Design and simulation of a logic switching circuit for reconfigurable superconducting reversible logic circuits

*Aoto Tanaoka[1], Nobuyuki Yoshikawa[1,2,3] and Yuki Yamanashi[1,2,3]

[1] *Department of Electrical and Computer Engineering, Yokohama National University, 79-5 Tokiwadai, Hodogaya, Yokohama, Kanagawa, 240-8501, Japan*

[2] *Institute of Advanced Sciences, Yokohama National University, 79-5 Tokiwadai, Hodogaya, Yokohama, Kanagawa, 240-8501, Japan*

[3] *Institute for Multidisciplinary Sciences, Yokohama National University, 79-5 Tokiwadai, Hodogaya, Yokohama, Kanagawa, 240-8501, Japan*

Abstract

The circuit implementation of invertible neural networks has never been achieved. To realize it, the use of the Reversible Quantum Flux Parametron (RQFP) [1], based on the Adiabatic Quantum Flux Parametron (AQFP) [2], can be considered. RQFP is a logic circuit that has logical and physical reversibility but does not have reconfigurability. To be used as neurons in invertible neural networks, it must be able to change its logic function. A previous study proposed that connecting logic switching circuits to RQFP enables logic reconfiguration [3]. However, the logic switching circuit in that study produced a small output current, resulting in a critical margin of approximately 2% for the subsequent AQFP [3]. It made experimental demonstration difficult.

In this study, to demonstrate the operation of a reconfigurable reversible logic circuit, we designed a circuit that switches between buffer and not functions based on whether a phase shift is induced by magnetic flux. Figure 1 shows the proposed circuit. When no bias current I_b is applied, no magnetic flux is induced in the $L_1 - J_0 - L_2$ loop. As a result, the input current propagates without inversion. The circuit operates as a buffer gate. On the other hand, when I_b is applied such that the superconducting phase shift induced in the $L_1 - J_0 - L_2$ loop is π, applying an input current results in an inverted output current due to the DC Josephson effect. The circuit operates as a not gate.

We analytically derived the parameter conditions for correct operation and found that parameter sets satisfying these conditions could not provide a large output current. We modified the circuit structure by directly connecting AQFPs to the input and output terminals of the proposed circuit to increase the output current. As a result of parameter optimization considering the parameter conditions and energy consumption, the critical margin reached 14.17% for buffer operation and 19.30% for not operation. We confirmed that the circuit operates correctly and adiabatically through simulation and by calculating energy consumption.

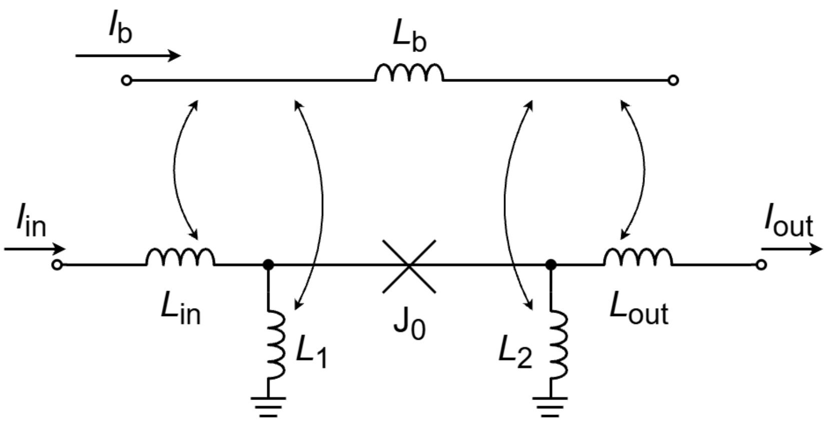

Figure 1. The proposed circuit. L_1, L_2, L_{in}, and L_{out} are magnetically coupled to L_b. The parameters are set symmetrically because this circuit is intended for reversible operation.

References

[1] N. Takeuchi, Y. Yamanashi, and N. Yoshikawa, "Reversible logic gate using adiabatic superconducting devices," *Sci. Rep.*, vol. 4, art. no. 6354, Sep. 2014.

[2] N. Takeuchi, D. Ozawa, Y. Yamanashi, and N. Yoshikawa, "An adiabatic quantum flux parametron as an ultra-low-power logic device," *Supercond. Sci. Technol.*, vol. 26, no. 3, art. no. 035010, Jan. 2013.

[3] Y. Ito, Y. Yamanashi, and N. Yoshikawa, "Design and Evaluation of the Reconfigurable and Reversible Adiabatic Quantum-Flux-Parametron Logic Gate Using the Superconductive Phase Control," *The 64th Spring conference of the Japan Society of Applied Physics*, Yokohama, Japan, Mar. 2017.

Acknowledgement

This work was supported by JSPS KAKENHI Grant Number JP25K01284. The circuits were fabricated in the Superconducting Quantum Circuit Fabrication Facility (Qufab) in National Institute of Advanced Industrial Science and Technology (AIST).

Keywords: Adiabatic quantum flux parametron, Reversible logic circuits, Invertible Neural Networks

