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B—7—1 Proposal of a Superconducting Magnetic-Flux-Quantum Transfer Device

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INTRODUCTION Logic devices based on Josephson effect, especially single flux quantum (SFQ) devices such as "flux shuttle", are very attractive because of their ultra-fast switching and extremely low power dissipation.[1] In this paper, a new SFQ device, or a new configuration of "flux shuttle",[2] is proposed and its design procedures are discussed.

DEVICE CONFIGURATIONS The configuration of the proposed device is schematically shown in Fig. 1. A number of superconducting quantum interferometers (SQUID cell) with a single Josephson junction are arranged in the form of a long chain, where the adjacent cells are inductively coupled with each other. Sets of three control lines for inducing the external magnetic flux in the cells are disposed around every joint of the chain, and three-phase current clock ϕ_1, ϕ_2, ϕ_3, are supplied to the corresponding line. Loop inductance-Josephson current product, LI_J, of the cells is chosen near magnetic flux quantum $\Phi_0 = 2.07 \times 10^{-15}$ Wb. In this situation, three-phase shift register operation, similar to that of "flux shuttle", can be realized as explained below.

DESIGN CONSIDERATIONS In designing the present new device, the inter-cell coupling and the amplitude of external clock are determined, taking the following conditions into accounts.

(1) "1" transfer condition: When the SQUID cell ① holds a flux quantum, i. e. "1" state, the next adjacent cell ② should also capture a quantum by the aid of simultaneous application of the external clock ϕ_1 and ϕ_2 .

(2) "0" transfer condition: When the cell ① holds no quantum, the next adjacent cell ② should never capture a quantum even if the clock ϕ_1 and ϕ_2 are applied.

(3) Flux hold condition: The flux quantum, once captured, should be held so long as the clock is kept on.

(4) Reset condition: When the current clock is removed, the cell should be reset to the initial zero-quantum state.

These conditions were analyzed numerically by the stationary state equations,[3] extended to the present coupled SQUID chain. A typical solution is shown in Fig.2. It is demonstrated that the coupling inductance M and the external clock flux ϕ

should be chosen within the hatched region.

COMPUTER SIMULATIONS AND DISCUSSIONS Computer simulations of shift register operation were carried out for the cross point in Fig. 2 to confirm the above-mentioned design procedure and to estimate the logical performances. The circuit parameters used for simulations are summarized in the caption of Fig. 3, where the junction resistance R_J and capacitance C are chosen so as to realize the appropriate damping of the SQUID cells. As can be seen in Fig. 3, a flux quantum, i. e. "1" state, is successfully transferred first from the cell ③ to ① , then ① to ② and ② to ③, accompanied by the appearence of voltage spikes across the junction. The transfer time of the flux quantum is only about 20 ps, and mainly restricted by the voltage response of the junction, $\tau = CR_J$, as well as the loop current response, $\tau = L/R_J$. Energy dissipation during quantum transfer is approximately given by $\Phi_0 I_J \fallingdotseq 2 \times 10^{-18}$ J. Thus, the proposed device is expected to operate with the clock frequency higher than 10 GHz and with extremely low power dissipation.

CONCLUDING REMARKS A new superconducting logic device, operating as a three phase shift register, was proposed. In comparison with "flux shuttle" proposed previously, more simplified device structures and external driving procedures are expected. Moreover, it could be easily developed to some binary logic gates.

1) T. A. Fulton et al.: Proc. IEEE 61 (1973) 28
2) A. Ishida et al.: Topical Meeting on Semiconductors, IECE Japan, 1977
3) A. H. Silver et al.: Phys. Rev. 157 (1967) 317

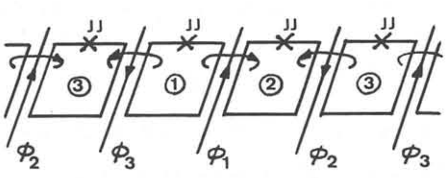

Fig. 1 Schematic drawings of the proposed device configuration.

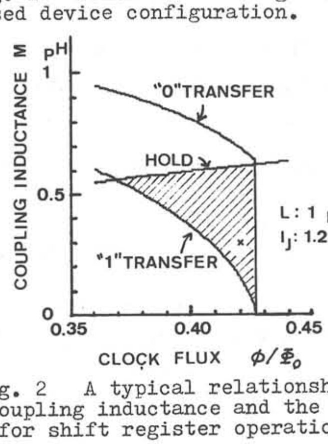

Fig. 2 A typical relationship of the coupling inductance and the clock flux for shift register operation.

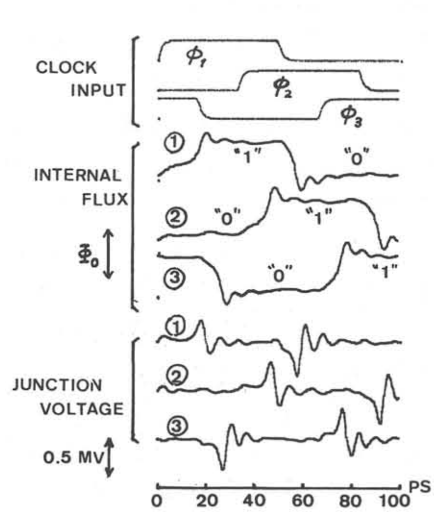

Fig. 3 Simulated internal flux and junction voltage signals.
L = 1 pH, I_J = 1.2 mA, M = 0.3 pH
R_J = 0.5Ω, C = 5.3 pF