Ion-Channel and Synaptic Noise in a Cortical Neuromorphic Circuit

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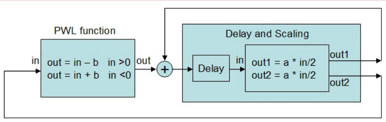
Overview

- Variability is a prominent feature of neural behavior
- One type of variability is noise. Another type might be chaotic behavior
- Two main sources of intrinsic neural noise are synaptic release noise and ion-channel noise
- Gaussian noise or a chaotic signal is used to control intrinsic behavior of a synapse circuit to vary neurontransmitter release in an unpredictable manner, modeling synaptic release noise
- There are two variable intrinsic signals in the axon hillock circuit: one could force the neuron to fire and the other one could prevent the neuron from firing
- An intrinsic signal forcing the neuron to fire when there is no PSP in fact models the spontaneous firing of the neuron
- A chaotic signal generator using carbon nanotube transistors is presented
- The chaotic generator, synapses and an axon hillock were simulated using carbon nanotube SPICE models, with voltages scaled to match possible electronics range

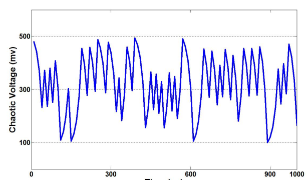
Chaotic Signal Generator Circuit



Block diagram of the improved chaotic signal generator.

$$x_{n+1} = f(x_n) = \begin{cases} ax_n + b : x_n < 0 \\ ax_n - b : x_n \geq 0 \end{cases}$$

a chaotic piecewise linear one-dimensional map



Chaotic voltage with Vpp=400mv, Vmid=300mv, Vinit=480mv,
period of each sample=10ns
(converted from simulated current produced by chaotic signal generator)

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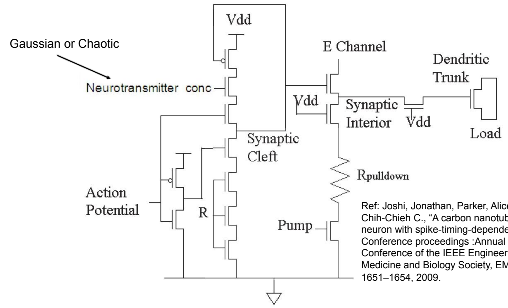
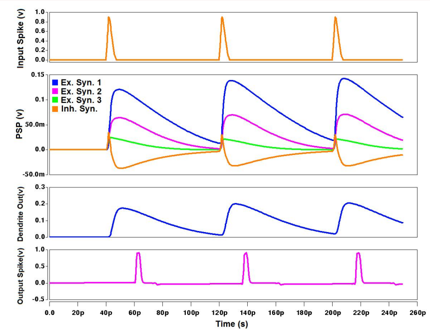
Synaptic Noise



Ref: Joshi, Jonathan, Parker, Alice C. and Hsu, Chih-Chieh C., "A carbon nanotube cortical neuron with spike-timing-dependent plasticity", Conference proceedings :Annual International Conference of the IEEE Engineering in Medicine and Biology Society, EMBC, pp. 1651–1654, 2009.

The carbon nanotube excitatory synapse.

Synaptic Release Noise Results



Input spike, PSP's, dendrite output and output spike for the neuron with no variability included

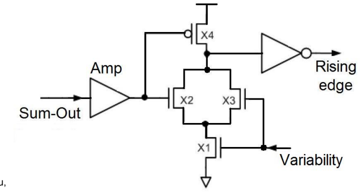
	Chaos Vpp=100mv	Gaussian σ=100mv
Exc. Syn. 1	62.3 %	61.3 %
Exc. Syn. 2	60.3 %	59.7 %
Exc. Syn. 3	59.0 %	56.2 %
Inh. Syn.	58.2 %	55.1 %

Predicted probability of firing when variability is intrinsic to each synapse.

Variable Neuron Results and Discussion

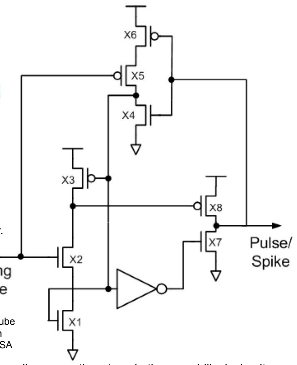
- Two main source of intrinsic variability, ion-channel and synaptic release variability are modeled.
- Results for synaptic release variability shows the inhibitory synapse is more sensitive to the synaptic release variability than the excitatory synapses. Also among the three excitatory synapses, the neuron is more sensitive to the synaptic release variability applied to a weak synapse as compared to variability applied to a strong synapse.
- A chaotic signal generator in carbon nanotube technology is presented.

Ion-Channel Noise in an Axon Hillock



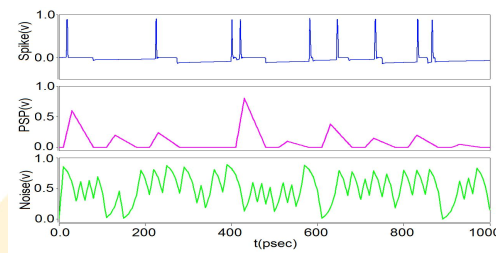
The axon hillock input stage circuit with intrinsic variability.

Ref: J. Joshi, C. Hsu, A. C. Parker, and P. Deshmukh, "A carbon nanotube cortical neuron with excitatory and inhibitory dendritic computations," in IEEE/NIH 2009 LIfe Science Systems and Applications Workshop (LiSSA 2009), 2009..

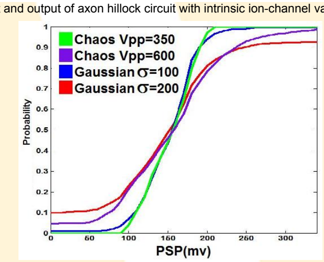


The spike generation stage in the axon hillock circuit.

Ion-channel Noise Results



Input and output of axon hillock circuit with intrinsic ion-channel variability



Probability of firing vs. PSP amplitude for two different types of ion-channel variability (Gaussian and chaotic signal)

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