Noise-Assisted Spike Transmission on an Array of Electrical FitzHugh-Nagumo Models

Gonzalez-Carabarin Lizeth*, Tetsuya Asai, and Masato Motomura

Graduate School of Information Science and Technology, Hokkaido University

It is known that brain is able to complete certain tasks successfully under noisy environments, therefore it is important to explore the role of noises in certain biological processes to improve the performance. Recently, Ochab-Marcinek *et al.* demonstrated that in myelinated axons having several intermediate nodes (known as Ranvier nodes), transmission of spikes initiated by subthreshold stimuli can be enhanced by exploiting membrane-potential-dependent dynamic noises [1]. Motivated by this work, we investigate how noise and fluctuations enhance the performance of spike transmission in serially-connected electrical *excitable* circuits receiving subthreshold inputs.

We here employ an electrical circuit of the FitzHugh-Nagumo model [2] operating in the excitable mode, and embed a current noise source in parallel with a tunnel diode (Fig. 1). The dynamics of the 1-D excitable medium (our virtual axon), where the excitable circuits were locally coupled, are represented by the following continuous forms:

$$\begin{aligned} C\frac{\partial v(x)}{\partial t} &= g\frac{\partial^2 v(x)}{\partial x^2} + i(x) - i_{\rm d}[v(x)] + I_{\rm n}[v(x)], \\ L\frac{\partial i(x)}{\partial t} &= E - R \cdot i(x) - v(x), \end{aligned}$$

where x represents the space, $i_d(\cdot)$ the I-V characteristics of the tunnel diode, $v(x)$ the membrane potential at x, E the resting potential, and $I_{\rm n}[v(x)]$ the $v(x)$-dependent dynamic noise current where the noise current is generated only when $v > E$. The characteristics of $I_{\rm n}(\cdot)$ is crucial for successive spike transmission; *i.e.*, if noises were generated independently of v, excitable circuits that should not be depolarized (receiving no input) may be depolarized by the noise, whereas if noises were generated only when $v > E$, the circuits may be depolarized only when inputs (external stimuli or firing of the neighbors) are given, even if the input is below the threshold of the depolarization.

We conducted SPICE simulations for the model (tunnel diode: NEC 1S1760, $C = 0.1$ nF, $R = 0.2\ \Omega$, $L = 10\ \mu$H, $E = 50$ mV, $I_{\rm n}(v) = I(t)\theta(v - E)$ where $I(t)$ represents the Gaussian noise (update period: 50 ns) with zero mean and standard deviation σ, and $\theta(\cdot)$ the step function) to confirm properties of the spike transmission. Nine excitable circuits ($i = 1 \sim 9$) were locally connected by resistors $R_{\rm c}$ ($\sim g$), and the first circuit on the boundary was stimulated by an external current pulse (amplitude: 0.5 mA, width: 1 μs). When $R_{\rm c}$ was 1 kΩ, we could observe successive spike transmission (from the first to ninth circuit) without noise assistance ($\sigma = 0$), whereas spike transmission was randomly terminated when $R_{\rm c}$ was 1.5 kΩ. On this setup, when $\sigma = 0.45$ mA, we could observe successive spike transmission with the noise assistance (Fig. 2), which clearly exhibited noise-assisted spike transmission in the chained excitable circuits. We will further investigate the relationship between the noise strength (or σ) and the rates of successive transmission, to develop noise-assisted active transmission line consisting of coarse-grained devices and materials.

*email: lizeth@lalsie.ist.hokudai.ac.jp

References

[1] Ochab-Marcinek A. *et al.*, Phys. Rev. E, 79, 011904, 2009.

[2] http://www.scholarpedia.org/article/FitzHugh-Nagumo_model

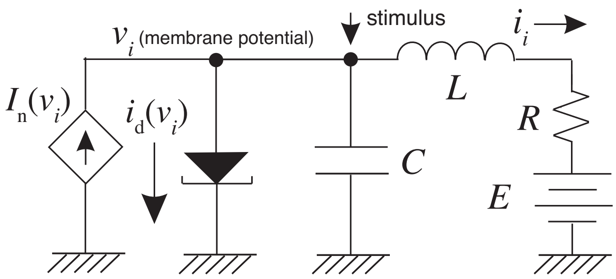

Fig. 1. Noise-driven FitzHugh-Nagumo circuit.

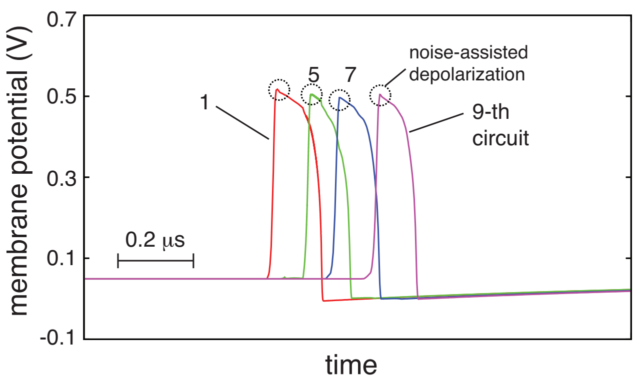

Fig. 2. Results: noise-assisted spike transmission.