# Stochastic Resonance among Single-Electron Neurons on Schottky Wrap-Gate Devices

Takahide Oya (YA), Tetsuya Asai, Ryo Kagaya, Seiya Kasai, and Yoshihito Amemiya
Graduate School of Information Science and Technology, Hokkaido University,
Kita 14, Nishi 9, Kita-ku, Sapporo, 060-0814, Japan
E-mail: oya@sapiens-ei.eng.hokudai.ac.jp

Neuromorphic computing based on single-electron circuit technology has become widely noticed because of the recent claim about its massively increased computational efficiency and its increasing relevance between computer technology and nanotechnology. Its impact will be strongly felt when single-electron circuits based on a fault- and noise-tolerant neural structure are able to operate in a room-temperature environment. To fabricate such robust single-electron devices, we investigated stochastic resonance (cf. [1]) in an ensemble of single-electron boxes (SEB) [2]. We here employ a single-electron transistor (SET) on a schottky wrap-gate (WPG) device [3], instead of a SEB, as a neuron, and examine statistical results of the network by numerical simulation.

The reason why we employ WPG-SETs instead of SEBs is that SETs have a switching characteristic as CMOS transistors do. A general SET consists of a capacitor ($C$) for an input terminal and two tunneling junctions ($C_j$s), as shown in Fig. 1. A SET has three terminals, and we can connect controllable voltage sources to the terminals. In this report, we connected terminals with bias $V_d$, input $V_g$ and ground, respectively. We controlled the switching characteristic by controlling the voltage sources. When the SET is in operation, an electron can tunnel through two $C_j$s (between ground and a node, or between a node and $V_d$) in a low-temperature environment because electron tunneling is governed by the physical phenomenon called the Coulomb blockade effect. In addition, we should be able to easily observe the operations of practical SET devices. However, we must also be careful when we use single-electron circuits in a high-temperature environment. The reason is that electrons randomly tunnel through $C_j$s because the Coulomb blockade effect is disturbed by thermal fluctuations.

Now let us consider an SR among $N$ SETs in a network, as shown in Fig. 1. When SETs are not connected with each other, electron tunneling in each SET's junction occurs independently. As in [1], we applied a common input to all the SETs and calculated the sum of outputs of the SETs. For simplicity, we applied a common input voltage $V_{in}$ to all the SETs as $V_g$, and did not consider practical circuits that calculate the sum of the changes in each node's electric charge $Q_i$. The $i$-th SET's $Q_i$ was increased with the input voltage, while the magnitude of the input was set to a very low value so that no electron would tunnel through $C_j$s. Under this condition, increasing the magnitude of thermal noise (temperature) enables electrons to tunnel through each $C_j$.

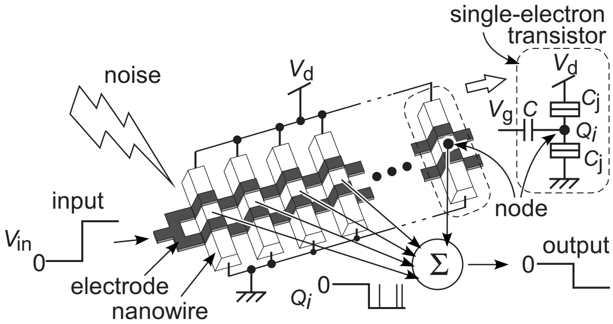


Fig. 1: Summing network of $N$ WPG-SETs [3].

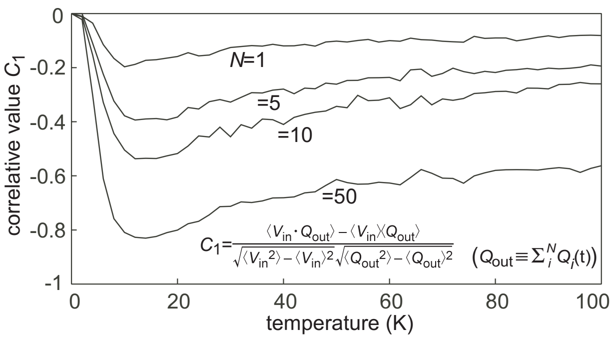


Fig. 2: Stochastic resonance in ensemble of SETs.

Figure 2 shows simulation results of an ensemble of SETs for $N = 1$, 5, 10 and 50. We increased the temperature from 0 K to 100 K and calculated correlation values ($C_1$) between the input voltages and the summed output. The results showed characteristic signatures of SR-type behavior: a rapid rise to a peak, and then a decrease at high temperatures. We observed that the magnitude of $|C_1|$ increased as $N$ increased, as expected. The resonant temperatures were approximately 10 K for all the values of $N$. In addition, $C_1$ took a large value –0.6 at 100 K when $N = 50$, and increased as $N$ increased. According to [1], the correlation value should become almost 1.0 when $N$ = 1000. The results indicate that when one employs such an SR network in single-electron circuits, it certainly acts as a transmission line that can cancel noises on the line, as well as, cancel the devices' intrinsic noises.

## References

[1] Collins J.J., *et al.*, *Nature*, **376**, 236-238, 1995.
[2] Kagaya R., *et al.*, *Proc. 9th Int. Conf. Cognitive and Neural Systems*, II-#28, 2005.
[3] Kasai S., *et al.*, *Jpn. J. Appl. Phys.*, **36**, 1678-1685, 1997.