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Resonant response of a Hodgkin-Huxley neuron to a spike train input

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Introduction

Experiments show that neurons have a tendency to respond to signals tuned to a resonant frequency [1]. In order to understand the general properties of a resonant response of a neuron, we study the silent Hodgkin-Huxley neuron driven by periodic input. The current arriving through the synapse consists of a set of spikes $I_p(t) \sim g_{syn} \sum(t/\tau) \exp(-t/\tau)\ C(t)\ (V_a - V_{syn})$, where g_{syn} is the synapse conductivity, τ is the time constant associated with the synapse conduction, V_a is the maximum membrane potential and V_{syn} is the reversal potential of the synapse.

Results

See Figures 1 and 2.

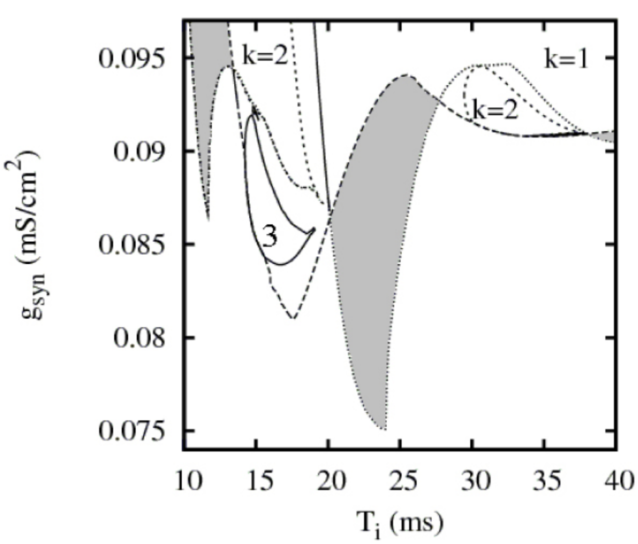

Figure 1

The phase diagram for typical HH model parameters [2]**in the limit of small synaptic conductivity**. There is a well-pronounced minimum at T_i = 17.5 ms. The resonant nature of the response can be seen also at multiples of this value, at $T_i \approx$ 34 ms and $T_i \approx$ 50 ms. Near the resonance the system has the tendency to mode locking with high values of *k*, where $k = T_o/T_i$ is the ratio of the output ISI to the input ISI. For example near the main resonance frequency we find narrow regions with *k* = 5, 6 or 9. Areas with bistable solutions are shown in grey. We expect the resonance at T_i = 17.5 ms to survive in the presence of noise.

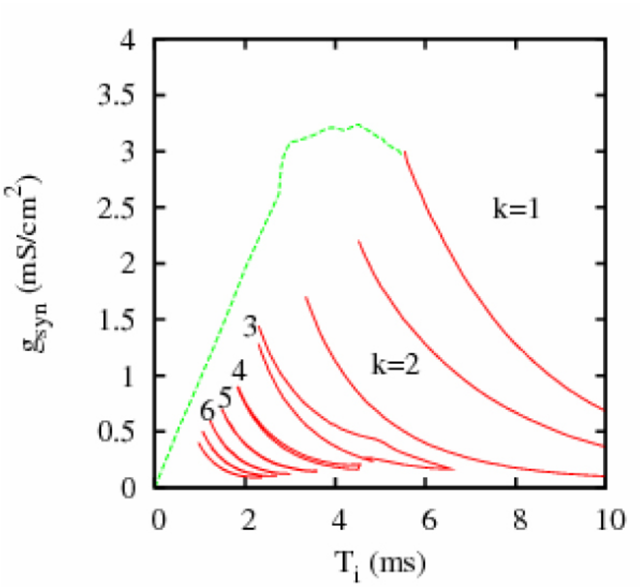

Figure 2

In the limit of small T_i the distinction between the firing spikes and subthreshold oscillations disappears and the output signal decreases to 0 for sufficiently large g_{syn}. Broken line in the figure indicates a transition to nonfiring behavior. In the area below this transition the amplitude of the spikes gradually increases. Solid lines are borders of the mode-locked states with different values of *k*. Properties of this model are similar to the HH model with a sinusoidal driving current at intermediate values of input ISI T_i = 5–12 ms. However the results in both the high and the low frequency regime are qualitatively different. In the case of a sinusoidal input there is only one resonance frequency and reported values of *k* are lower [3].

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References

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