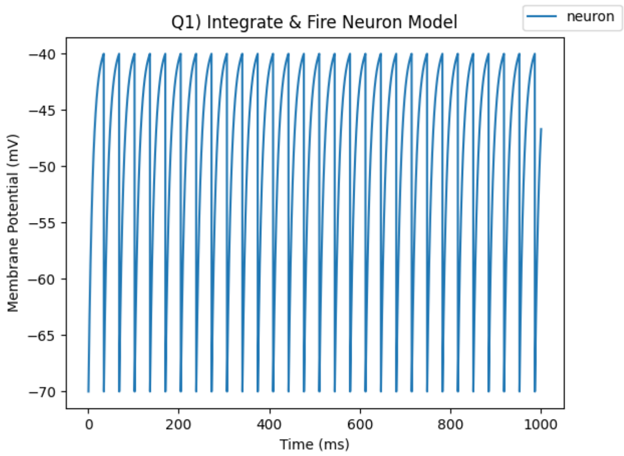
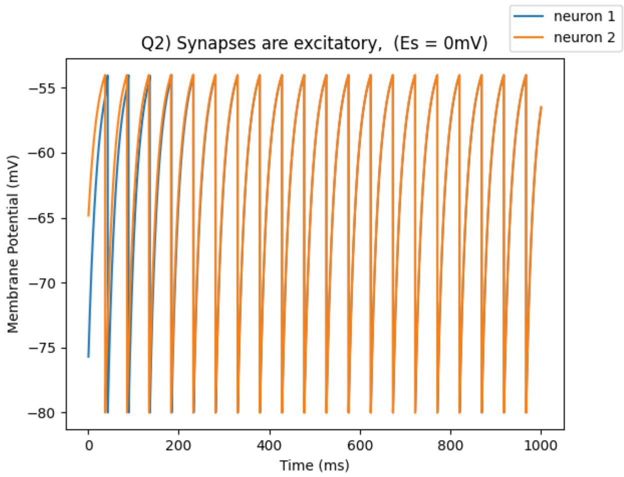
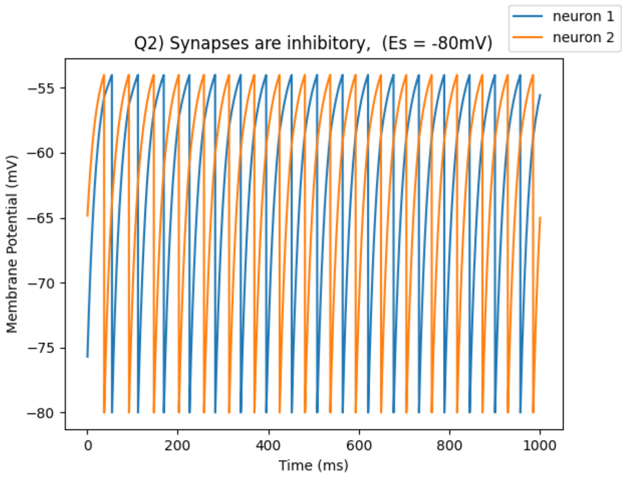
Integrate & Fire Neuron Model

QUESTION 1:



QUESTION 2:





Comment on what is happening in each case. Offer an explanation for what you observe

Synapses are excitatory:

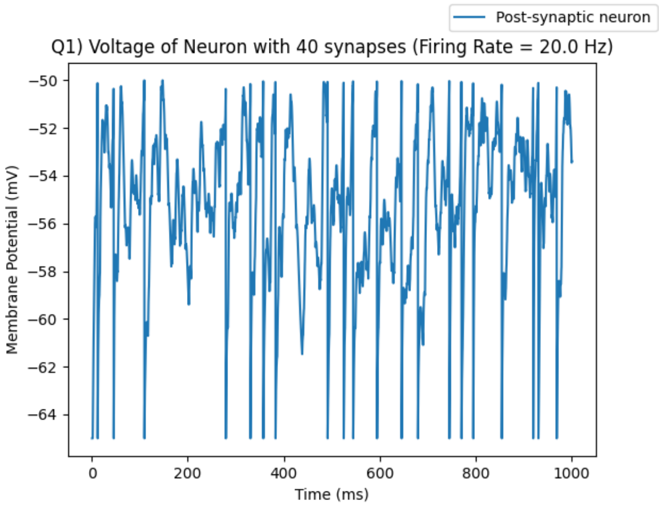
When Es is 0 mV, the RmIs or the input current received from the either neurons will always be positive which in turn helps them spike faster. When one neuron spikes, the other neuron receives an increase in the input current from the synapse which helps them spike faster. The system tries to pull the spikes closer to one another. This process keeps repeating until both the spikes are completely aligned and become stable.
Synapses are excitatory not just for Es = 0 mV but for all Es values greater than threshold voltage.

Synapses are inhibitory:

When Es is -80 mV, the RmIs or the input current received from the either neurons will always be negative which delays the spike time. With inhibitory synapse it's the opposite: when one neuron spikes, the other neuron receives a decrease in the input current from the synapse which makes them spike slower. The system is trying to push the spikes away from each other. They system becomes stable when they are evenly spaced away from each other. Each neuron spiking when the other is at their lowest i.e. rest voltage.
Synapses are inhibitory for all Es values less than threshold voltage.

Spike Timing Dependent Plasticity (STDP)

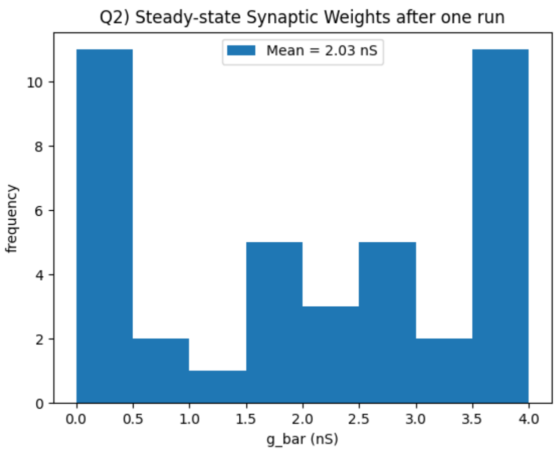
QUESTION 1:

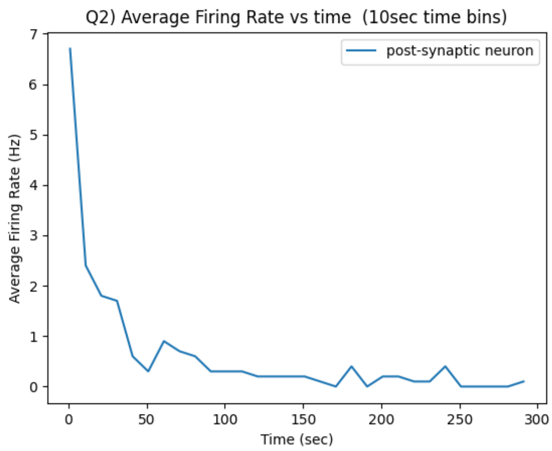


QUESTION 2:

What qualitative shape does the synaptic strength distribution converge towards at the end of the simulation time?

After the end of the simulation, the synaptic strength forms a U-shape. Upon running multiple simulations the average value of mean synaptic strength was found to be **2.03 nS**.





Report the steady-state firing rate (as averaged over the last 30 seconds of the simulation) for both the STDP ‘on’ and ‘off’ simulation modes.

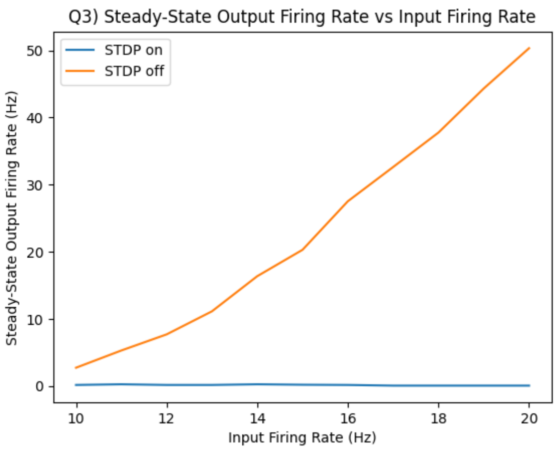
STDP off :
Steady-state Firing rate (last 30 sec) = **0.03 Hz**

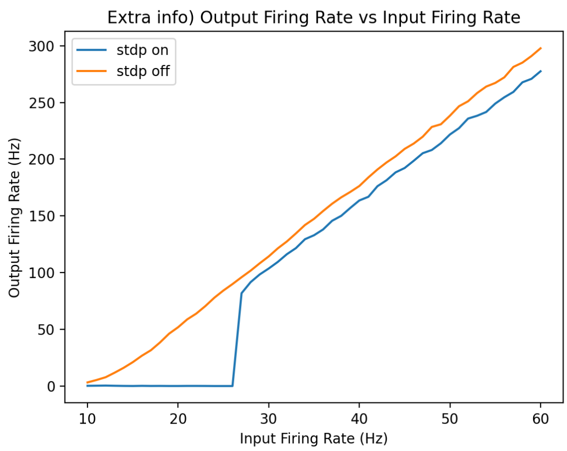
STDP on :
Steady-state Firing rate (last 30 sec) = **0.0 Hz**

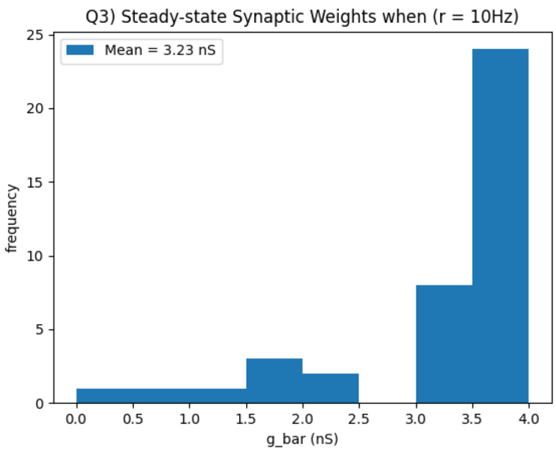
QUESTION 3:
How does the steady-state output firing rate depend on the input firing rates in both cases?

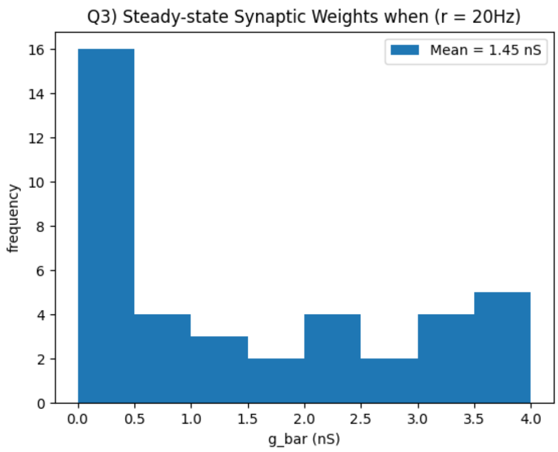
(a) STDP off - The Output Firing Rate is **directly proportional** to Input Firing Rate. Their graph is almost a straight line with **linear growth**.

(b) STDP on - The steady-state Output Firing Rate seems to be inversely proportional to the Input Firing Rate. Sometimes it also displays very slight irregular periodicity while remaining in the range of 0-1 Hz. After further research it is found to be **inversely proportional only** to Input Firing Rates **lower than ~ 26 Hz**. It is found to be **directly proportional** to Input Firing Rates **greater than ~ 26 Hz** and **grows linearly similar to the stdp off**.









Give an explanation of what is happening and why you think it makes sense.

(a) STDP off - When stdp is off there is no depression or potentiation and Synaptic weights always stay fixed at 4 nS. Therefore the no. of pre-synaptic spikes needed for every post-synaptic spike to fire remain fairly constant. When we increase the Input Firing Rate we increase the probability of getting pre-synaptic neuron spikes. More pre-synaptic spikes leads to more post-synaptic spikes getting fired. Hence the Output Firing Rate linearly increases with the increase in Input Firing Rate.

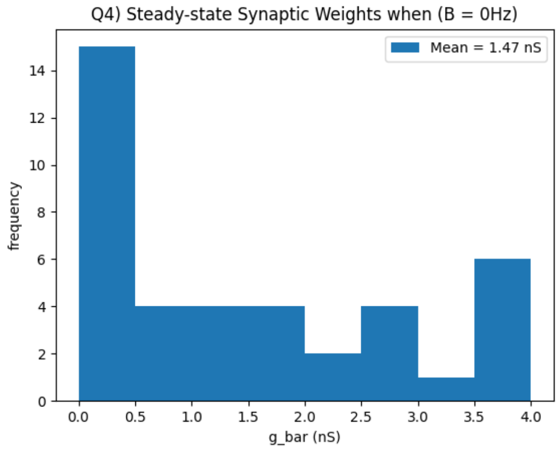
(b) STDP on - The steady-state Output Firing Rate is inversely proportional to Input Firing Rates lower than ~ 26Hz. The reason for this unexpected behaviour is that the Input rates below 26 Hz does not fire sufficient no. of pre-synaptic neuron spikes and in turn post-synaptic neuron spikes to have a net positive impact on the synaptic strengths. The synaptic weights get more depressed than potentiated and the depression rate being greater than potentiation rate, results in the synapses losing strength. This makes it more and more difficult to produce post-synaptic spikes. Hence Output Firing Rate ultimately follows a decreasing trend with increase in Input Firing Rate up-to a certain point(~26 Hz).

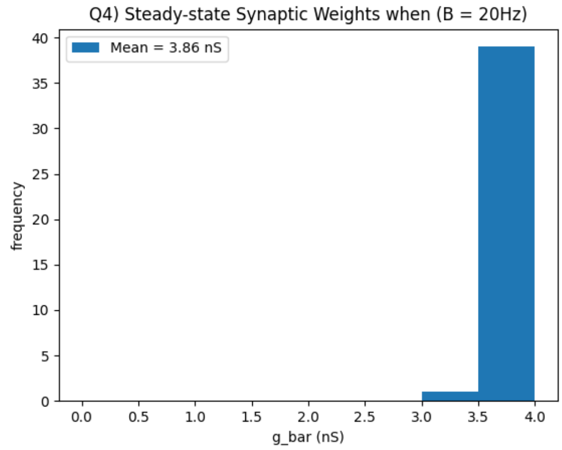
When Input Firing Rates are greater than 26 Hz it produces more than 1000 Hz of pre-synaptic spikes which is more than enough to overcome the negative impact of depression on synaptic weights and fire enough post-synaptic spikes such that, there are more potentiation than depression of the synapses. Since there are more potentiation than than depression the synapses do not lose strength. We are capping the synaptic strength at 4 nS so the distribution settles down in the range 3.5 - 4.0 nS. Therefore the no. of pre-synaptic spikes needed for every post-synaptic spike to fire remain fairly constant. Hence the Output Firing Rate linearly increases with the increase in Input Firing Rate greater than ~26 Hz.

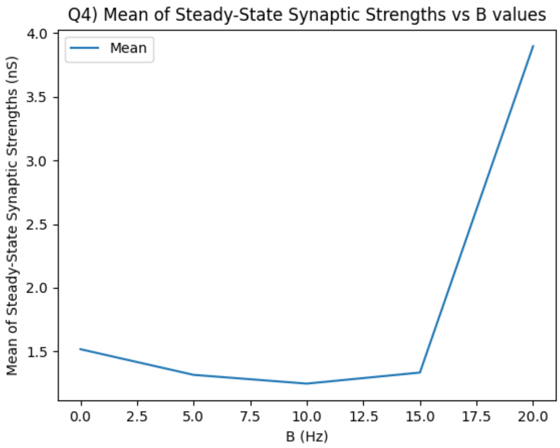
QUESTION 4:

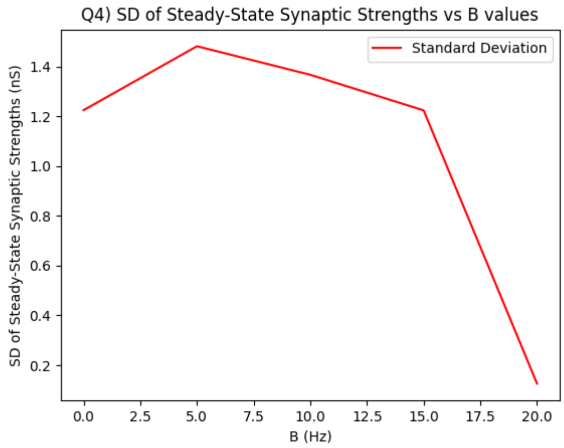
How does the degree of correlation affect the steady-state synaptic weights?

The increase in B values keeps slightly decreasing the steady-state synaptic weights until B= 15 Hz after which it starts rising rapidly with the increase in B values.
The degree of correlation is directly proportional to B values.
Hence the increase in degree of correlation between the input spike trains **slightly decreases** the steady-state synaptic weights **at first** but then **increases** the steady-state **synaptic weights with** the **increase in degree of correlation**.









Give an explanation for what you think is happening.

B values determine the amplitude of variation in the input firing rates. The higher the B value the greater will the input firing rate vary away from average rate i.e. 20 Hz. Now with B= 0Hz, the input firing rate stays constant at 20Hz. With B= 5Hz, 10Hz the input firing rate varies from ranges (15-25 Hz), (10-30 Hz).

We learned from previous question 3 that for the synapses to gain strength the input firing rate has to be greater than 26 Hz or else they will lose their strength. The input firing rate for most of the time stays below 26 Hz benchmark rate in an increasing trend for B= 0Hz, 5Hz, 10Hz until it reaches B= 15Hz which causes more loss than gain of strength for the synaptic weights. Hence the increase in B values slightly decreases the Synaptic Weights at first.

From B=15 Hz onwards the input firing rate varies above 26 Hz for sufficient time such that, the potentiation of synapses dominates over depression of synapses resulting in synapses gaining strength which in turn increases mean and decreases SD (standard deviation) of steady-state Synaptic Weights.