Noise shaping pulse-density modulation in inhibitory neural networks with noise-sensitive subthreshold neuron circuits

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Abstract: An inhibitory network model that performs noise-shaping pulse-density modulation [1] was implemented with subthreshold analog MOS circuits, aiming at the development of ultralow-power ΣΔ-type AD converters. Through circuit simulations, we evaluate the effects of the noise shaping produced by the network circuit.

Method: The network consists of N integrate-and-fire neurons (IFNs) with all-to-all inhibitory connections [1]. A common analog input is given to all the IFNs, while 1-bit digital output is given by the sum of firing events of the IFNs. Static and dynamic noises are introduced into the analog input and the reset potential of IFNs after each firing, respectively. Since the wiring complexity of the network; i.e., $O(N^2)$ in [1], can be reduced to $O(N)$ by introducing a global inhibitor [2], we designed a network circuit as shown in Fig. 1. The static and dynamic noises are given to the circuit as device mismatches of current sources (I_i) and external random (Poisson) spikes, respectively.

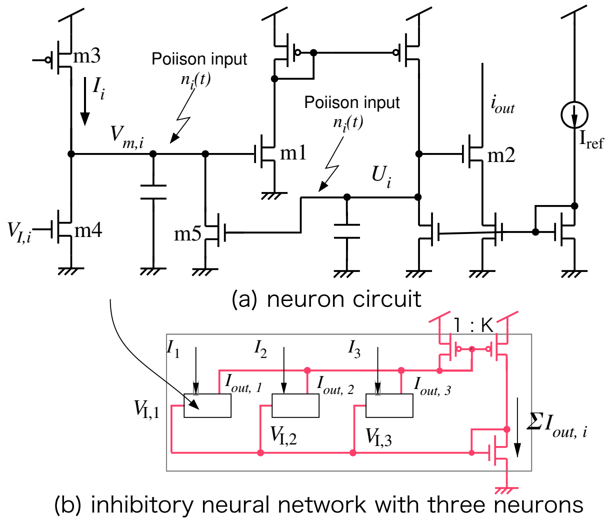

Fig. 1: Circuit structure of neuron and network.

Results: Figure 2 shows an example of the circuit simulations (N = 3, I_i = [1:1.2] nA, amplitudes of the Poisson spikes: 1 nA, the width: 10 μs, the mean and variation: 5000). When IFNs were uncoupled (K = 0: mirror rate of a pMOS current mirror in the network circuit), inter-spike intervals (ISIs) of the output spike trains looked almost random (upper left in Fig. 2), whereas they were almost uniform when the IFNs were coupled with K = 3 (upper right in Fig. 2). Figure 2 (bottom) shows a histogram of ISIs for K = 0 and 3. As expected in [1], the coupled network produced a Gaussian-like distribution of ISIs, while the uncoupled one had a broad distribution. Figure 3 shows the power spectrum of the coupled and uncoupled network with sinusoidal inputs ($I_i = I_0 + A\sin(2\pi f t)$, I_0 = 1 nA, A = 50 pA, f = 100 Hz). A measured SNR of the uncoupled network was 10.2 dB, while that of the coupled one was 18.1 dB, which indicated that the network reduced the noises significantly, although noise-sensitive (but low-power) subthreshold CMOS devices were used in the circuit. The cutoff frequency was able to be increased by decreasing capacitances or by increasing the magnitudes of input currents.

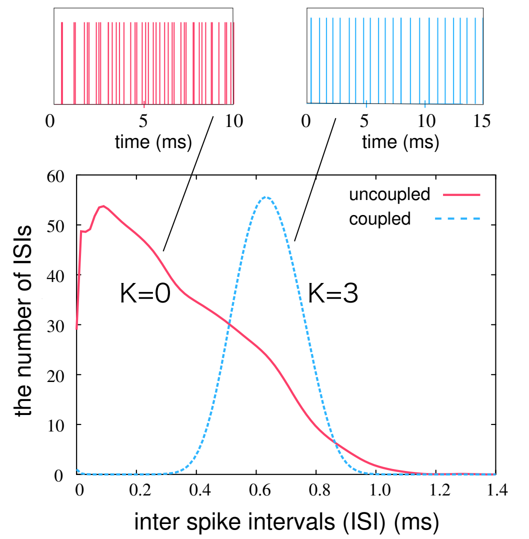

Fig. 2: Output spikes of the network circuit (top) and the histogram of ISIs (bottom)

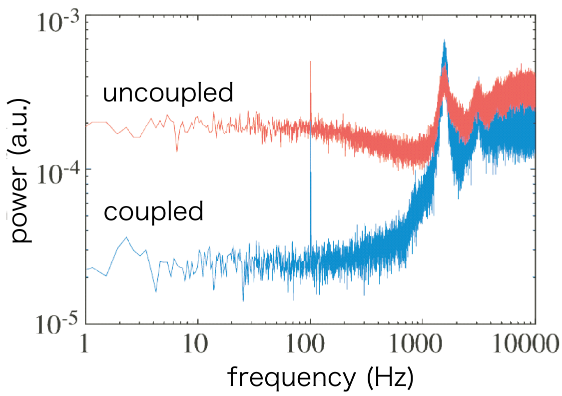

Fig. 3: Power spectrum of sum of output spikes.

References

[1] Mar DJ, Chow CC, Gerstner W, Adams RW, and Collins JJ, Neurobiology, vol. 96, pp. 10450-10455, 1999.

[2] Asai T, Kanazawa Y, Amemiya Y, IEEE Trans. Neural Networks, vol. 14, no. 5, pp. 1308-1312, 2003.