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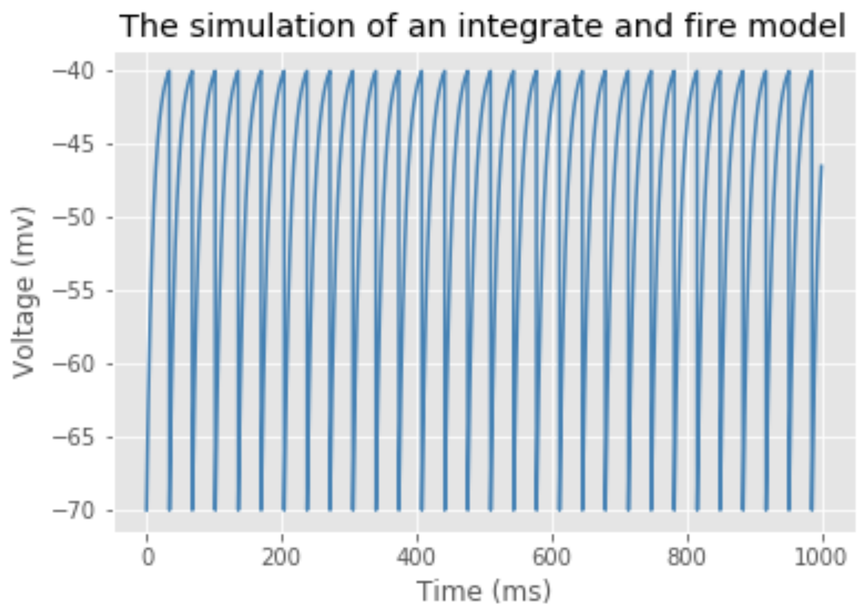
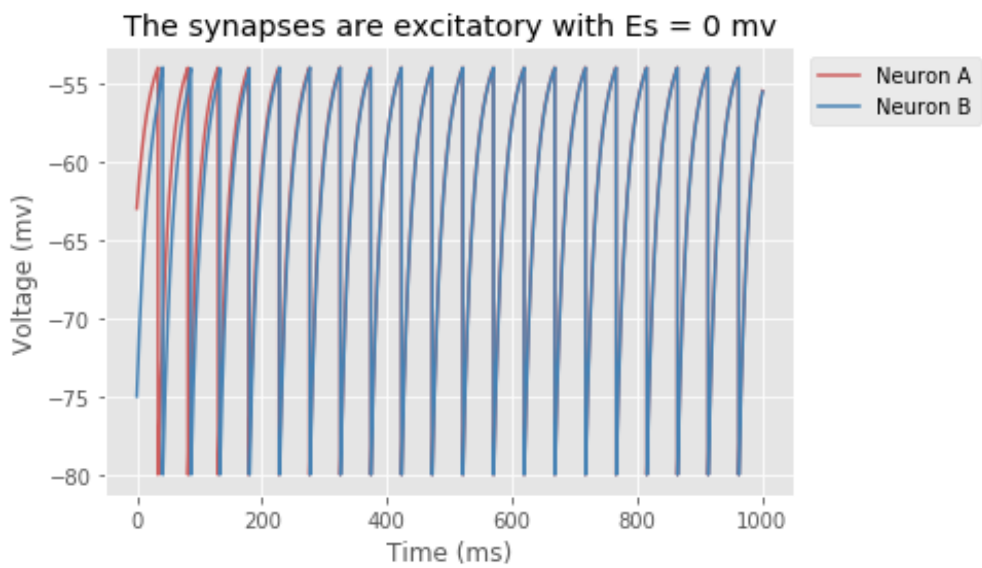
## Part A Question1

*The plot of the voltage as a function of time:*

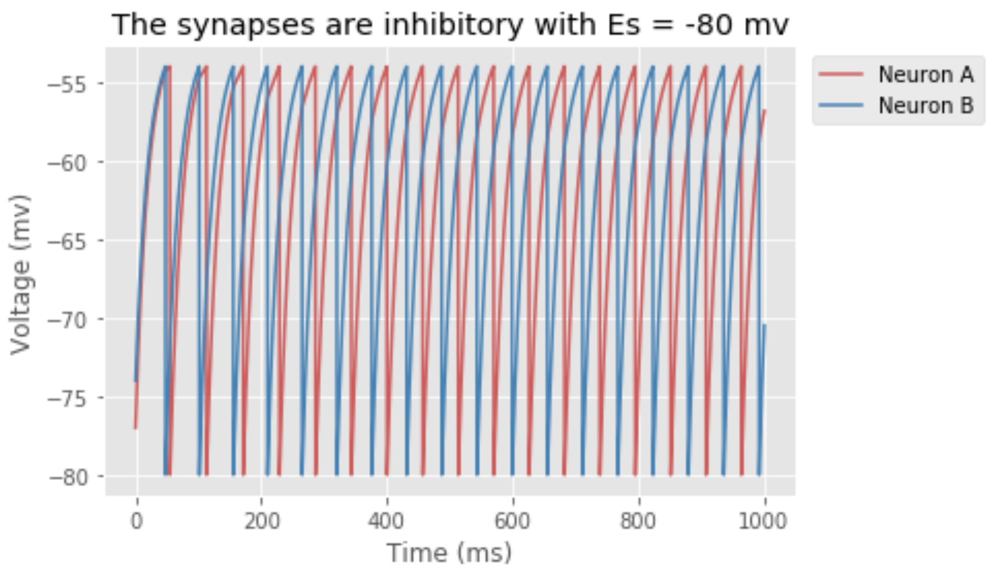



## Part A Question2

*The plots of the voltages of the two neurons for two cases:*



In this case, the figure shows that the synapses are excitatory with Es = 0ms. It can be seen that the change of voltage of two neurons are synchronous from 0ms to 1000ms. This is because that excitatory synapses can make the neurons more likely to fire an action potential, which results in the synchronous voltage change between two neurons.




The above figure shows that synapses are inhibitory with Es = -80ms, which can be seen that the change of voltage of two neurons are asynchronous from 0ms to 1000ms. This is because that inhibitory synapse can make neurons less likely to generate an action potential, which results in the asynchronous voltage change between two neurons.

## Part A COMSM2127

1. According to the equation:

$$\tau_m \frac{dV}{dt} = E_L - V + R_m I_e$$

There are no spikes for low values of the current. So, the equilibrium value for constant $\mathbf{I_e}$ is the value where **V** stops changing.

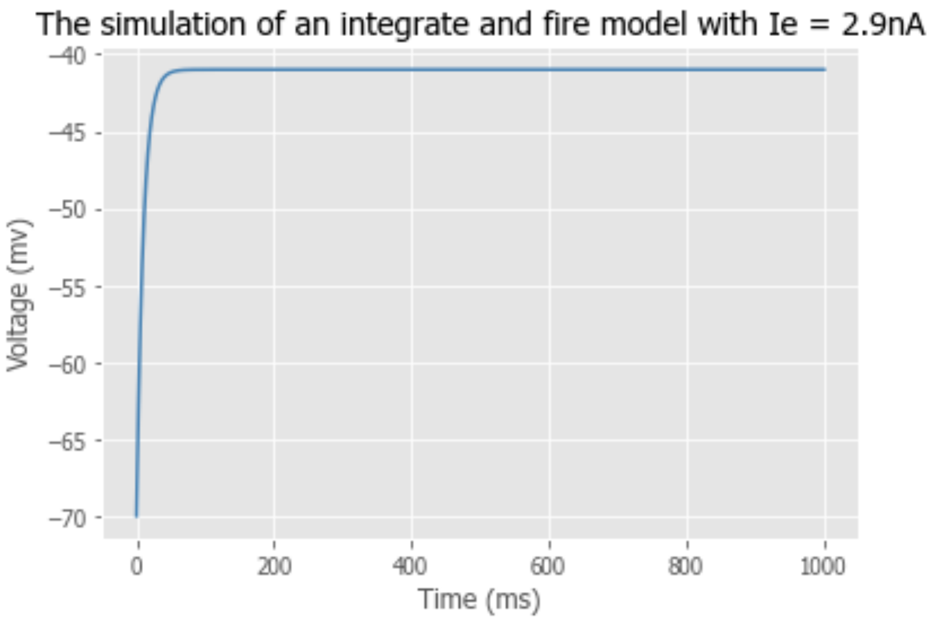
$$\bar{V} = E_L + R_m I_e$$

If $\bar{V} > V_T$, the neuron will produce an action potential. Therefore,

**$I_e > 3nA$**

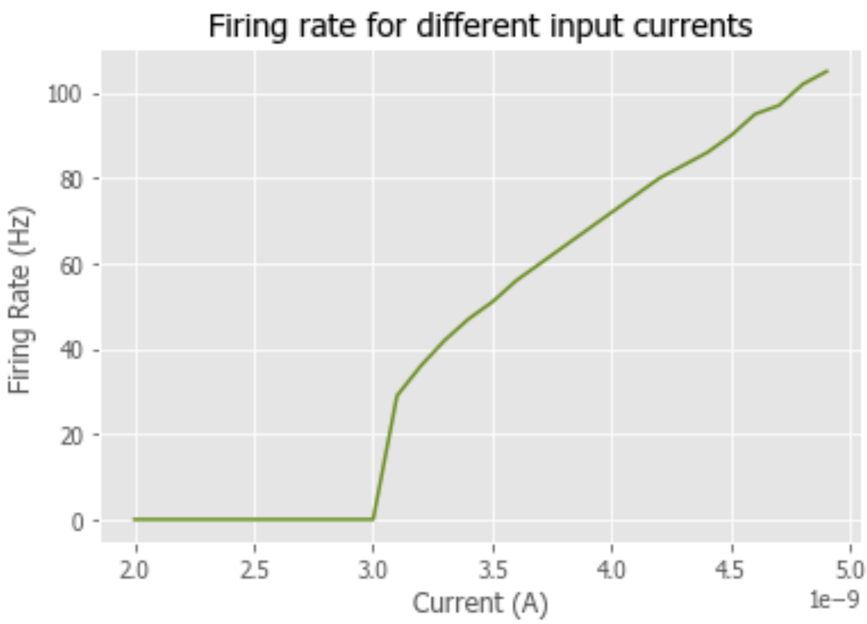
2. Let **$I_e = 2.9nA$:**

   *The plot of the voltage as a function of time when Ie=2.9nA:*



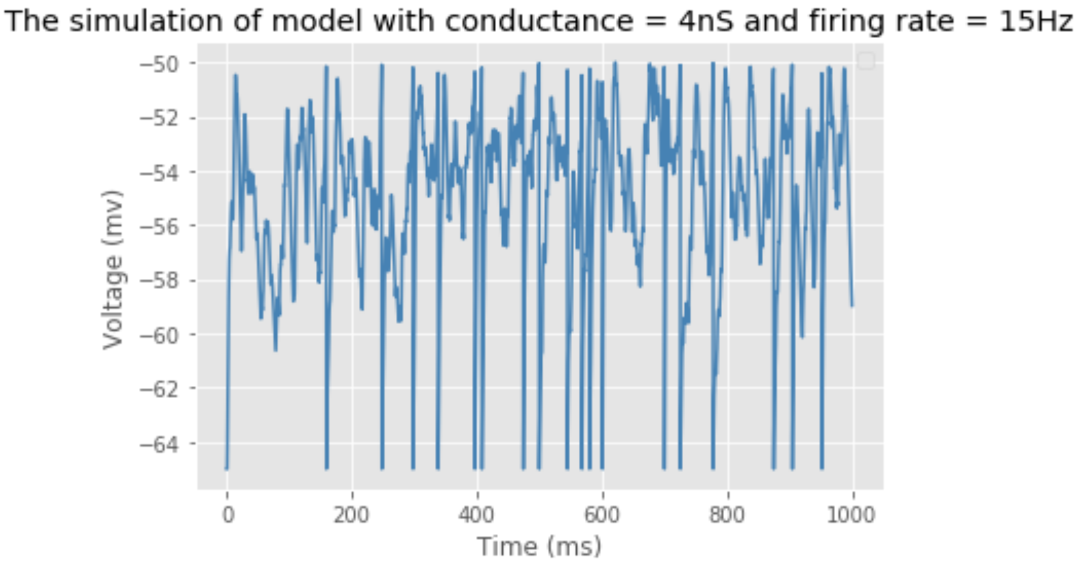

3.

*The plot the firing rate as the function of the input current from 2nA to 5nA in steps of 0.1nA:*



## Part B Question1

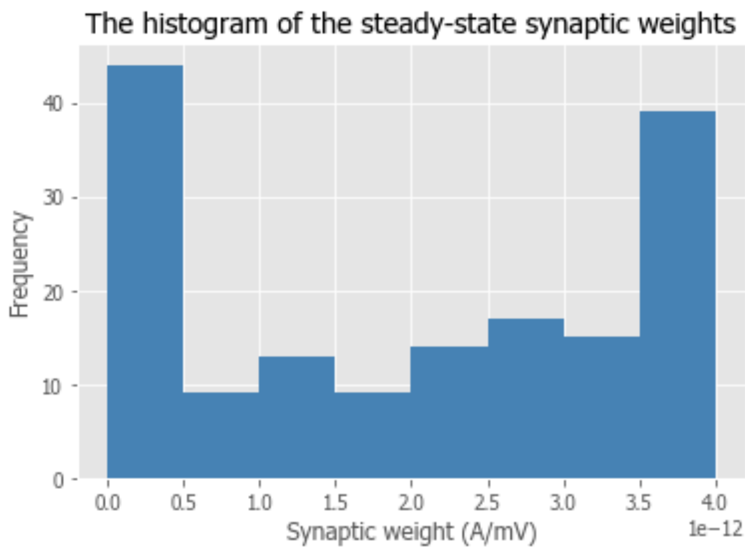
*The plot of the neuron's voltage for one second of simulation time:*




## Part B Question2

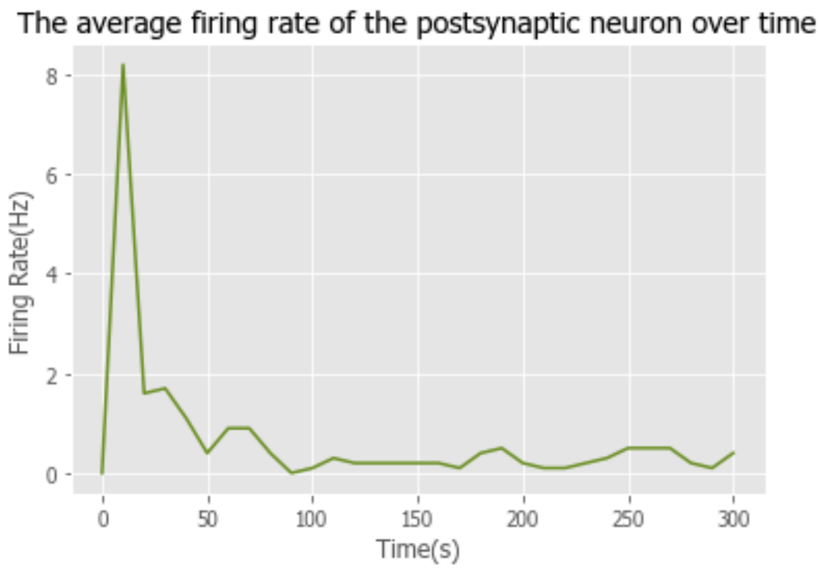
The synaptic strengths distribution looks like U-curve shape, which can be seen in the below figure. In this figure, most synaptic strength values are located in the 0.0-0.5 and 3.5-4. To obtain an exact histogram, I calculated the synaptic strengths at the end of the simulation time for 4 times and plotted the histogram using 160 values of synaptic strengths.

*The histogram of the steady-state synaptic weights after one run of the simulation:*



The average firing rate of the postsynaptic neuron is steady at approximately 0.1~0.2 HZ across the entire 300 second simulation (taking 10-second time bins).

*The plot of the average firing rate of the postsynaptic neuron as a function of time across the entire 300 second simulation (taking 10-second time bins):*




I calculated the steady firing rates which are the averaged firing rate over the last 30 seconds for fout times. I used the mean value of the steady-state synaptic strengths in the STDP 'on' simulation as the fixed synaptic strengths in the STDP 'off'. The average estimate firing rates that I got for both STDP 'on' and 'off' over the last 30 seconds of the simulation are respectively:

When flag = on, the estimate firing rate is 0.19166666666666665 Hz

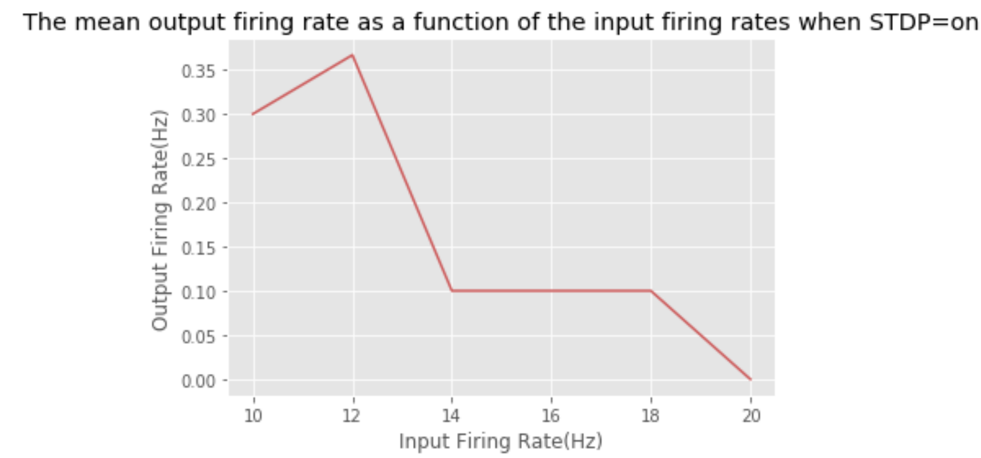
When flag = off, the estimate firing rate is 0.03333333333333333 Hz

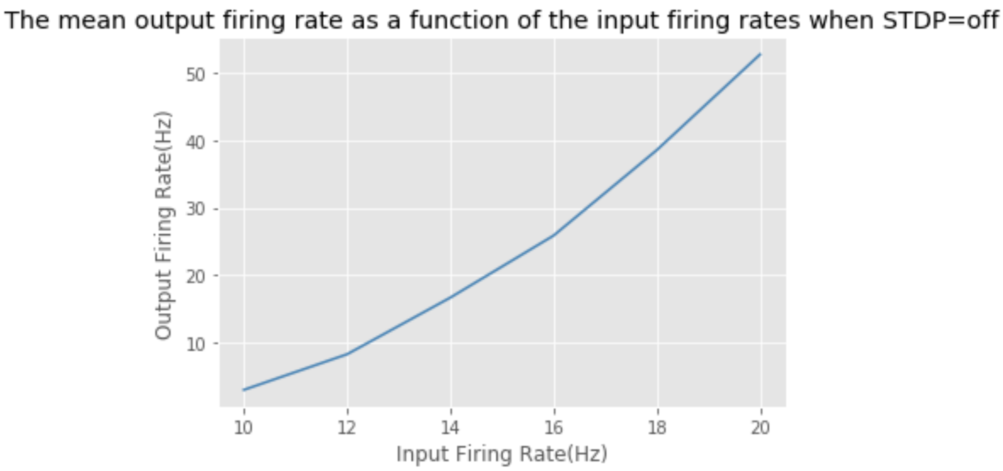
## Part B Question3

I tried to obtain the mean output firing rate over the last 30 seconds for several times.

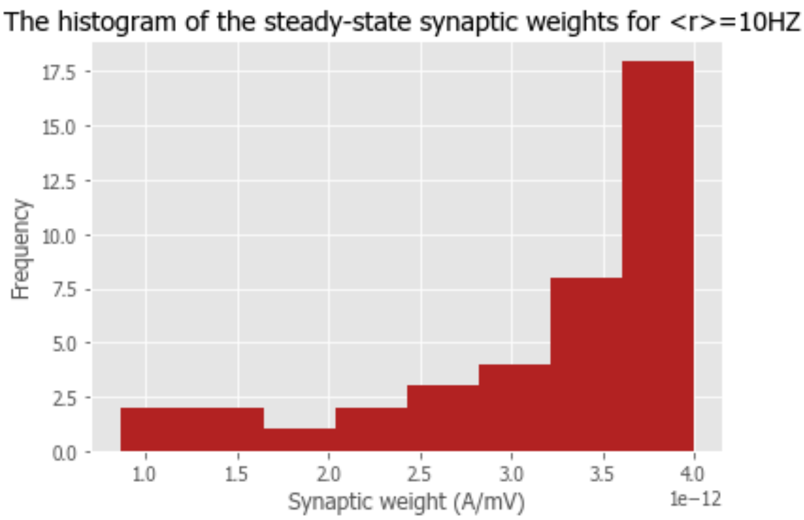
According to the below figure, we can see that the overall trend is the output firing rate decreases when the input firing rate increases. However, the trend for STDP=off is that the output firing rate always increases as the increase of input firing rate.
Moreover, the output firing rates are less than or equal to 0.1Hz when input firing rate is 20Hz in STDP=on.

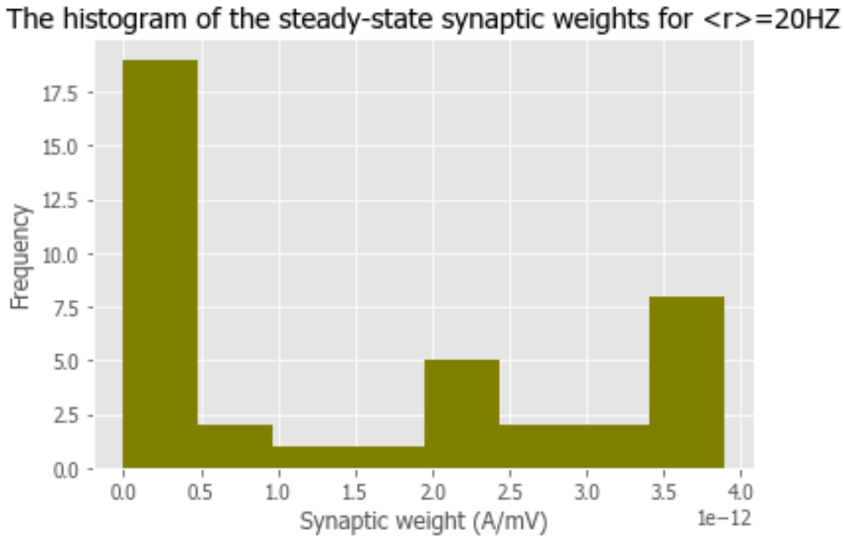
*The plot of the mean output firing rate as a function of the input firing rates for both cases:*




*The plots of the steady-state synaptic strength distribution for <r>=10Hz and <r>=20Hz:*






According to the above plots, most of steady-state strengths are distributed in the between 3.5 and 4.0 when <r> is 10Hz. However, most of steady-state strengths are distributed in the between 0 and 0.5 when <r> is 20Hz. It seems that steady-state strengths increase as the input firing rate decreases.

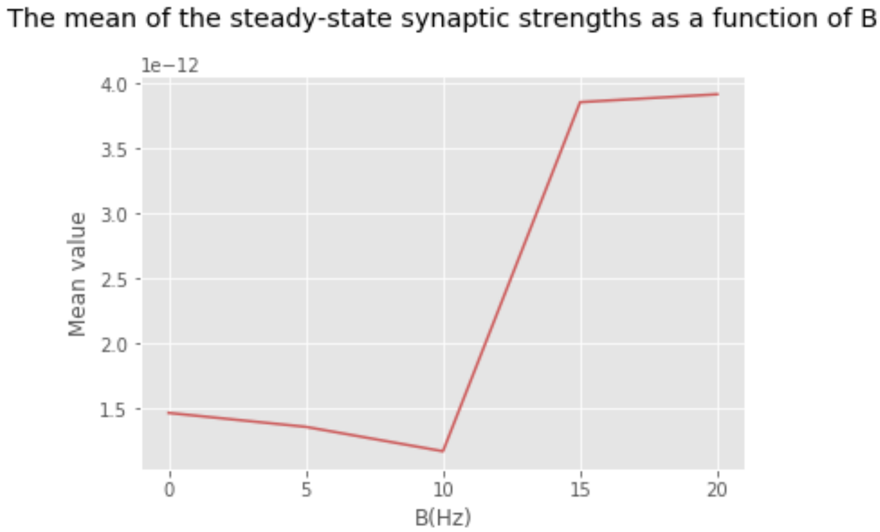
When the input firing rate increases, the probability of the generated random number is less than input_fire_rate * delta_t increases. At the same time, more spikes will happen in the pre-synaptic neurons and the depression will happen at the synapses that receive a pre-synaptic spike. Therefore, the synaptic strengths will be depressed by receiving more pre-synaptic spikes and vice versa.

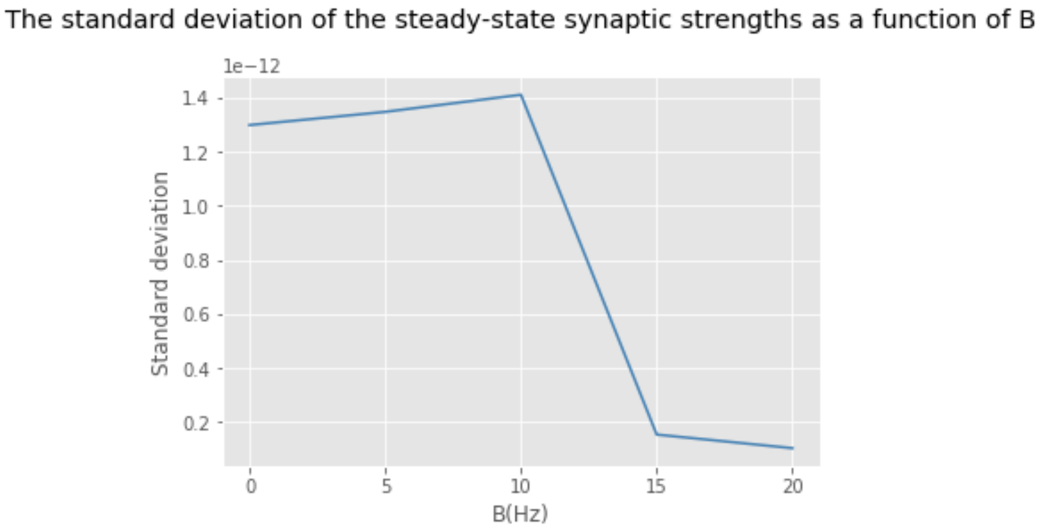
## Part B Question4

The degree of correlation B is used to affect the current input firing rate on pre-synaptic neurons and then the depression from pre-synaptic spikes will influence the synaptic weights.

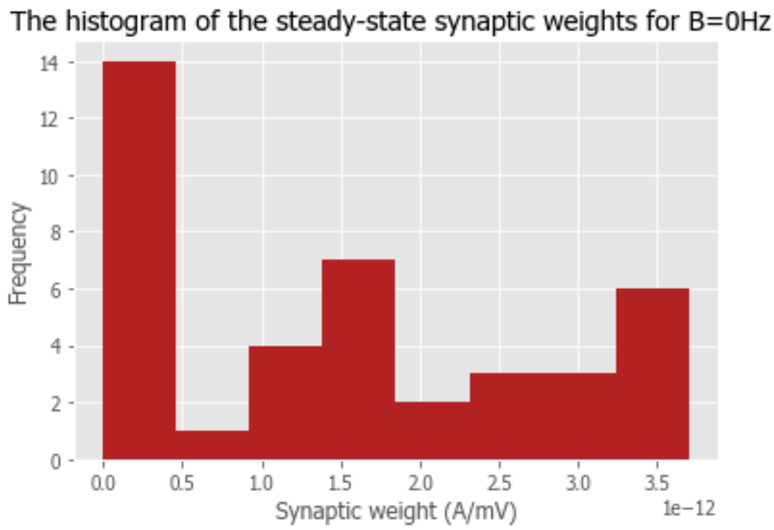
As we can see from the two below figures, the mean of the steady-state synaptic strengths reaches the minimum value at B=10Hz while the standard deviation reaches the maximum value. When B is greater than 10Hz, the mean value significantly rises and standard deviation drops with the increase of B.

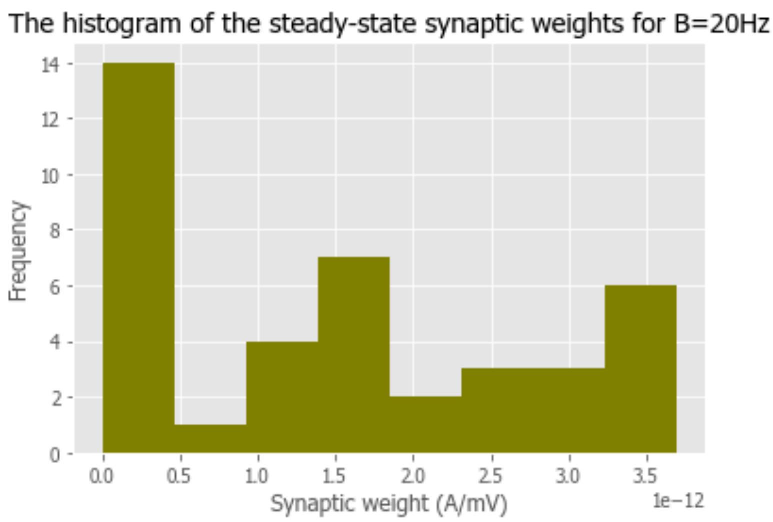
*The plots of the mean and standard deviation of the steady-state synaptic weights as a function of B:*



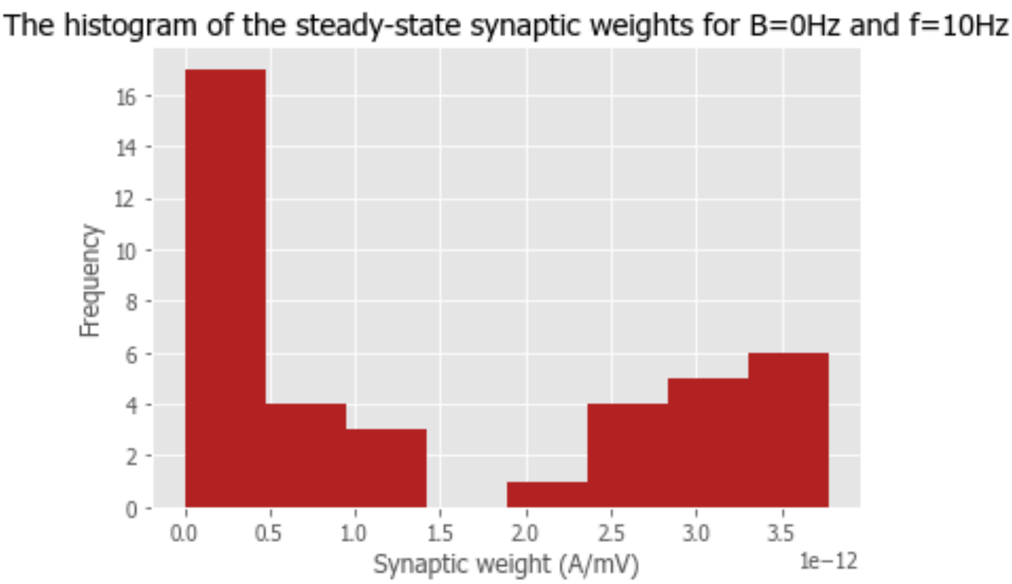

*The histograms of the steady-state synaptic strengths for B=0Hz and B=20Hz:*

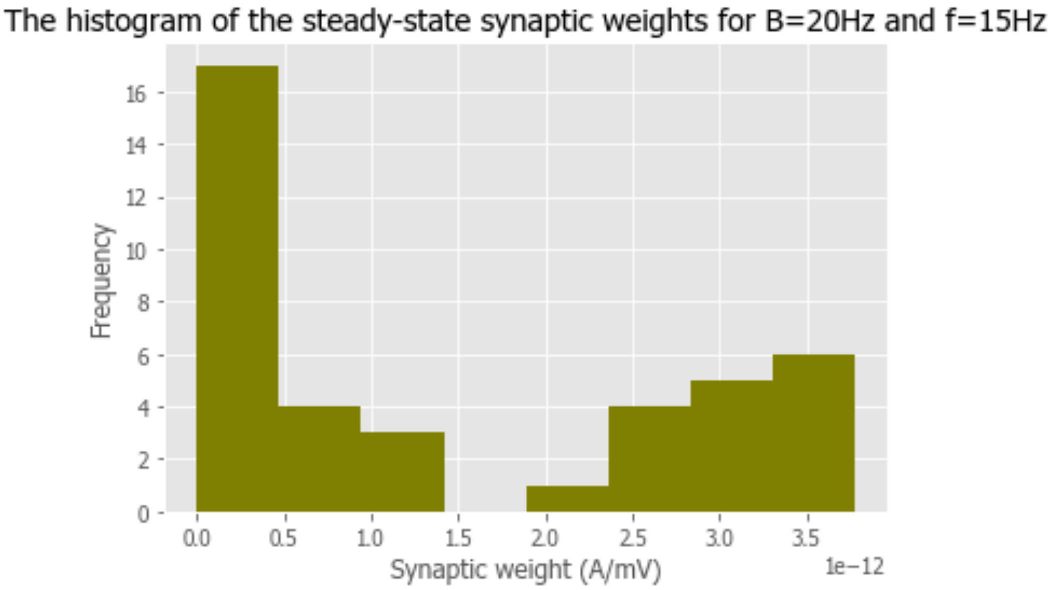





I tried to generate the above histograms for B=0Hz and B=20Hz for several times. I always get the same histogram. To prove that, I also tried to generate the histogram for B=10Hz. The result shows that the steady-state synaptic weights with different B values all have the same distribution although each distribution is different.

It seems that B value (degree of correlation) will influence the mean and standard variation of synaptic weights, but it cannot affect the distribution of synaptic weights. The distribution of synaptic weights depends on other variables. To further research the distribution, I changed the f (temporal extent of correlation) to 15Hz when B=20Hz. According to below two histograms and histograms from Question 3, we can see that the distribution is not related to the B (degree of correlation) and f (temporal extent of correlation). The distribution of synaptic weights is dependent of the input firing rate.

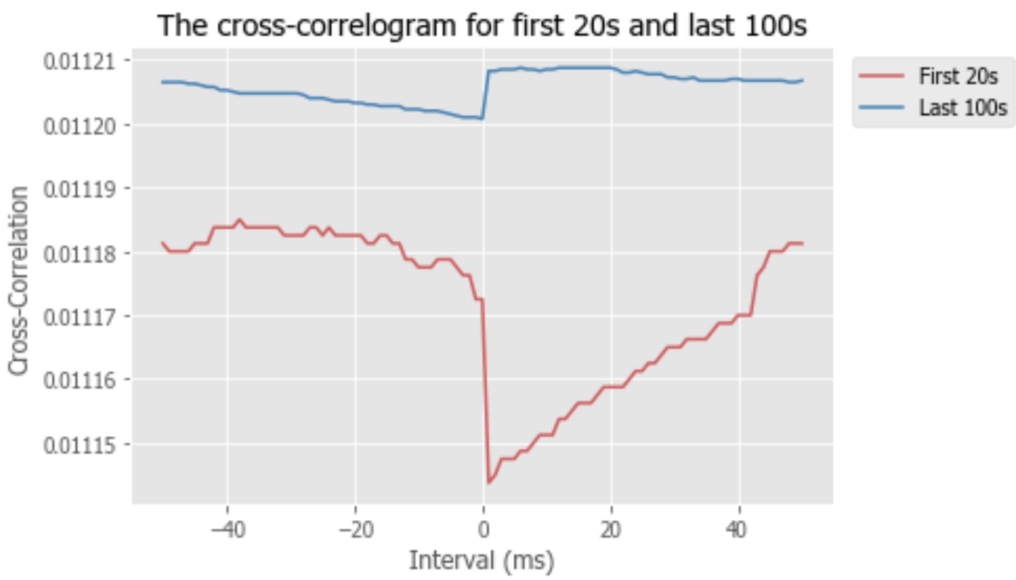





## Part B COMSM2127

To generate the cross-correlogram, I first obtain the spike_train array for 40 pre-synaptic neurons and the post-synaptic neuron across the entire 300 seconds simulation. If a spike happens in a 1ms range (= 4*delta_t), its value will be set 1. If no spike happens, the value will be assigned as 0. After that, I calculated the pre-synaptic spike counts over -50ms to +50ms window in steps of 1ms for 40 pre-synaptic neurons and the spike counts divided by the total count of the post-synaptic spike. Finally, I got the mean values for plotting the below cross-correlogram over -50 to +50ms in steps of 1ms.

*The cross-correlogram for the first 20 seconds and the last 100 seconds:*



According to the above cross-correlogram, we can see that the cross-correlation decreases rapidly in $\Delta t$= 0ms for first 20 seconds while the cross-correlation increases rapidly in $\Delta t$= 0ms for last 100seconds. For first 20 seconds, the cross-correlation for $\Delta t$ is slightly less than the -$\Delta t$. However, the cross-correlation for $\Delta t$ is slightly greater than the -$\Delta t$ for last 100 seconds. There is a similarity for both two cases, which is the cross-correlation difference reaches the maximum value near $\Delta t$=0.

From the STDP curve f($\Delta t$) on question 2, we can see that the opposite change rapidly happens when tpost = tpre ($\Delta t$=0) for synaptic strength. Due to A- > A+, the f($\Delta t$) cannot recover the same level although the |$\Delta t$| is equal. Therefore, this feature of f($\Delta t$) influences the cross-correlation.