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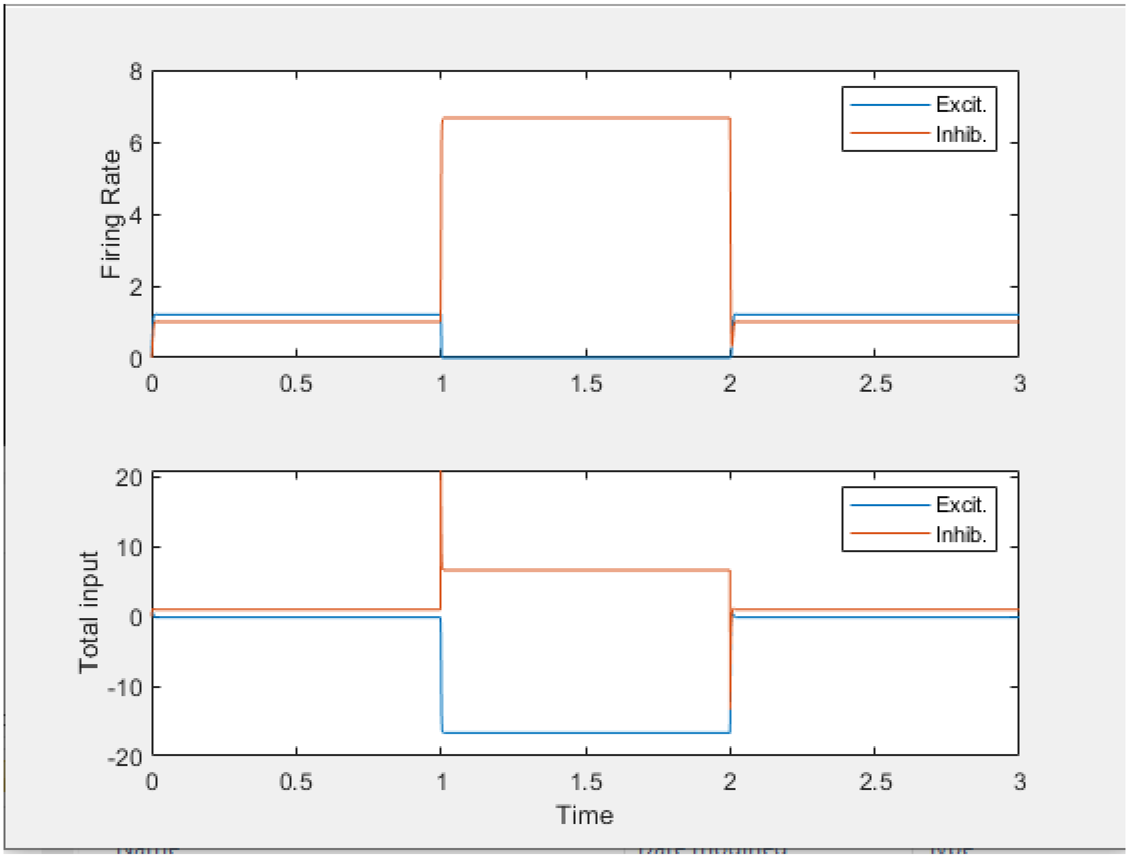
Tutorial 7.1 and Final

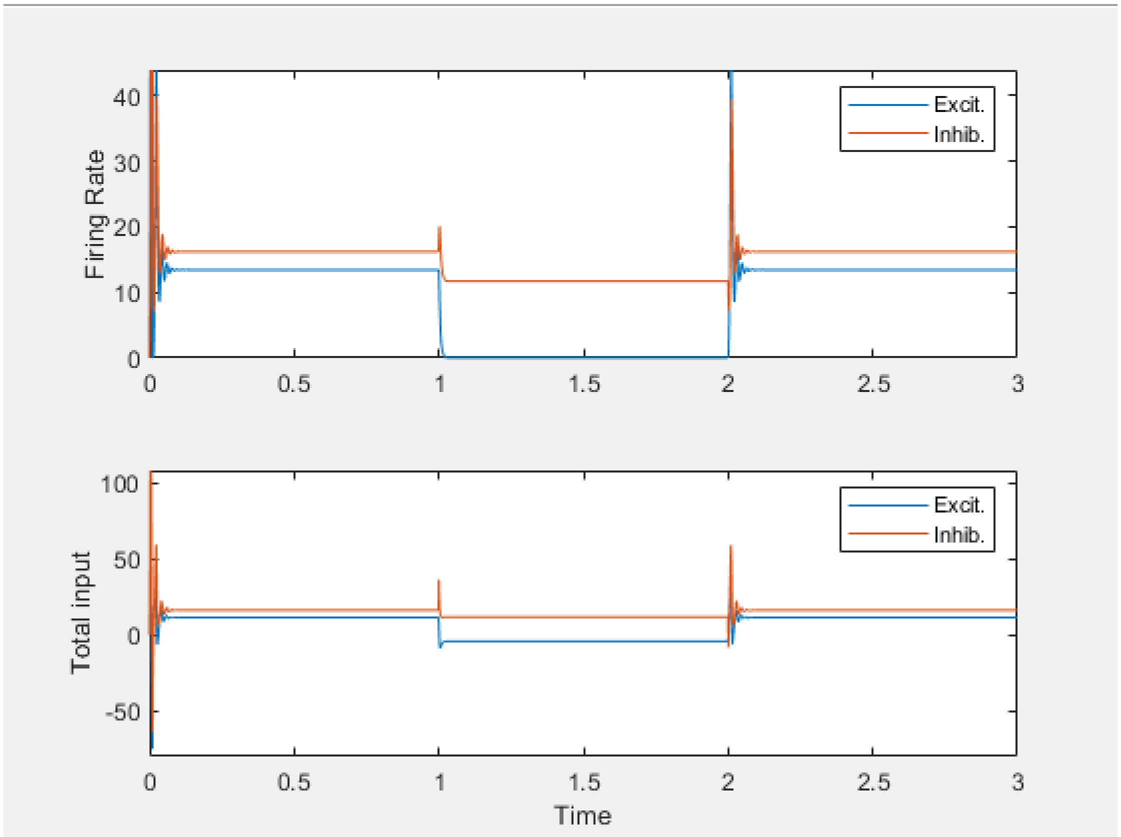
A1.)



Above is a 2-unit inhibition stabilized network with a large amount of applied current to the inhibitory unit between t=1 and t=2. Here The stable state before and after the period of perturbation has the inhibitory unit firing at just over 1 hz (1.0004) and the excitatory unit firing at just over 1.2 hz (1.20048). During the long period of applied current, we provide sufficient positive current to the inhibitory unit to completely stop all excitatory unit activity (the net input to the excitatory unit is more negative than its threshold for spontaneous activity), and inhibitory unit activity increases to about 6 and 2/3 hz (6.6667). The inhibitory unit’s firing rate increases only slightly from the “norm” due to several factors alluded to in the second graph. Firstly, much of the applied current if offset by the lack of excitation now coming from the excitatory unit. Further, the inhibitory unit has self-inhibition.

In both states pictured above, the inhibitory unit follows a steady state where its total input is equal to its firing rate.

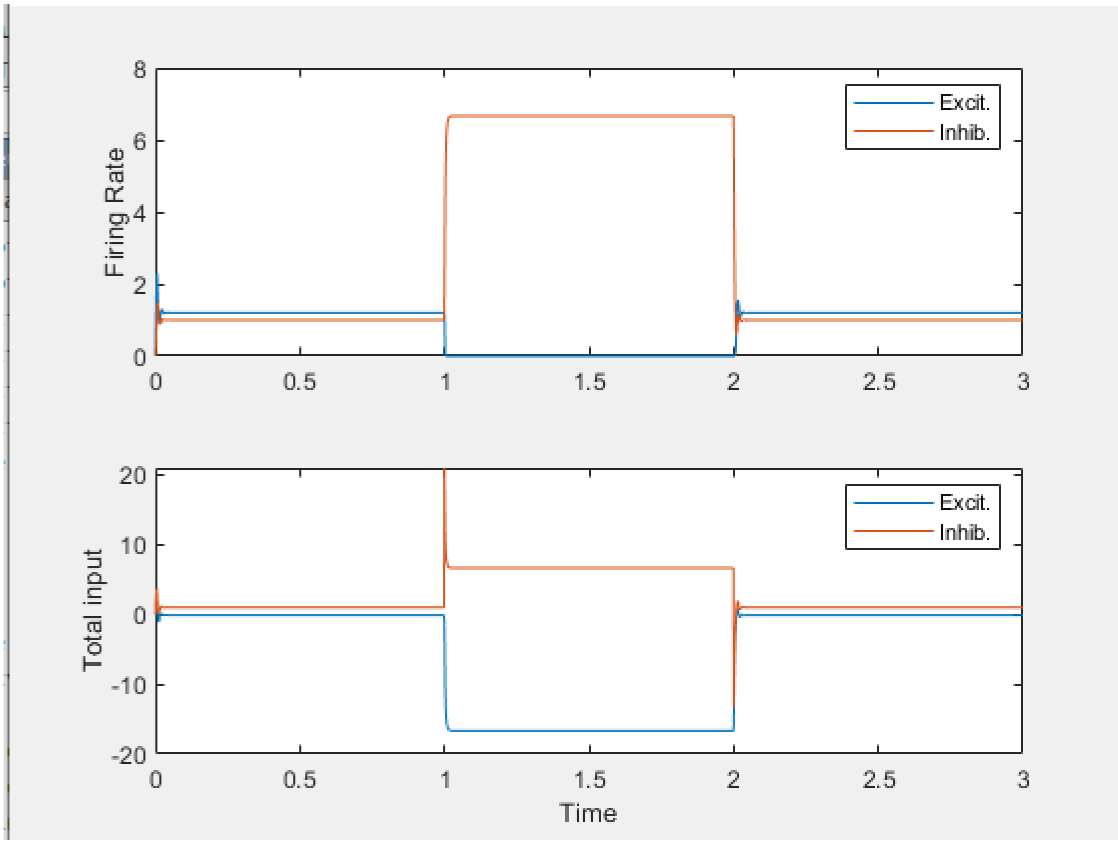
A2.)



Above is the same 2 unit network, but now with differing levels of baseline current, favoring the excitatory unit. The difference in baseline current is in fact just small enough to allow the inhibitory unit to stabilize the fixed. If the baseline current for the excitatory unit was at all significantly higher, or the baseline current for the inhibitory unit lower, the system would have oscillating firing rates. As things are however, the system has a steady stable state both during and in the absence of applied current. During the period of applied current, the extra inhibition is not quite enough to decrease the excitatory unit to a firing rate of 0, and this ends up decreasing the inhibitory unit's firing rate as well (see below). During input the system is stable at a excitatory firing rate just above 0 and inhibitory at around 11.7 hz. Both of these firing rates are higher in the absence of applied current.

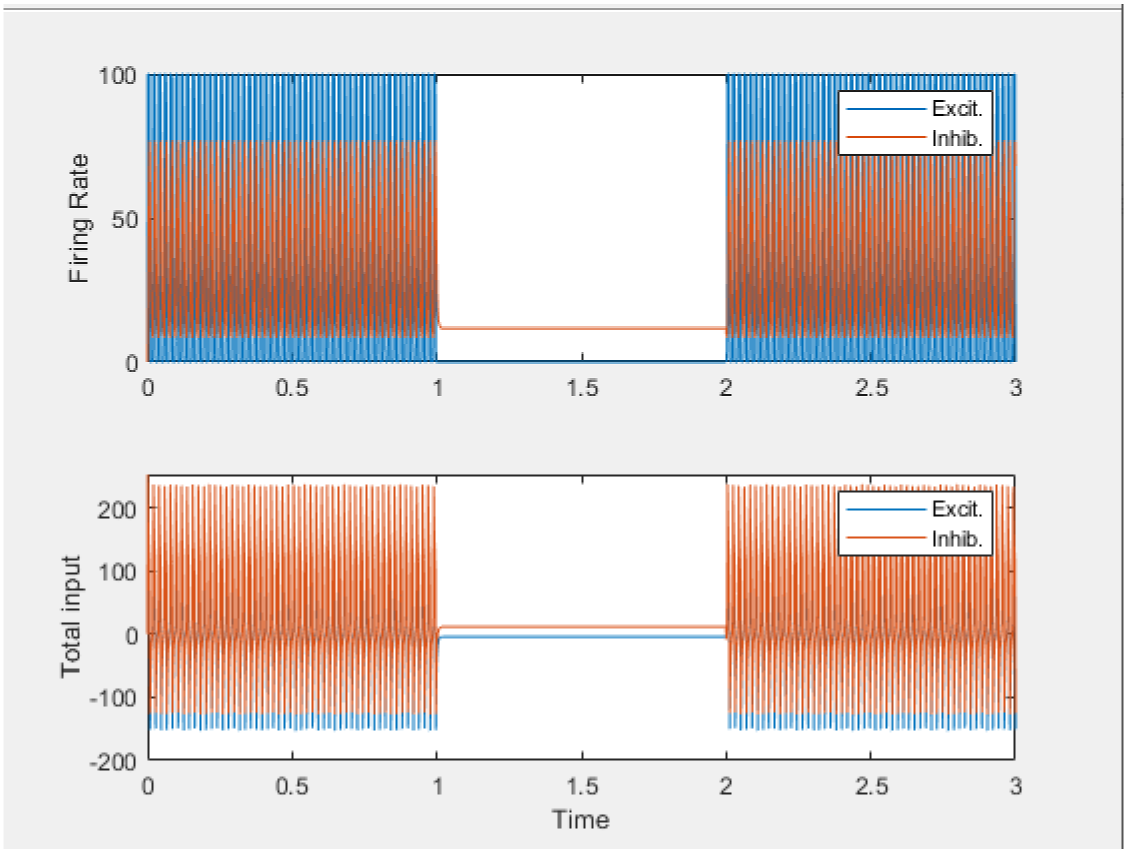
The results above are very indicative of the inhibition stabilized network's curious activity. Despite being provided with additional excitation between the t=1 and t=2 marks, firing rate of BOTH units of the network decrease during this time period. This is because the principal input to inhibitory unit is from the excitatory neurons which typically provide significant input due to their self excitation. The decrease in excitatory activity more than makes up for the increase in applied current to inhibitory units.

A3.)



No real observable difference from a1, despite different time constants, with the exception of a nearly indistinguishable delay in the time it takes for the inhibitory unit to settle to its stable states. The lack of difference in activity here makes sense, as the only difference a slower time constant should have on the system is in the scenario where the inhibitory feedback becomes insignificant to stabilize the faster self excitatory feedback. (see A4 for an explanation as to why such activity is not the case here)

A4.)

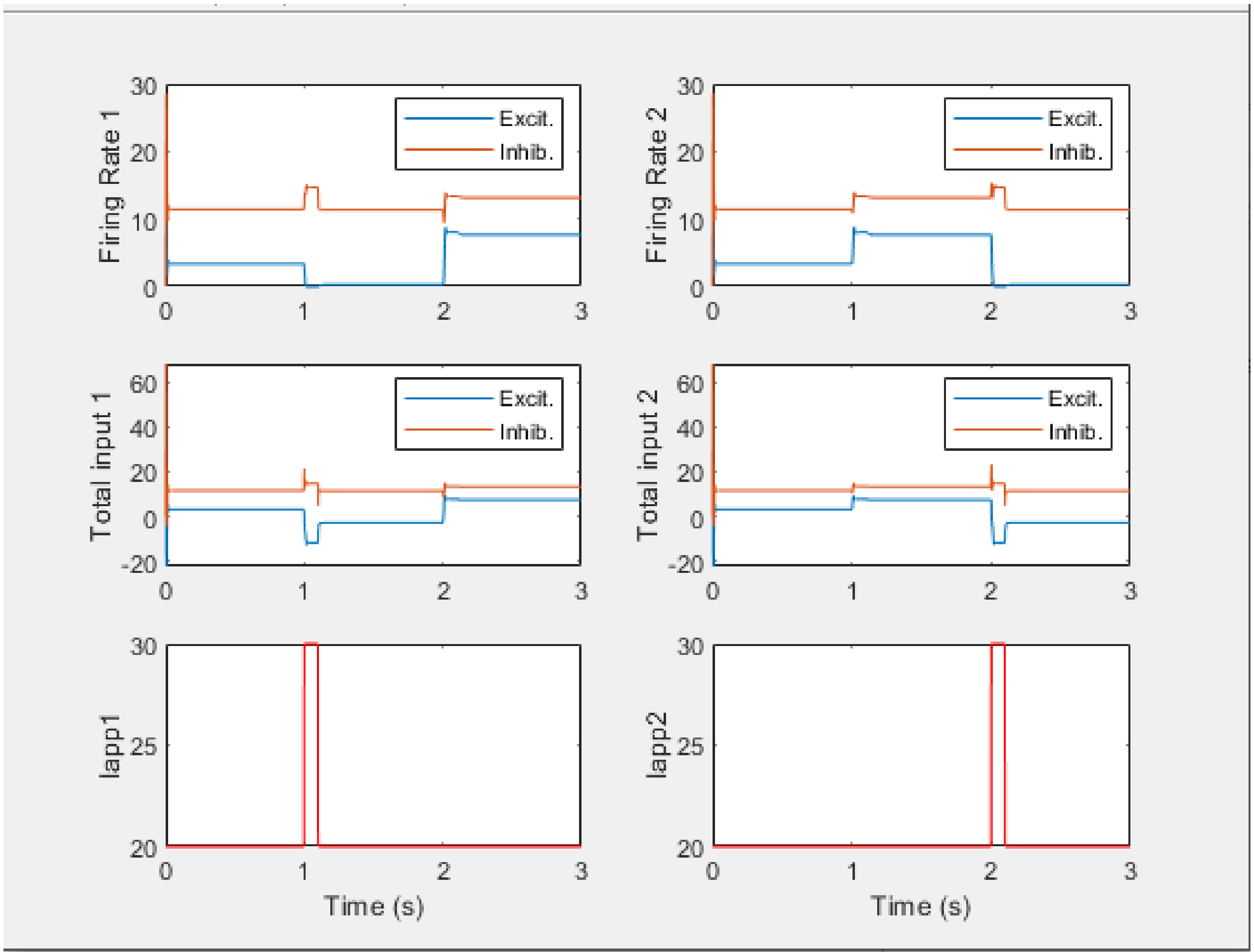


In section A2 we mentioned that the difference in baseline inputs was nearly enough to destabilize the stable fixed point in the absence of applied current. The same destabilizing impact is created here, but instead of by changing the baseline current values, the time constants were changed in such a way that the excitatory unit updates significantly faster than the inhibitory unit. As we have seen in a multitude of other scenarios (synaptic depression and tutorial 5.3 come to mind) when we have regular fast excitation and slower inhibition, oscillation is possible.

That being said, during the period of applied current, the system finds the identical steady state that it did in section A2. This is because the most significant input to the inhibitory unit ceases to be an input varying at a different rate, and instead becomes constant.

The reason we didn't see oscillation in the prior scenario (A3), is an insufficient difference in rates of change between the firing rate of the excitatory and inhibitory unit. The difference between A3 and A4 here is twofold, firstly, in A3 both units had the same baseline current making the rate of change of their firing rates fairly similar despite the different time constants. Secondly, the baseline current was low in both units. The oscillating activity is still possible with these time constants and an identical baseline current, the baseline current just has to be high enough to make the impacts of the difference in time constant more significant.

B5.)



Firing Rate 1
Firing Rate 2
Excit.
Inhib.
Total input 1
Total input 2
Iapp1
Iapp2
Time (s)

Figure 1

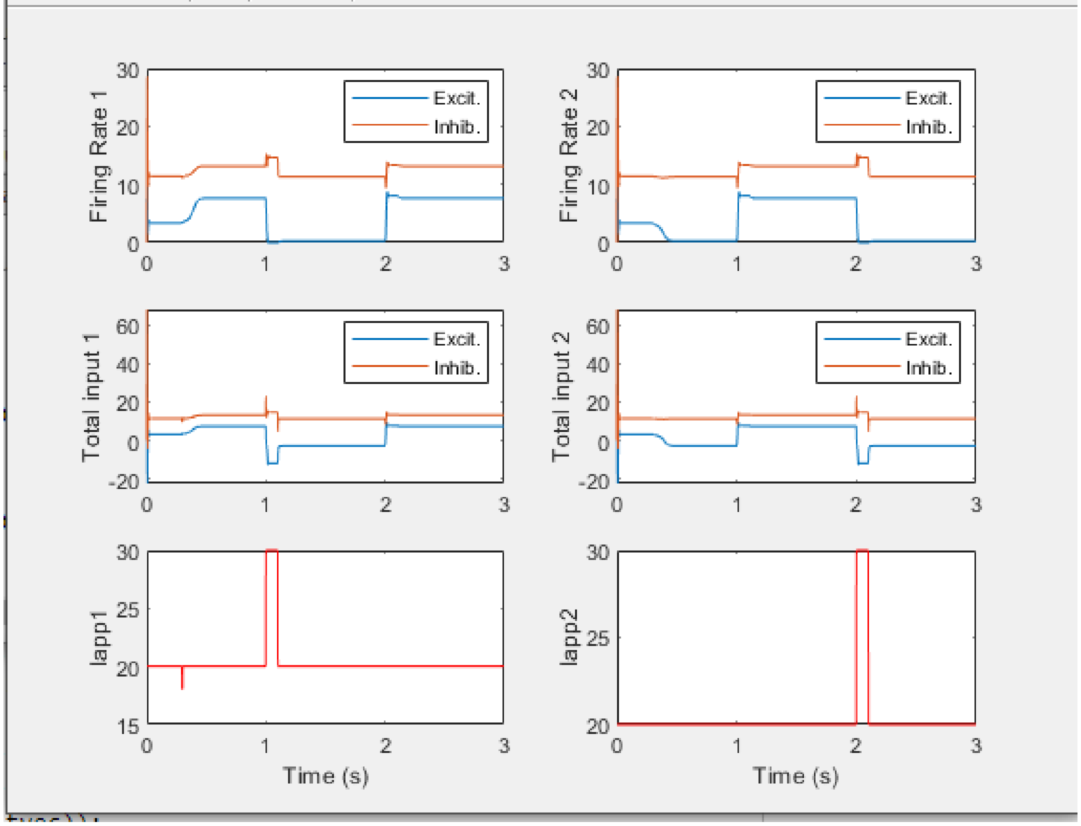


Figure 2

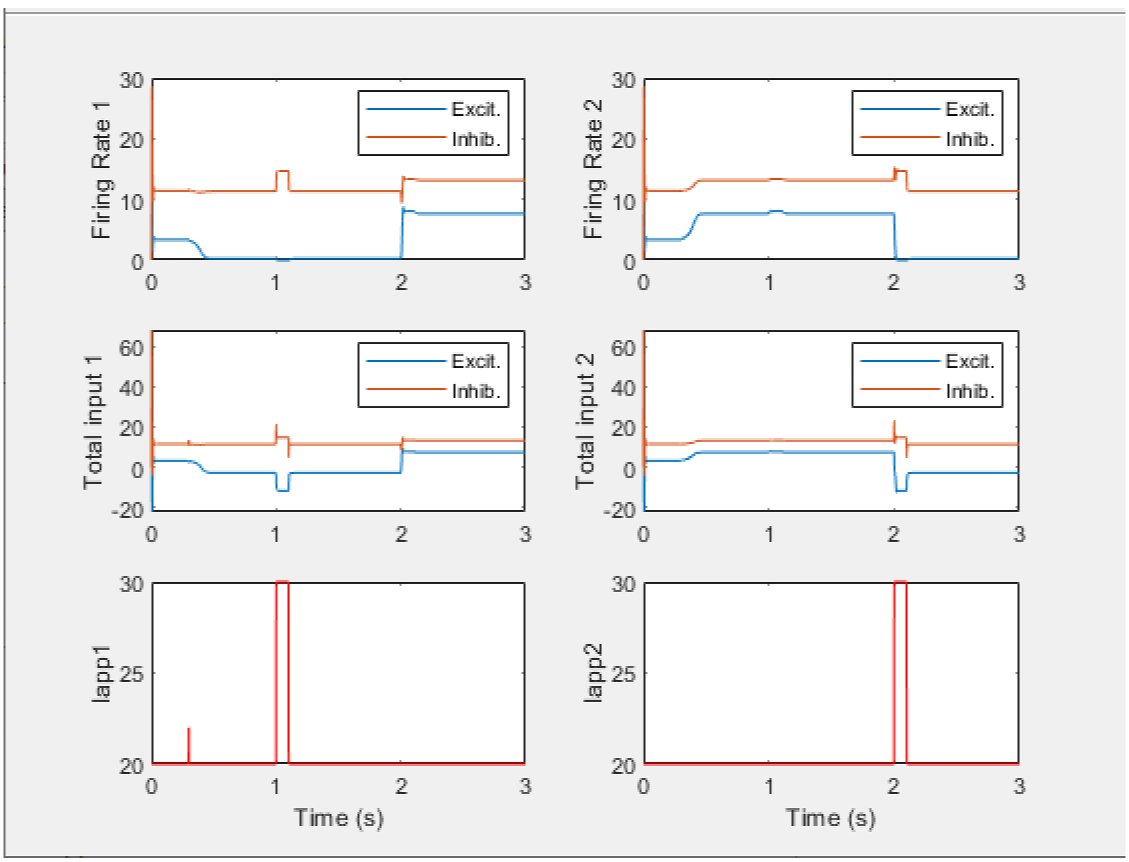


Figure 3

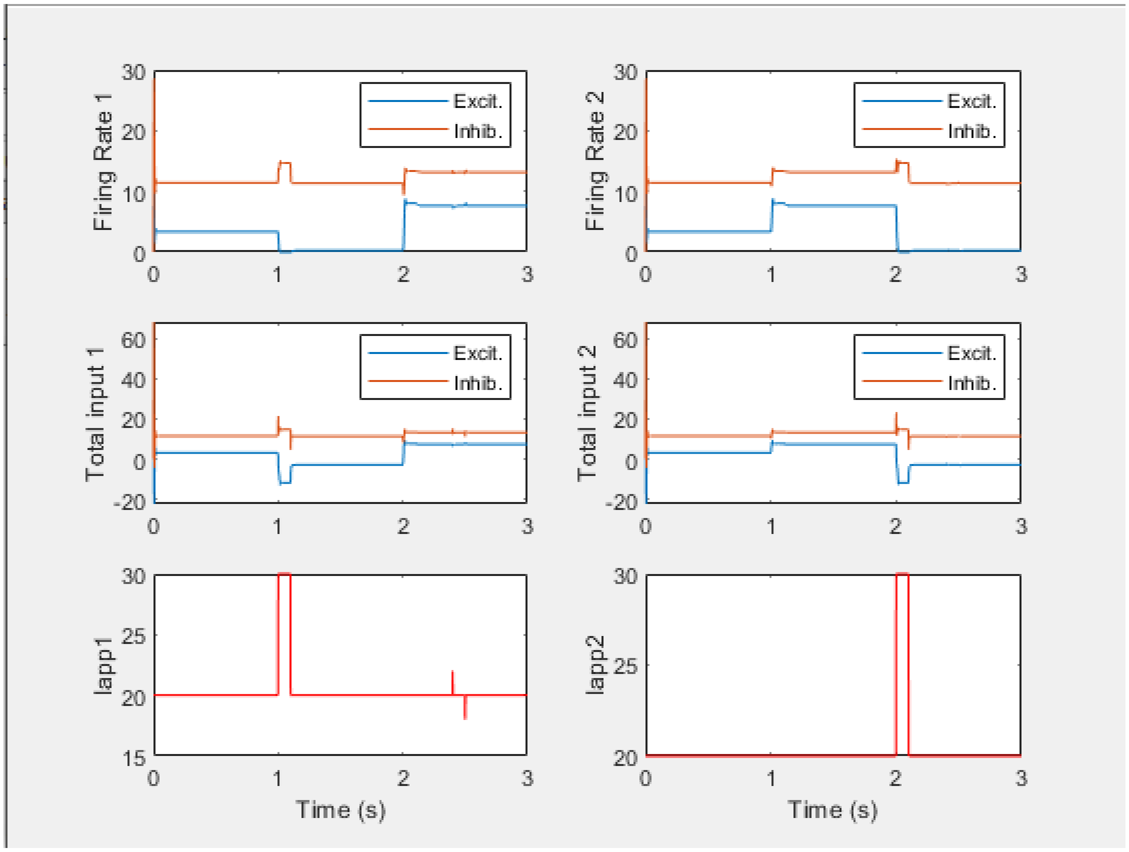


Figure 5

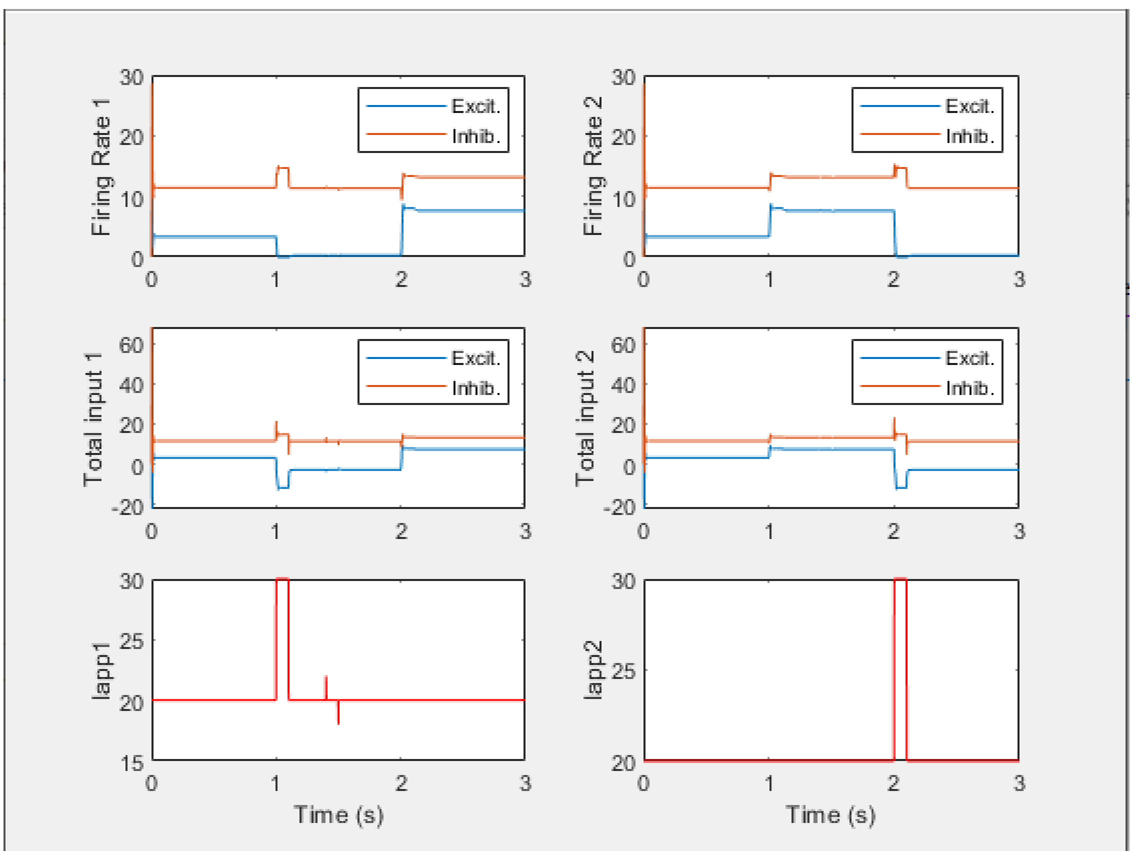


Figure 4

Whereas a single Inhibition stabilized network had 0 or 1 stable steady states in the absence of input, coupling 2 such networks together yields a second steady state, and an unstable steady state.

Unstable Steady State: Both excitatory units firing at about 3.344hz, both inhibitory units at 11.404 hz

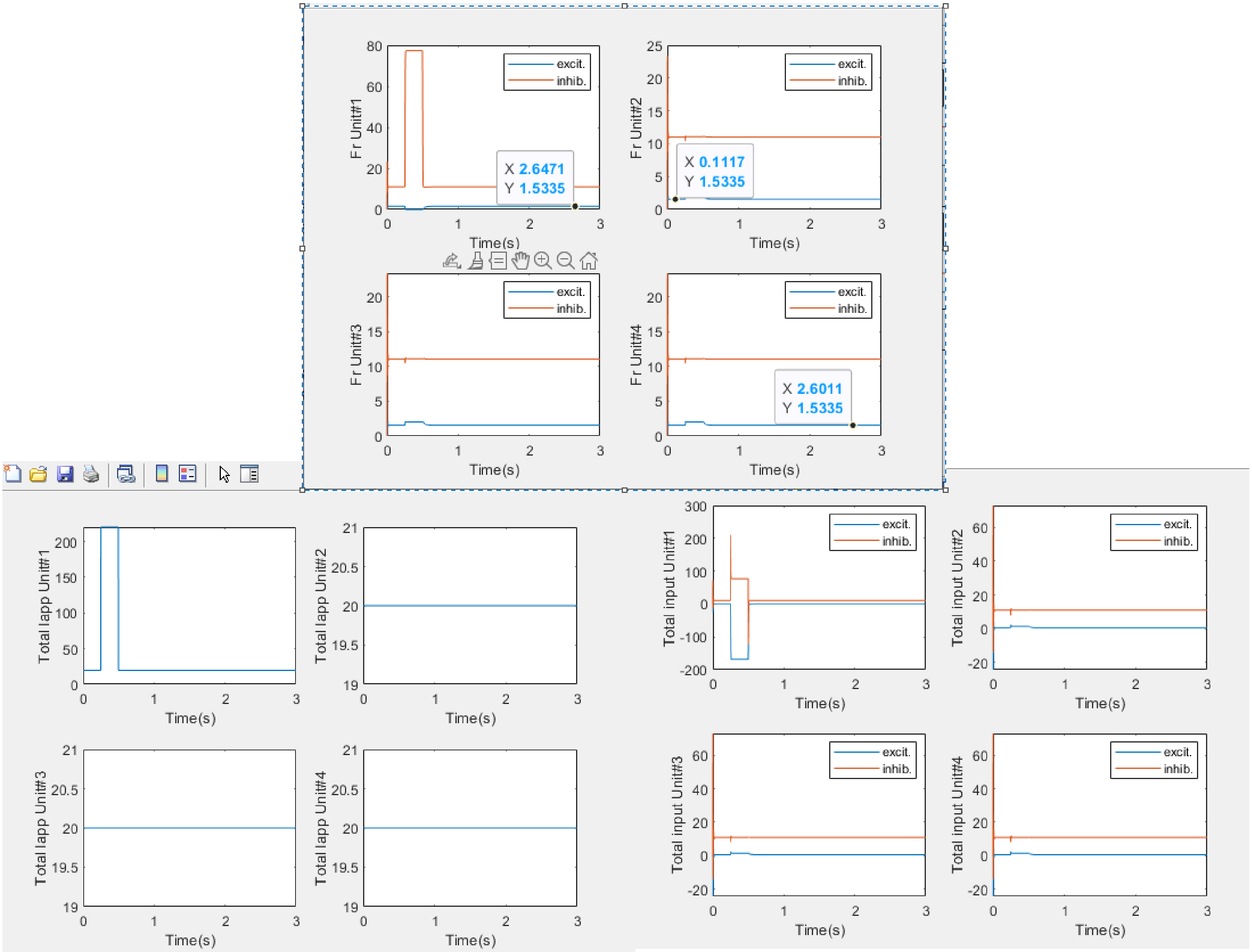
Stable Steady States: One excitatory unit at very low activity (about 0.242023 hz) the other at 7.62039 hz. One inhibitory unit at 13.1582hz the other at 11.3136hz

Unstable steady state was found to move towards one of the stable steady states at smallest sign of positive or negative perturbation to the inhibitory unit of the “first” unit. Seeing as how both units were identical in properties, testing the impact of perturbation on one of the units is sufficient to understand how it impacts the system. Both of the other steady states (mirrors of one another) were found to be stable in the face of positive and negative perturbation.

We see that one of the excitatory units must have a nearly inactive firing rate for the system to be stable. This is because of the combination self excitation and cross inhibition. Much like in a decision making circuit, when one of the excitatory units gets a “lead”, it will continue to increase via positive feedback, and therefore continue to excite both inhibitory units, further decreasing the opposite excitatory unit’s firing rate.

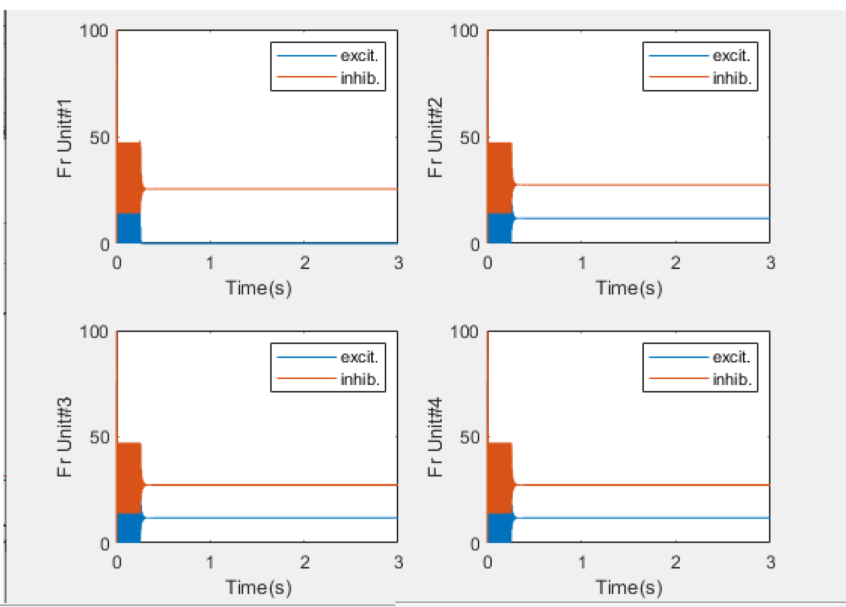
Final Portion: “How many states can be possible with increasing number of E-I coupled units in the inhibition-stabilized regime?”

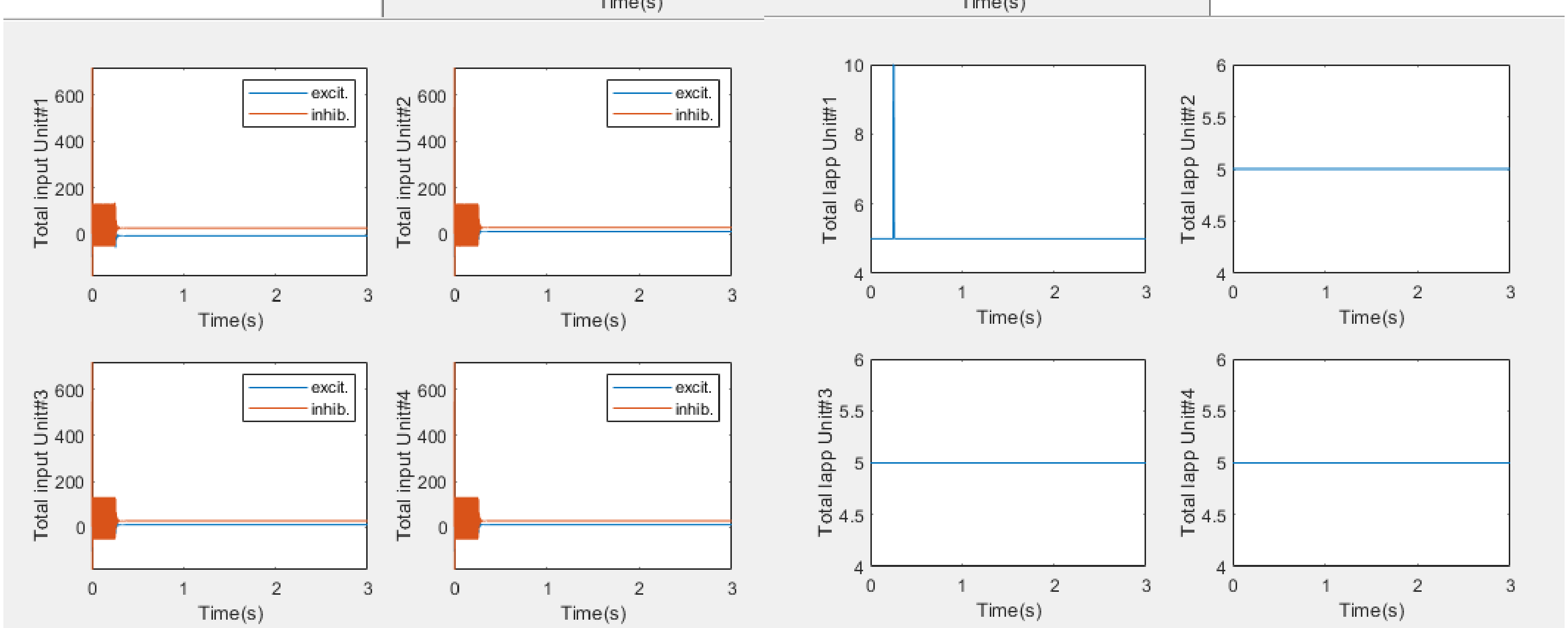
Given that with one inhibition stabilized network we had a single steady state in the absence of input, and with 2 coupled inhibition stabilized networks we had 2 stable steady states and an unstable one, it stands to reason that we could have even more or perhaps other interesting activity with an increasing number of networks. At first I attempted to couple each network with each other in a manner identical to the instructions and parameters given in part B of tutorial 7.1, trying 3 and then 4 units.



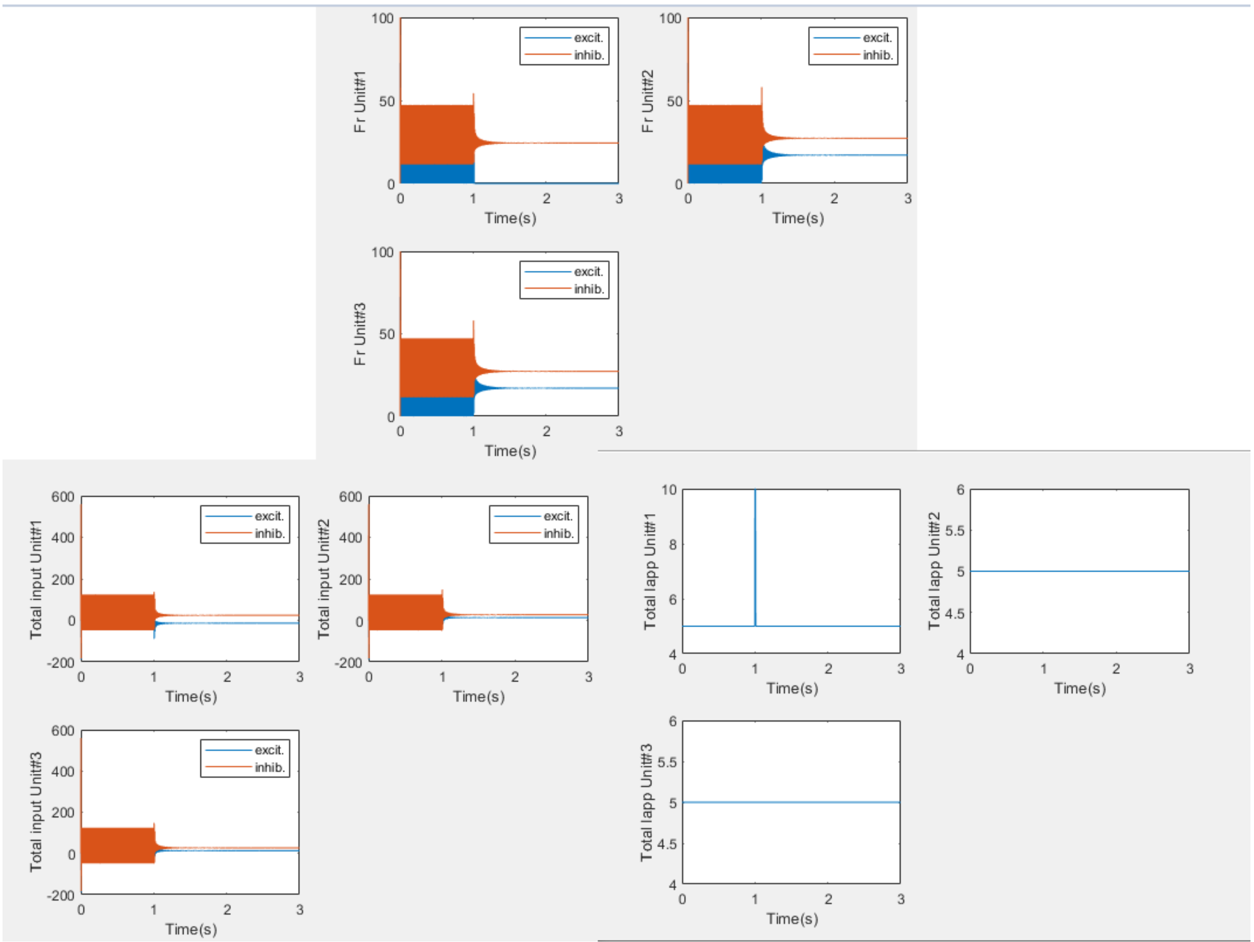
As you can probably see from the above figure, 4 units clearly didn't produce the originally hypothesized paradigm, and I got a similar result with only 3 units, and could not change states no matter how much excitation was applied to how many units. The system stayed at one stable steady state and returned to it after any level of perturbation. In fact, the only piece of evidence I had that the system was still in the inhibition stabilized regimen at all was that if I provided significant inhibition to one of the inhibitory units, the system would oscillate for the duration of said input, implying dynamics similar to that seen in question A4.

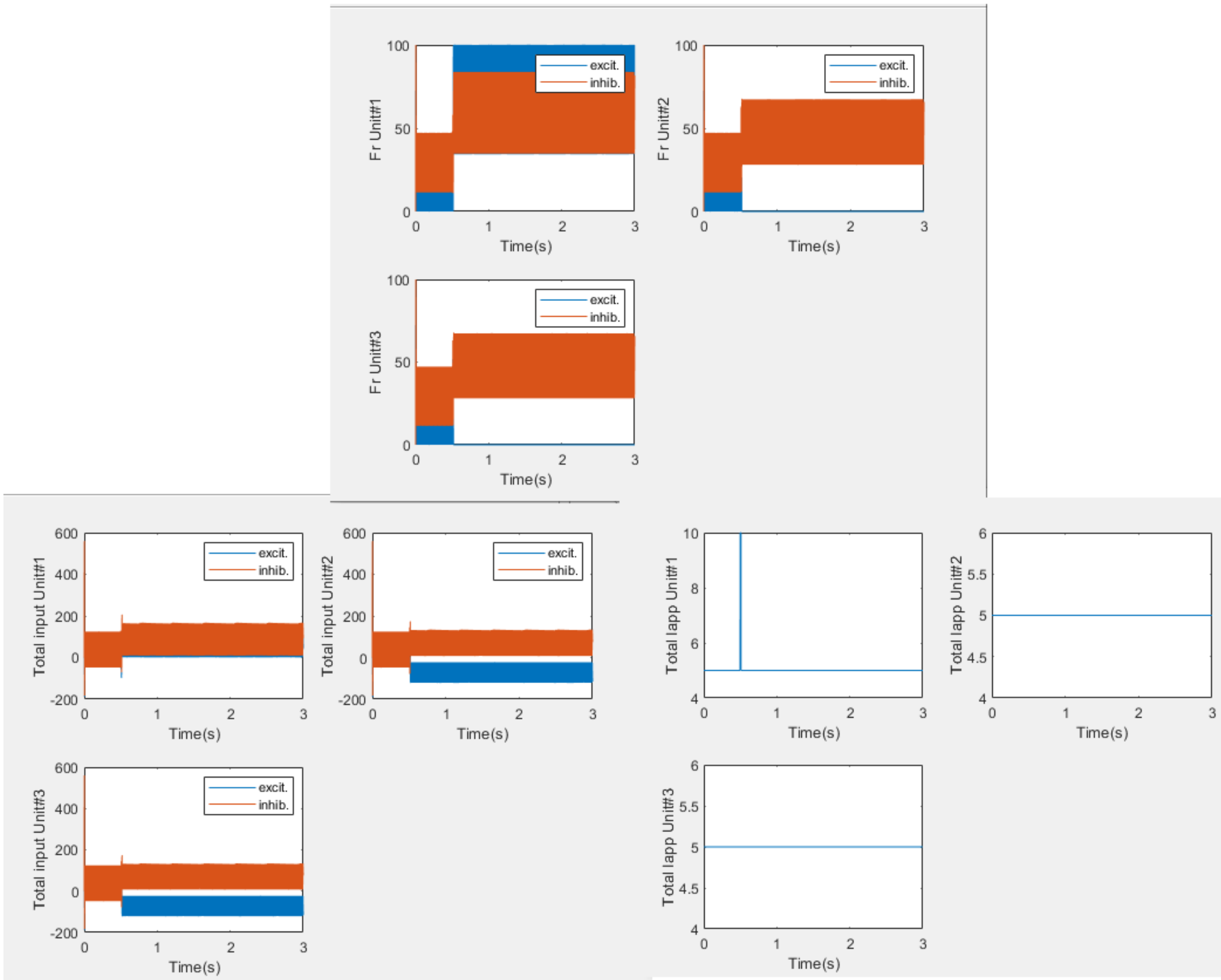
This did however get me thinking, as the only real difference in one unit's activity to the other from a simulation with fewer units was an added excitatory connection to it's inhibitory unit, this must be what's causing this difference. I believe that perhaps each coupled excitatory and inhibitory unit pair simply had an overactive inhibitory unit, and this is why the system activity is so different. I figured I could remedy this by changing baseline currents until I found a level at which the inhibition was actually insufficient to stabilize at all, and our system would oscillate, then simulate just short of that threshold. I ended up (in the case of 4 units) having to go as far as inhib. Baseline = 5 and excit. Baseline = 55 (iB =5 and eB = 54 failed to cause the system to oscillate). At this point I was curious to see if I could replicate the scenario in A4, where I temporarily stabilize the system by providing applied current to the inhibitory unit. However, the system stopped oscillating entirely when tested this way.





Sure enough, the oscillating state of the system proved to be unstable, as the slightest bit of applied current to any of the inhibitory units stopped the oscillating for the rest of the simulation. When I attempted a similar procedure (slowly incrementing the difference in baseline currents until I find a combination that just barely causes oscillation) on a N=3 simulation (3 coupled units), I found something fairly interesting. The system behavior after applied current ceased varied based on the duration and size of the applied current.





If the graphs above seem a little odd, that is in part because the frequency of oscillation is incredibly fast, so fast that viewing the changes across a 3 second long time window leads to an obscuration of any whitespace between points of identical amplitude. In the first of the two sets of graphs above, oscillation ceased entirely when applied current. In the second, oscillation of unit 1 both shifted upwards (higher firing rates) and increased in amplitude. In both other circuits the excitatory circuit became completely inactive at this time, but the oscillatory input from the first network's excitatory input kept their inhibitory units oscillating.

At this point we can already say confidently that the number and quality of states possible with an increasing number of inhibition stabilized networks entirely depends on their parameters, and separately, if N>=3 the system is chaotic. This isn't really that profound of a discovery, but it certainly does make putting a concrete answer on the question difficult.

That being said, I am coming to several realizations, those being that there is much more to talk about with this system, I have reached a natural stopping point/conclusion, and that my current explanation is getting a bit long-winded. I very much look forward to working with this circuit (and ones like it) this summer, and I feel like this final has prepped me quite a bit to do so. See you this summer Professor!