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Study of Stochastic Resonance in Circular Single-electron Oscillator Array

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Extended Abstract

In this study, a new type of a neuromorphic single-electron (SE) circuit is described and its operation is also evaluated by computer simulation. The circuit that can control individual electrons by controlling Coulomb blockade effect is expected as a new information-processing device. However, it is known that the circuit is very sensitive to noise and fluctuation, so that many researchers have studied how to prevent such noise affecting its operation. Recently, unique technique that imitates stochastic resonance (SR) behavior in neural networks has been proposed to solve the problem. The SR phenomenon, which was discovered in studies on the brains of living things, can be considered as a type of noise-energy-harnessing system. In the natural world, the brains of creatures can operate correctly as a whole under a noisy environment because the brain harnesses the noise energy to process information correctly. Here, we apply the SR system that is based on a model proposed by Collins et al. (1995) to our SE circuit, because by doing so we can expect the circuit to obtain noise redundancy. As a previous step in this ongoing study, we reported that the SE circuit has thermal-noise- and device-error-redundancies (Kurotaki et al., 2009, Murakami et al., 2014). In this paper, we focus on internal noise as the third noise source for the SR system in our SE circuit. Recently, the SR phenomenon driven by internal noise or fluctuation in a real brain system has been observed. It is known that there are many neurons and they construct networks in the brain. The neurons generate action potentials in the network as results of information processing. However, the generated action potential from a neuron should be noise (internal noise) for other neurons or networks. Therefore, such action potentials can be considered as important noise sources for information processing in the brain.

As another previous work, we have also 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 (Ishimura et al., 2014). 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 four neighbor neurons. As results of the demonstration, we confirmed our network could operate as the SR system by harnessing the internal noises.

Here, we apply the circular neural network to the SE circuit and demonstrate its operation by Monte Carlo simulation. The main component of the circuit is an SE oscillator that consists of a resistance, a tunnelling junction, and a bias voltage source. We can construct the circular neural network by using the arrayed SE oscillators because the operation of them is similar to neurons. To imitate the network, we also connect each oscillator with a few neighbors by coupling elements. The proposed SE oscillator network is expected to show the SR phenomenon caused by internal noises.

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