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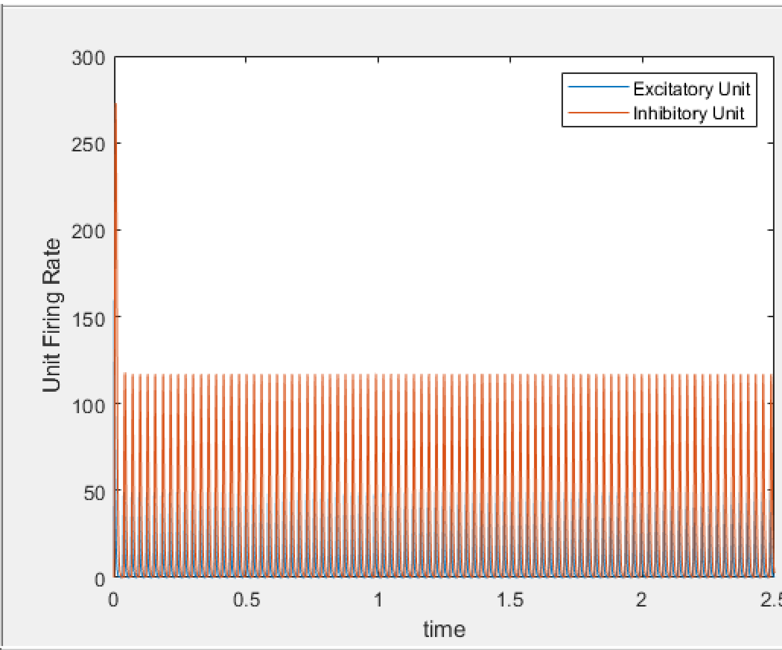
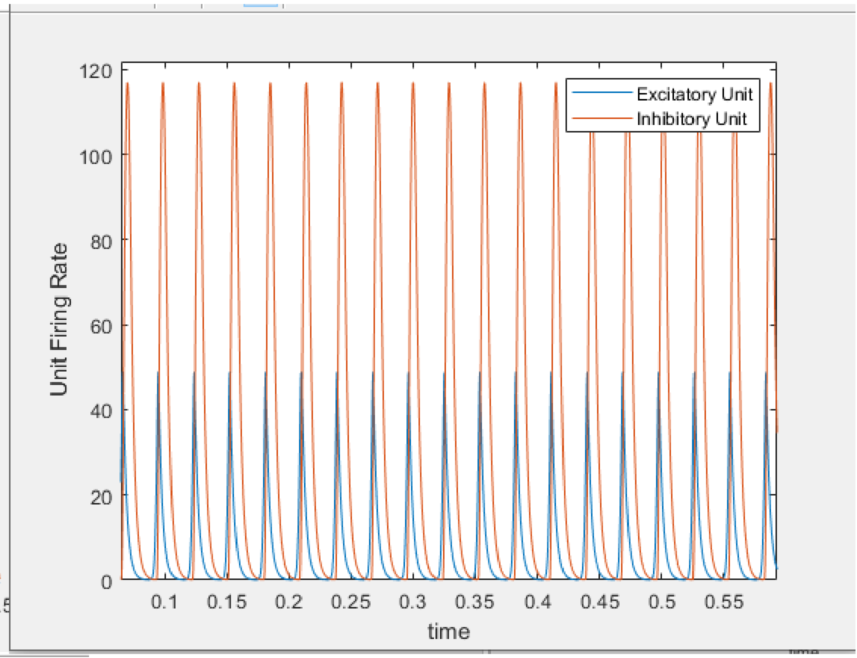
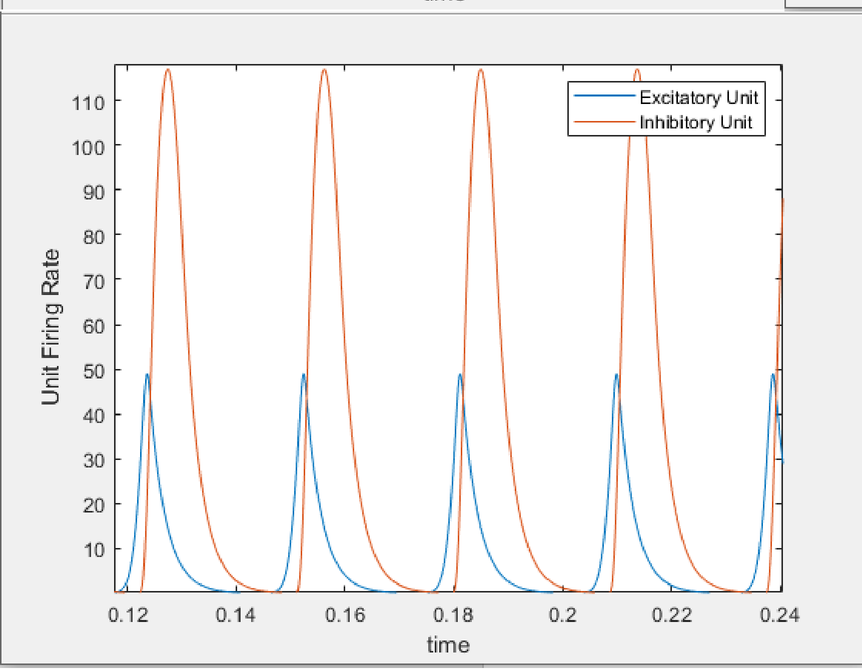
Tutorial 5.3

1.)







Note:

These are all the same graph, just a few different views of the same trial

Units seem to just under 0.029 seconds, making their frequency just above 34.5Hz but below 35.

More text on next page

See notes; The coupling of an excitatory and inhibitory unit with specific parameters can lead to oscillation. Activity generally follows the following pattern…

Cells in the excitatory unit rise because of strong recurrent connections (the unit is self-excitatory). This positive feedback continuously increases the firing rate of the unit until interrupted. Simultaneously, an increase in firing rate also excites the second, inhibitory unit. This inhibitory unit, now firing at a fairly high frequency, provides strong inhibition to the excitatory unit, decreasing its firing rate. Eventually, this drives the excitatory unit down to a firing rate that provides insufficient excitation to the inhibitory unit, causing it too to plummet in firing rate. Now that the inhibitory unit is firing at a much reduced rate (providing very little inhibition), the excitatory unit is free to self excite once more.

In order for this oscillation to be possible, there must be some sort of delay between the excitatory cells increasing their own firing rate and subsequently being inhibited by the inhibitory unit receiving this same excitation. In this case, that delay is present even if synaptic time constants were equal, because in order for excitation to cause inhibition, it must go through two synapses (first from E unit to I, then back again,) but for excitation to cause further excitation it needs only go through one (E unit to E).

2.)

Time of "first" peak: 0.5263s

Time of last peak: 2.4832s

Number of peaks: 69

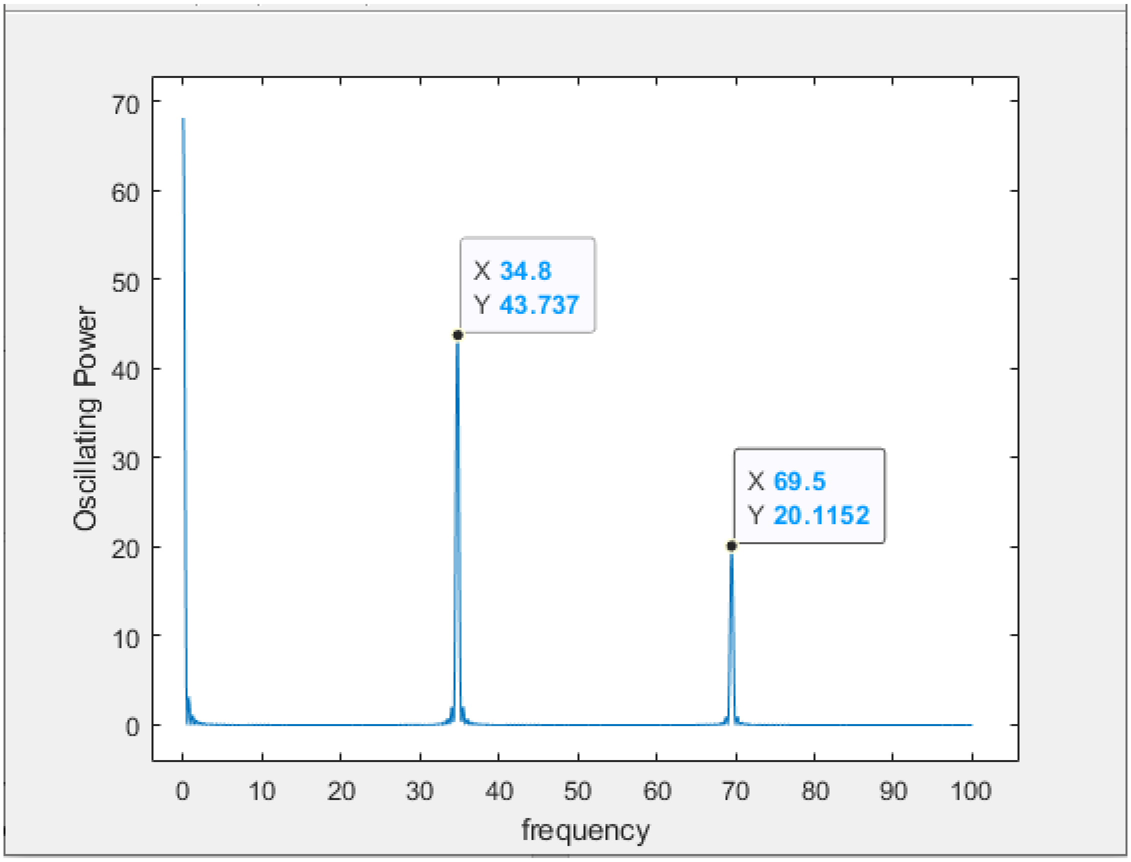
Period = time between first and last peaks / number of peaks = 2.4832s-0.5263s/69 peaks =

0.0284 seconds/spike

Frequency = 1/Period = 1/(0.0284 seconds/spike) = 35.2598 peaks/second

Data analyzed was after an initial period of 0.5 seconds, allowing for units to stabilize (hence the "first" peak time). In order to calculate the frequency of oscillation, we must first know how many oscillations occur in the a given time period, and how long the time period is. To do this, a near min and near max variable were initialized (value just below max and just above min of a single oscillation.) Then, discrete time points of each time the near max value of firing rate was surpassed were recorded. The duration of the time period is therefore defined as the difference between the first and last of these time points. The number of peaks in this time period divided by the time period should give us the frequency of oscillation. We can additionally calculate the period of the oscillation as 1/frequency. Calculations here closely match observations in part 1, confirming results.

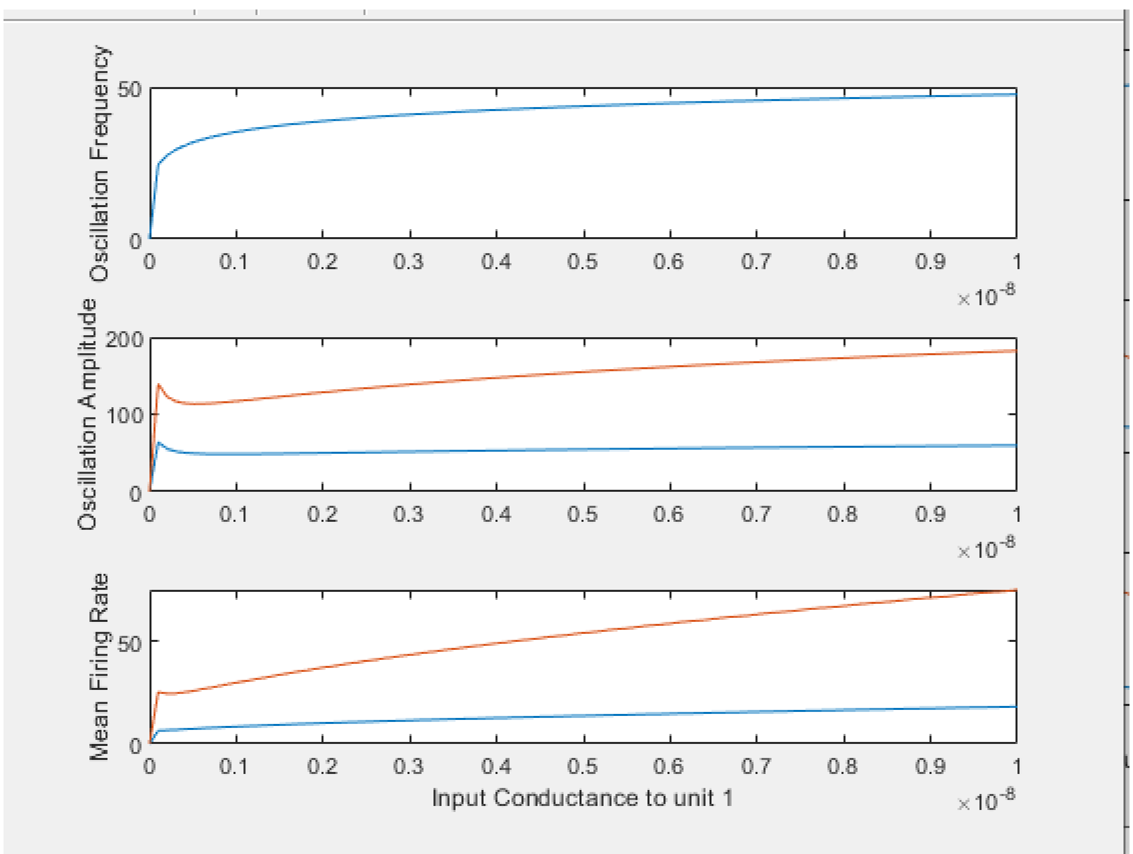
3.)



The frequency that produces the highest oscillating power (ie the frequency of oscillation in our model; the fundamental frequency) seems here to be around 34.8. This agrees closely with visual analysis of firing rate over time observed in the first question. Because of how we performed this functional “Fourier transform”, other frequencies that are integer multiples are also visualized. Namely, the “second harmonic” that is visible at about twice our frequency has about half its oscillating power. We would expect to see this trend continue if we tested further frequency values, expecting another smaller peak at around 104.4.

In order to understand why f=0 produces an outlier in this analysis, we should go back to how exactly oscillating power is calculated here. P(f) is calculated as the sum of the squares of the average of our rate vector * a cos or sin function dependent on 2*pi*time*f. Substituting f for 0 here means that Pf = (the average of a lot of zeros)^2 + (the average of our rate vec)^2. This will produce a peak because the squared mean firing rate is larger than our actual amplitude at our frequency.

4.)


Oscillation Frequency
50
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
×10^-8
Oscillation Amplitude
200
100
0
Mean Firing Rate
50
0
Input Conductance to unit 1

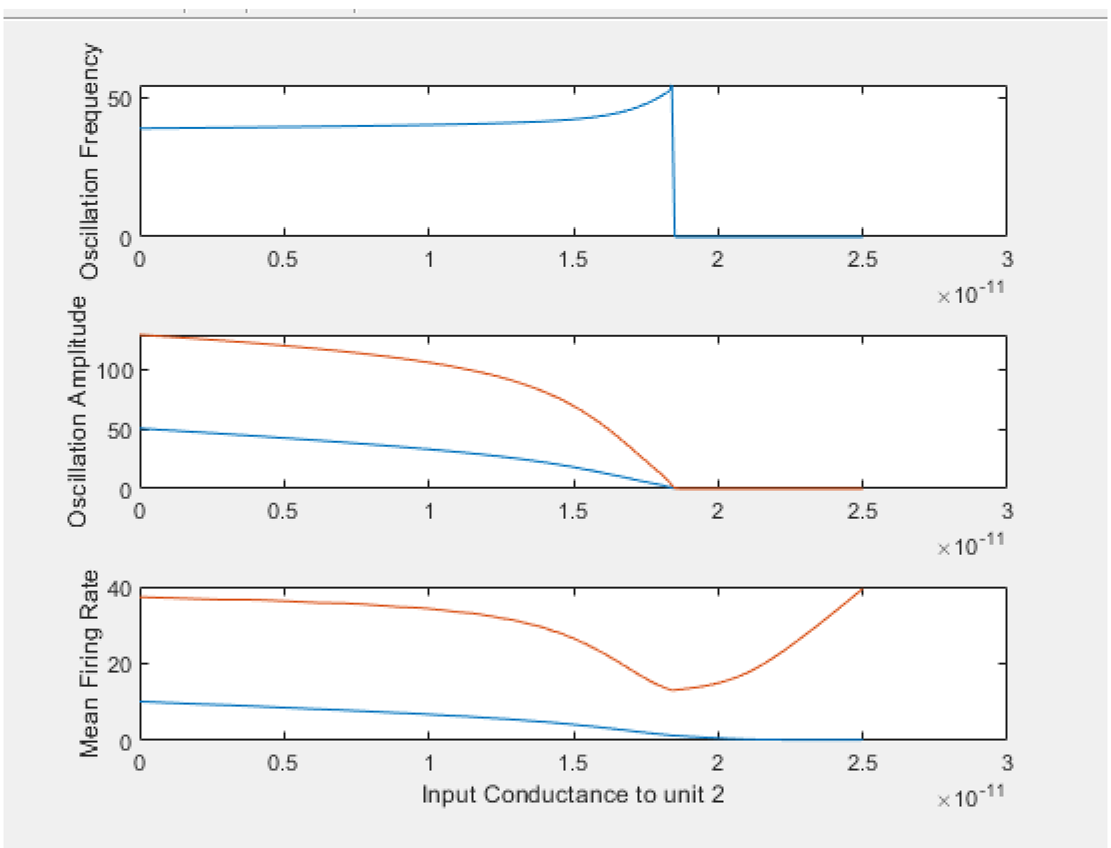
Legend:

Orange line = Inhibitory Unit

Blue line = Excitatory Unit

Visualized above are some of the impacts that increasing input to the excitatory unit has on the previously described model. As to be expected, an excitatory input to the excitatory unit has a positive impact on the mean firing rate of both units. Both units spend more time in an excited state as input conductance increases due in part to a decrease in time that it takes the excitatory unit to reach a high enough firing rate to induce its own inhibition through the inhibitory unit. This decrease in duration also contributes to a higher oscillation frequency, although the increase in frequency is limited by the very delay that lets the model oscillate in the first place. The inhibition to cell 1 can only come so quickly, and while it arrives earlier with an increase in input conductance to unit 1 in general, eventually this increase will saturate because the signal still needs to travel across 2 synapses according to the appropriate time constants. Finally, Oscillation amplitude increases in the inhibitory unit but stays relatively constant in the excitatory unit. This is because while the firing rate of the excitatory unit needed to activate the inhibitory unit remains the same, the inhibitory unit requires considerably greater firing rates in order to fully inhibit the excitatory unit if it is given greater input.

5.)



Legend:

Orange line = Inhibitory Unit

Blue line = Excitatory Unit

Unsurprisingly, varying input to the inhibitory unit has significantly different impacts on the model than varying input to the excitatory input. Firstly, introducing small amounts of input to unit 2 decreases the mean firing rate of the excitatory unit. This makes intuitive sense, as more inhibition should cause less excitation. What is less intuitive is the mean firing rate of the inhibitory unit also decreasing. While at first this may seem confusing, it makes plenty of sense when you consider that this just means that the increase in activity corresponding to the outside input is less significant than the decrease in activity associated with the negative impact this outside input has on the excitatory unit. (see final para for discussion of end behavior).

Amplitude of oscillation for both units also decreases with an increase in input to the inhibitory unit. This occurs because the “baseline” (essentially the minimum value of firing rate in a single oscillation) for the excitatory unit is increasing as input conductance does. For the inhibitory unit this decreases the space between the minimum and maximum values of its oscillation, decreasing amplitude. For the excitatory unit the opposite is happening, the max value of its oscillation is decreasing as it gets harder and harder for the unit to achieve high firing rates.

Finally, the oscillation frequency raises slightly as input increases until a given point where oscillation ceases (see below for discussion of disappearance of oscillatory activity). This increase in frequency is perhaps more intuitively though of as a decrease in period, i.e. the model takes less time to reach the next peak in more input to the inhibitory unit. When considering this in context of a decrease in amplitude this makes plenty of sense, as a decrease in difference between min and max firing rates in a single oscillation would of course cause the time required to go from min to max firing rates to decrease.

Also worth discussing is what occurs around the 18nS second mark. Here we see a complete disappearance of oscillatory activity. This is because at this level of input conductance to the inhibitory unit, the minimum level of activity is enough to fully suppress the oscillations in the excitatory unit, consequently ceasing the oscillatory input to the inhibitory unit. Obviously this causes oscillation frequency and amplitude to be fixed at 0 because of a lack of oscillation. Mean firing rate of the inhibitory unit then ceases to continue falling (an activity explained in the first paragraph) and begins to rise with input conductance, as you would expect from an “isolated” unit. Consequently input conductance continues to decrease from its already very low value eventually to 0 as the inhibition grows strong enough to permanently disallow activity in the inhibitory unit.