C — 2 — 5 Current Injection Logic Gate with Four Josephson Junctions

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Josephson quantum interferometer devices are potential elements for high performance computers because of their fast switching speed and very low power dissipation[1]. Recently, a Josephson interferometer logic device which is gated by an injection current, instead of a magnetic field of the control line, has been reported[2]. This current injection logic device is very attractive for logic elements because it has higher gain and wider operating margin.

In this paper, we report a novel current injection logic device in which four Josephson junctions are directly coupled each other. In this device, inductances do not dominantly act on switching of the gate since switching is essentially determined by a phase balance between individual Josephson junctions, which allows us to choose the loop inductance as small as possible. This feature of the present device has the possibility to realize faster switching speed and smaller device size since the time delay and the space of the inductance can be eliminated[3].

The four-junction switching gate is schematically shown in Fig. 1. As shown in the figure, the control current is injected into the device at the intermediate point between J_1 and J_2 and the gate current is biased at the symmetric feed point in the loop. In this configuration, the switching threshold can be calculated by using the Josephson phase-current relationship, i.e.,

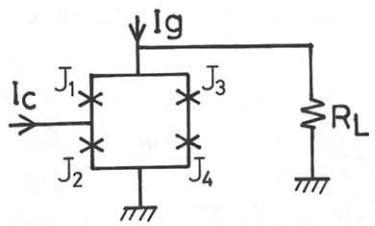

Fig.1. Four-junction switching device.

$$I_1^0 \sin\theta_1 + I_c = I_2^0 \sin\theta_2 \quad , \quad (1)$$

$$I_g = I_1^0 \sin\theta_1 + I_3^0 \sin\theta_3 \quad , \quad (2)$$

$$I_3^0 \sin\theta_3 = I_4^0 \sin\theta_4 \quad , \quad (3)$$

and

$$\theta_1 + \theta_2 = \theta_3 + \theta_4 \quad , \quad (4)$$

where I_i^0 and θ_i are the critical current and the phase of ith junction, respectively. The calculated threshold curve in the I_g-I_c plane is shown in Fig. 2. In this calculation, we assume all of the junctions have the same critical current, i.e., $I_1^0=I_2^0=I_3^0=I_4^0=2$ mA. Switching operation can be performed by using the regions where both I_g and I_c have the same polarity. In these regions the slope of the threshold curve is greater than unity, which means that the gain of the gate becomes higher than the conventional Josephson tunneling logic gate.

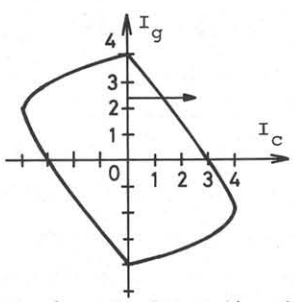

Fig.2. Calculated threshold curve.

Experimental devices were fabricated with Pb-In alloy by using rf sputter-oxidation technique. Figure 3 shows a photograph of the experimental gate. Each junction size was 20 μm x 20 μm.

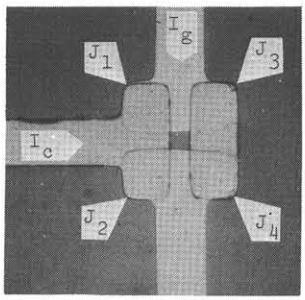

Fig.3. Photograph of switching device.

The switching threshold curve was measured by using pulses for driving I_g and I_c, and results are plotted in Fig. 4. As shown in the figure, the measured threshold curve is in good agreement with the calculated one shown in Fig. 2. We have found that there are several modes when the gate switches into the voltage state. In relatively large I_g regions, the gate generates the voltage equal to $2V_g$(V_g:the gap voltage) when the gate switches. The threshold of this mode is marked by 'o' on the threshold curve in Fig. 4. Decreasing I_g, the gate begins to generate the gap voltage V_g in the transition(the threshold of this mode is marked by '•'). Interesting features appear in the regions marked by '▽'. In these regions, only J_1 and J_2 switch to the voltage state and generate voltages with opposite polarities each other, so that the gate remains in the zero-voltage state. These behavior can be systematically explained by a dynamic analysis of the gate.

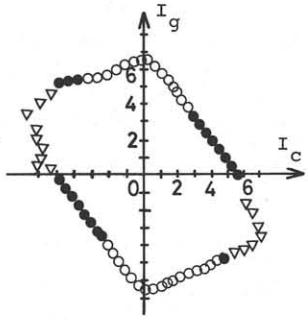

Fig.4. Measured threshold curve.

Employing this switching gate, a family of logic functions such as AND,OR, and INVERT can be easily achieved. Figure 5 shows an experimental AND logic gate consisting of two switching gates. The result of the experimental operation of the AND gate is shown in Fig. 6. In this preliminary experiment, the gate is operated with a clock cycle of 1 kHz. As shown in Fig. 6, the operation of AND function is consistently performed.

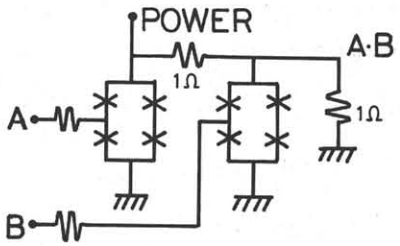

Fig.5. AND gate test circuit.

In conclusion, we have proposed a novel Josephson switching gate controlled by current injection and measured switching threshold characteristics which are in good agreement with the calculation. We have also demonstrated the AND gate successfully using these switching gates.

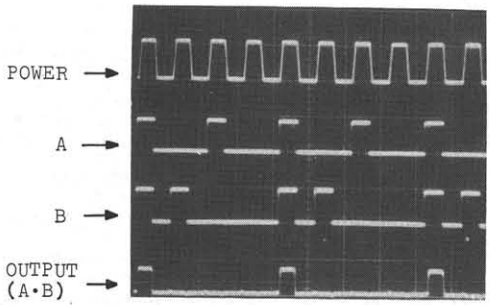

Fig.6. Experimental operation of the AND gate.

1)H.H. Zappe,Appl.Phys.Lett.27,432(1975).
2)T.R. Gheewala,Appl.Phys.Lett.33,781(1978).
3)T.Yamashita et al.,J.Appl.Phys.(to be published).