【Grant-in-Aid for Scientific Research (S)】
Science and Engineering (Engineering)

Title of Project : Study on Adiabatic Single-Flux-Quantum Circuits Operating in the Thermodynamic Energy Limit

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Research Area : Electronics devices and systems
Keyword : Electronics devices, integrated circuits

【Purpose and Background of the Research】

For realizing future exascale high-performance computers, extremely energy-efficient logic is highly demanded. The aim of this study is the realization of extraordinarily energy-efficient logic circuits operating in the thermodynamic energy limit using superconducting logic circuits. Our approach utilizes the adiabatic operation of adiabatic quantum-flux-parametron (AQFP) by changing its phase difference adiabatically or very slowly. Figure 1 show the relationship between the bit energy and the clock period of several logic circuits, including CMOS, single-flux-quantum (SFQ) and AQFP circuits, which are proposed in this study. The bit energy of the AQFP circuits is six orders of magnitude smaller than that of the state-of-the-art CMOS circuits. In this project, we study the fundamental technology to realize energy-efficient integrated circuits based on the AQFP circuits. The final target of the project is to demonstrate the high-speed operation of 16b AQFP processors at 5 GHz.

【Research Methods】

In the AQFP circuits, the energy consumption can be reduced proportional to the clock frequency by changing the energy potential from single-well to double-well adiabatically as shown in Fig. 2. The energy supplied to the logic gate is not consumed at the logic, but is completely recovered by a power source. The energy-efficient property of the AQFP circuits can be fully utilized in superconducting circuits due to loss-less features of superconducting circuits.

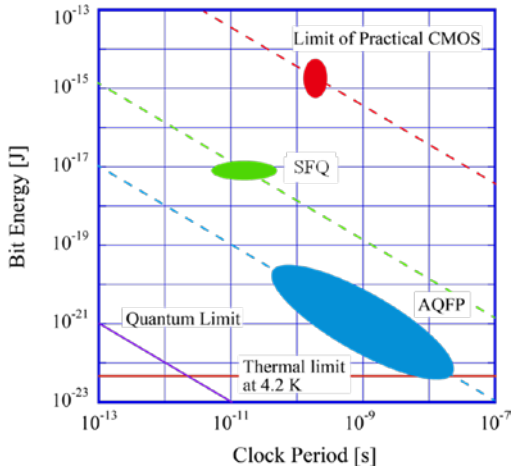

Figure 1　The bit energy and the clock period of CMOS, SFQ and AQFP circuits.

【Expected Research Achievements and Scientific Significance】

The study of the AQFP circuits enables us to understand the physical limit of the bit energy of logic gates. In application, the AQFP circuits will achieve the reduction of the power consumption of integrated circuits by more than six orders of magnitudes, resulting in the power reduction of high-end computing systems including cryocoolers.

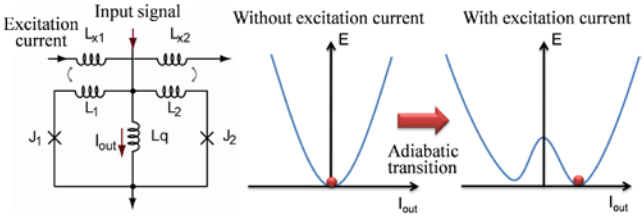

Figure 2　AQFP logic gate and its potential change

【Publications Relevant to the Project】

・N. Takeuchi, Y. Yamanashi and N. Yoshikawa, "Measurement of 10 zJ energy dissipation of adiabatic quantum-flux-parametron logic using a superconducting resonator," Appl. Phys. Lett., 102, 052602 (2013).
・N. Takeuchi, Y. Yamanashi and N. Yoshikawa, "Simulation of sub-k_BT bit-energy operation of adiabatic quantum-flux parametron logic with low bit-error-rate," Appl. Phys. Lett., 103, 062602 (2013)

【Term of Project】 FY2014-2018

【Budget Allocation】 150,300 Thousand Yen

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