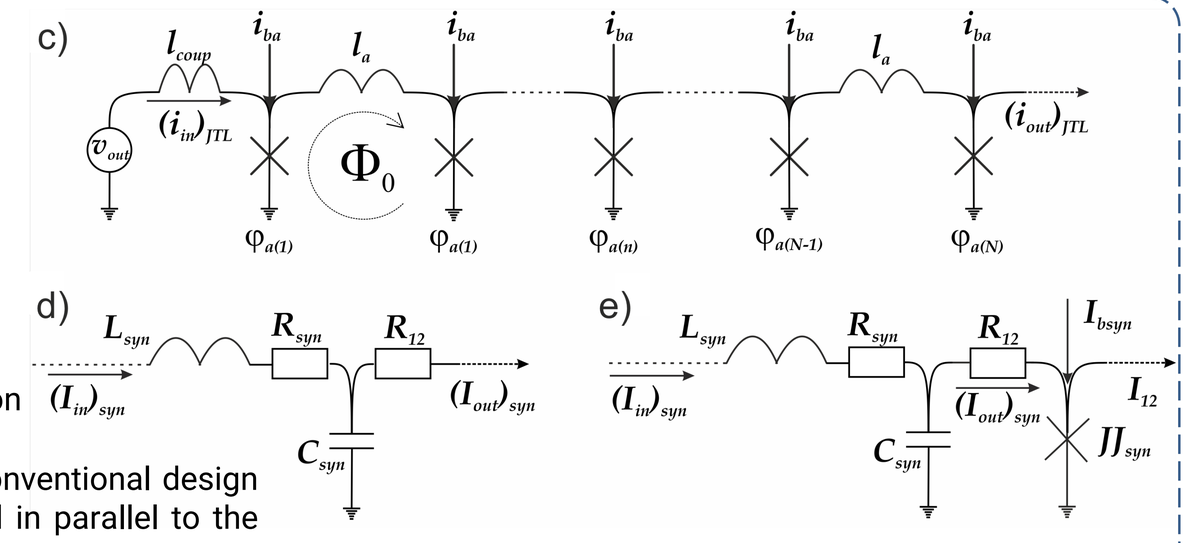
Introduction

Imitative modelling of processes in the brain of living beings is an ambitious task. However, advances in the complexity of existing hardware brain models are limited by their low speed and high energy consumption. A superconducting circuit with Josephson junctions closely mimics the neuronal membrane with channels involved in the operation of the sodium-potassium pump. The dynamic processes in such a system are characterized by a duration of picoseconds and an energy level of attojoules. In this work, two superconducting models of a biological neuron are studied [1,2]. New modes of their operation are identified, including the so-called bursting mode, which plays an important role in biological neural networks [3-4]. The possibility of switching between different modes in situ is shown, providing the possibility of dynamic control of the system. A synaptic connection that mimics the short-term potentiation of a biological synapse is developed and demonstrated.

Design of neurons and synapses

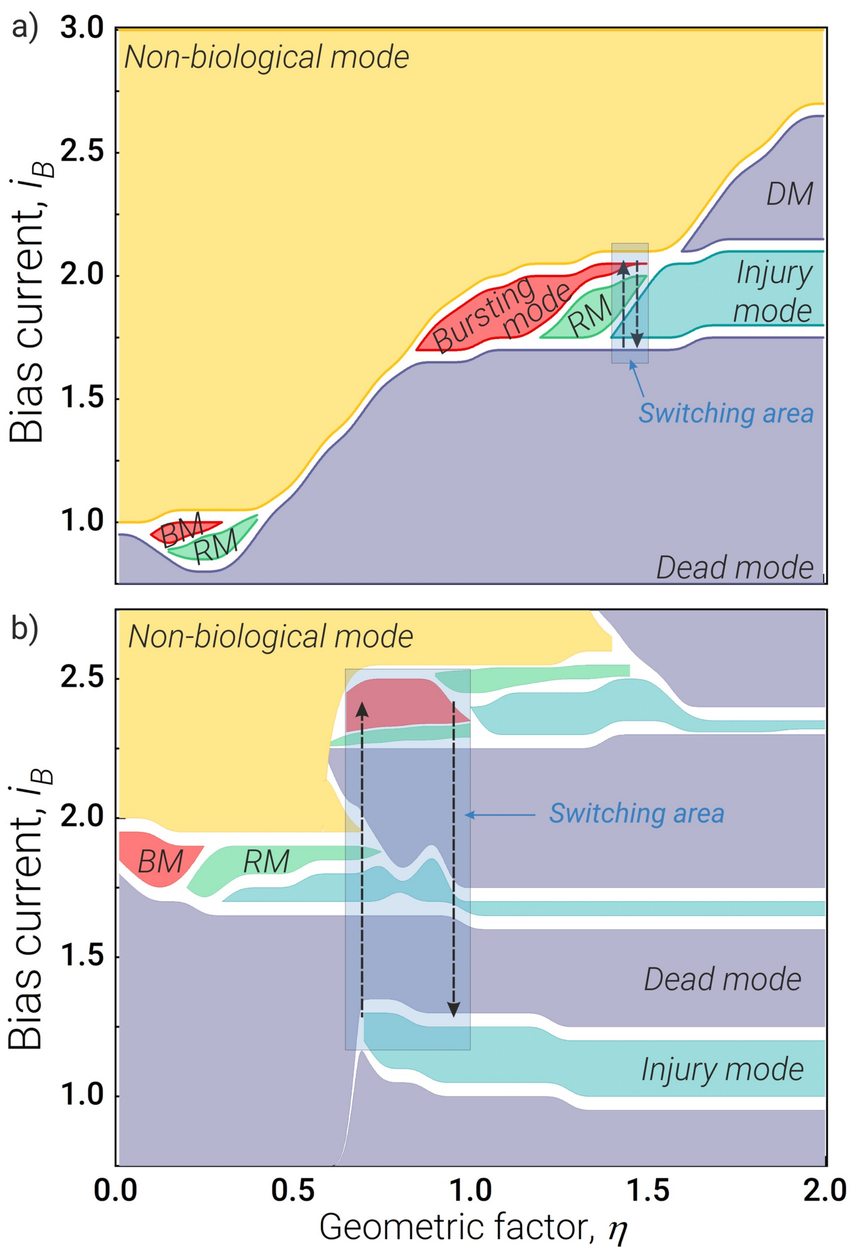


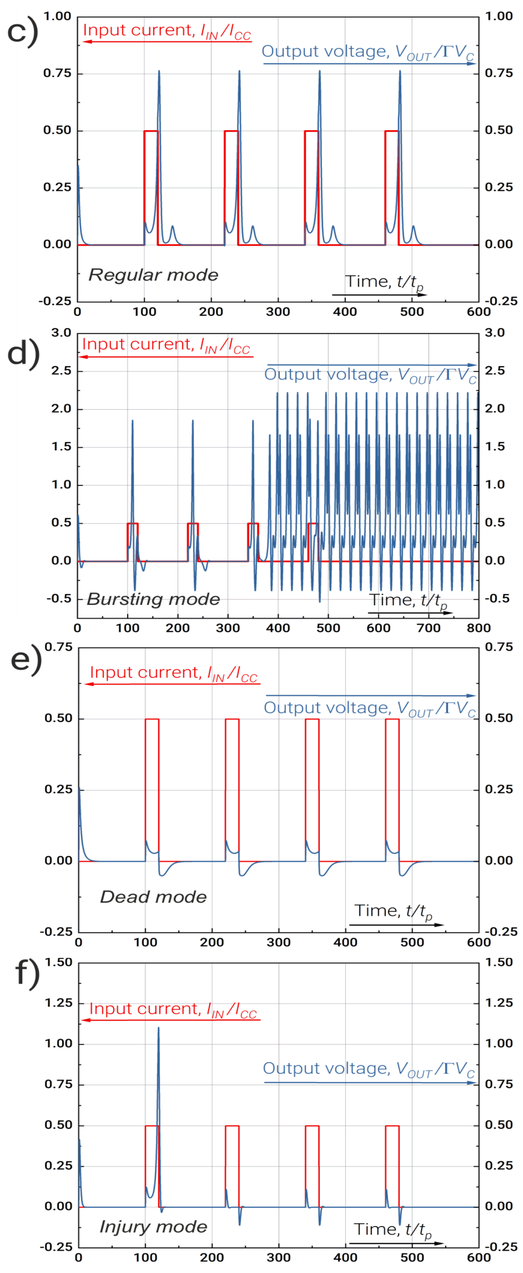
a) Circuit diagram of 2JJ-neuron from the work [1] and b) schematic representation of modified spiking neuron (3JJ-neuron) [2].



Schematic representation of c) Josephson transmission line and synapses: d) conventional design [1] and e) modified *RLCJ*-synapse with additional Josephson junction connected in parallel to the *RLC*-filter.

Simulation results of neurons





a) Parameter ranges for the operating modes of the neurons for the bias current I_B (which can be adjusted *in situ*) and the geometric factor η for (a) the 2*JJ* − *neuron* and (b) the 3*JJ* − *neuron*. (c)-(d) panels correspond to different operating modes of the 2*JJ* − *neuron* (which are qualitatively similar to the operating modes of the 3*JJ* − *neuron).*

Simulation results of synapses

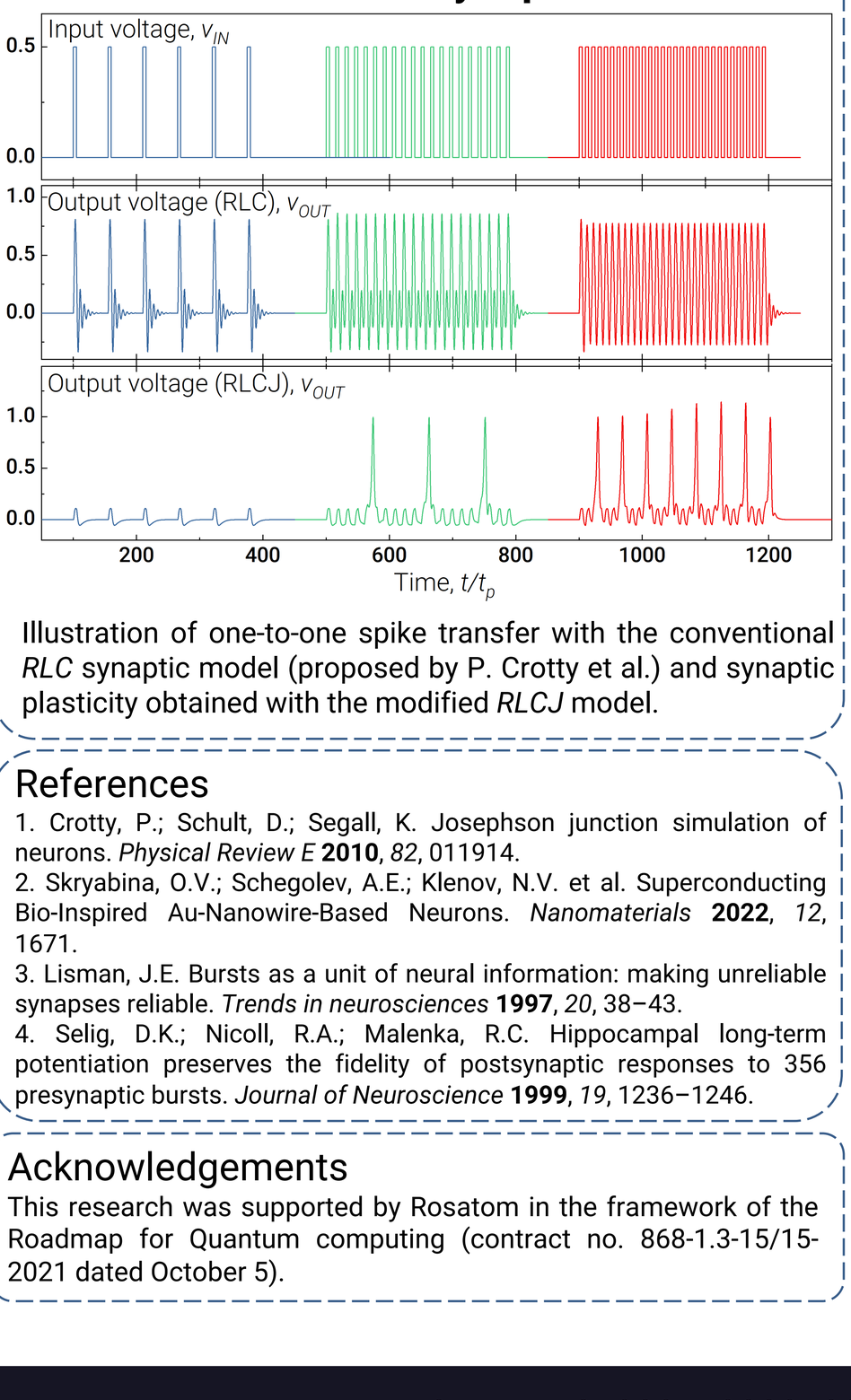


Illustration of one-to-one spike transfer with the conventional *RLC* synaptic model (proposed by P. Crotty et al.) and synaptic plasticity obtained with the modified *RLCJ* model.

References

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Acknowledgements

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