Neuromorphic Engineering

Assignment 1

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Question 1:

Part 1:

Minimum threshold current = 2.7 nA

(At steady state, dV/dt = 0

Vsteady = (Iapp/gl) + El

Thus, Iapp min = (Vsteady – El)*gl, such that Vsteady > 0.02 V

Part 2:

```
Command Window
>> q1p2
Enter number of neurons : 3
Enter total time : 0.2
Enter number of iterations : 2000
Enter input current for neurons :12
Enter input current for neurons :15
Enter input current for neurons :8

V =

  Columns 1 through 11

   -0.0700   -0.0688   -0.0676   -0.0665   -0.0653   -0.0641   -0.0630   -0.0619   -0.0608   -0.0597   -0.0586
   -0.0700   -0.0685   -0.0670   -0.0656   -0.0641   -0.0627   -0.0613   -0.0599   -0.0585   -0.0571   -0.0557
   -0.0700   -0.0692   -0.0684   -0.0676   -0.0669   -0.0661   -0.0653   -0.0646   -0.0638   -0.0631   -0.0624

  Columns 12 through 22

   -0.0575   -0.0564   -0.0554   -0.0543   -0.0533   -0.0523   -0.0512   -0.0502   -0.0492   -0.0482   -0.0473
   -0.0544   -0.0530   -0.0517   -0.0504   -0.0491   -0.0478   -0.0466   -0.0453   -0.0440   -0.0428   -0.0416
   -0.0617   -0.0610   -0.0602   -0.0595   -0.0589   -0.0582   -0.0575   -0.0568   -0.0562   -0.0555   -0.0548

  Columns 23 through 33
```

Given input current for each of the neurons, number of iterations, and time of program, program gives the N*M matrix, and plot of potential of each of the neurons.

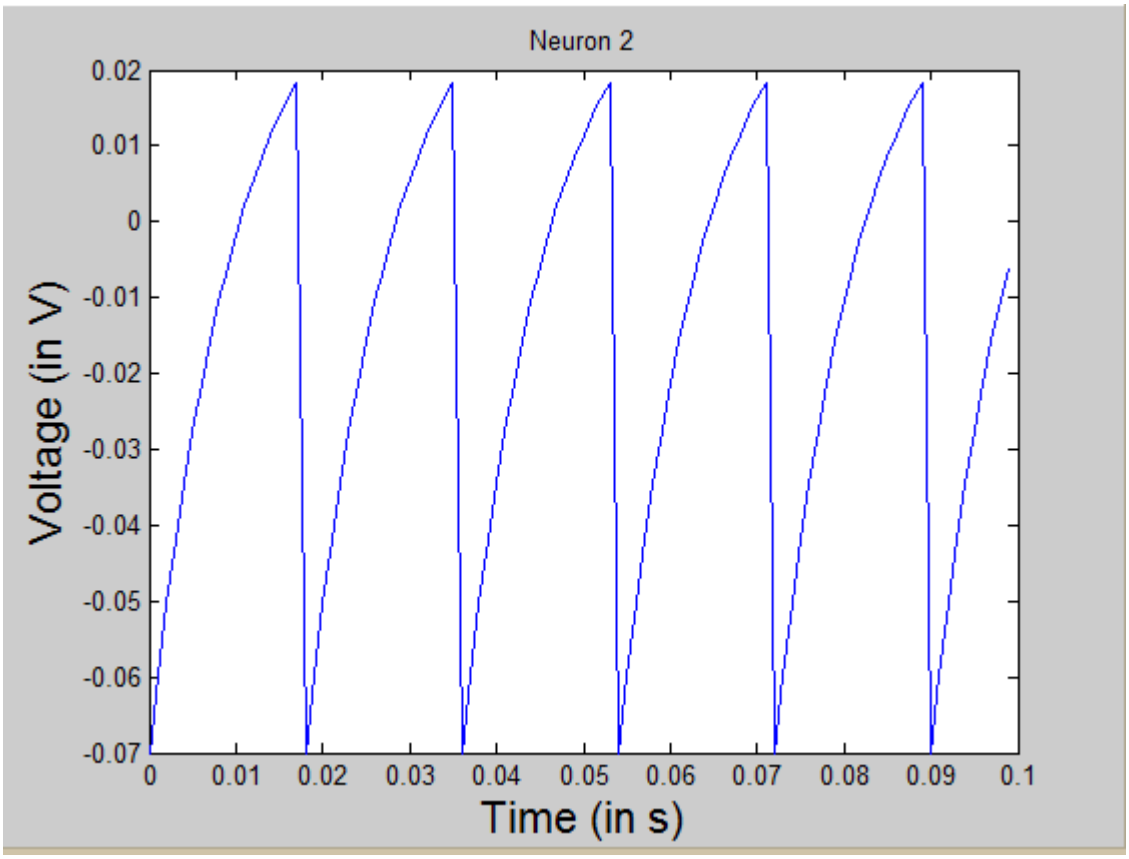
Part 3:

Leaky integrate and fire model, current is a function of the neuron number, as,

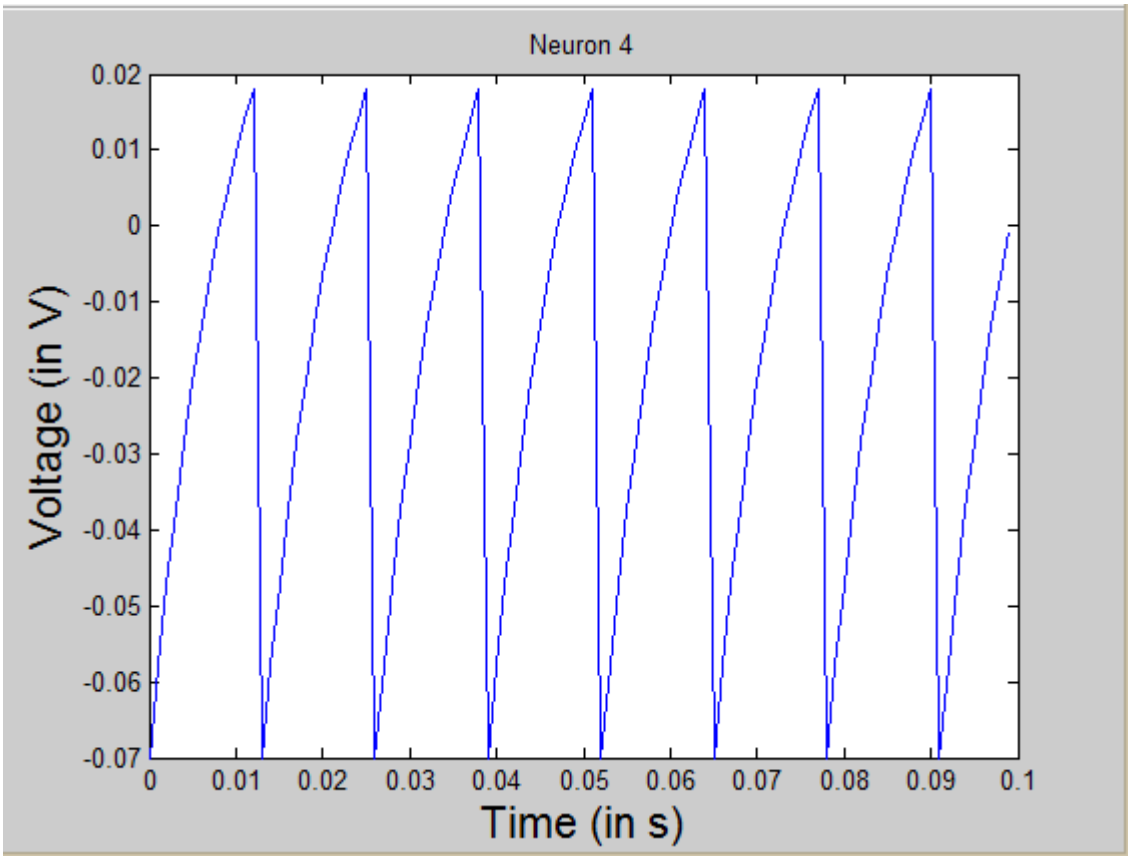
$I_{app;k} = (1 + k\_)I_c$

Plots seen:

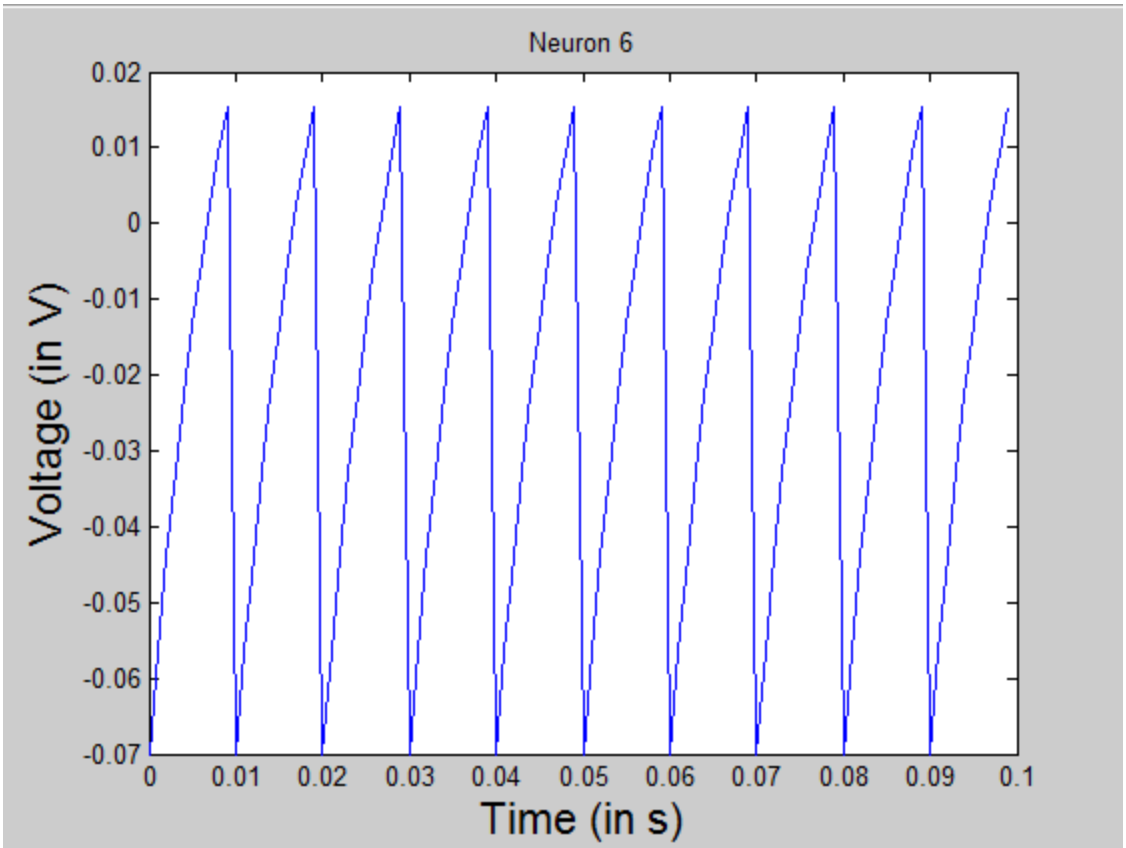
For k = 2:



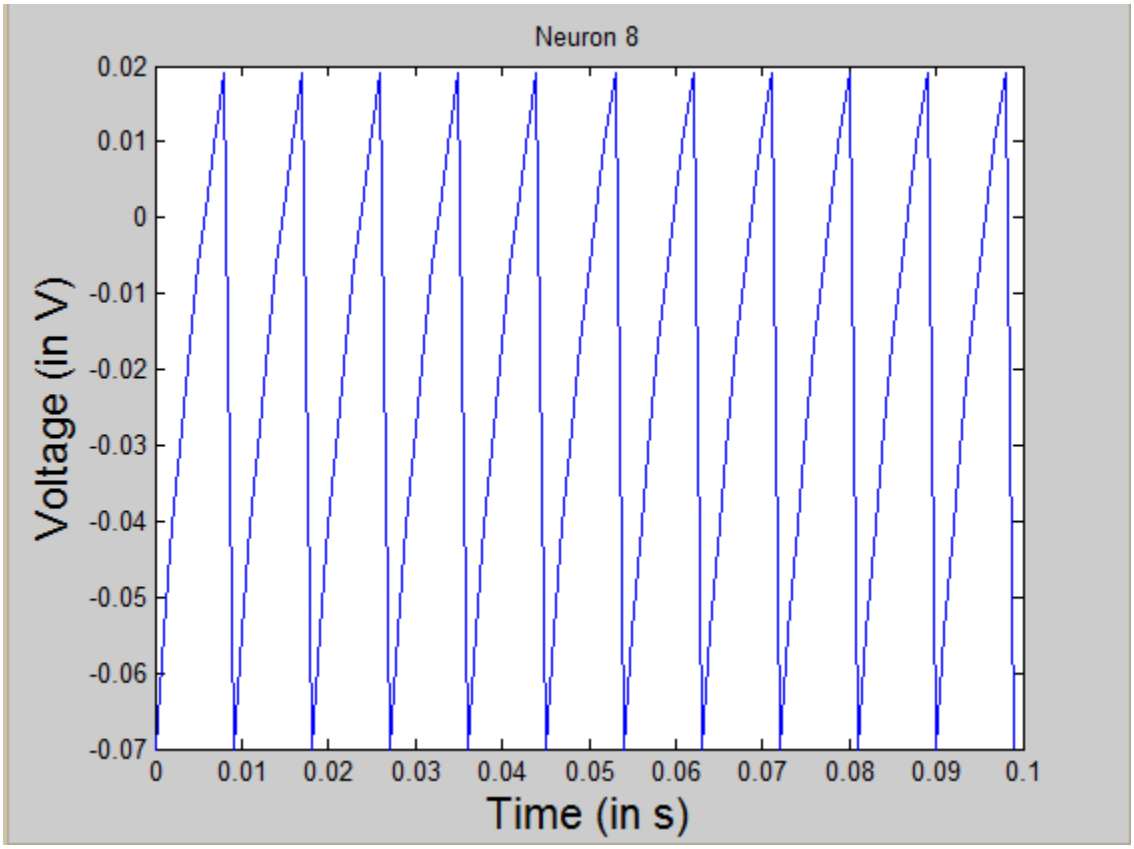
For k = 4



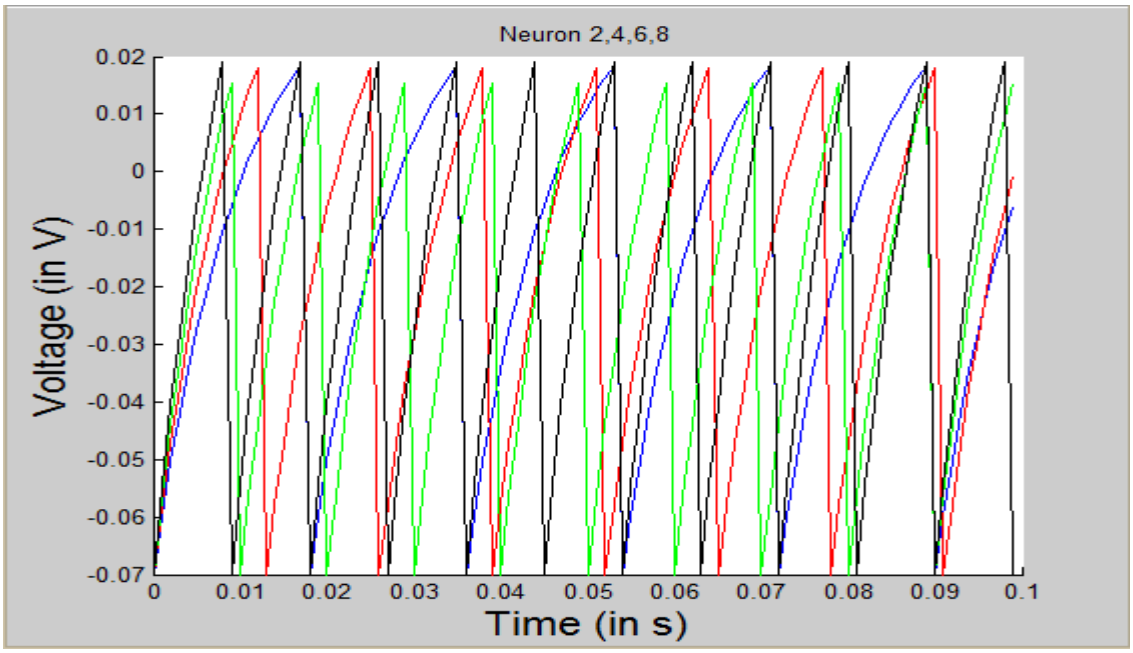
For k = 6


Neuron 6
Voltage (in V)
Time (in s)
0.02
0.01
0
-0.01
-0.02
-0.03
-0.04
-0.05
-0.06
-0.07
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.1

For k = 8

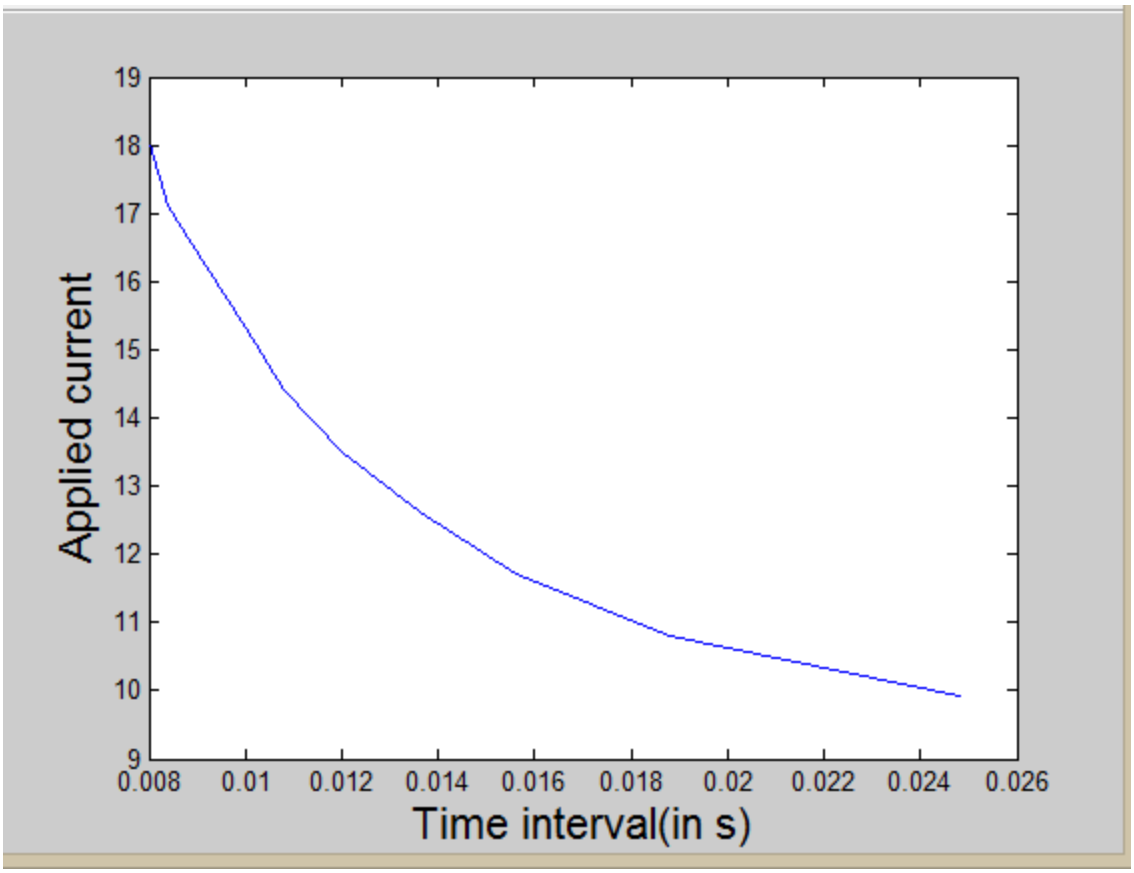

Neuron 8
Voltage (in V)
Time (in s)
0.02
0.01
0
-0.01
-0.02
-0.03
-0.04
-0.05
-0.06
-0.07
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.1

Comaprison:



Part 4:

Plot between average time and input current



Question 2:

Part 1:

Steady state values:

```
Command Window
Enter neuron type : RS

Vsteadystate =

   -0.0429


Usteadystate =

  -3.4286e-11

>> q2p1

prompt =

Enter neuron type :

Enter neuron type : IB

Vsteadystate =

   -0.0408
```

```
Command Window
Vsteadystate =

   -0.0408


Usteadystate =

   1.7083e-10

>> q2p1

prompt =

Enter neuron type :

Enter neuron type : CH

Vsteadystate =

   -0.0393


Usteadystate =
```

Part 2:

Difference equations:

$$k1 = (kz(Vn - Er)(Vn - Et) - Un + Iapp)/C$$

$$k2 = (kz\left(\left(Vn + \frac{dt}{2} * k1\right) - Er\right)\left(\left(Vn + \frac{dt}{2} * k1\right) - Et\right) - (Un + \frac{dt}{2} * l1) + Iapp)/C$$

$$k3 = (kz\left(\left(Vn + \frac{dt}{2} * k2\right) - Er\right)\left(\left(Vn + \frac{dt}{2} * k2\right) - Et\right) - (Un + \frac{dt}{2} * l2) + Iapp)/C$$

$$k4 = (kz\big((Vn + dt * k3) - Er\big)\big((Vn + dt * k3) - Et\big) - (Un + dt * l3) + Iapp)/C$$

$$l1 = a(b(Vn - Er) - Un)$$

$$l2 = a\left(b\left((Vn + \frac{dt}{2} * k1) - Er\right) - (Un + \frac{dt}{2} * l1)\right)$$

$$l3 = a\left(b\left(\left(Vn + \frac{dt}{2} * k2\right) - Er\right) - \left(Un + \frac{dt}{2} * l2\right)\right)$$

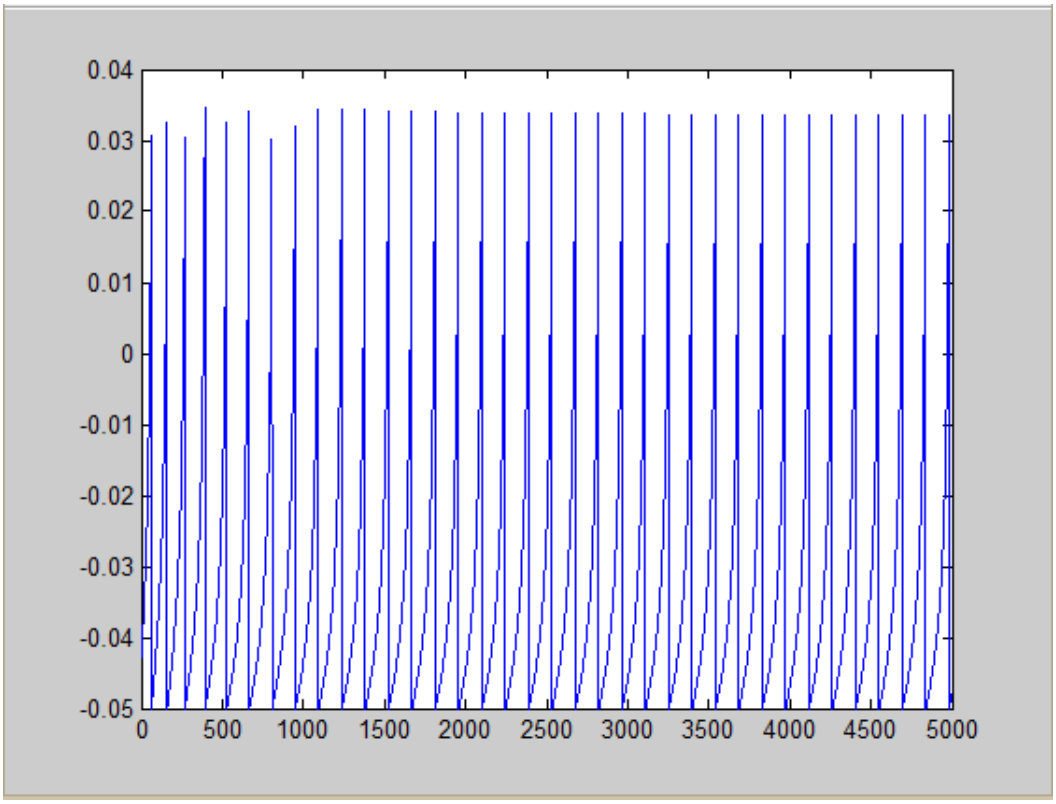
$$l4 = a(b((Vn + dt * k3) - Er) - (Un + dt * l3))$$

$$Vn + 1 = Vn + dt/6(k1 + 2 * k2 + 2 * k3 + k4)$$

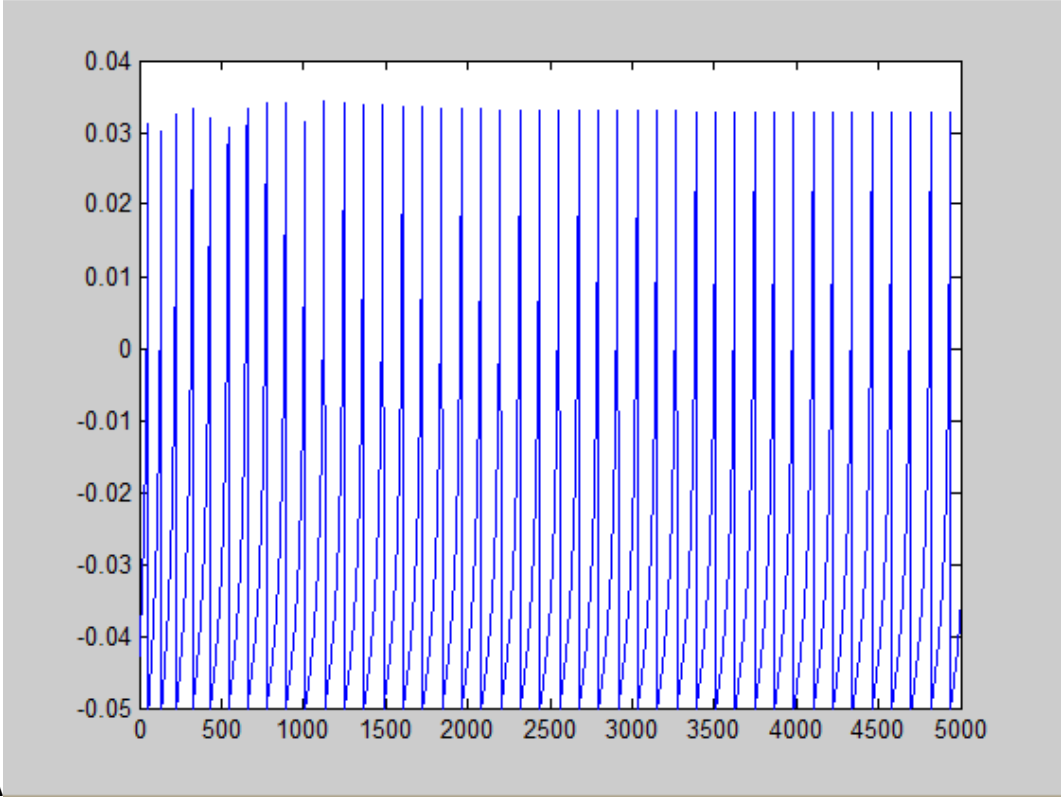
$$Un + 1 = Un + dt/6(l1 + 2 * l2 + 2 * l3 + l4)$$

Part 3:

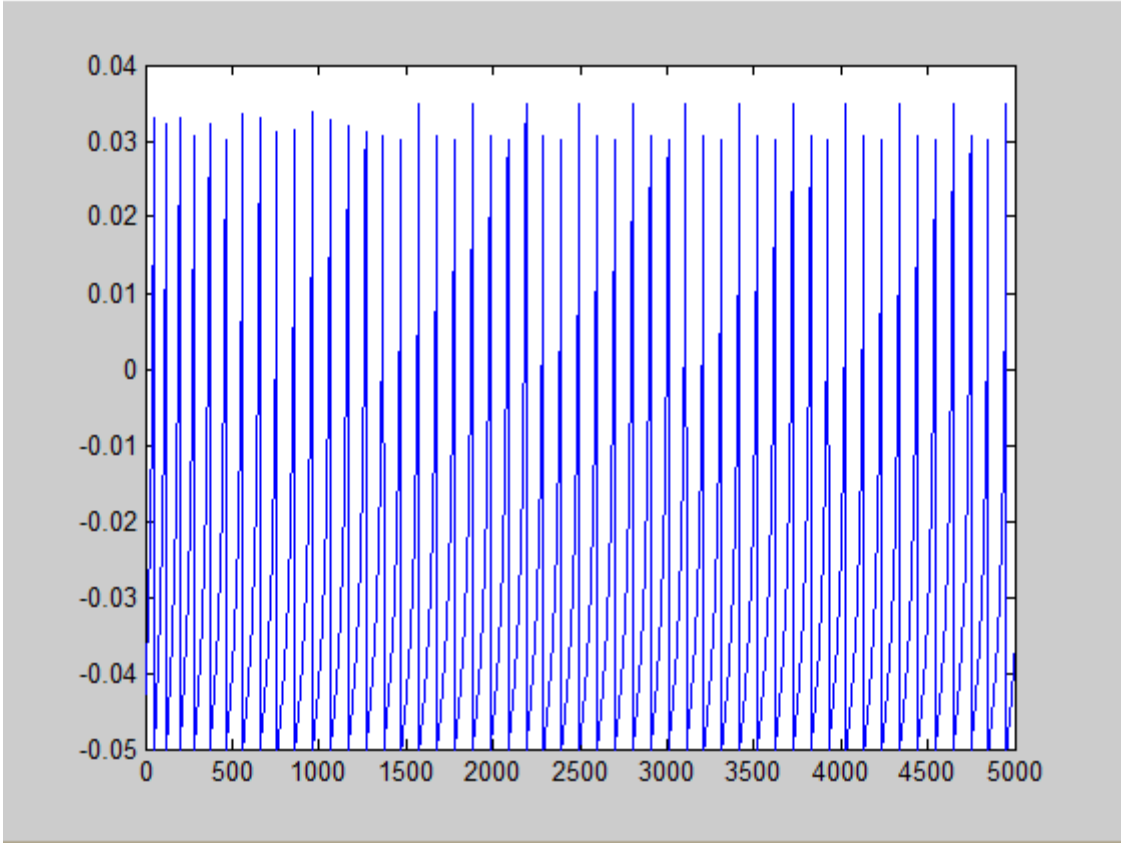
Neuron RS, 400 pA



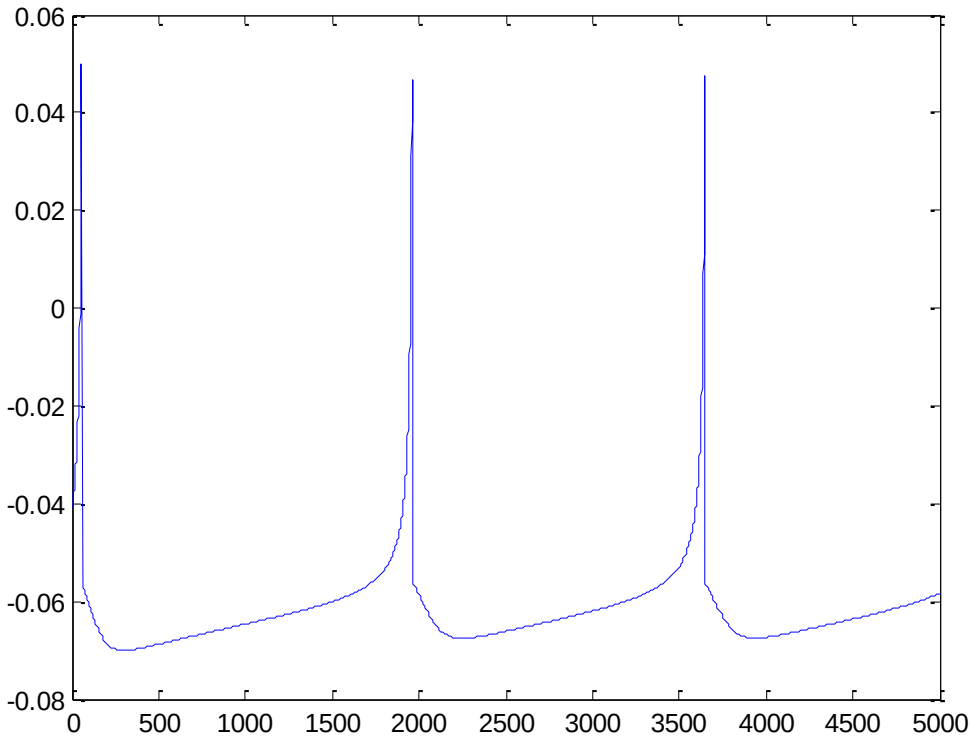
Neuron RS, 500 pA



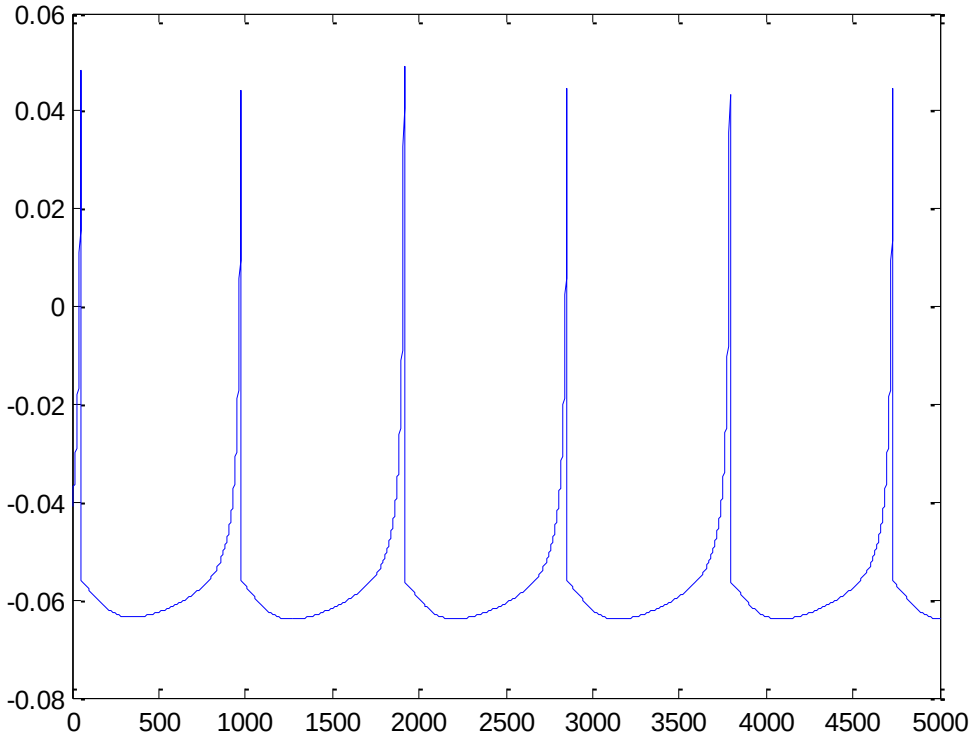
Neuron RS, 600 pA



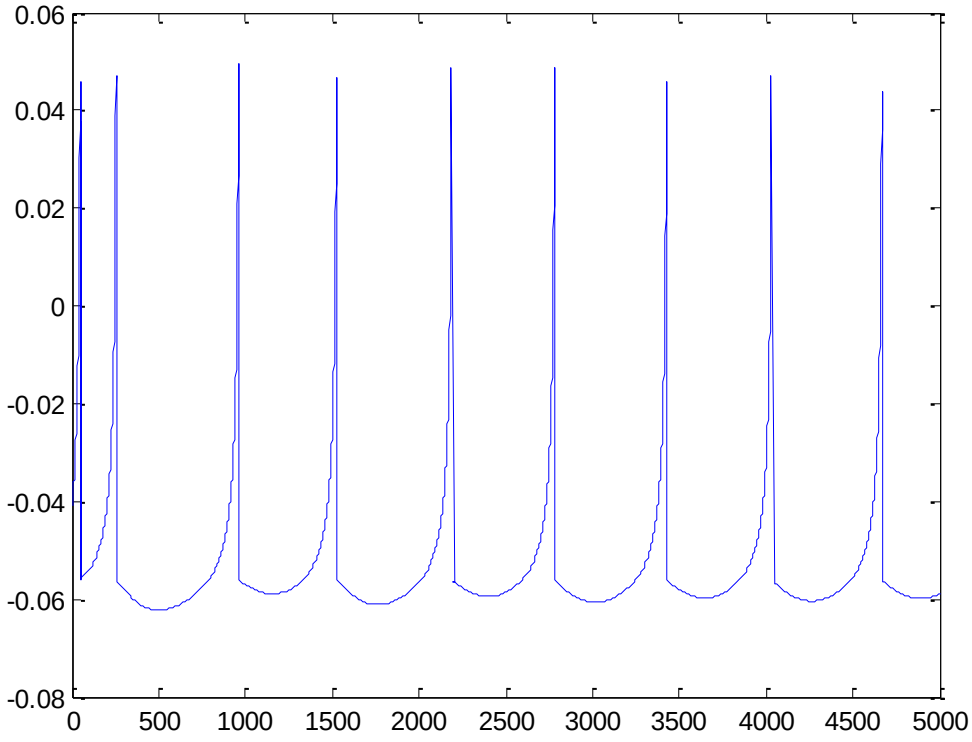
Neuron IB, current = 400 pA



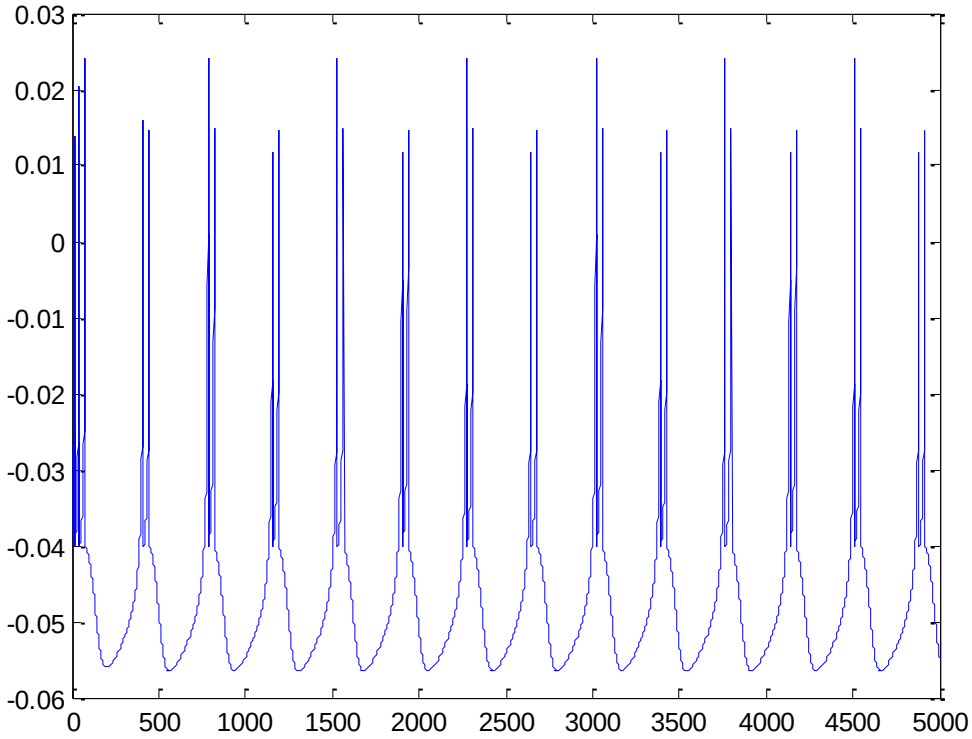
Neuron IB, current = 500 pA



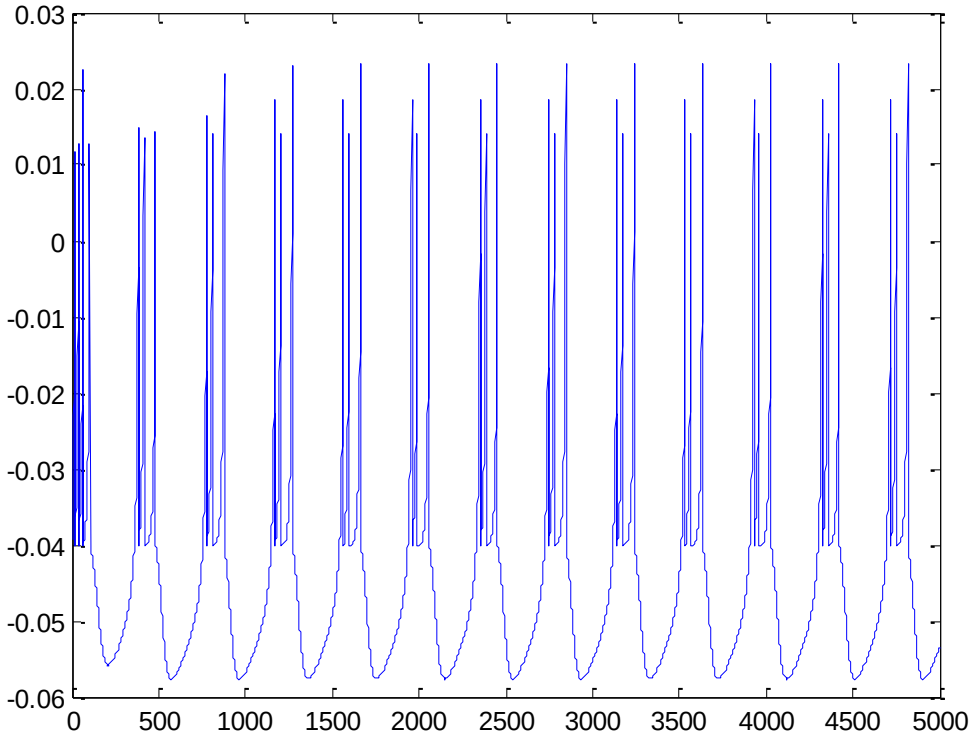
Neuron IB, current = 600 pA



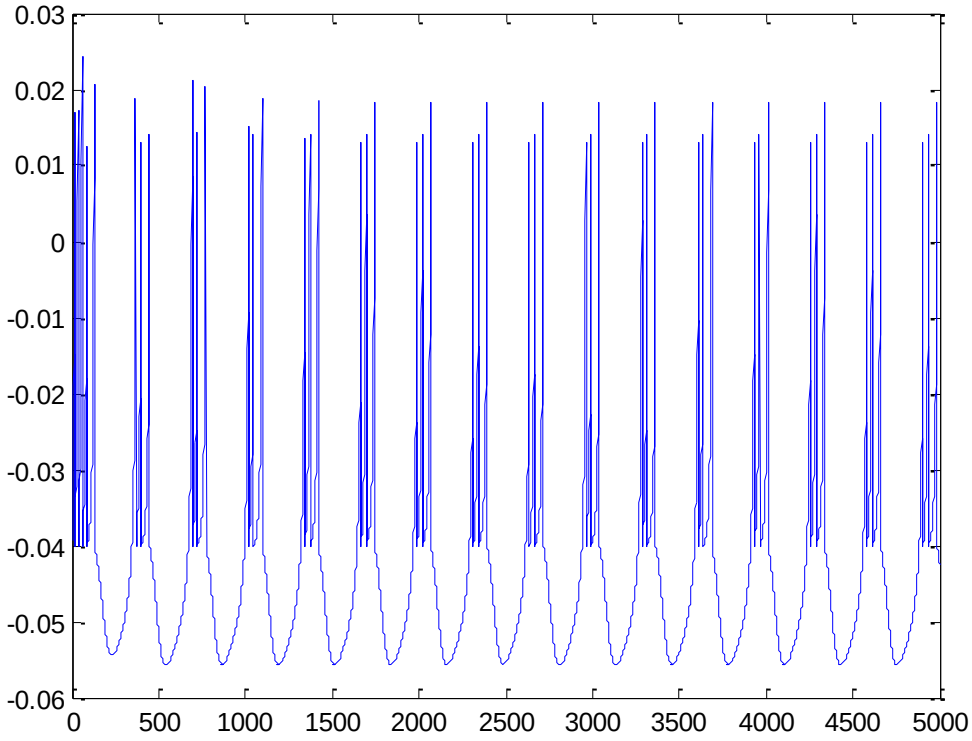
Neuron CH, current = 400 pA



Neuron CH, 500pA



Neuron CH, 600 pA



Question 3:

Part 1:

Command Window

```
>> q3p1
Enter neuron type : RS

Vsteadystate =

-0.044548067935088822513110169154776


Usteadystate =

0.000000000050903864129822358144153331046378

>> IB
Undefined function or variable 'IB'.

>> q3p1
Enter neuron type : IB

Vsteadystate =
```

Command Window

```
Enter neuron type : IB

Vsteadystate =

-0.046018170358873565926296011194 73


Usteadystate =

0.000000000047927318564505739279805629722493

>> q3p1
Enter neuron type : CH

Vsteadystate =

-0.046062237929260661436965423302044


Usteadystate =
```

Part 2:

Difference equations:

$$k = (-gl(Vn - El) + gl * \Delta t * \exp((Vn - Vt)/\Delta t) - Un + Iapp)/C$$

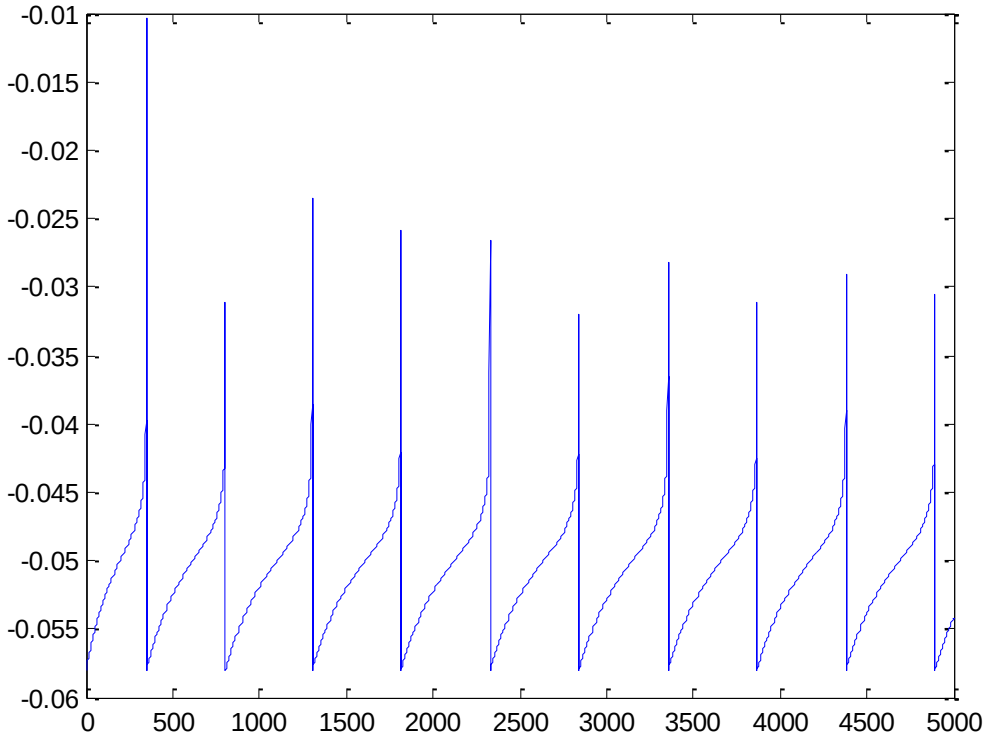
$$l = (a(Vn - El) - Un)/\tau w$$

$$Vn + 1 = Vn + dt * k$$

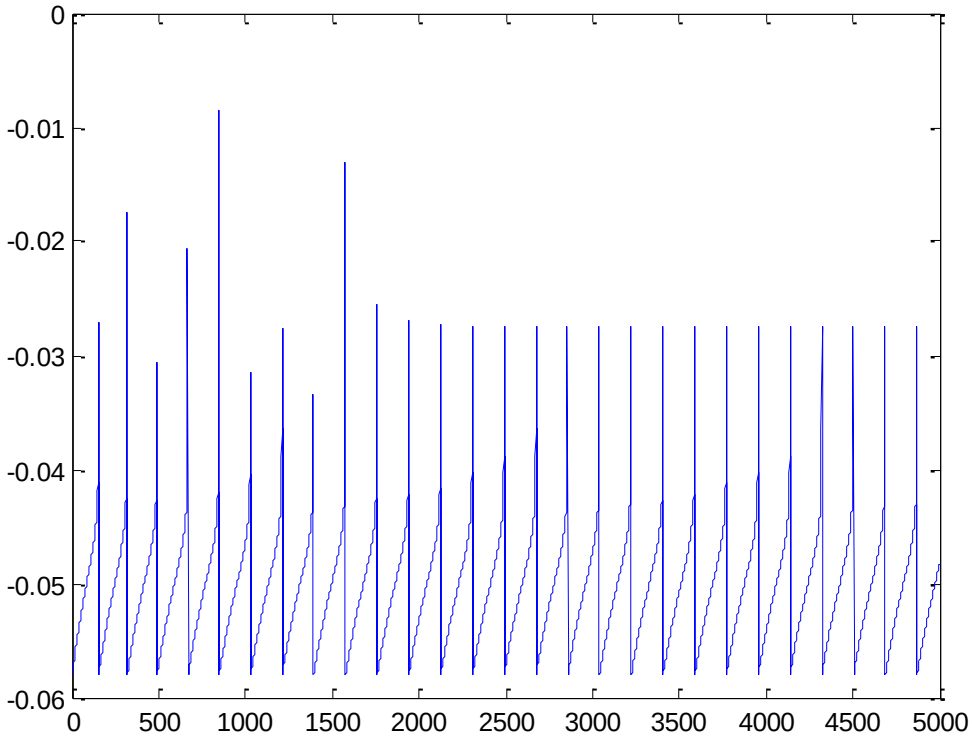
$$Un + 1 = Un + dt * l$$

Part 3:

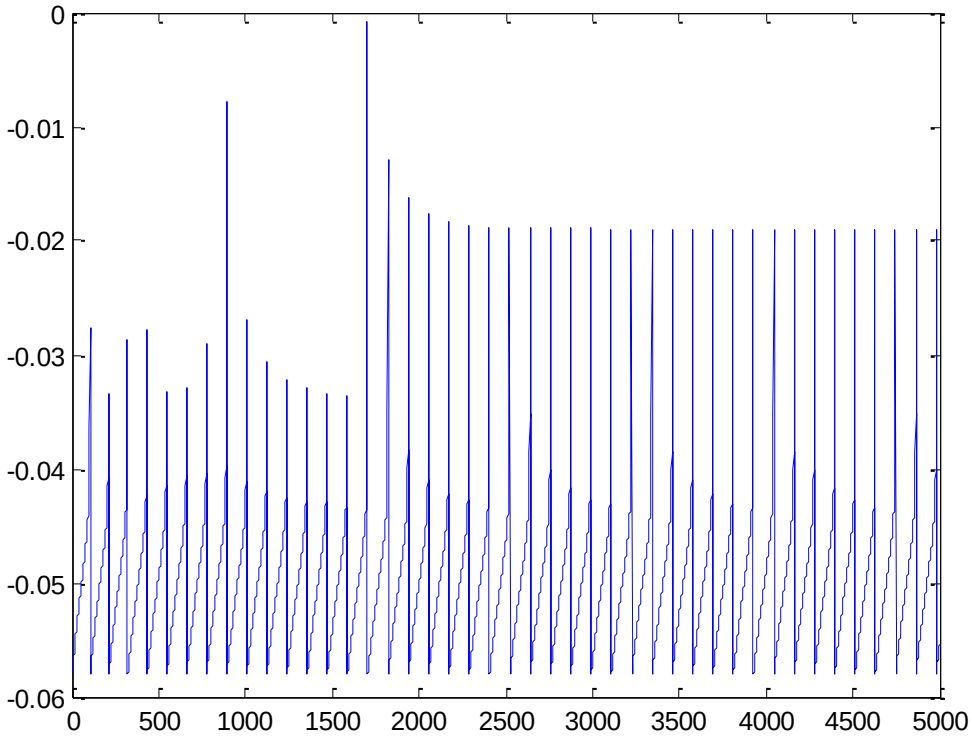
Neuron RS, current = 250 pA



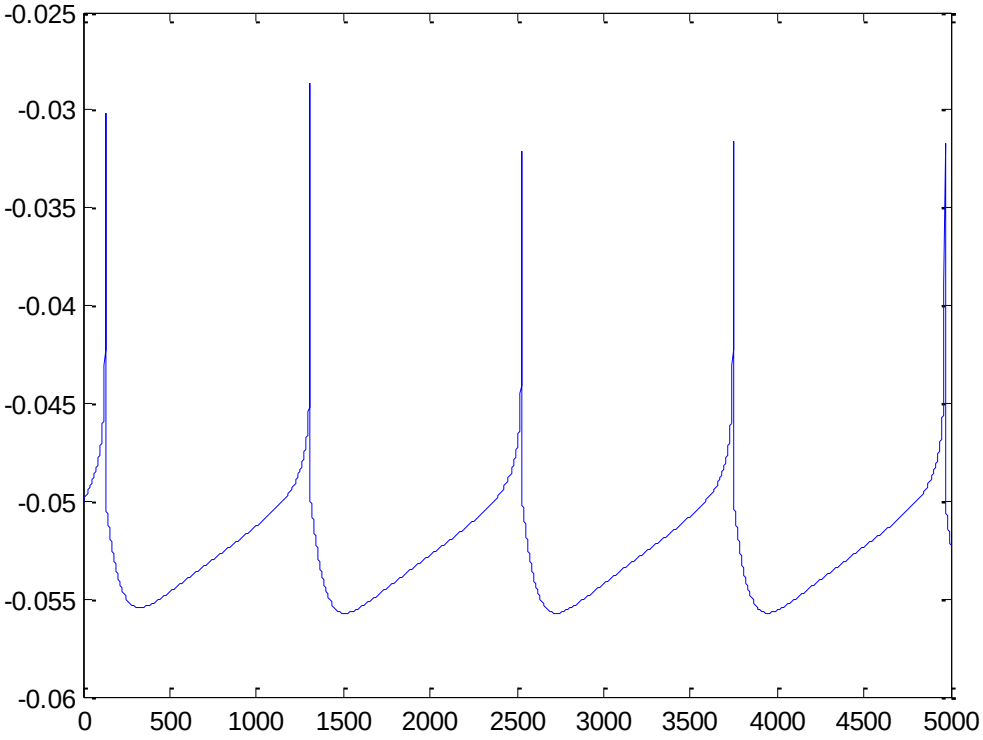
Neuron RS, current = 350 pA

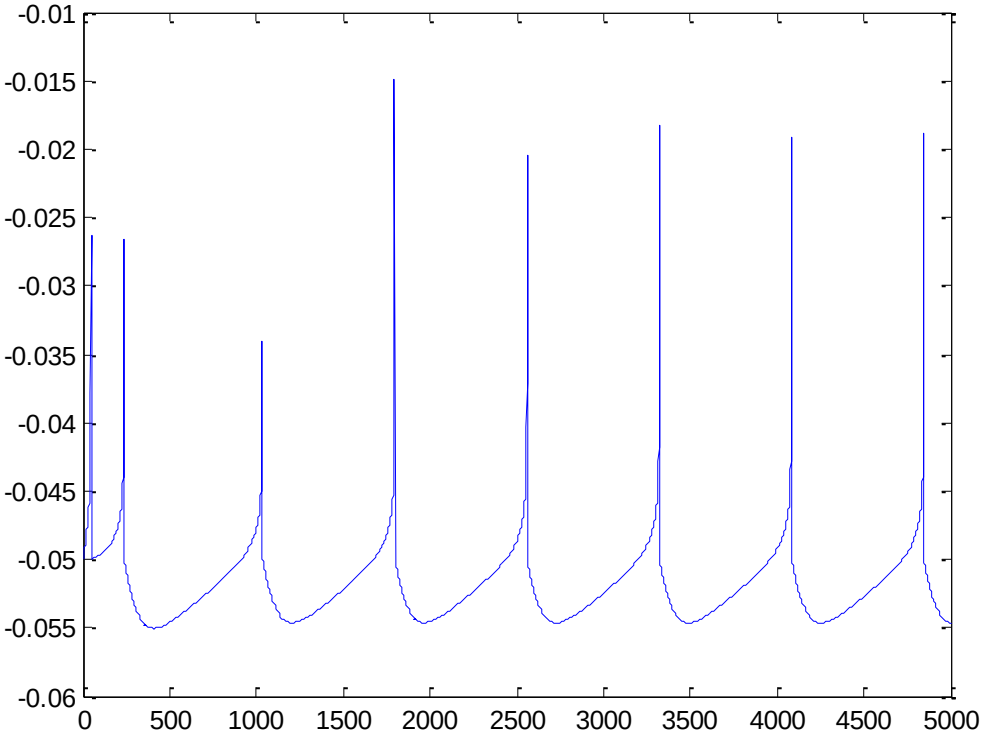


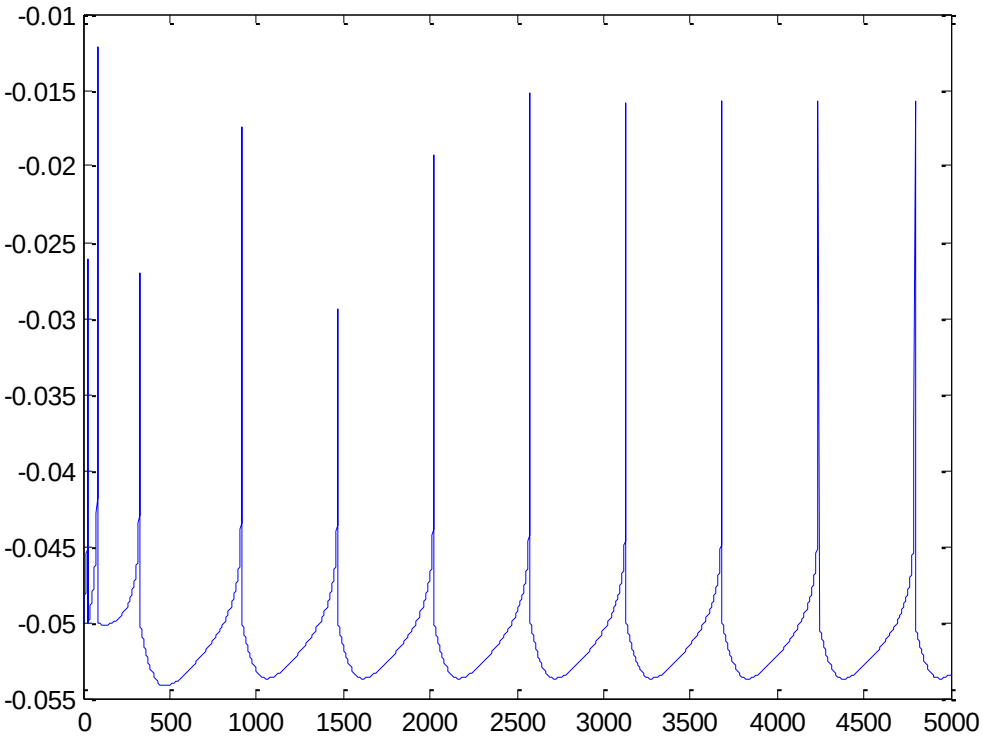
Neuron RS, 450 pA



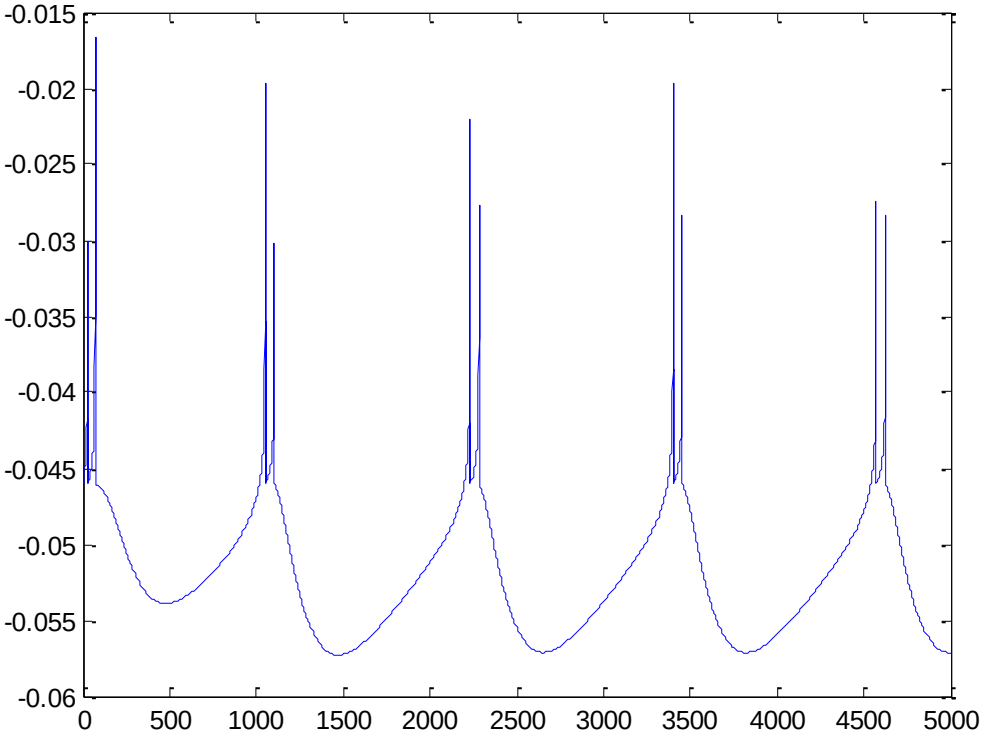
Neuron IB, current= 250 , 350, 450 pA

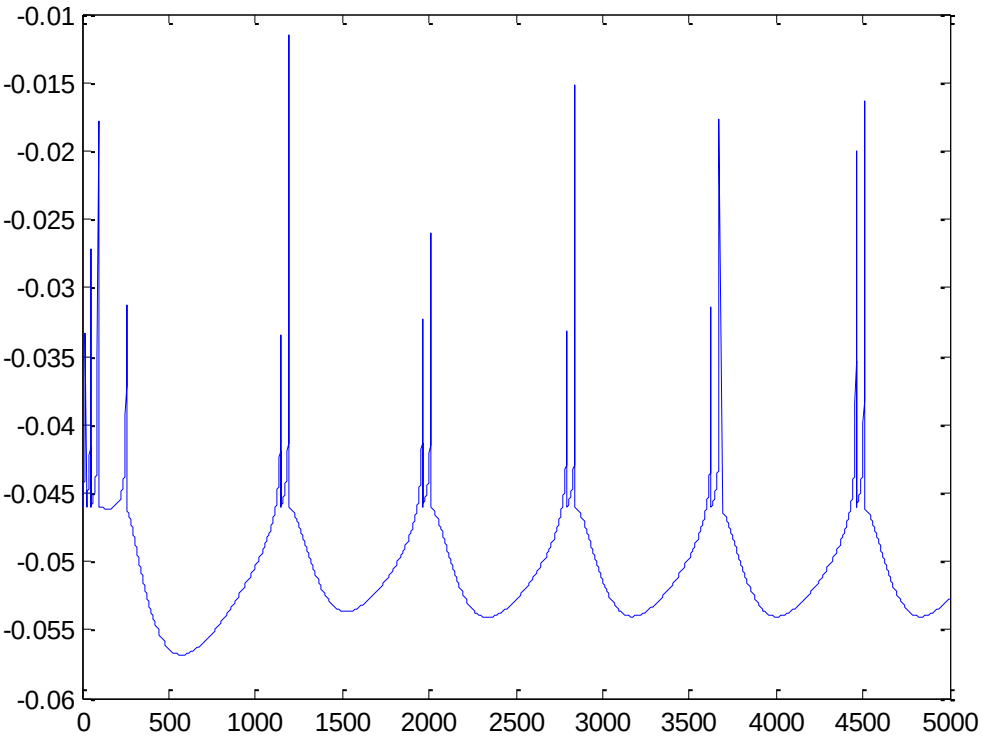


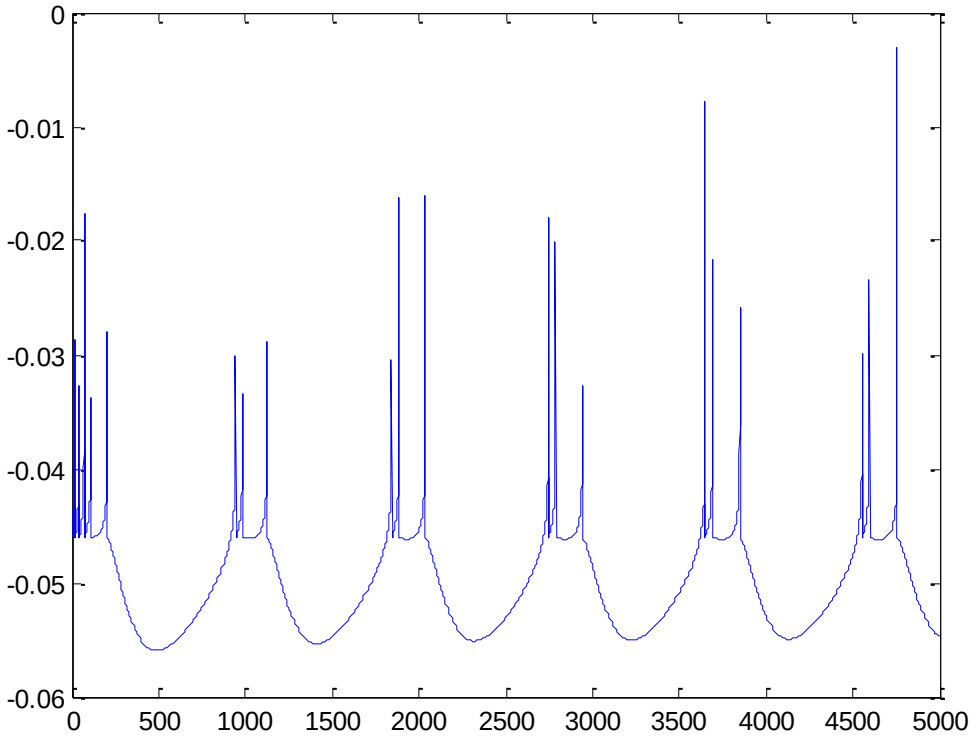




Neuron CH, current = 250, 350, 450, pA



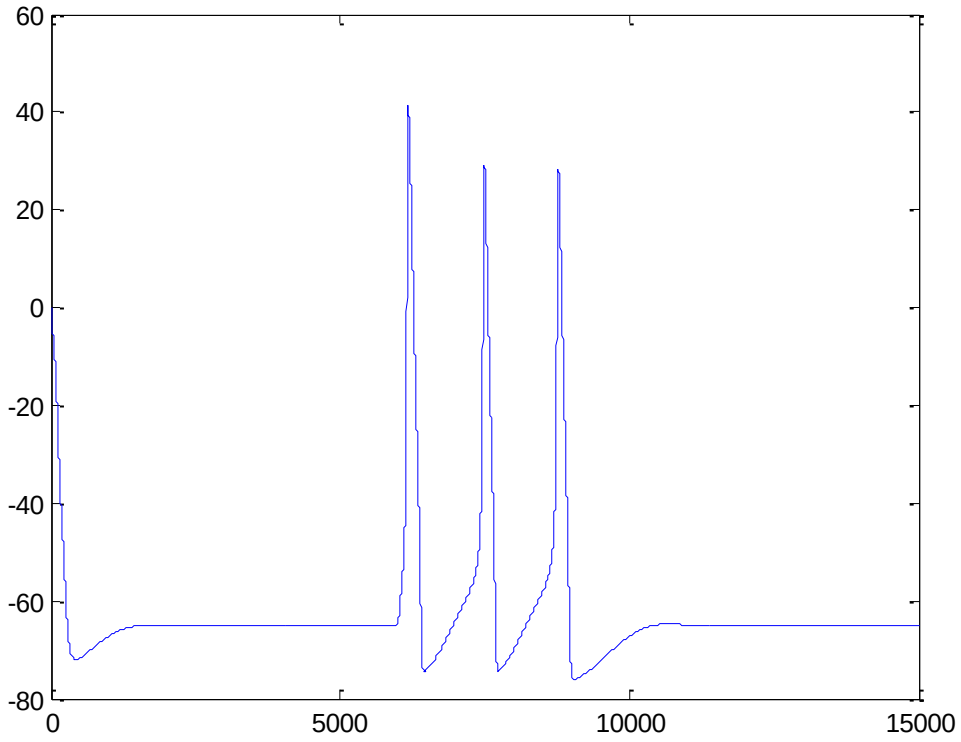

-0.01
-0.015
-0.02
-0.025
-0.03
-0.035
-0.04
-0.045
-0.05
-0.055
-0.06
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000


0
-0.01
-0.02
-0.03
-0.04
-0.05
-0.06
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000

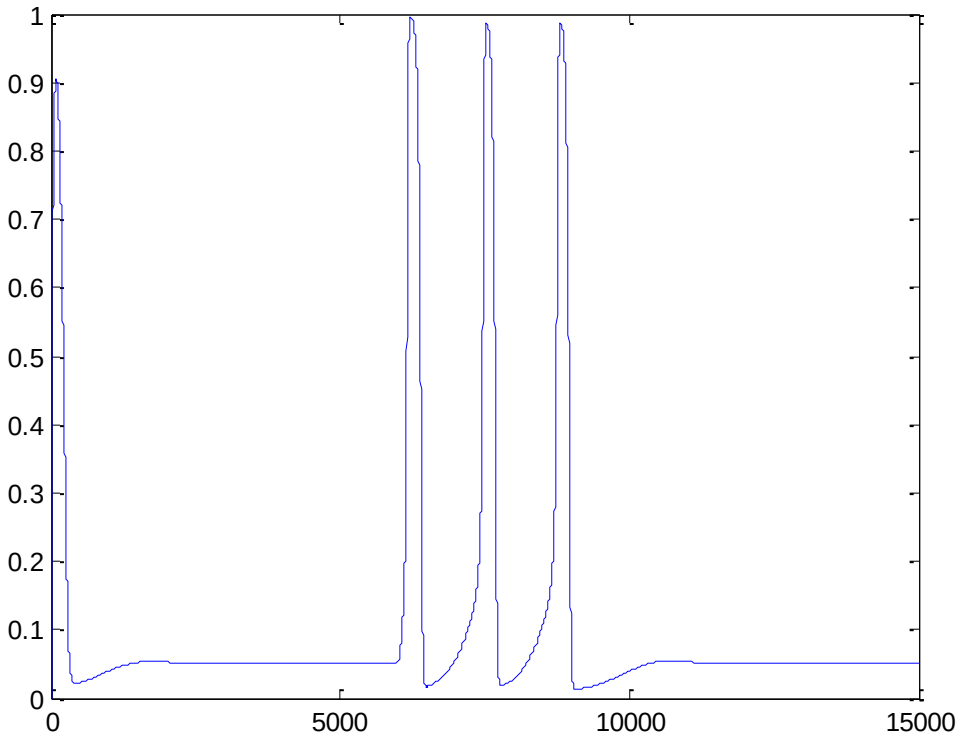
Question 4:

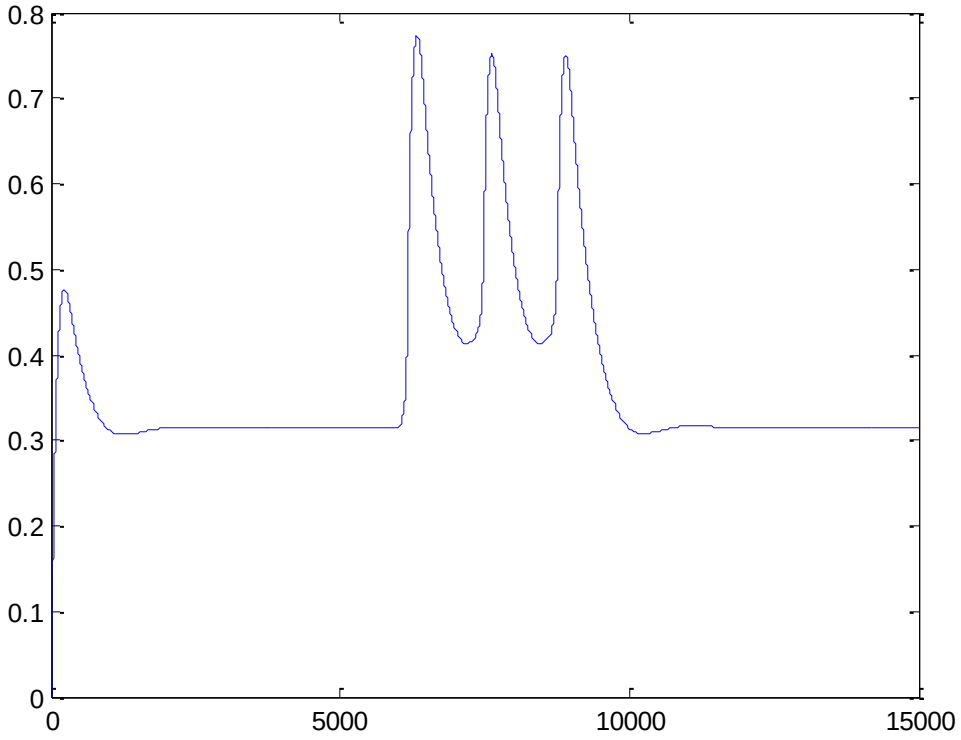
Part 1:

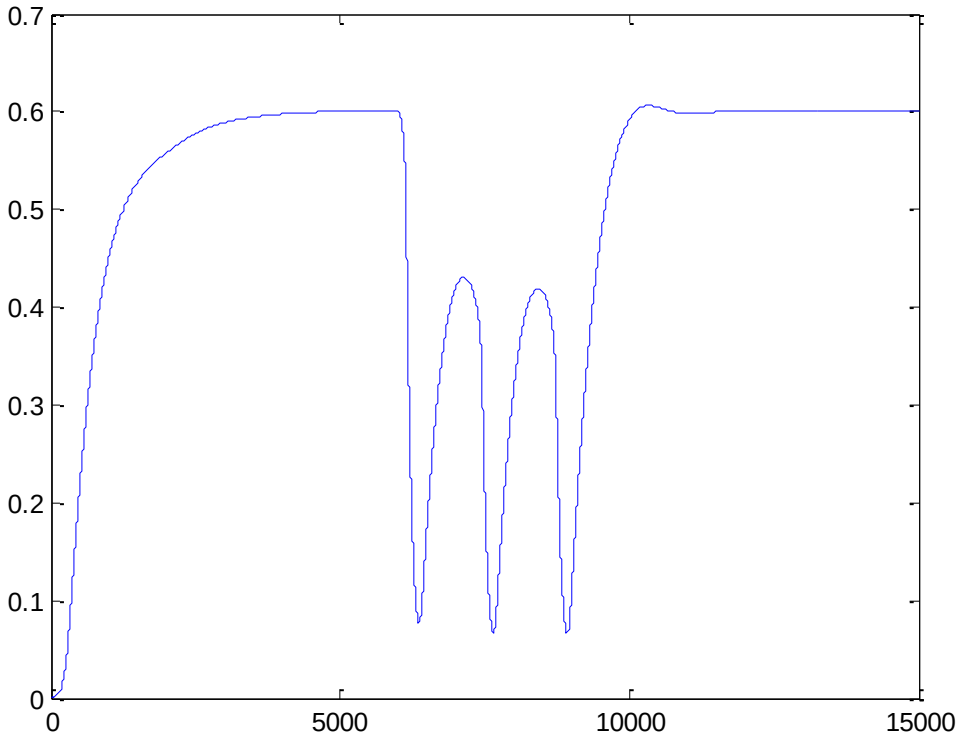
Plot of membrane potential:



Plots of ion channels:


1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
5000
10000
15000

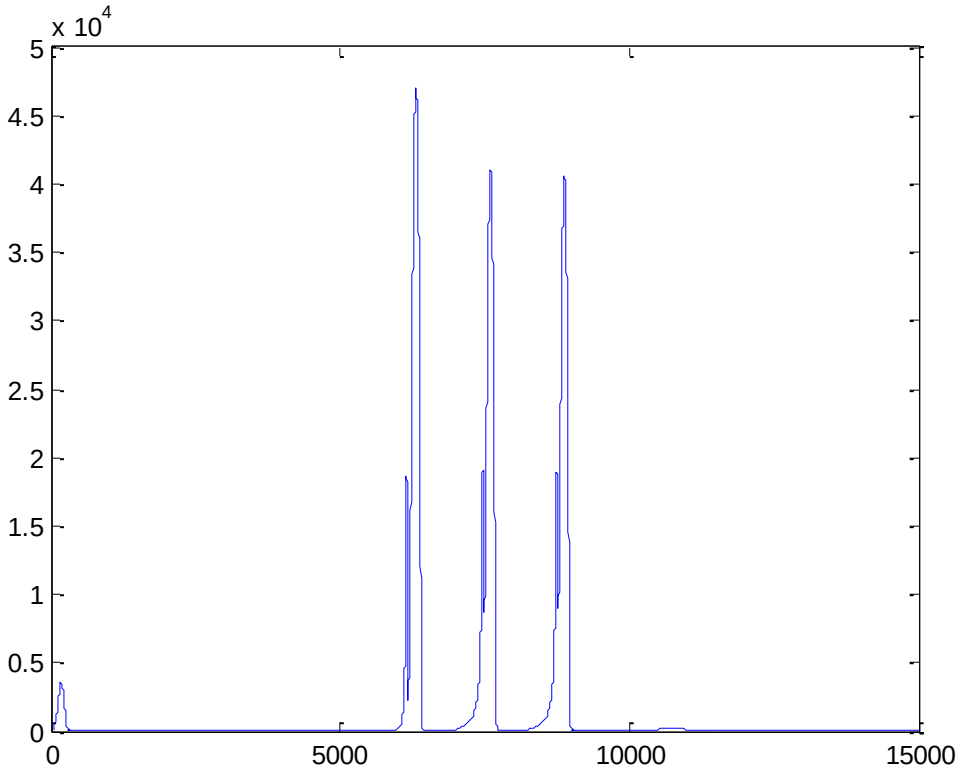

0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
5000
10000
15000



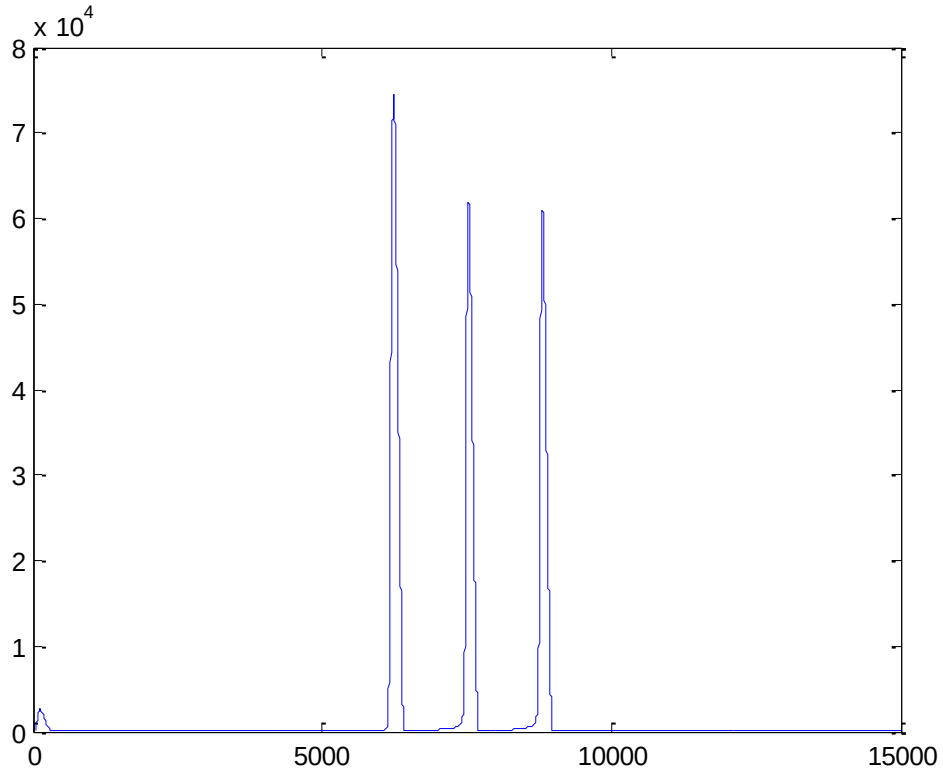
Part 2:

Plot of power:

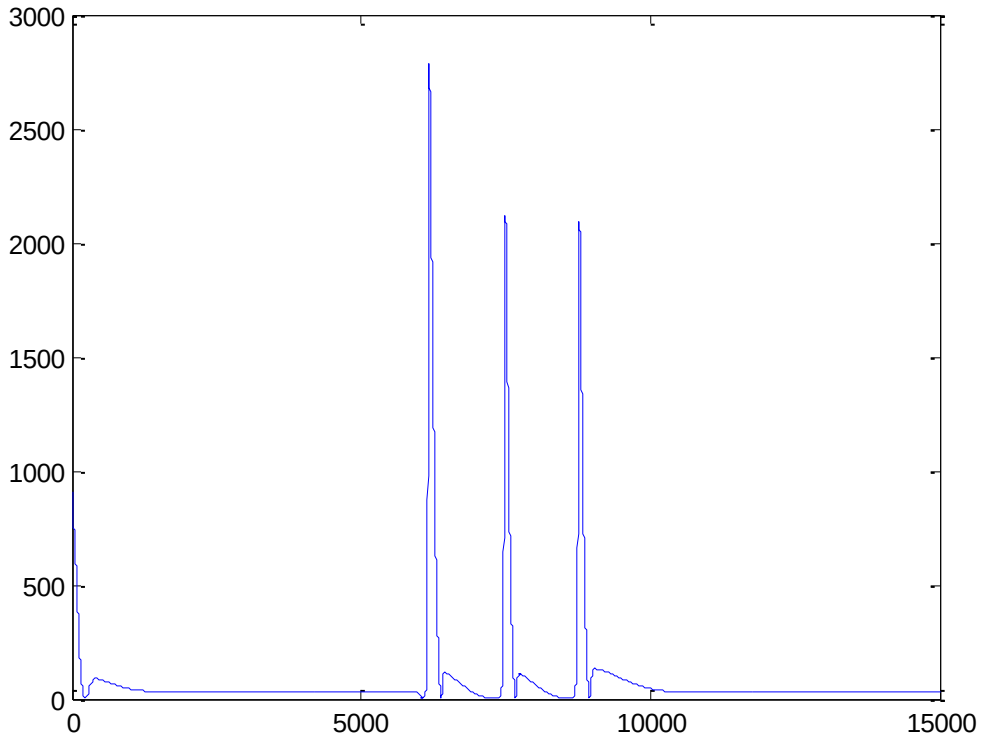
PNa:



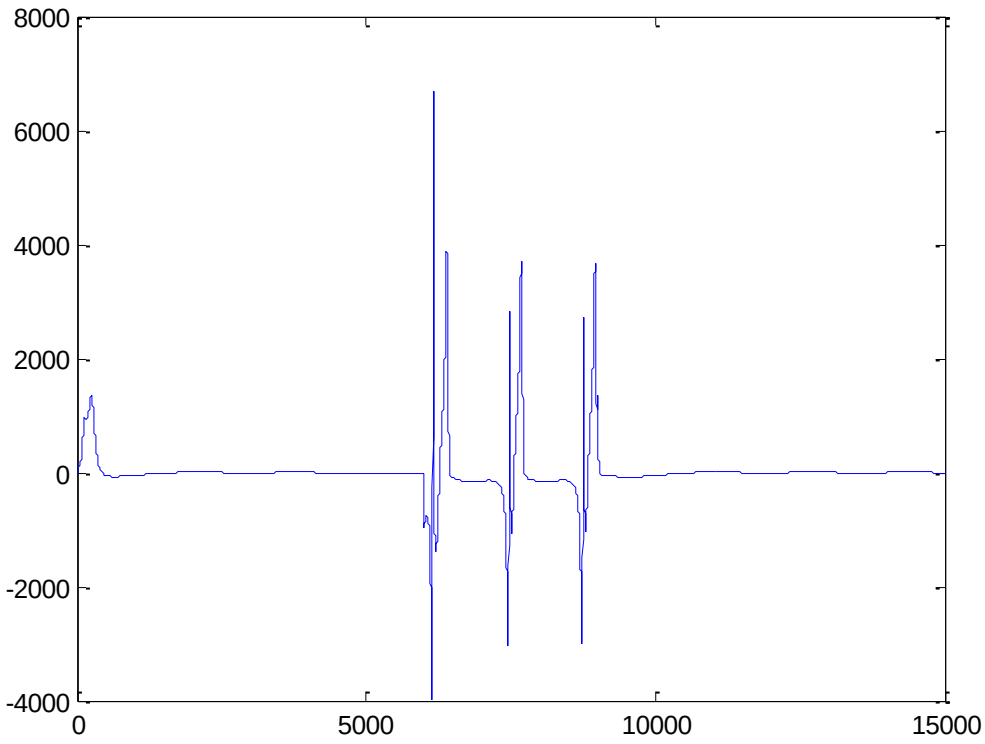
PK:


x 10^4
8
7
6
5
4
3
2
1
0
0
5000
10000
15000

Pl:


3000
2500
2000
1500
1000
500
0
0
5000
10000
15000

Pmembrane:



Part 3:

Energy dissipated :

```
Command Window
>> q4p3

Energyna =

    0.2279


Energyk =

    0.2762


Energyl =

    0.0127


Energym =

    0.0018
```

Neuron IB, current = 600 pA