STOCHASTIC RESONANCE IN THE LIF MODELS WITH INPUT OR THRESHOLD NOISE

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ABSTRACT

Since the first application of its paradigm to the recurrences of Earth's ice ages [4], the Stochastic Resonance (SR) has been suggested as occurring in a number of phenomena in biology, chemistry and physics; in particular, in the activity of certain sensory neurons [6, 5] and in neuronal networks from the mammalian brain [7].

Moreover, although the early natural examples of SR were modeled in terms of the classical double-well potential [9], the SR paradigm was recently extended to different model systems. Among these, the threshold or excitable devices have received much attention [13].

The leaky integrate-and-fire (LIF) neural model has been extensively employed to account for both the linear and the nonlinear features of information coding in single neurons [8, 12]. There, the input signal mimicking the "ionic current" (usually a periodic one) is integrated up to a threshold level, then a spike is fired, the integral function (corresponding to the "membrane voltage") is reset to zero and the integration restarted.

Such a simple model can be made more realistic by introducing noise in its operation; and there are two ways to do this.

The most used one is by adding noise to the input signal. In fact, the SR behaviour of such a model was thoroughly investigated in the case of underthreshold signals and gaussian white noise [1, 10, 11].

However, the system activation can also be obtained by supposing the noise to affect the firing threshold. In this case, by using a gaussian-distributed stepwise noise with a high innovation pace, the corresponding model can be well approximated by suitably defining an instantaneous firing rate [2, 3]. This allowed us to analytically solve the relevant equations and obtain the main statistical functions describing the system's activity. Its "resonant" behaviour could thus be demonstrated [2, 3]. But besides the regular SR, also bimodal resonance curves were found, either for low frequencies and large amplitudes of modulation or for high modulation frequencies [3] - a behaviour that can be explained in terms of firing patterns phase-locked to the input signal.

The question arises whether the bimodal feature of SR is shared from the LIF model with noise on the input signal. In this report, a comparative analysis of behaviour of the two models affected by the same type of noise is performed by numerically simulating their firing activities.

Keywords: Stochastic resonance, Leaky integrate-and-fire, Interspike interval distribution.

References

[1] Barbi M., S.Chillemi, A Di Garbo, The leaky integrate-and-fire with noise: a useful tool to investigate SR. *Chaos, Solitons and Fractals*057 **11**:1849-1853, 2000.

[2] Barbi M., S.Chillemi, A Di Garbo, Stochastic resonance in a sinusoidally forced LIF model with noisy threshold. In *Mathematics and Computers in Science and Engineering*. C.E. D'Attellis, V.V. Kluev and N.E. Mastorakis eds., WSES Press, pp. 169-172, 2001.

[3] Barbi M., S.Chillemi, A Di Garbo, L. Reale, Stochastic resonance in a sinusoidally forced LIF model with noisy threshold. *Biosystems*, in press.

[4] Benzi R., A. Sutera, A. Vulpiani, The mechanism of stochastic resonance. *J. Phys. A* **14**:L453-L457, 1981.

[5] Collins J.J., T.T. Imhoff, P. Grigg, Noise-enhanced tactile sensation. *Nature* **383**:770, 1966.

[6] Douglass J.K., L. Wilkens, E. Pantazelou, F. Moss, Noise enhancement of information transfer in crayfish mechanoreceptors by stochastic resonance. *Nature* **365**:337-340, 1993.

[7] Glukman B.J., T.I. Netoff, E.J. Neel, W.L. Ditto, M.L. Spano, S.J. Schiff, Stochastic resonance in a neuronal network from mammalian brain. *Phys. Rev. Lett*. **77**:4098-4101, 1996.

[8] Keener J.P., F.C. Hoppensteadt, J. Rinzel, Integrate-and-fire models of nerve membrane response to oscillatory input. *SIAM J. Appl. Math*. **41**:503-517, 1981.

[9] MacNamara B., and K. Wiesenfeld, Theory of stochastic resonance. *Phys. Rev. A* **39**:4854-4869, 1989.

[10] Plesser H.E. and T. Geisel, Markov analysis of stochastic resonance in a periodically driven integrate-and-fire neuron. *Phys. Rev. E* **59**:7008-7017, 1999.

[11] Shimokawa T., K. Pakdaman, S. Sato, Time-scale matching in the response of a leaky integrate-and-fire neuron model to periodic stimulus with additive noise. *Phys. Rev. E* **59**57 :3427-3443, 1999.

[12] Tuckwell H., *Introduction to theoretical neurobiology*. Cambridge University Press, Cambridge, 1988.

[13] Wiesenfeld K., D. Pierson, E. Pantazelou, C. Dames, F. Moss, Stochastic resonance on a circle. *Phys. Rev. Lett*. **72**:2125-2129, 1994.