Signal Amplification by Circular Single-Electron Oscillator Network with Stochastic Resonance

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ABSTRACT
In this paper, a new type of a neuromorphic single-electron(SE) circuit is described and its operation is also evaluated by conducting Monte Carlo simulation. The circuit is expected as a new information-processing device. However, it is known that the circuit is very sensitive to noise and fluctuation, so that we have studied how to overcome such noise effect. Recently, unique technique that imitates stochastic resonance (SR) behavior in neural networks has been proposed to solve the problem of noise. We focus on internal noise for the SR system. To confirm the SR phenomenon caused by the internal noise, we change the circuit form to a circular structure. We can construct the circular neural network by using the SE circuit because the operation of them is similar to neurons. The proposed SE circuit network was able to show the SR phenomenon. Moreover, the circuit we found could amplify the output signal.

Categories and Subject Descriptors
G.3 [**Stochastic Processes**]

General Terms
Design

Keywords
Neural network, Stochastic resonance, Single-electron circuit

INTRODUCTION
Single-electron (SE) circuits, which are just one type of nanodevices, have been attracting attention because of their unique behavior, i.e., the Coulomb blockade phenomenon[1]. In this study, a new type of a neuromorphic SE circuit is described and its operation is also evaluated by Monte Carlo simulation. The SE circuit is expected as a new information-processing device. However, it is known that the circuit is very sensitive to noise and fluctuation, so that we have studied how to overcome such noise effect for the correct circuit operation[2, 3].

Recently, unique technique that imitates stochastic resonance (SR) behavior in neural networks has been proposed to solve the problem of noise in circuits. Here, we apply the SR system that is based on a model proposed by Collins, et al.[4] to our SE circuit, because by doing so we can expect the circuit to obtain noise redundancy. In this study, we focus on internal noise in our SE circuit for the new SR system. As a first study, we have already designed and demonstrated a new type of the SR system harnessing the internal noises based on the Collins model network that consists of FitzHugh-Nagumo model neurons[5]. In the first study, to generate the internal noise in the network and confirm the SR phenomenon, we changed the network form to a circular structure and connected with neighbor neurons. As results of the demonstration, we confirmed our network could operate as the SR system by harnessing the internal noises.

We can construct the circular neural network by using the arrayed SE circuit because the operation of them is similar to neurons[6]. As our previous work, we have confirmed the SR phenomenon caused by internal noises in the circular SE network[7]. However, we have never confirmed increase of output signal amplitude generated by the circular SE network. Therefore, in this study, we try to design the modified circular SE network that is able to amplify output signal compared with input signal.

SIMULATION
To design the circular SE network, we use a SE oscillator (SEO) that consists of a bias voltage, a resistance, and a tunneling junction connected in series. The tunneling junction has a threshold value for the electron tunneling through it, i.e., we can control the flow of electrons by changing the bias voltage. Our SEO also has a threshold value for changing the voltage at both ends of the tunneling junction caused by the electron tunneling. If bias voltage is bigger than the threshold value of the tunneling junction, electron tunneling occurs and node voltage changes rapidly.

We use arrayed SEOs connected together using coupling capacitors to represent signal propagation on the SE circuit. When the signal is inputted at a SEO as a trigger, the electron tunneling occurs and the node voltage of the SEO changes rapidly. In addition the drastic voltage change of the SEO becomes the input trigger for neighboring SEOs. In this way, the electron tunneling occurs one after another. We regard this operation as signal propagation.

To obtain the SR phenomenon, we design circular SEO network. Figure 1 shows a schematic of the circular SEO network. In this figure, a circle represents a SEO. To obtain the SR phenomenon in our circular SEO network, it is important to loop the signal of electron tunneling unidirectionally. In Fig. 1, the signal of electron tunneling propagates one way as described the arrows. The circular SEO network consists of M SEOs. Each SEO is connected to some oscillators ahead, i.e., first destination to N-th destination. In Fig. 1, we set M=12, N=3.

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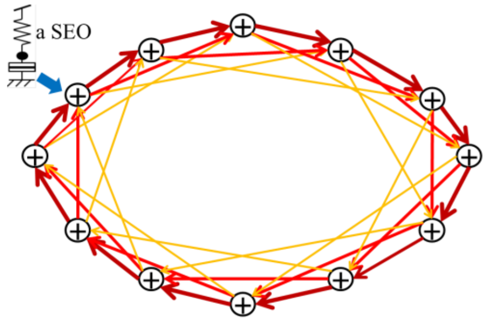

Figure 1: Schematic of circular SEO network

We gave a subthreshold sine wave as an input signal to the circular SEO network. We here assumed that an output signal is average value of node voltages of SEOs consisting of circular SEO network. Figure 2 shows sample operation of the circular SEO network. In Fig. 2, the upper line is the output signal and the lower line is input signal. From Fig. 2, the output signal was similar to the input signal. This result indicates the circuit could detect the subthreshold signal, so that we succeeded to confirm SR in circular SEO network.

Moreover, to amplify the output signal, we changed circuit parameters, because the parameters were not suitable values in the first trial. Figure 3 shows sample operation when we set lower resistance value of SEOs consisting of circular SEO network. From Fig. 3, we could see output signal was amplified. Figure 4 shows sample operation when we increased a frequency of the input sine wave. From Fig. 4, we could also confirm the output signal was amplified.

CONCLUSION

In this study, we tried to obtain the SR phenomena in the SE circuit, and to find a signal-amplifying function. By using the circular SEO network, we could confirm the SR phenomenon in the circuit, firstly. To obtain the amplifying function, we changed the circuit parameter of our circular SEO network. When we lowered resistance value of the SEOs and when we increased the frequency of the input sine wave, the circuit we found could amplify the output signal.

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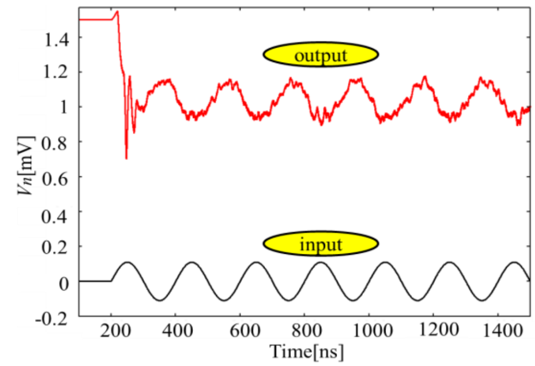

Figure 2: Sample operation of Figure 1
R=77[MΩ], C_l =2[aF], C_j =10[aF], R_j =0.2[MΩ], V_d=1.5[mV], M=1000, N=10
Input sine wave: amplitude=0.055[mV], frequency=5[MHz]

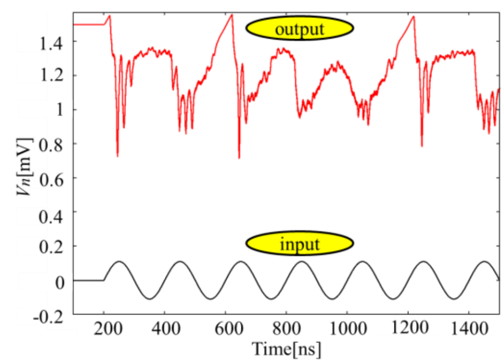

Figure 3: Sample operation of Fig. 1. Resistance is lowered as R=77[MΩ]→R=50[MΩ]

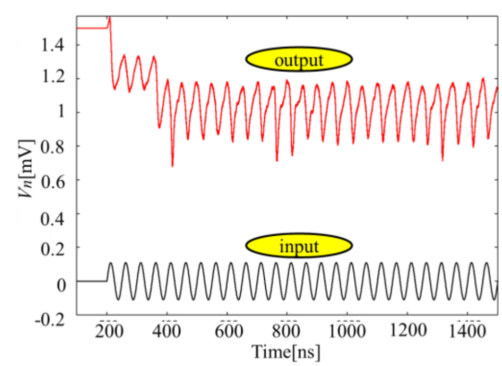

Figure 4: Sample operation of Fig. 1. Frequency is increased as frequency=5[MHz]→frequency=20[MHz]