BME 572 HW1

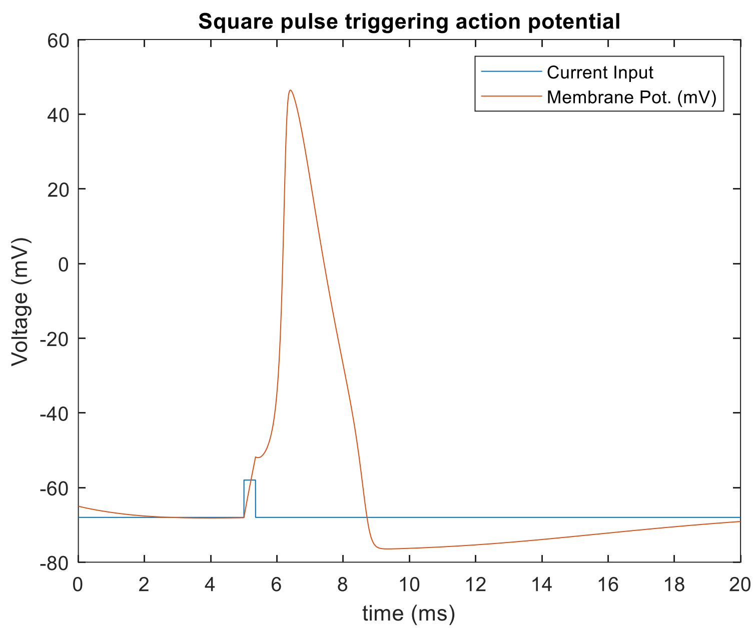
Young Beum Cho

Young Beum Cho

• Problem 1

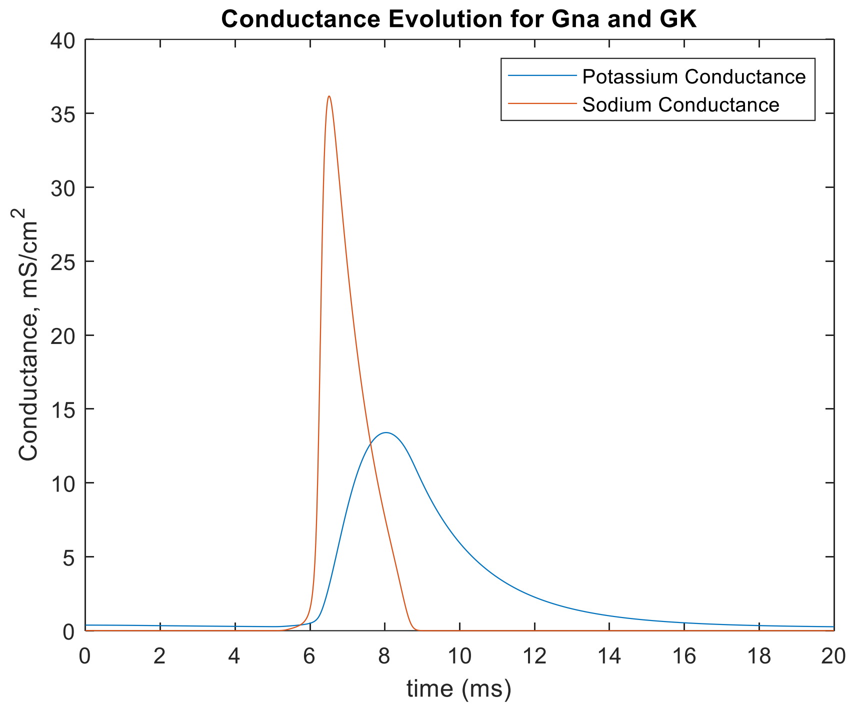
a. The graph shows evolution of the Action Potential (mV) in Hodgkin Huxley Model. The current stimulation begins at t = 5ms, where the beginning of depolarization is observable. After brief time, the membrane goes under repolarization status, and hyperpolarizing near 9 to 10ms mark. Current input (blue) does not follow the axis displayed, but rather, amps.

Figure 1: Action Potential Evolution



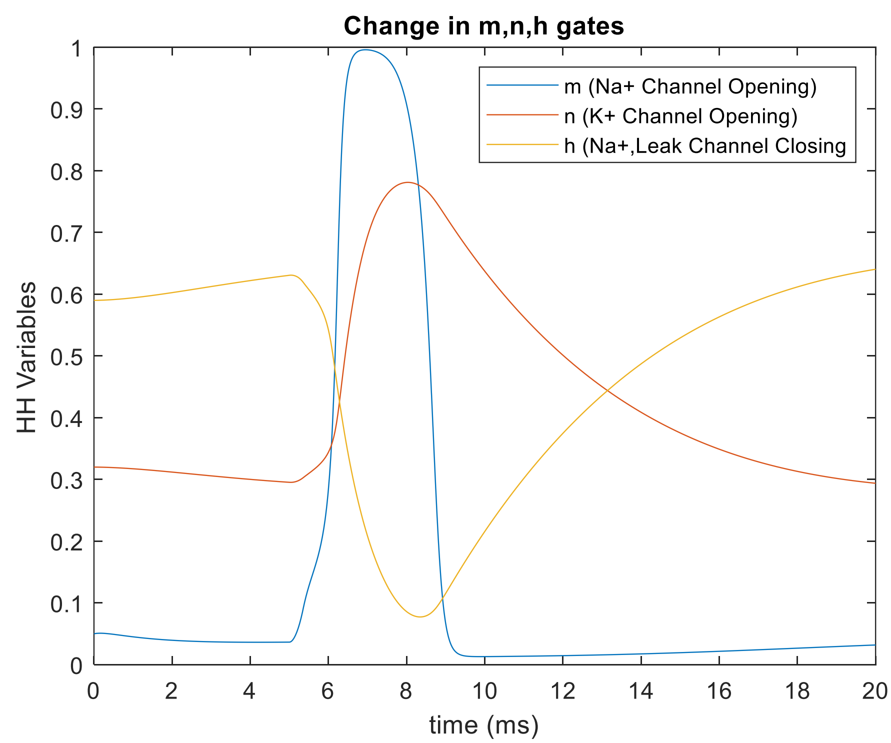
b. Following graph shows evolution of potassium and sodium conductances over the same time period as above. One of the significant interpretation which can be given from the graph is that the sodium conductance's abrupt increase is where the depolarization occurs fast. This can be translated that the sodium is a huge contribution in this phenomena

Figure 2: Conductance Evolution



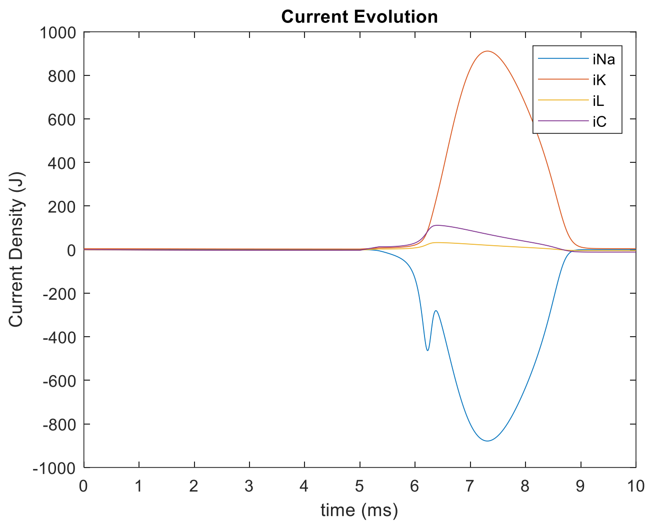
c. The m, n, and h gates' evolution over time is shown in the following graph. As like above, m-gate (mainly works as Na+ Channel) is a high contributor in depolarization period

Figure 3: m, n, h gate Evolution



d. Current Evolution is shown below. iC here is a capactive current represented as a product of derivative in membrane voltage and capacitance which is set to 1uF. Other than that, all current type evolution visual representation expectation is met.

Figure 4: Current Evolution



e. Following graph shows threshold and rebound behavior. In which, rebound behavior is also known as an anode break (~70ms); A neuron produces action potentials in reaction to the end of a hyperpolarizing current

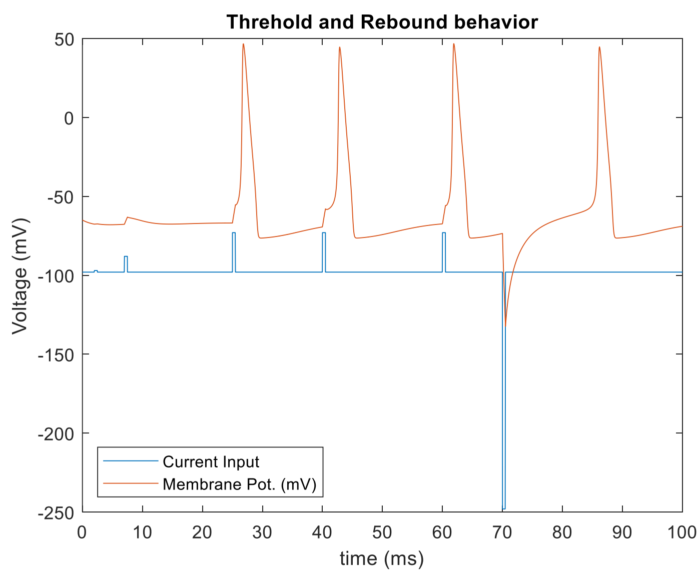


Figure 5: Threshold and Rebound behavior

$$\text{Reduced}\, C\dot{V} = I - \overbrace{g_K n^4 (V - E_K)}^{I_K} - \overbrace{g_{Na} m_\infty^3 (V)(0.89 - 1.1n)(V - E_{Na})}^{\text{instantaneous } I_{Na}} - \overbrace{g_L (V - E_L)}^{I_L}$$

f. Reduced form of C(dV/dt) was calculated using the equation shown above. In code, the transition is shown in the code “q1p1_reduced.m” and “hhdiff_reduced.m”. The corner which m, n, and h values change drastically seemed to take a sharper turn comparative to when original C(dV/dt) function was used. Other than that, the pattern shows similar behavior with m as the one that reaches highest amplitude, and y-axis is scaled larger.

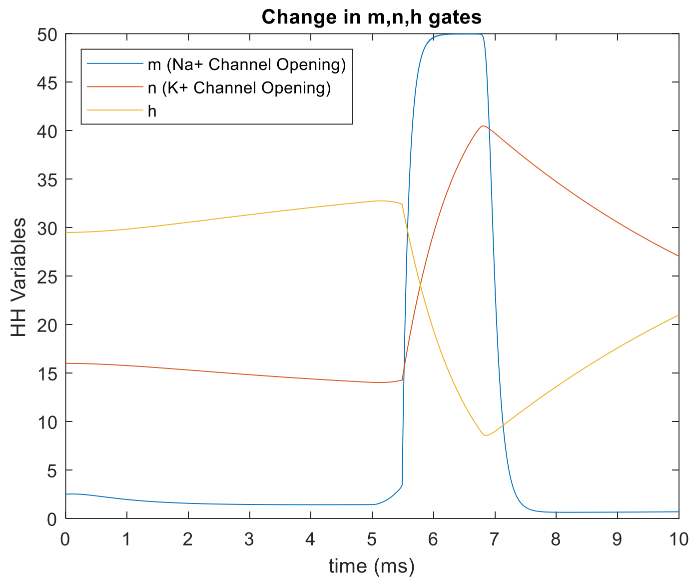


Figure 6: Reduced HH m, n, and h evolution

g. Reduced form of HH and its m, n, h gate evolution, along with threshold and rebound behavior is displayed below. All current input along time interval were made the same as the instruction. Even though, the anode break excitation has not visibly occurred on the graph as compared to original HH. Different form of expressing C(dV/dt) is seemed to cause this phenomenon.

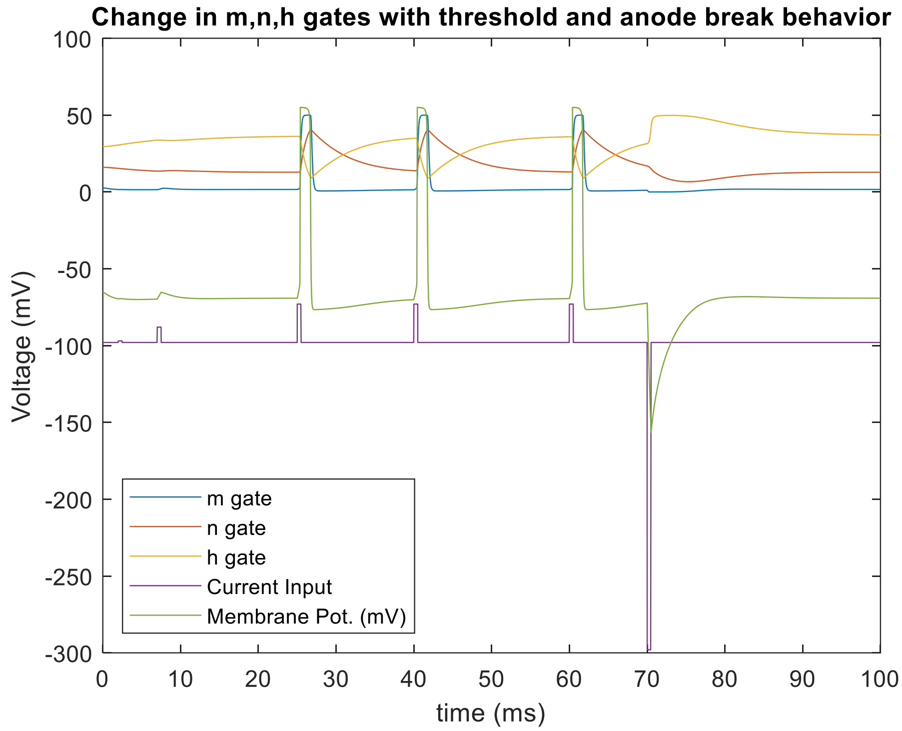


Figure 7: Reduced HH m, n, h gate evolution, threshold, and anode break behavior

• Problem 2

a. Below graph shows current stimulation used for part a

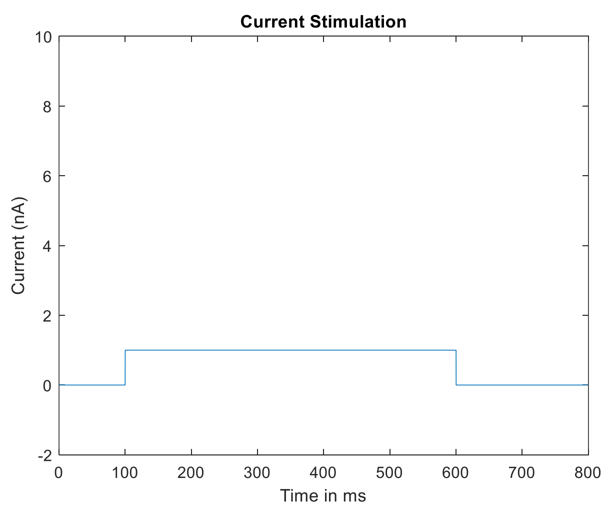


Figure 8: Current stimulation for problem 2 part 1

b. Spike behavior for above current stimulation to the system provided is shown below. Even though a constant square wave was applied from t = 10ms to t = 60ms, only 6 spikes were observed in total. This creates a speculation that there exists what can be known as a refractory period; When a nerve cell is unable to discharge an action potential over an extended period after its previous firing.

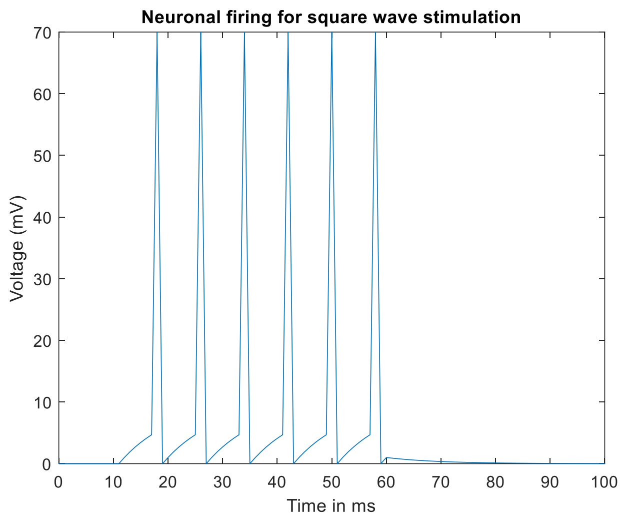


Figure 9: Neuronal Firing for a square wave

c. Differentiated frequency (1, 2, 5, 10, 20, 50, 100) was applied to create 7 sinusoidal wave types, all originating from the formula sin(wt). 0~1000ms represents one whole cycle which a sinusoidal input with frequency of 1 can go through within 1 period. The highest frequency (blue – 100 Hz) is located at the top of the graph and decreases as it goes below.

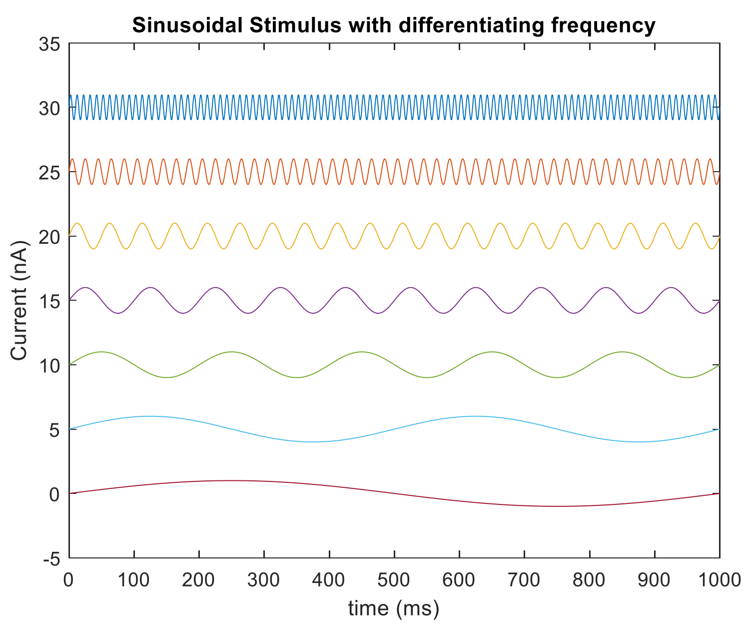


Figure 10: Sinusoidal Stimulus with differentiating frequency

d. Integrate and Fire (IAF) model responses to above sinusoidal stimulus input with differentiating frequencies are shown below. The response rates (in this case, reaching a threshold voltage, and therefore 70mV action potential voltage) showed tendency to decrease as frequency of current stimulus increases.

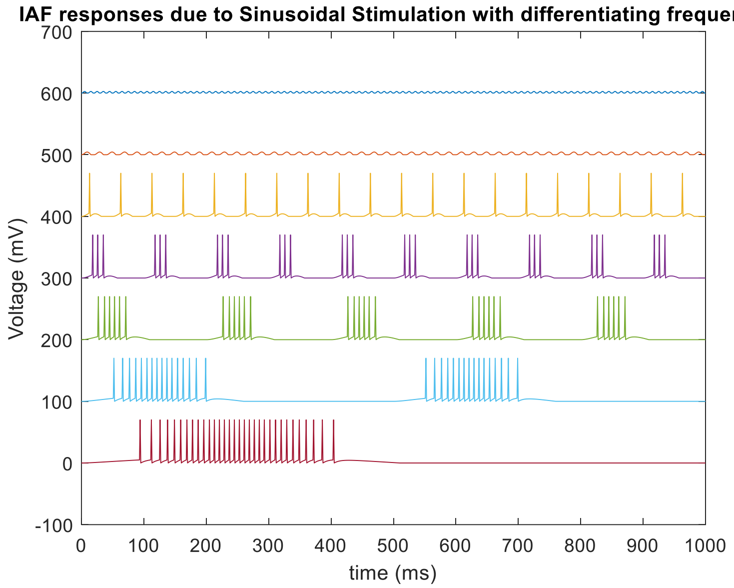


Figure 11: IAF Responses due to Sinusoidal Stimulus

e. Spike Count VS Stimulus Frequency plot is shown below. Spikes show tendency to decrease drastically at > ~10 Hz stimulus frequency. With all above data for problem 2 and this one, if scope is to generate overall more spikes, then it can be concluded that building model with lower frequency works the best.

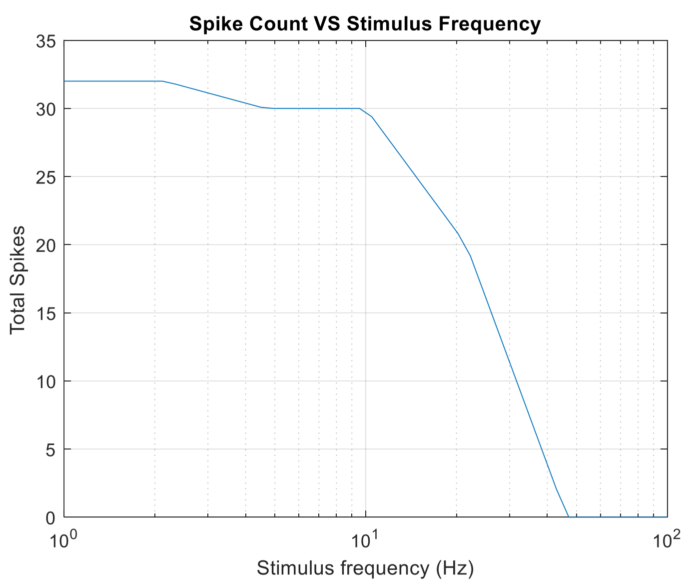


Figure 12: Spike Count VS Stimulus Frequency

• Problem 2-b

a. IAF response graph and u-response graph are shown at the top at bottom of the below figure. For these two, Higher frequency is in upper level (blue) and a current stimulation effect of 1Hz sinusoidal wave are shown in lowest level (red). Unlike the IAF response formulated in 2a, the Spike Count VS stimulus Frequency shows a big difference and unique property in such that the peak spike count is achieved at ~20Hz. It's interesting how a differentiating model enables system to do so.

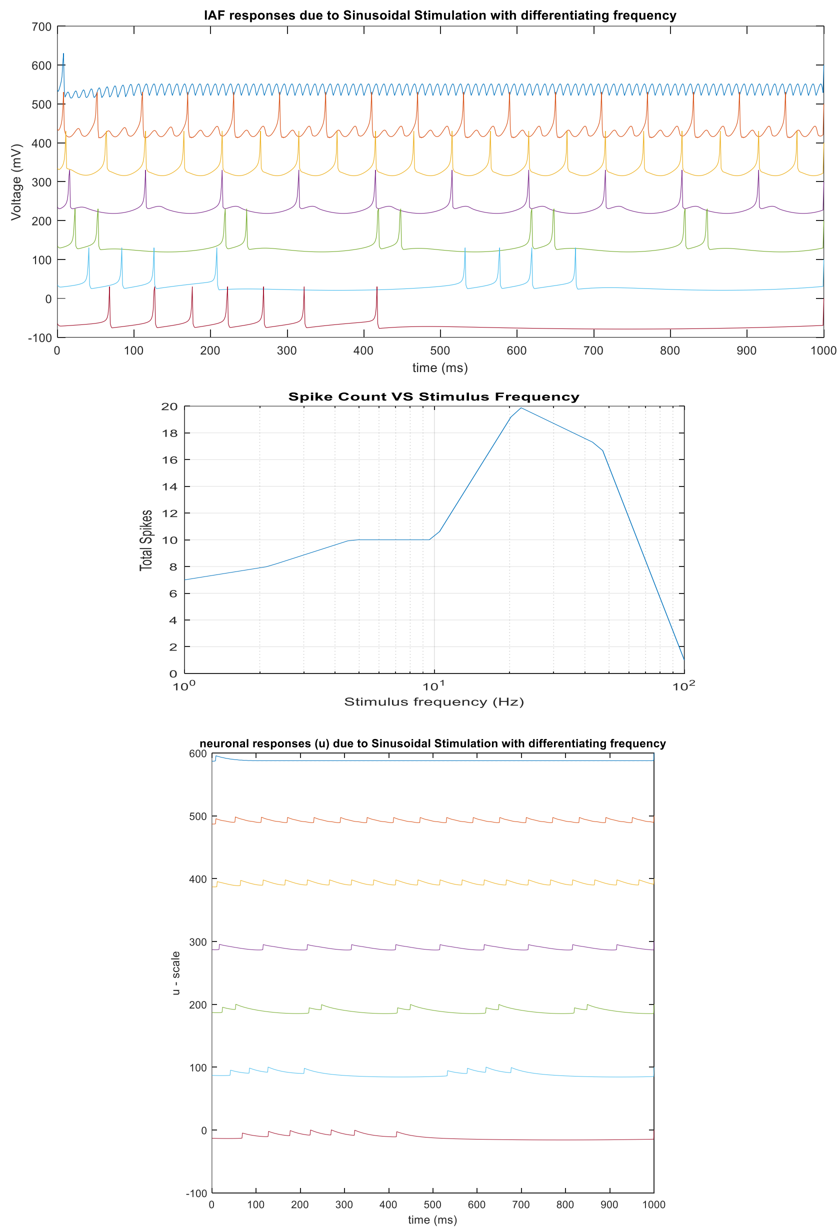


Figure 13: IAF Response, U-Response, and Spike count for different frequencies

- # Problem 2c

    a. Constant Current input 1.1nA and 0.9nA were used to stimulate neuron 1 and neuron 2 from t = 1 to t = 1500. Theta1 and Theta2 were used to be utilized as a dynamic threshold for each neuron. It is interesting how slight variations in current and therefore affecting the other dependent variables create different form of Action Potential pattern.

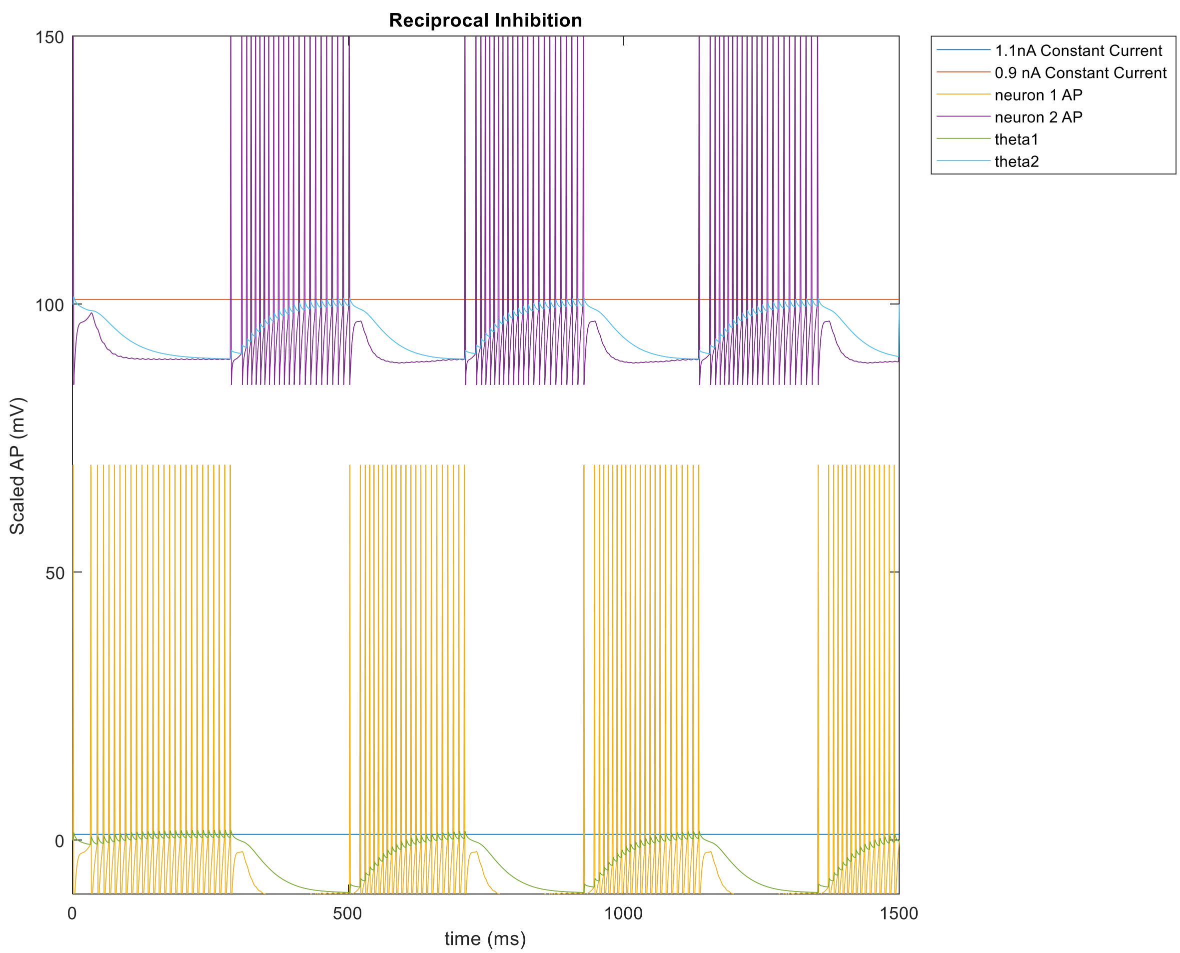


Figure 14: Reciprocal Inhibition

References

1) Geffen, MN, Broome, BM, Laurent, G and Meister, M. (2009). "Neural encoding of rapidly fluctuating odors." Neuron 61(4): 570-586
2) E. M. Izhikevich, Simple model of spiking neurons, IEEE Transactions on Neural Networks, Vol. 14, no. 6, pp. 1569-1572, 2003.
3) Matrix Inversion: Finding the Inverse of a Matrix: https://www.purplemath.com/modules/mtrxinvr.htm
4) Insert efficiently elements into sorted array: https://www.mathworks.com/matlabcentral/answers/387099-insert-efficiently-elements-into-sorted-array
5) reshape a matrix and fill empty indices by zeroes: https://www.mathworks.com/matlabcentral/answers/495680-reshape-a-matrix-and-fill-empty-indices-by-zeroes