Noise Impact on Spike Transmission through Serially-Connected Electrical FitzHugh-Nagumo Model with Subthreshold and Suprathreshold Interconductances

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It is known that brain is able to complete certain tasks successfully under noisy environments; therefore it is important to explore the role of noise in certain biological processes to improve the performance. Recently, Ochab-Marcinek *it 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 noise [1]. Motivated by this work, we investigated how noise and fluctuations enhance the performance of spike transmission in serially-connected electrical *excitable* circuits receiving subthreshold inputs. Moreover, this work is extended to study how fluctuations of interconductances affect spike transmission rate, from the subthreshold to the suprathreshold interconductance case.

We here employ an electrical circuit of the FitzHugh-Nagumo model [2] operating in the excitable mode, and embedded 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:

$$C\frac{\partial V(x)}{\partial t} = g\frac{\partial^2 v(x)}{\partial x^2} + i(x) - i_d[v(x)] + I_n[v(x)],$$
$$L\frac{\partial i(x)}{\partial t} = E - R \cdot i(x) - v(x)$$

Where x represents the space, $i_d(\cdot)$ represents the I-V characteristics of the tunnel diode, $v(x)$ represents the membrane potential at x, E is the resting potential, and $I_n[v(x)]$ is the $v(x)$-dependent dynamic noise current where the noise current is activated only when $v > E$. The characteristics of the $I_n[\cdot]$ is crucial for successive spike transmission; *i.e.*, if noise sources were activated independently of v, excitable circuits that should not be depolarized (receiving no input) may be depolarized by the noise, whereas if noise sources were activated 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 = 0.1nF, R = 0.2Ω, L = 10μH, E = 50 mV, $I_n[v] = I(t)\theta(v - E)$ where $I(t)$ represents the Gaussian noise (updating 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 ($i = 1\sim9$) were locally connected by resistors R_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_c was 1 kΩ, we could observe successive spike transmission (from the first to the ninth circuit) without noise assistance ($\sigma = 0$), whereas spike transmission was randomly terminated when R_c was 1.5 kΩ. Following 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 show the relationship between the noise strength (or σ) and the rates of successive transmission, and how fluctuations of interconductances affect transmission in order to develop noise-assisted active transmission line consisting of coarse-grained devices and materials.

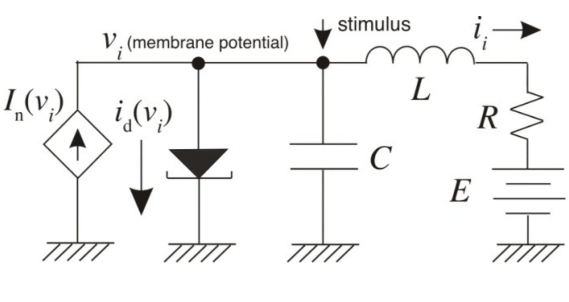

Fig. 1 Noise-driven FitzHugh-Nagumo circuit

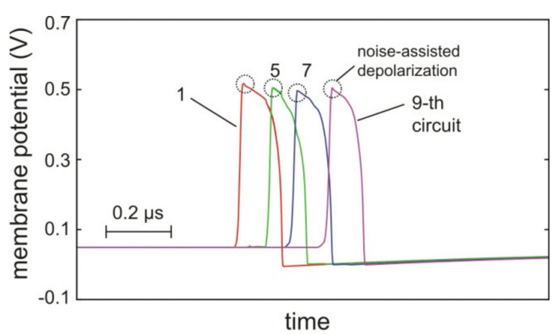

Fig. 2 Results: noise-assisted spike transmission

[1] Ochab-Marcinek A. *it et al.*, Phys. Rev. E, 79, 011904, 2009.
[2] http://www.scholarpedia.org/article/FitzHugh-Nagumo_model