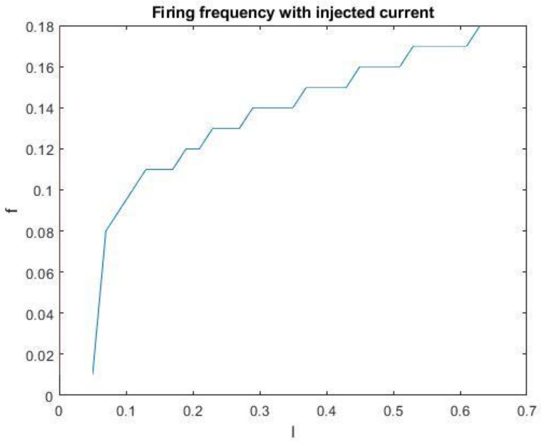
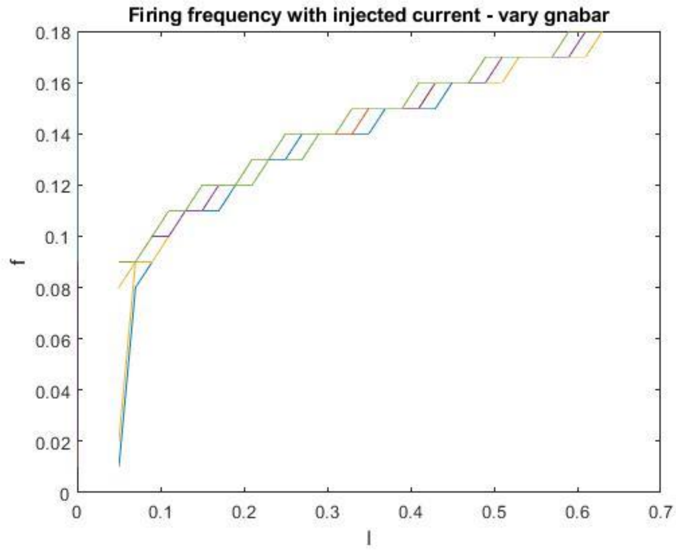
ASSIGNMENT 3 SOLUTIONS

Question 1



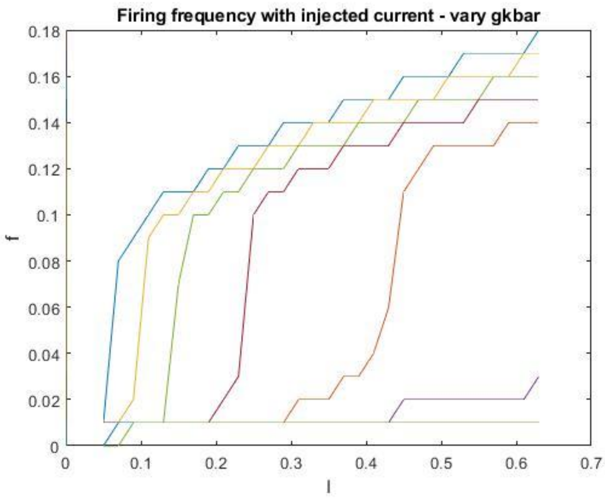
Basic plot of Firing frequency and current. Injected current is depolarising in nature. Hence, as current increases, depolarisation level increases. Since there’s more depolarization than hyperpolarization (normal level) at that instant, we get the next consecutive spike. As long as depolarization and hyperpolarization levels are comparable, we’ll see spikes and hence higher firing frequency rate.

(i)Vary the densities of sodium and potassium channels



As gnabar increases, firing frequency increases.

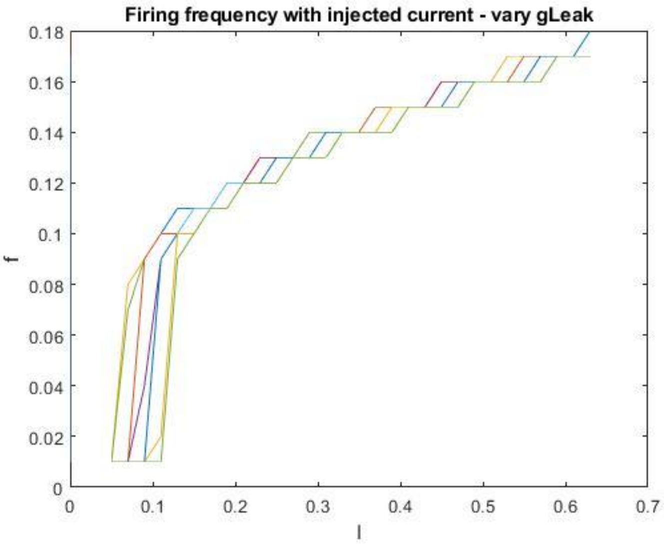
Reason - Increase in gnabar increases Na+ conductance. This results in inward current that indeed results in depolarization. Hence firing frequency increases.



As gkbar increases, firing frequency decreases.

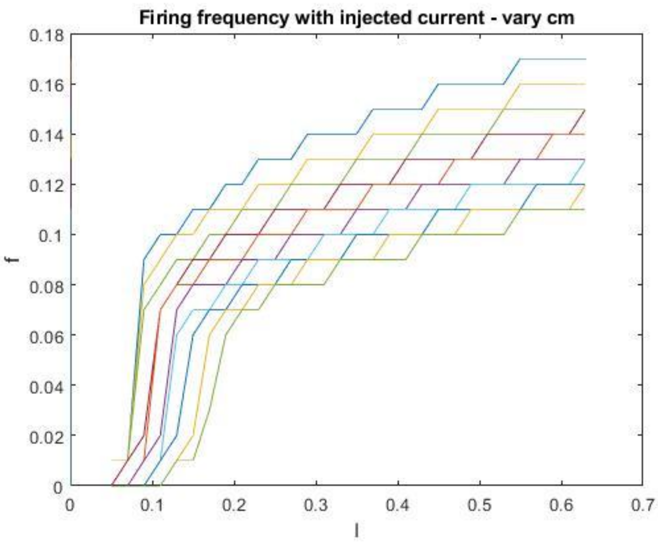
Reason - Increase in gkbar increases K+ conductance. This results in outward current that indeed results in hyperpolarization. Hence firing frequency decreases drastically.

(ii) **Vary Rm and Cm**



As gLeak increases, firing frequency decreases.

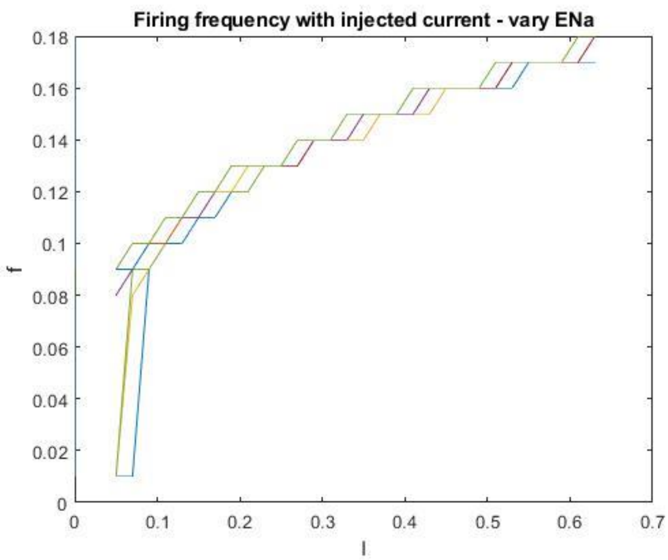
Reason - If gLeak is increased, the rate of change of the subthreshold voltage is actually lower because increasing gLeak/ decreasing Rm increases the leak current. Therefore, the spiking neuron reaches threshold quite late. Hence, firing frequency decreases.



As Cm increases, firing frequency decreases.

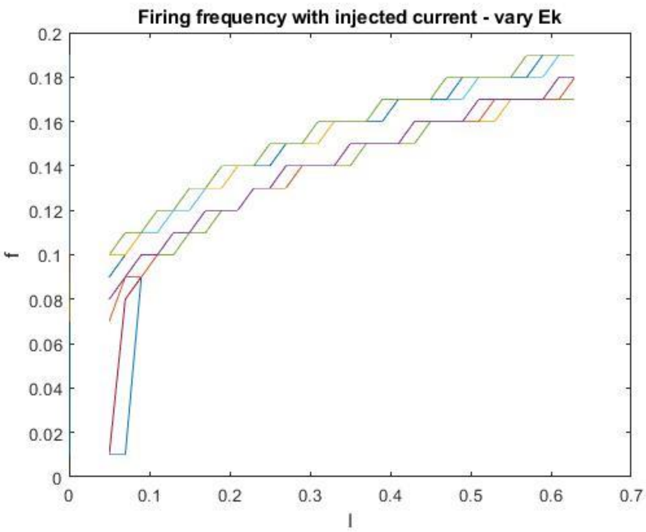
Reason – As cm increases, time constant increases. Hence, voltage at any instant/position is attenuated. Depolarization will affect the adjacent region slowly, and will bring the adjacent region to threshold quite later. Conduction velocity of the action potential is decreased, meaning firing frequency decreases.

(iii) **Vary reversal potentials of Na and K channels.**



As Ena increases, firing frequency increases.

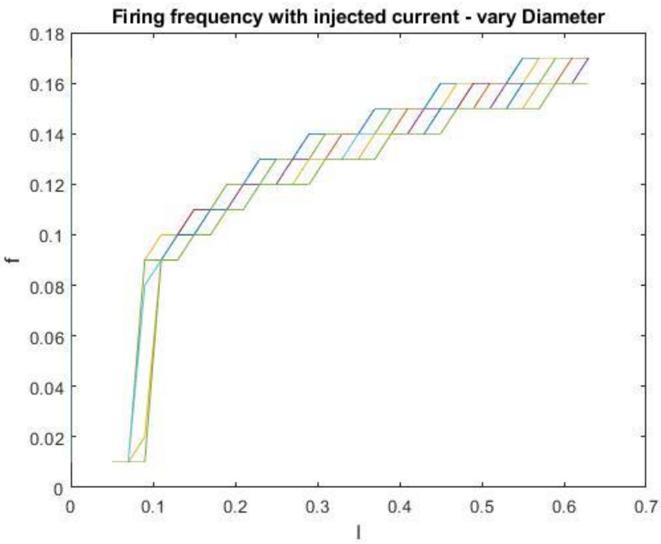
Reason - Increase in ENa -> increasing Na+ concentration outside the cell, which leads to higher depolarization. Since there's more depolarization than hyperpolarization (normal level) at that instant, we get the next consecutive spike. As long as depolarization and hyperpolarization levels are comparable, we'll see spikes and hence higher firing frequency rate.



As Ek increases, firing frequency increases.

Reason - Increase in Ek -> increasing K+ concentration outside the cell, which leads to lower hyperpolarization. Since there's more depolarization than hyperpolarization at that instant, we get the next consecutive spike. As long as hyperpolarization and depolarization levels are comparable, we'll see spikes and hence higher firing frequency rate.

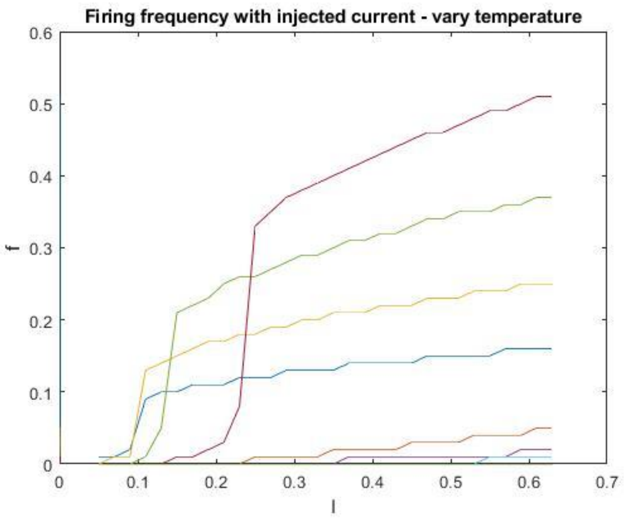
(iv) **Vary diameter values**



As diameter increases, firing frequency decrases.

Reason - As diameter increases, the cross-sectional area through which current passes increases. Hence, the amount of current that reaches farther places decreases. Hence, due to lesser depolarizing current, firing frequency decreases.

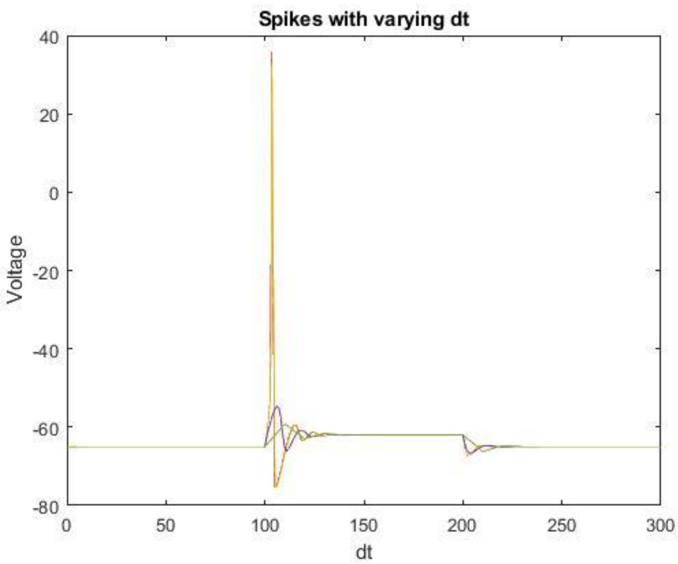
(v) **Vary temperature values**



As temperature increases, firing frequency increases.

Reason - As the temperature is increased, the amplitude of action potential is decreased and its duration is reduced. Alterations in temperature affect the rates of diffusion through ion channels. As Temperature is increased, Reversal potential is decreases. This leads to higher depolarisation. Since there's more depolarization than hyperpolarization (normal level) at that instant, we get the next consecutive spike. As long as depolarization and hyperpolarization levels are comparable, we'll see spikes and hence higher firing frequency rate.

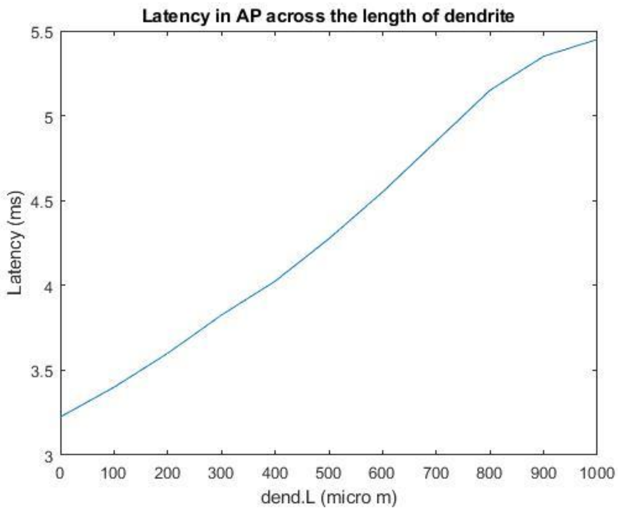
Question 2



As dt increases, by equation, m (activation term – Na+), h (inactivation tern – Na+), n (activation term – K+) decreases. Sodium ion conductance is related by m^3*h. Hence, as m decreases, m^3 decreases even further. Hence the activation level drastically decreases over the effects of inactivation. This leads to reduce in AP amplitude.

Question 3

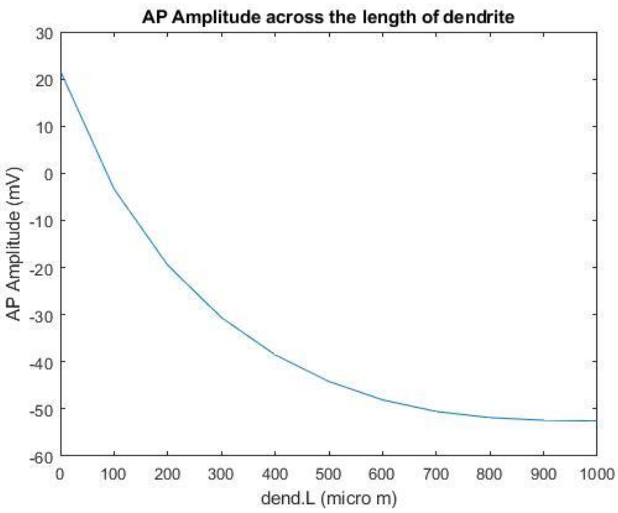
(i)



Latency is defined as the time taken by the voltage to cross the threshold and reach its maximum from the point of injection of current. Latency is also an inverse index of neural conduction velocity. The propagation velocity is directly proportional to the space constant and inversely proportional to the time constant. This give us the following equation.

$$Velocity \quad \alpha \quad \frac{1}{C_m}\sqrt{\frac{d}{4R_mR_i}}$$

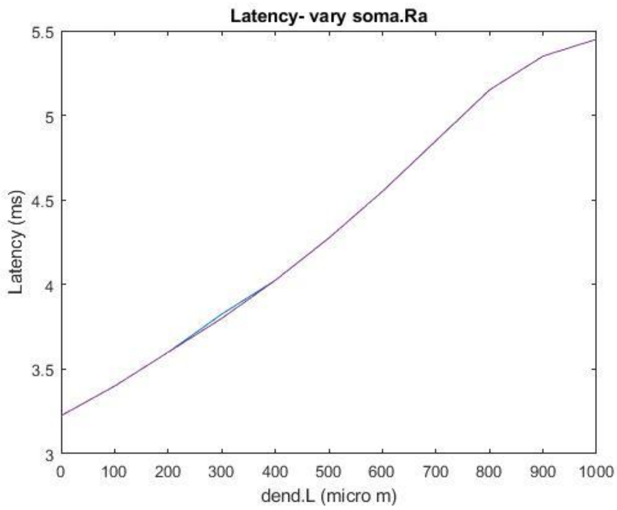
In general, the action potential takes time to traverse along the dendrite. Hence Latency prevails. But usually latency for adjacent positions along a dendrite is less than a couple of milliseconds. Hence Latency increases as we move along the length of the dendrite.

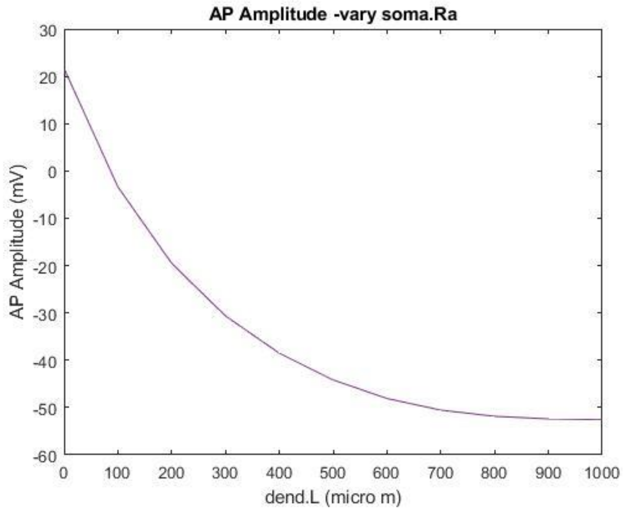


The Action potential due to current injected at the centre of the soma, gets attenuated along the dendrite as it moves forward due to presence of leak channels.

(ii)

Increasing Ra of soma

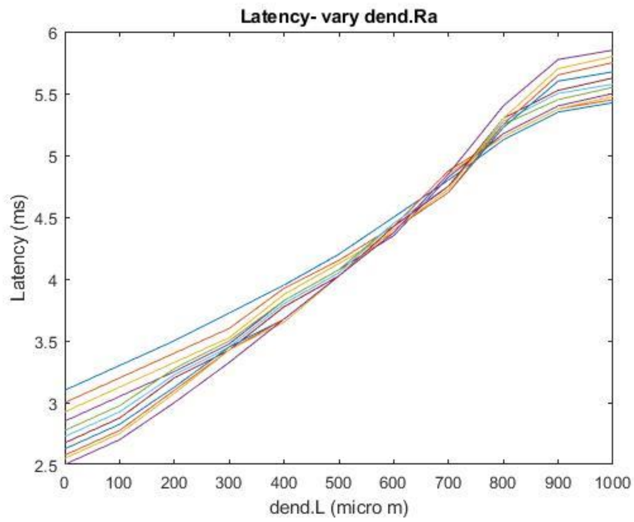




We notice that Ra of soma does not have any impact on Latency and the amplitude of action potential.

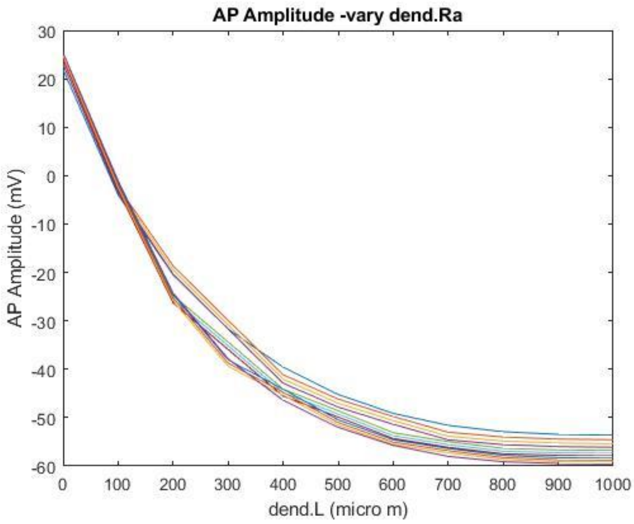
This is primarily due to shorter size of this compartment. Length and the diameter of soma is 18.8 micro m only, and hence attenuation is not much.

Increasing Ra in the dendrite -



Latency decreases and then increases.

Reason - As axial resistance increases, for the same injected current, voltage at a given instant increases. Hence, the spike reached threshold faster and hence Latency is reduced. However, due to increase in attenuation as Ra increases, latency further increases along the length of the dendrite.

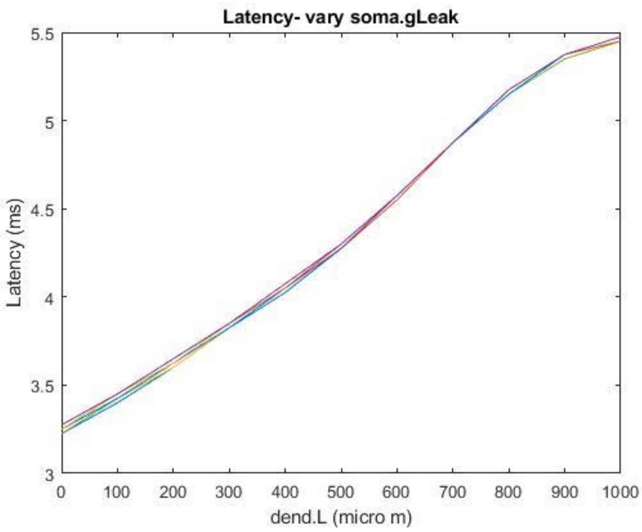


AP Amplitude increases.

Reason - The length constant is inversely proportional to the axial resistance. Hence a lower axial resistance will allow more of the depolarizing current to flow along the dendrite. Hence, AP amplitude increases, as Ra increases. However, voltage also attenuates faster due to decrease in length constant.

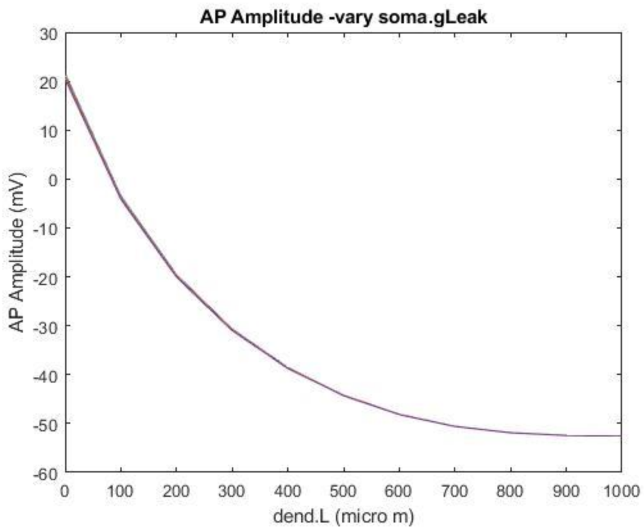
(iii)

Increasing gLeak of Soma.



Latency increases, but faintly.

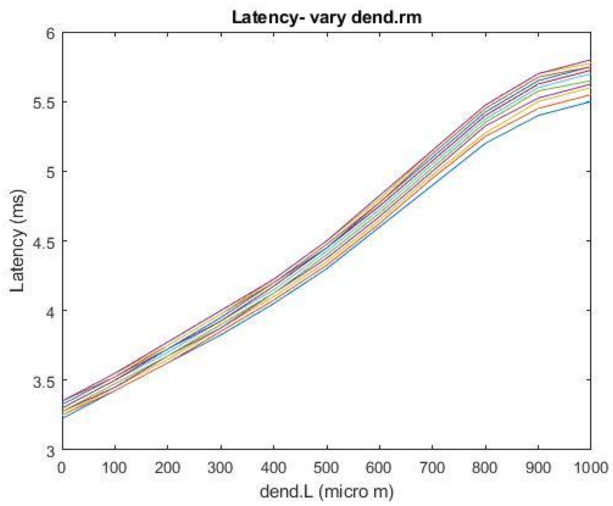
Reason – With increase in soma.gLeak, depolarizing current at a given section decreases. Hence, conduction velocity also decreases, which leads to increase in Latency.



AP Amplitude decreases.

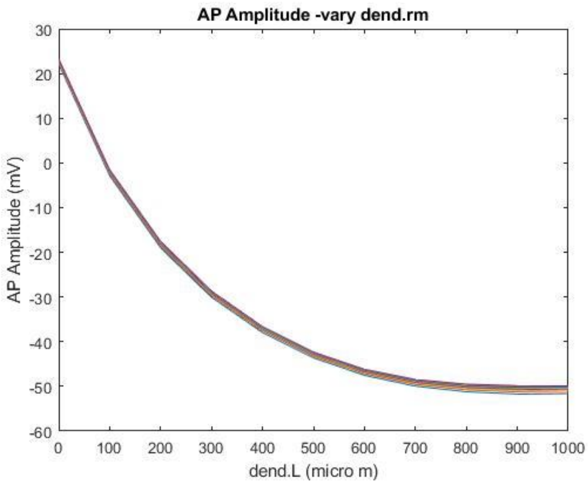
The length constant is proportional to the membrane resistance. Hence, lower membrane resistance or a higher gLeak will allow lesser of the depolarizing current to flow along the dendrite. Hence, AP Amplitude decreases.

Increasing Rm of dendrite.



Latency increases.

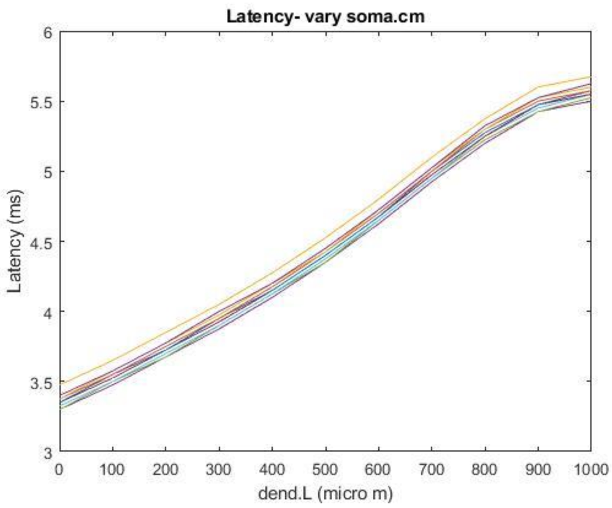
Reason - Higher the time constant (due to increase in dend.Rm), depolarization will affect the adjacent region slowly, and will bring the adjacent region to threshold quite later. Therefore, the higher the time constant, the less rapid will be the propagation velocity. Hence, latency increases.



AP Amplitude increases.

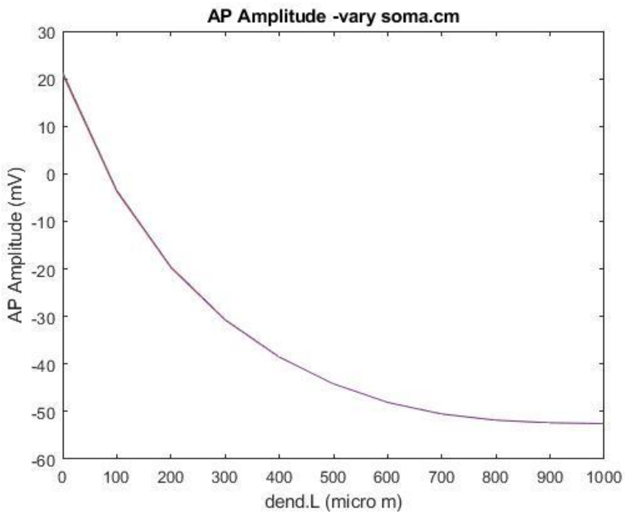
Reason- As membrane resistance increases, higher depolarising current flows along the length of the dendrite. Hence AP amplitude increases.

Increasing Cm of soma.



Latency increases.

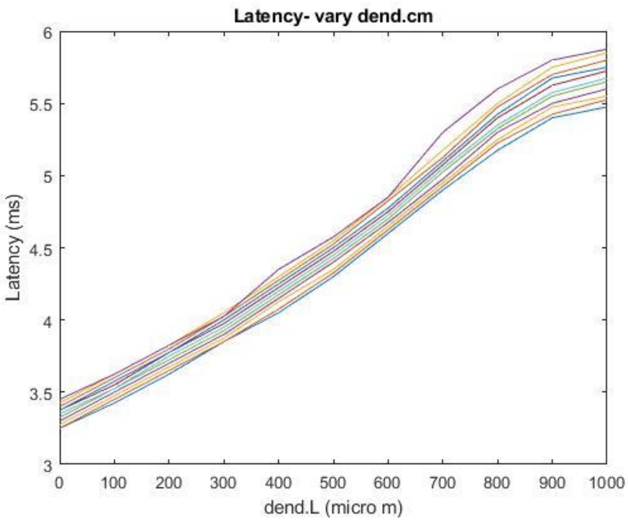
Reason - Higher the time constant (due to increase in dend.cm), depolarization will affect the adjacent region slowly, and will bring the adjacent region to threshold quite later. Therefore, the higher the time constant, the less rapid will be the propagation velocity. Hence, latency increases.



AP Amplitude decreases, but very slightly.

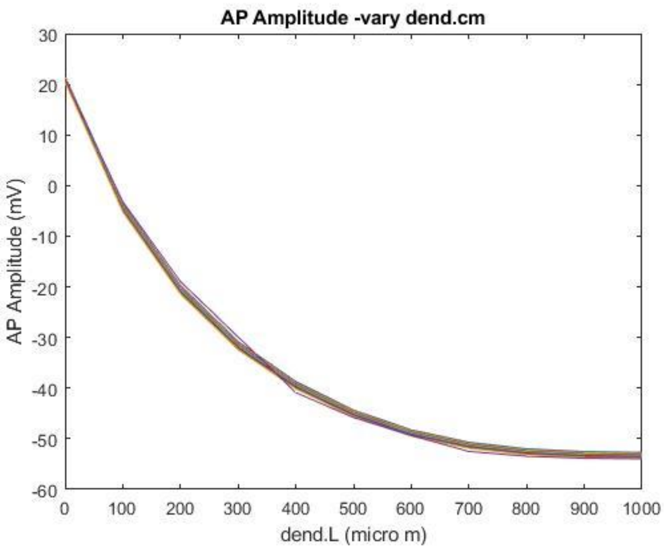
Reason - Time constant increases, due to increase in soma.Cm. Hence, voltage is attenuated at the sub-threshold level. Therefore, consecutively, AP amplitude decreases. However, increase in soma.cm does not affect the decrease significantly because of the smaller size of the compartment itself.

Increasing cm of dendrite



Latency increases.

Reason- Higher the time constant (due to increase in dend.cm), depolarization will affect the adjacent region slowly, and will bring the adjacent region to threshold quite later. Therefore, the higher the time constant, the less rapid will be the propagation velocity. Hence, latency increases.

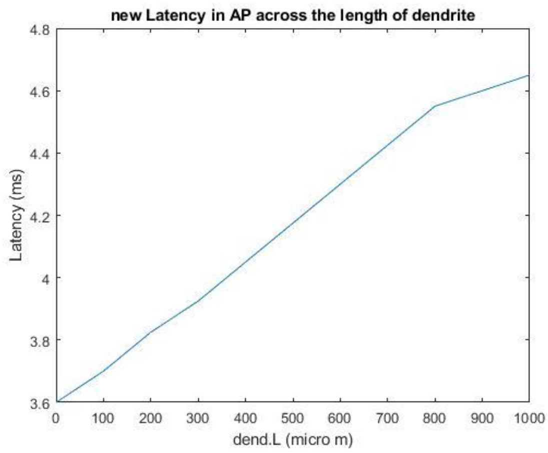


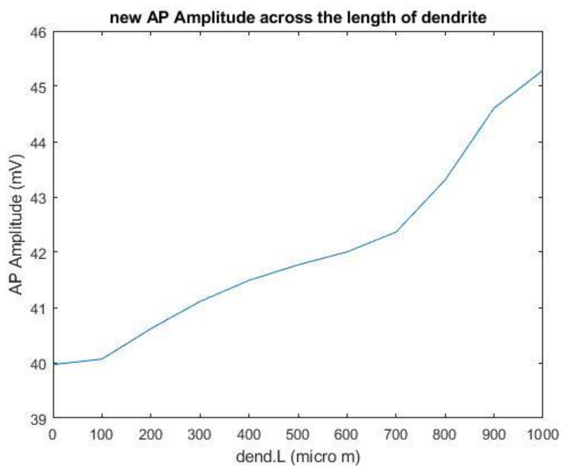
AP Amplitude decreases.

Reason- Time constant increases, due to increase in dend.Cm. Hence, voltage is attenuated at the sub-threshold level. Therefore, consecutively, AP amplitude decreases.

(iv)

HH channels have been introduced to dendrite now.

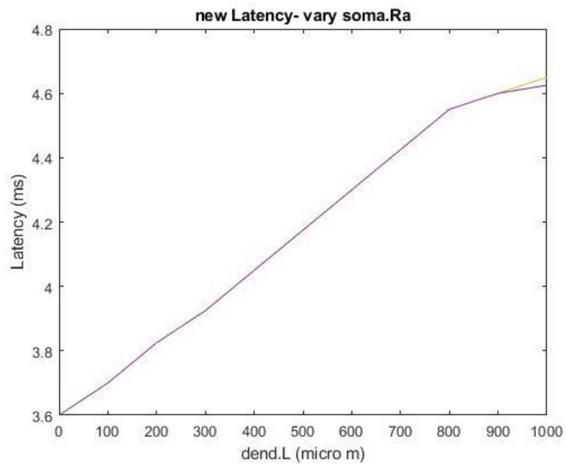


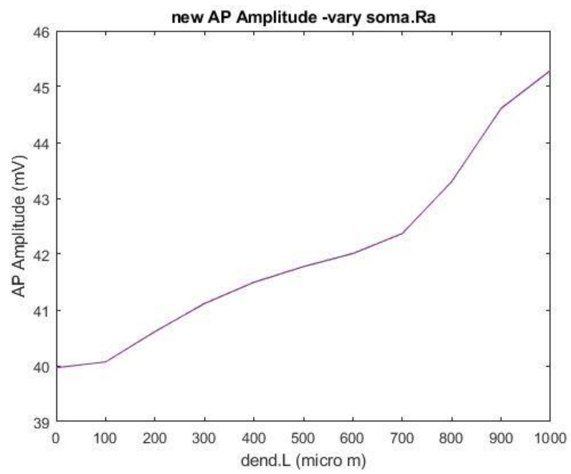


The general plot of Latency still increases, due to the aforementioned reasons.

However, AP Amplitude also increases due to backpropagation of signal. Due to the presence of ion channels, the action potential, now, not only undergoes passive conduction, but also propagates in both directions. Hence, when we record AP Amplitude at any instant, along the dendrite, it is the summation of forward-propagating AP and backpropagating AP.

(ii) Increasing Ra of soma

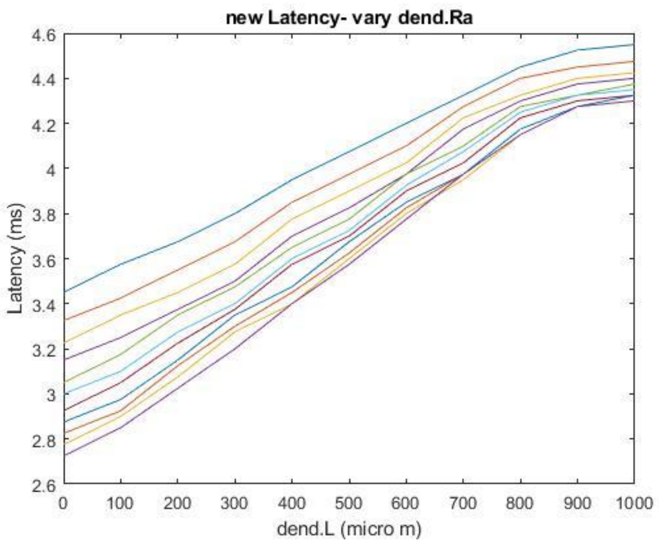




We notice that Ra of soma does not have any impact on Latency and the amplitude of action potential.

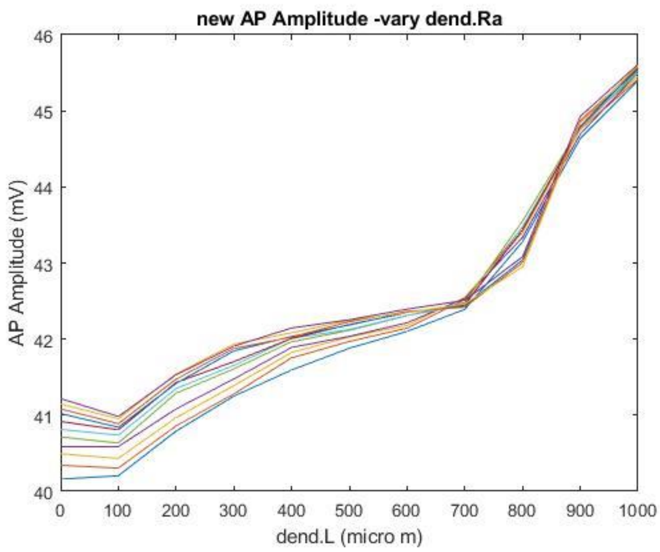
This is primarily due to shorter size of this compartment. Length and the diameter of soma is 18.8 micro m only, and hence attenuation is not much.

Increasing Ra of dendrite



n Latency increases.

Reason – As Ra increases, space constant increases and hence attenuation increases. Therefore, latency also increases, since conduction velocity is slowed down.

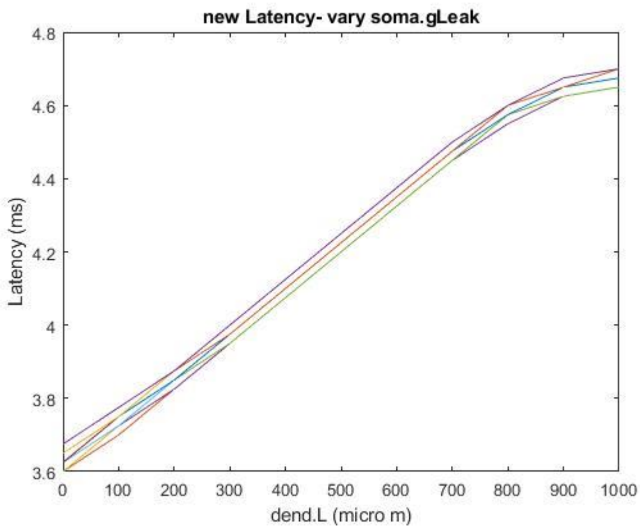


n AP Amplitude increases.

As dend.Ra increases, space constant also increases, which means lesser attenuation. Hence, voltage attenuation decreases, implying that AP Amplitude increases.

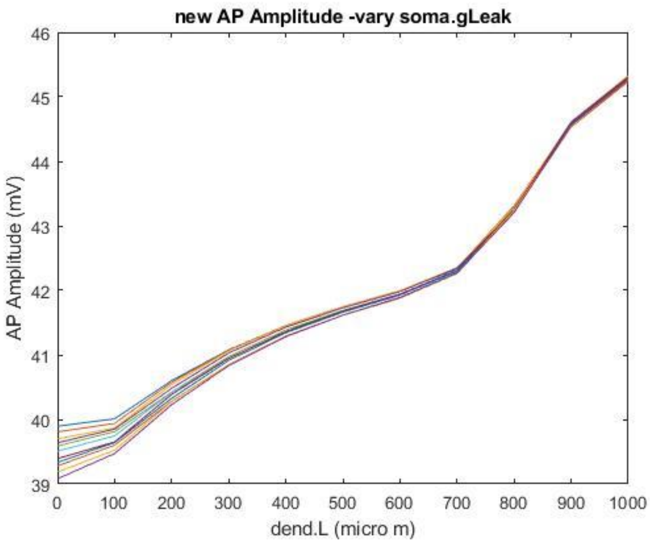
(iii)

Increasing gLeak of soma.



n Latency increases.

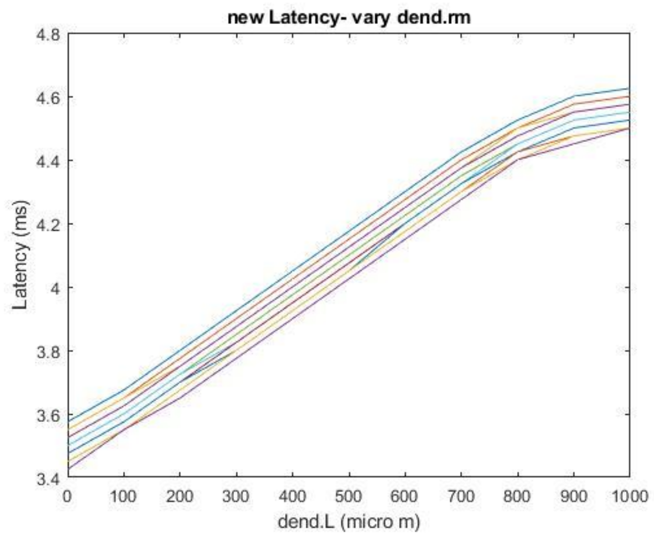
Reason – When soma.gleak is increased, depolarising current within the compartment is reduced. Therefore, it takes more time than regular to reach the threshold and hence fire an AP. Therefore, Latency increases.



N AP Amplitude decreases.

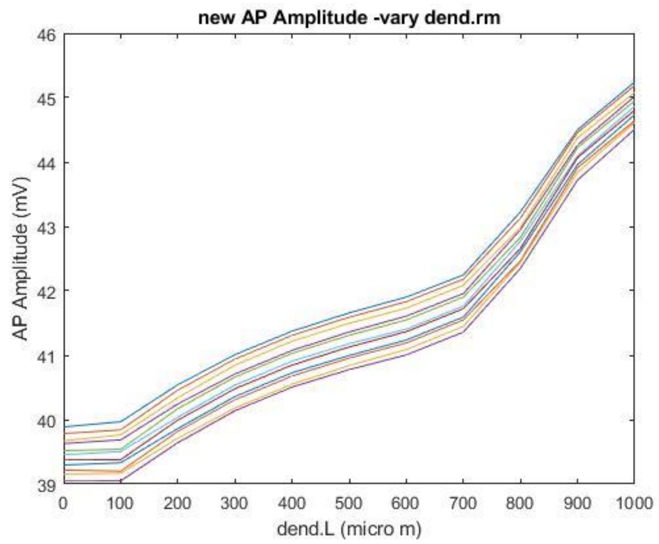
Reason - When soma.gleak is increased, depolarising current within the compartment is reduced. Asa result, voltage is also reduced slightly. Hence, AP Amplitude decreases.

Increasing rm of dendrite



N Latency decreases.

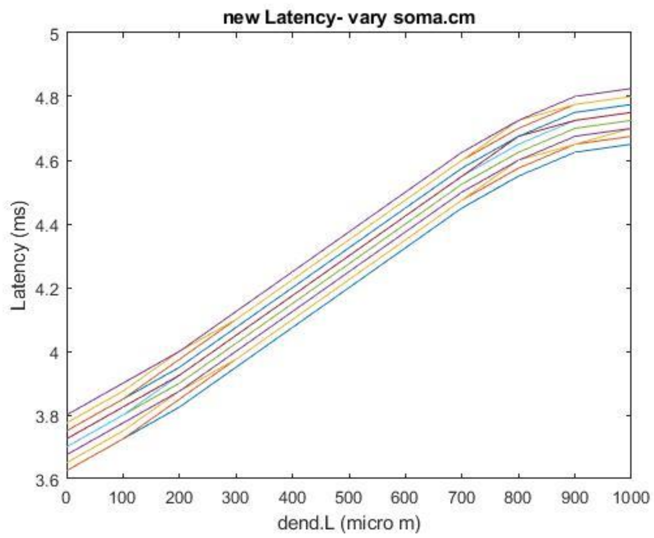
Reason – Usually, higher the time constant (due to increase in dend.Rm), depolarization will affect the adjacent region slowly, and will bring the adjacent region to threshold quite later. However, with active channels on the dendrite, AP is propagated on both the directions and hence conduction velocity is increased. Eventually, latency decreases.



n AP Amplitude decreases.

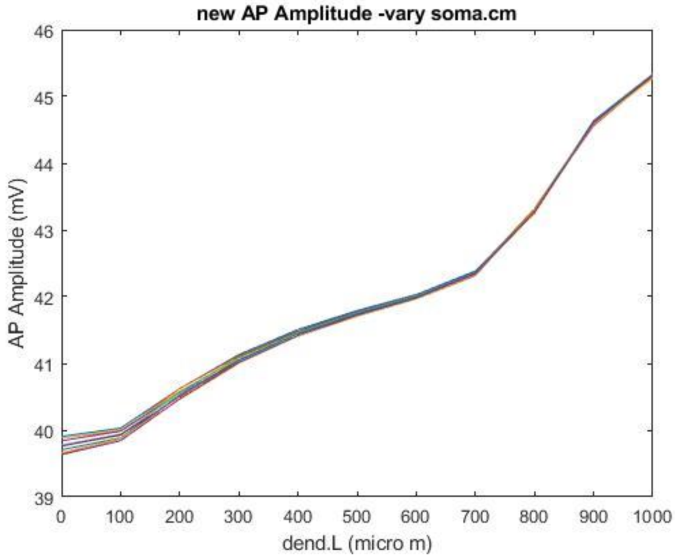
Reason – As Rm increases, time constant increases. Hence, voltage at any instant is decreases. Therefore, AP Amplitude decreases as well.

Increasing cm of soma



n Latency increases.

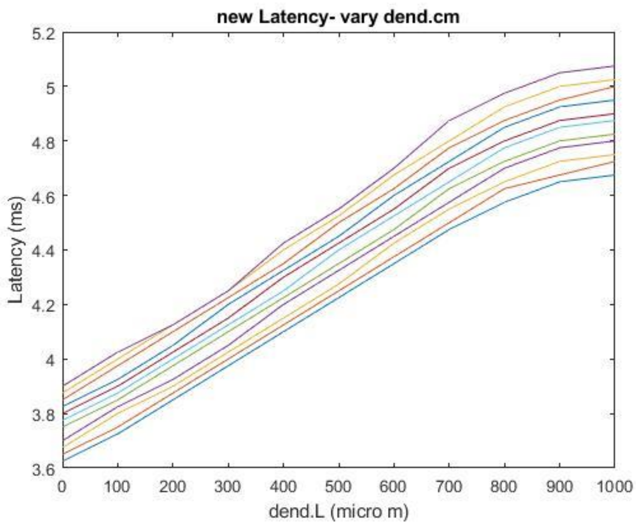
Reason - As soma.cm increases, time constant of the propagating voltage increases. Voltage at any point is reduced, hence it will take longer to reach the threshold. Therefore, latency increases. But the increase in latency is lesser than the increase, we'd observe when dend.cm is increased. This is mostly due to the smaller size of the compartment.



n AP Amplitude decreases.

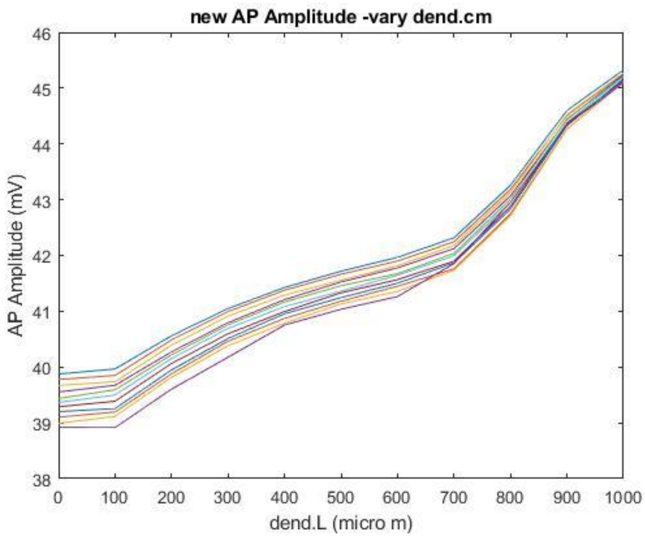
Reason - As Cm increases, time constant increases. Voltage at any point is reduced, hence AP Amplitude decreases. But the decrease in amplitude is lesser than the decrease, we'd observe when dend.cm is increased. This is mostly due to the smaller size of the compartment.

Increasing cm of dendrite



N Latency increases.

Reason – As Cm increases, time constant increases. Voltage at any point is reduced, hence it will take longer to reach the threshold. Therefore, latency increases.



N AP Amplitude decreases.

Reason - As Cm increases, time constant increases. Voltage at any point is reduced, hence AP Amplitude decreases.