Extended Abstracts of the 1998 International Conference on Solid State Devices and Materials, Hiroshima, 1998, pp. 194–195

Signal Transmission Circuit Using Single Electron Tunneling Junctions

Kouichirou Yamamura and Yoshiyuki Suda

Faculty of Technology, Tokyo University of Agriculture and Technology
2-24-16 Naka-cho, Koganei, Tokyo 184-8588, Japan
Phone/Fax: +81-423-88-7129, E-mail: sudayos@cc.tuat.ac.jp

1. Introduction

Single electron devices have been expected to control electrons one by one by the Coulomb blockade effect[1]. If the number of electrons held in a single electron device can be easily controlled, a signal can be transmitted to the next single electron device by transmitting a change in the number of electrons in the former single electron device, which is a sender of the signal. However, so far, these signal transmission circuits using this mechanism have not been reported yet. We have recently found the method to control the number of electrons in a memory device using a serially connected junction-capacitor-junction memory device structure[2] on the basis of the Monte-Carlo simulation[3]. Then, we have applied this method to realize the signal transmission circuits and have found a novel signal transmission circuit architecture which transmits a change in the number of electrons in single electron junctions. In this paper, we first present a method to realize the signal transmission circuit and demonstrate that the circuit successfully functions as a two-way transmission path. Next, we present a method to realize a branch circuit using the signal transmission circuit and demonstrate that the circuit successfully transmits a signal into three branches.

2. Signal Transmission Circuit

Figure 1 shows a schematic of the novel signal transmission circuit using single electron tunneling junctions. This circuit has nodes A_n and B_n between two control lines

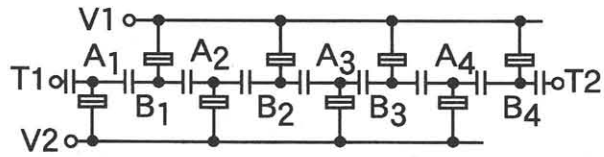

Fig. 1 Schematic of a signal transmission circuit using single electron tunneling junctions.

Table I Operation method for the signal transmission circuit shown in Fig. 1. The electron configuration at nodes A_n and B_n is presented as (n_{An}, n_{Bn}). The V and V_{in} values are 0.37 x e/C_Σ, where C_Σ =2.65C and C is a capacitance of a single electron tunneling junction.

Operation		ON	ON	ON	OFF	OFF
Control line Voltage	V1	V	V	V	0	0
	V2	$-V$	$-V$	$-V$	0	0
Terminal Voltage	T1	0	V_{in}	0	0 or V_{in}	0
	T2	0	0	$-V_{in}$	0	0 or $-V_{in}$
Circuit state	(n_{An}, n_{Bn})	(0, 0)	(1, -1)	(1, -1)	(0, 0)	(0, 0)

V1 and V2. Nodes A_n and B_n are connected to the lines V2 and V1 through a single electron tunneling junction, respectively, and aligned alternately in a row between two terminals T1 and T2. The A_n and B_n nodes are connected through capacitors.

The electron configuration at nodes An and Bn is presented as (n_{An}, n_{Bn}). Since ± charges at these nodes attract each other, the adjacent nodes have multiple stable states corresponding to $(n, -n)$ states.

Using these stable states, we can transmit signals as follows. We first consider the case that the state is initially (0, 0) and voltages V, $-V$ and 0 V are applied to lines V1, V2 and terminal T2 in Fig. 1, respectively. When V = 0 V, the state doesn't change, since the (0, 0) state is most stable under these voltage conditions. When we transmit a plus signal, we apply specific voltages to V1, V2 and T2 such that a (1, -1) state becomes most stable. Then, we apply a plus signal voltage to terminal T1 to move an electron from line V2 to node A_1. When an electron moves to A_1, the electron in B_1 also moves to V1 and the (n_{A1}, n_{B1}) state changes to a (1, -1) state. In the same manner, (n_{An}, n_{Bn}) states change to the (1, -1) state sequentially from left to right in Fig. 1, since (1,-1) is the most stable state. Thus, we can transmit a signal by transmitting a change in the number of electrons in a single electron junction.

Since this circuit has a symmetrical structure with respect to the midpoint, we can transmit signals in a reverse direction from right to left. Therefore, this circuit can transmit signals bidirectionally.

These specific operation voltages are tabulated in Table I. The values of the voltages depend on the device parameters.

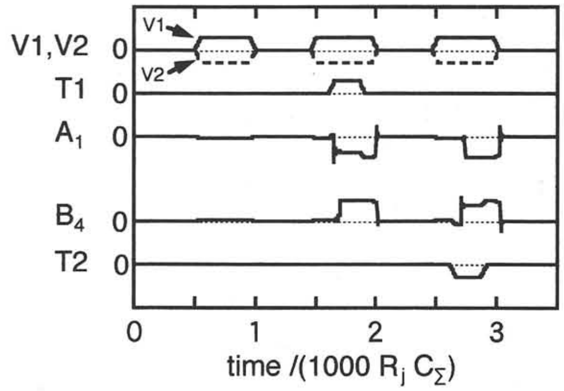

Fig. 2 Simulation results of signal transmission performances of the circuit indicated in Fig. 1. The thick solid and dotted lines show the applied voltages for lines V1,V2 and terminals T1 and T2. The thick lines A_1 and B_4 shows a voltage at node A_1 and B_4, respectively.

In this study, the capacitances of the junctions were set to be C and the capacitances of the capacitors were set to be 1.5 C. To reduce thermal errors[3], the capacitance C was fixed so that the ratio of an electrostatic energy to the thermal energy, E_c/k_BT, for a transition electron, was around 78, where E_c is the electrostatic energy when an electron exists at a node A_n and given by $e^2/(2C_\Sigma)$. C_Σ is a total capacitance of the node and approximately 2.65 C. The ratio of the transition rate from (0, 0) to (1,-1) at V_{in} = 0 V to the same rate at V_{in} = V should be large enough for the high stable circuit operation. To realize this requirement, we set the V and V_{in} at 0.37 x $e/C_\Sigma \approx 1.5$ x $(T/300)$ V so that the ratio is less than 10^{-6}. The junctions were assumed to have the resistance R_J.

The circuit in Fig. 1 has only 8 nodes, however, the above signal transmission mechanism is not limited by the length of the circuit line.

We simulated time-dependent signal transmission performances for the circuit in Fig. 1 using the Monte-Carlo method[2]. In the simulation, the junction resistance R_J was set to be 5GΩ to reduce co-tunneling processes[3].

The result is shown in Fig. 2. The thick solid and broken lines indicate applied voltages for lines V1, V2 and terminals T1 and T2. The thick lines A_1 and B_4 indicate voltages at nodes A_1 and B_4, respectively. When 0 V is applied to terminals T1 and T2 under V1 = -V2 = V, the voltages at nodes A_1 and B_4 do not change. When the voltage V_{in} or -V_{in} is applied to the terminal T1 or T2 under V1 = -V2 = V, the terminal signal voltage is transmitted to B_4 or to A_1, respectively. Therefore, the circuit in Fig. 1 transmits signals bidirectionally in correspondence with the results shown in Table I and the first and last junction nodes (A1 and B4) are also served for output-signal detection nodes.

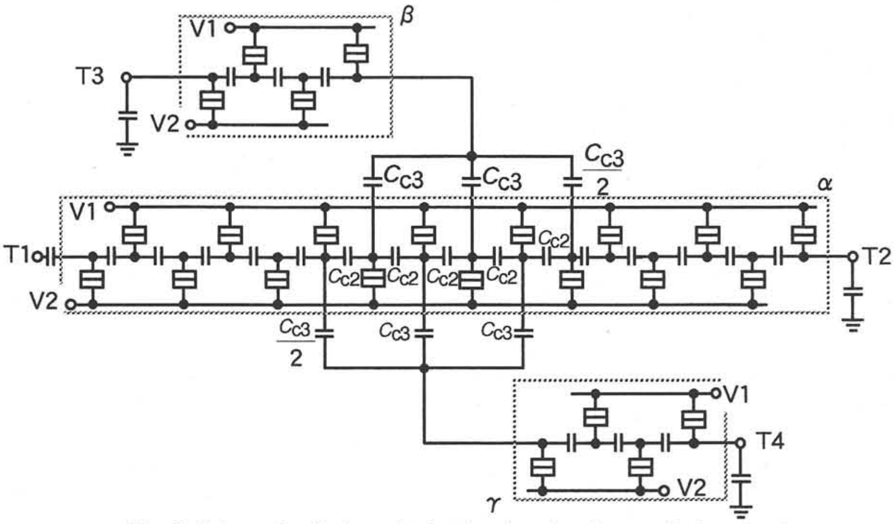

Fig. 3 Schematic of a branch circuit using signal transmission circuits.

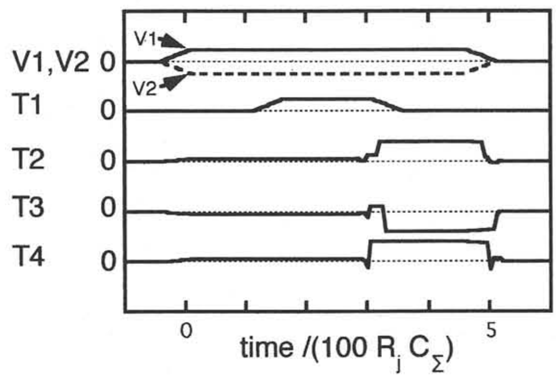

Fig. 4 Simulation results of signal transmission performances of the branch circuit indicated in Fig. 3. The thick solid and dotted lines show the applied voltages for lines V1,V2. The thick lines T1, T2, T3 and T4 show a voltage at node T1, T2, T3 and T4, respectively.

3. Branch Circuit

On the basis of the above results, we constructed a branch circuit, as shown in Fig. 3, and simulated its time-dependent signal transmission performances.

The branch circuit consists of three signal transmission circuits α, β and γ. The α circuit has terminal T1 and terminal T2. The β and γ circuits have terminal T3 and terminal T4, respectively. Three capacitors are connected between circuits α and β and between circuits α and γ. Capacitances C_{c2} and C_{c3} in Fig. 3 were set to be 5/4 C and $C/2$, respectively, so that this circuit can transmit a signal to three branches.

The simulation result is shown in Fig. 4. The thick solid and broken lines indicate voltages for lines V1, V2 and terminals T1, T2, T3 and T4. In this simulation, it is confirmed that the circuit can transmit a input T1 signal to three branches T2, T3 and T4.

4. Conclusions

We have proposed a method to realize a signal transmission circuit using single electron tunneling junctions. Using the numerical simulation based on the Monte-Carlo method, we have demonstrated that the circuit functions as a two-way transmission path, and that a branch circuit consisting of signal transmission circuits successfully transmits a signal into three branches. Since this circuit is simple and can transmit signals bidirectionally and make up branch circuits, the circuit is expected to widen the range of the application of single electron circuits to LSI.

References

1) M. J. Kelly: *Low-Dimensional Semiconductors*, (New York, Oxford University Press, 1995) p. 292.
2) K. Yamamura and Y. Suda: *Extended Abstracts of the 1997 Int. Conf. on Solid State Devices and Materials, Hamamatsu, 1997* (1997) p. 492.
3) K. Yamamura and Y. Suda: *IEICE Trans. Electron.*, **E81 -C** (1998) 16.