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Frequency response functions for cortical microcircuits

Philip Ulinski

Address: Committee on Computational Neuroscience, University of Chicago, Chicago, IL 60637, USA

Email: Philip Ulinski - pulinski@uchicago.edu

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Neurons in the cerebral cortex form interactions that can be described as a network of feedforward and feedback, excitatory and inhibitory loops. It is, consequently, natural to represent cortical microcircuits as a control system (e.g. [1]) with thalamic inputs and outputs to other brain regions. For example, the visual cortex in freshwater turtles contains pyramidal cells that receive inputs from the lateral geniculate nucleus and project to other cortical areas, the geniculate and structures in the brainstem [2]. The cortex also contains at least three populations of inhibitory interneurons called subpial cells, stellate cells and horizontal cells [3]. The subpial cells form a feedforward inhibitory loop while the horizontal cells form a feedback inhibitory loop. We have recently [4] used a large-scale model of turtle visual cortex to characterize this cortex as a control system. However, this model is too large and complex to allow analysis with methods from control and systems theory. We have taken an approach to characterizing the dynamics of cortical microcircuits by developing a dynamical systems model that consists of a family of linear non-autonomous ordinary differential equations. The activity of the i^{th} population of neurons, x_i, is given by the equation

$$dx_i(t)/dt = \sum_{j=1}^{N} a_{ij}(t)x_j(t)$$

where the summation is over all of the N populations of neurons. The time-dependent coefficients give the time course of synaptic interactions of all neurons in the i^{th} population by all of the neurons in the j^{th} population. The coefficients were determined by fitting the solutions of the above equation to the results of simulations using the large-scale model. In this study, we characterized the responses of the system to sinusoidal inputs of varying frequencies. The responses of the system consisted of a transient response and a steady-state sinusoidal response. The transient response consisted of two activity peaks that corresponded to the primary and secondary propagating waves seen in this cortex. The amplitudes of both peaks varied as a function of stimulus input and showed a resonant peak at 20 Hz. Individual neurons can show both low and high frequency resonance peaks [5,6] due to the passive properties of the neuronal membranes and active properties of voltage gated ion channels. This work suggests that cortical networks can have resonant properties that differ from those of their constituent neurons.

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