

Interspike Interval Distribution: a Sensitive Instrument for Diagnostic of Neuronal Dynamics.

Tatiana Verechtchaguina
tania@physik.hu-berlin.de

Lutz Schimansky-Geier
alsg@physik.hu-berlin.de

Igor M. Sokolov
igor.sokolov@physik.hu-berlin.de

Institute for Physics, Humboldt University at Berlin, Newton Str. 15, 12489 Berlin, Germany

Keywords: subthreshold and firing-rate resonance, Morris-Lecar model, FitzHugh-Nagumo model

1 Introduction

The subthreshold response of neurons to a weak membrane depolarization can follow one of the two patterns: The so-called resonant neurons show subthreshold oscillations with a voltage dependent frequency, while non-resonant neurons relax monotonously to the resting potential [2, 3]. The resonant behavior is typically indicated by a peak in the power spectrum of the subthreshold neuronal response or by periodicity of its autocorrelation function [1]. In firing resonant neurons the subthreshold oscillations lead to spikes following with the preferred frequency, giving rise to the bursting and the firing-rate resonance in the suprathreshold response [6]. However, these effects are not evident just from observing spike trains, looking rather similar on a shorter time scale. We show that the interspike interval distribution is an appropriate instrument to distinguish between resonant and non-resonant neurons in the firing regime.

2 Spectra and ISI distributions of the FN and ML Neurons.

We simulate the neuronal dynamics using two theoretical models exhibiting both resonant and non-resonant behavior: The FitzHugh-Nagumo (FN) model [4] and the Morris-Lecar (ML) model [4] driven by a white Gaussian noise $\xi(t)$ of intensity D . The results for both models are quite similar. The resonant case is characterized by two intrinsic times scales (besides the refractory time): by the time between the beginning of a spike and the first maximum of subsequent subthreshold oscillation ($T_1 = 2\pi/\omega_1$) and by the period of subthreshold oscillations ($T_2 = 2\pi/\omega_2$).

The form of the power spectra is rather the same in both regimes. The spectrum obtained numerically for the resonant FN model for $D = 0.001$ is presented in the fig. 1 with a black line and shows a high main peak accompanied with the second harmonic. In both regimes the main peak moves to higher frequencies with increasing noise intensity, however this shift is much less pronounced in the resonant regime: the corresponding frequency stays close to ω_1 . We stress that the difference in spectra of resonant and non-resonant neurons is seen in the response to changing external parameters. The assessment of dynamics based on one set of parameters is of limited value.

Subthreshold oscillations in resonant neurons modulate the distance to the excitation threshold and affect strongly the distribution of the interspike intervals (ISI). We obtained the ISI probability density function (pdf) $\rho(T)$ from the neuronal output reduced to the δ -spike sequence for resonant and non-resonant cases. The corresponding pdfs for the ML model are shown in fig. 2. These pdfs differ

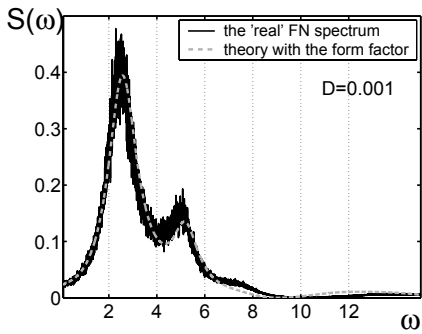


Figure 1: Power spectrum of the resonant FN neuron (black line). Power spectrum calculated from ISI pdf and from the form of a single spike (gray dashed line).

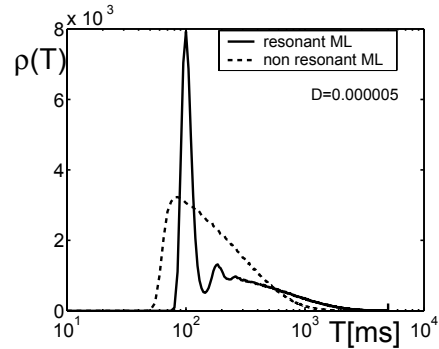


Figure 2: ISI pdf obtained from simulations of the ML model in resonant and non-resonant regimes for $D = 5.0 * 10^{-6}$. Note the logarithmic scales.

qualitatively in the two regimes: possessing only one maximum for a non-resonant neuron and showing oscillations for the resonant one. The first maximum (close to T_1) for resonant case corresponds to the ISI within a burst. Further maxima follow with the period of subthreshold oscillations T_2 . The tail of the resonant distribution is flat and long mirroring large intervals separating bursts. Power spectra can be reconstructed from the ISI pdf and from the form of a single spike assuming the renewal character of the process (Stratonovich formula) [5]. The example of reconstructed spectrum is given in fig. 1. A good agreement shows that the ISI pdf contains almost all relevant information about the system dynamics.

3 Discussions

We study the suprathreshold response of resonant and non-resonant neurons to noise-like signals. We show that *the interspike interval distribution* gives a sensitive instrument to distinguish between resonant and non-resonant neurons even in firing regime and contains all relevant information about the system dynamics.

References

- [1] Amir R., Michaelis M., and Devor M., Membrane Potential Oscillations in Dorsal Root Ganglion Neurons: Role in Normal Electrogenesis and Neuropathic Pain, *J. Neurosci.*, 19(19):8589–8596, 1999.
- [2] Gutfreund Y., Yarom Y., and Segev I., Subthreshold oscillations and resonant frequency in guinea-pig cortical neurons: physiology and modelling, *J. Physiol.*, 483(3):621–640, 1995.
- [3] Hutcheon B., Miura R.M., and Putil E., Subthreshold membrane resonance in neocortical neurons, *J. Neurophysiol.*, 76(2):683–697, 1996.
- [4] Koch C., *Methods in neuronal modeling*, MIT Pr., 1992.
- [5] R.L. Stratonovich, *Topics in the Theory of Random Noise*, vol. 1, Gordon and Breach, 1963.
- [6] Wu, N., Hsiao, C.-F., and Chandler, S.H., Membrane Resonance and Subthreshold Membrane Oscillations in Mesencephalic V Neurons: Participants in Burst Generation, *J. Neurosci.*, 21(11):3729–3739, 2001.