Open Source Models for neuromorphic Hardware

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In these experiments, the data acquired from a chip is replicated and empirical software models are developed for simulations. Both, the actual data acquired from chip and the biological values are used and results are reported. The postsynaptic inhibitory and excitatory potentials are also modelled and later used for simulating a small microcircuit. These experiments are based on LIF and Izhikevich spiking neuron models. The report concludes with some observations and guidelines for future work.

Software model of V_{psp} (chip data):

A software model was developed to replicate the postsynaptic potential measured by chip with the similar time scale (see figure 1).

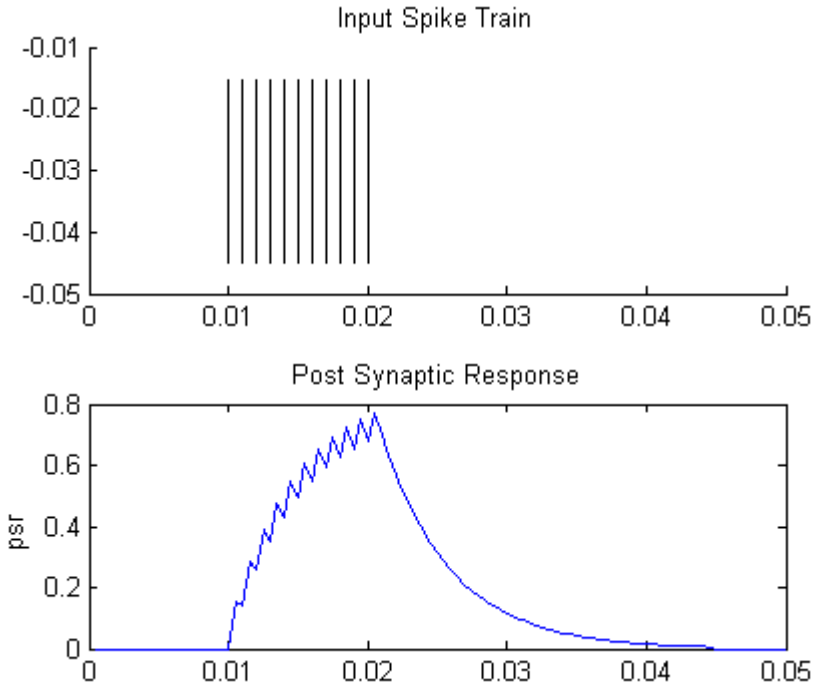

Figure 1: This figure replicates the data measured by chip with static synapses.

Parameters for excitatory synapse:

Delay = 0
Weight = 0.17

Tau = 0.005
Time = milliseconds

Static Spiking Synapse:

In figure 2, response to individual spikes and spike train was recorded (V_{psp}) with the time scale similar to chip measurements.

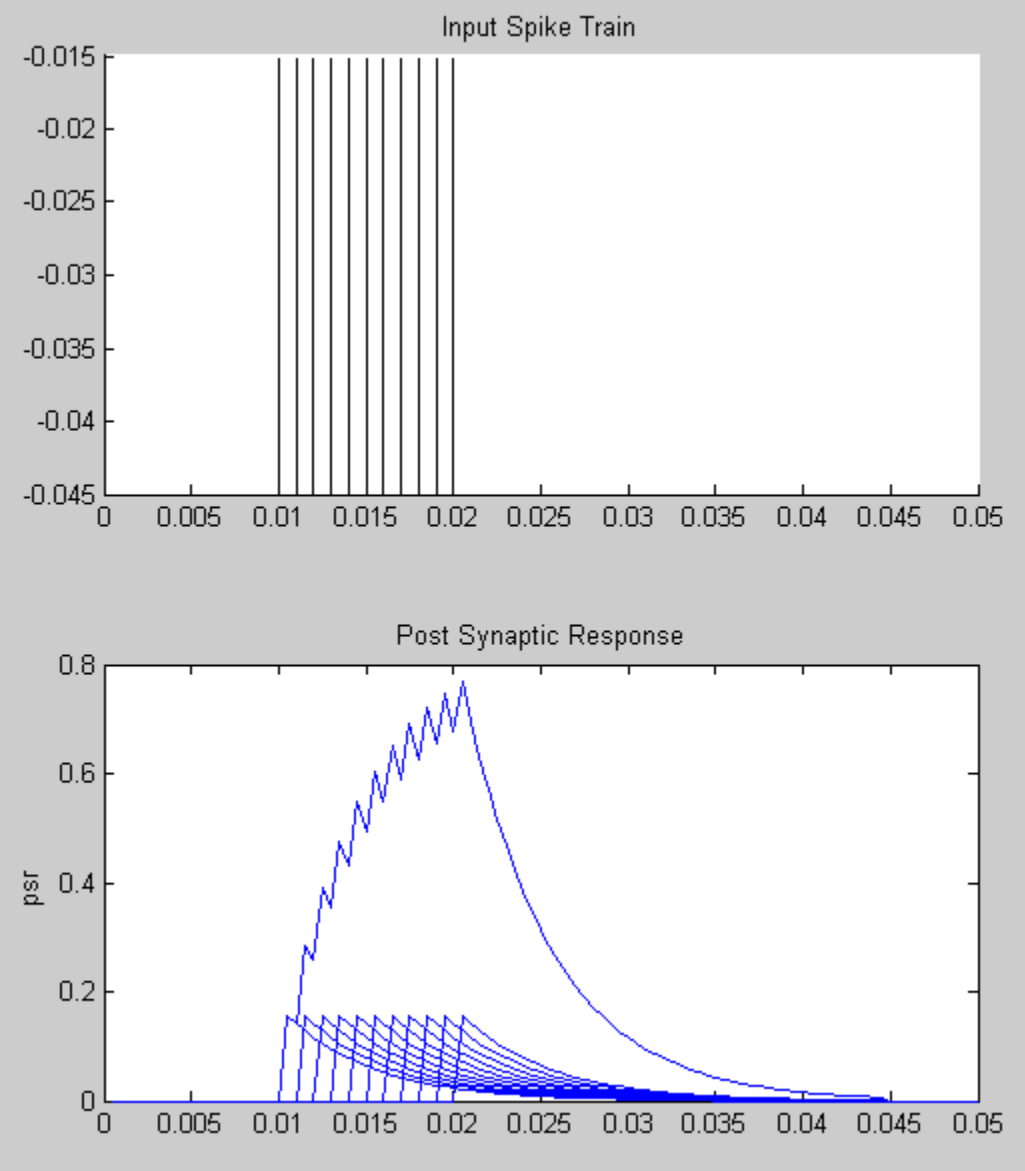

Figure 2: This figure shows a postsynaptic response to individual spikes and a spike train.

Parameters:
Weight = 0.17
Tau = 0.005

Time = milliseconds

Effect of individual spikes and spike trains with different tau values:

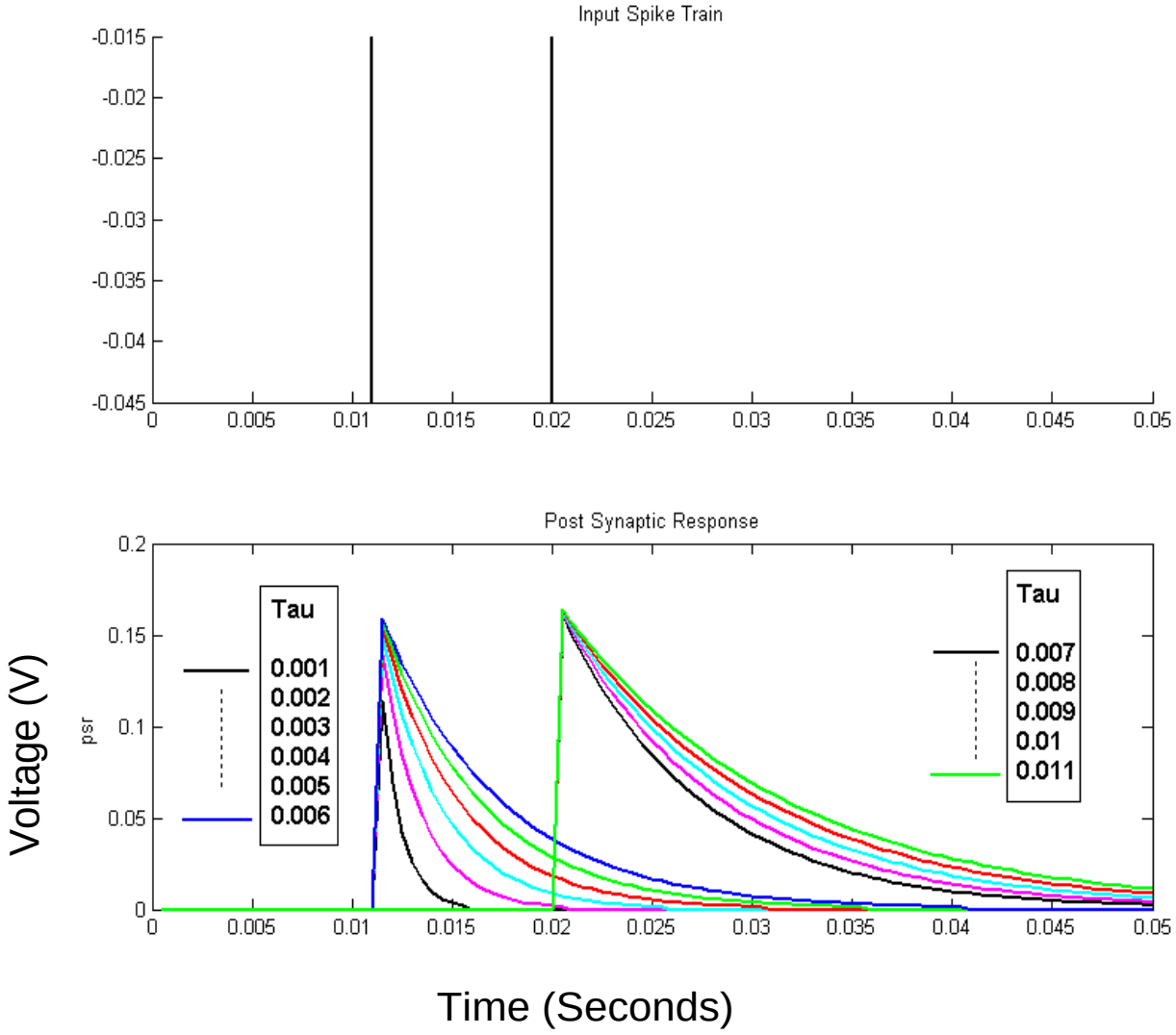

Figure 3: This figure shows post synaptic response to single spikes with different tau values.

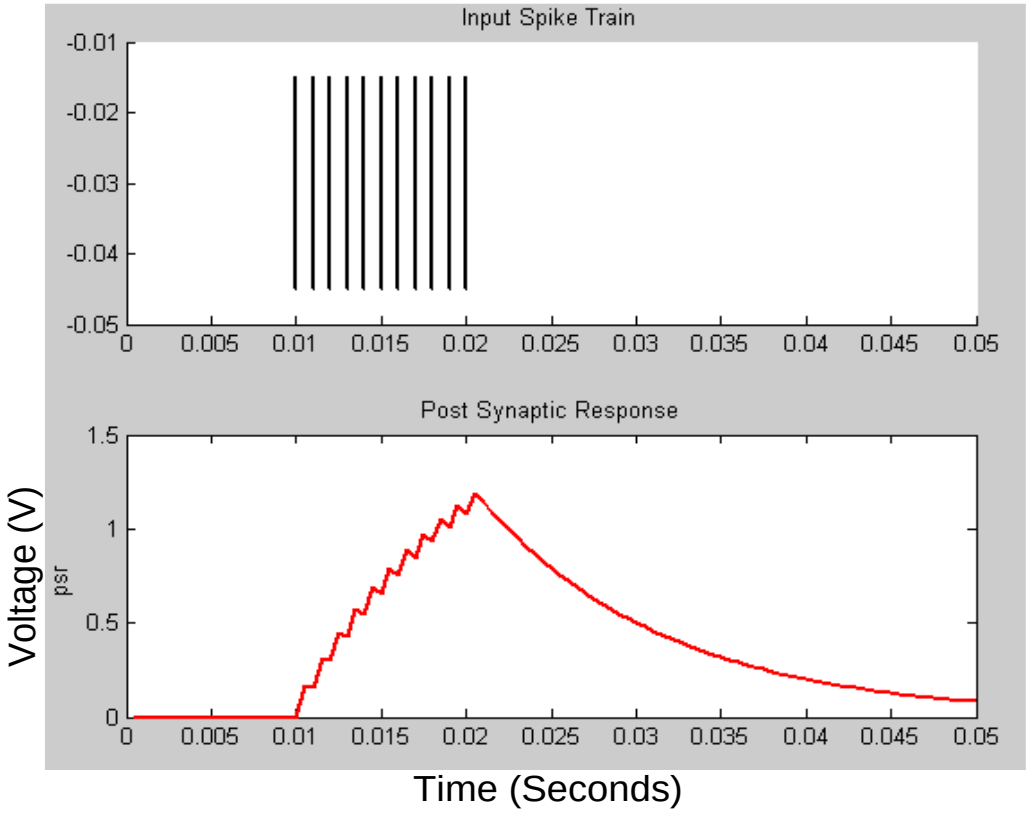

Figure 4: This figure shows a postsynaptic response to an input spike train with a fixed tau value.

Parameters:
Tau = 0.011
W = 0.17
Time = milliseconds

In the following figure (figure 5) the maximum synaptic strength (0.8 V) measured on chip is modelled with different tau values.

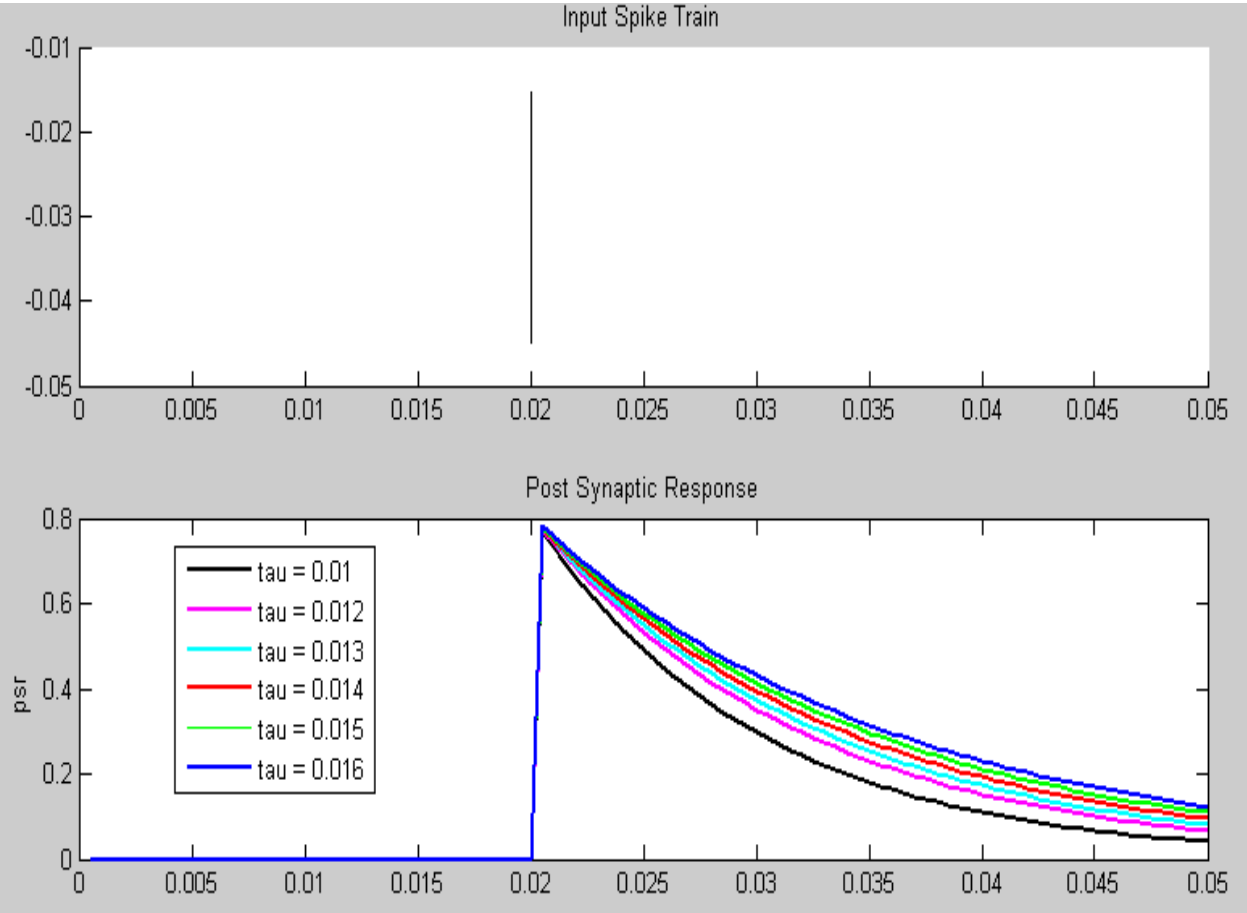

Figure 5: This figure simulates the V_{psp} (0.8 V) which is equivalent to the maximum post synaptic potential measured on chip. The simulations were performed to observe the impact of different tau values)

Note: Biologically, changes in synaptic strength can be either short term (from seconds to minutes) or long term. This phenomenon is termed as Short Term Potentiation (STP) or Long Term Potentiation (LTP), also known as synaptic plasticity. These are the basis for modelling synaptic memories.

In the following figure (figure 6) the time scale is converted from milliseconds to seconds and results are reported. The hardware results achieved are in milliseconds scale which is not biologically plausible. In order to have short term memory in the synapse, we need to have the time scale from seconds to minutes which will require longer tau values (see figures 6 and 7).

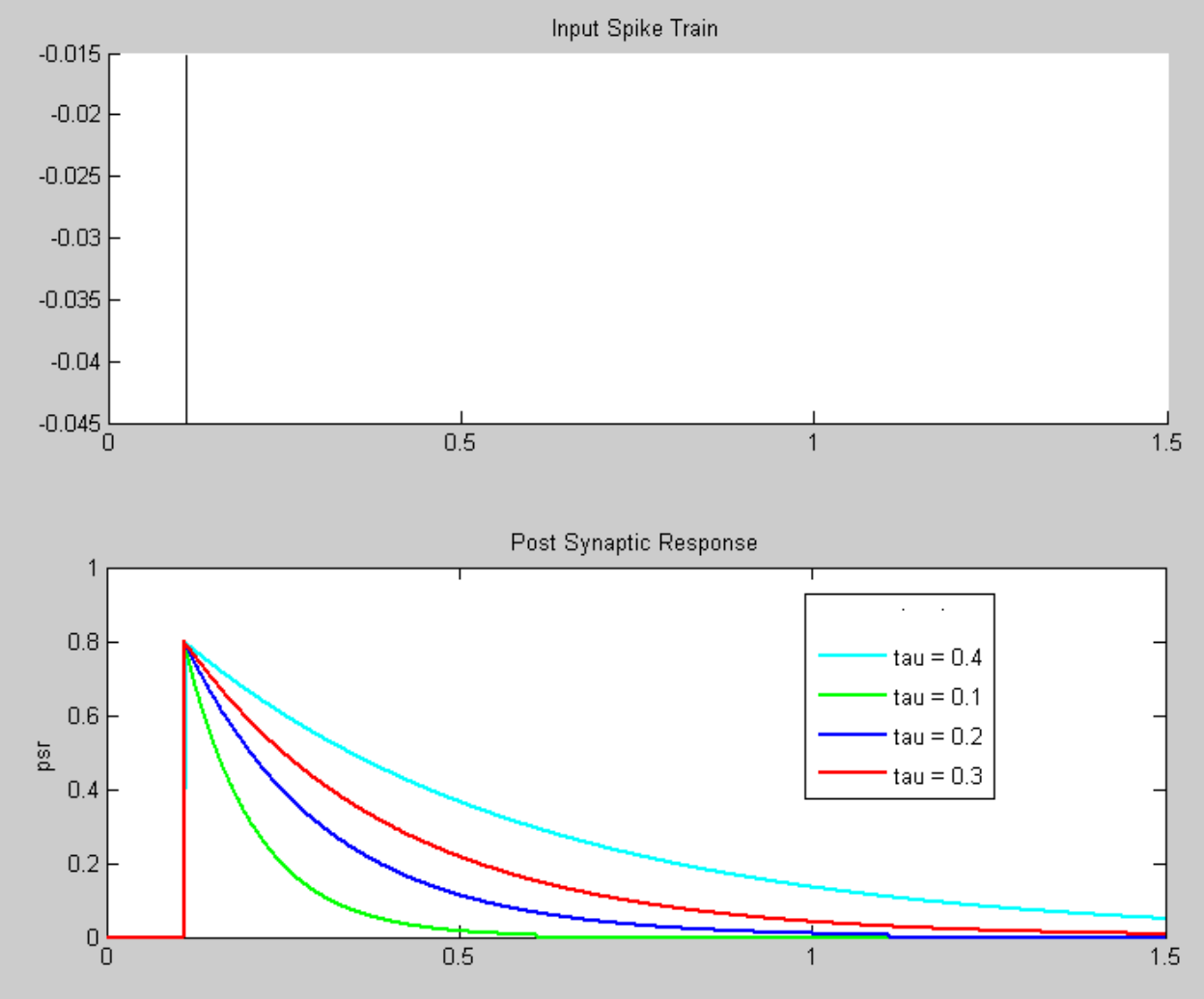

Figure 6: This figure shows a maximum V_{psp} (0.8 V) in response to a single input spike simulated with different tau values in seconds.

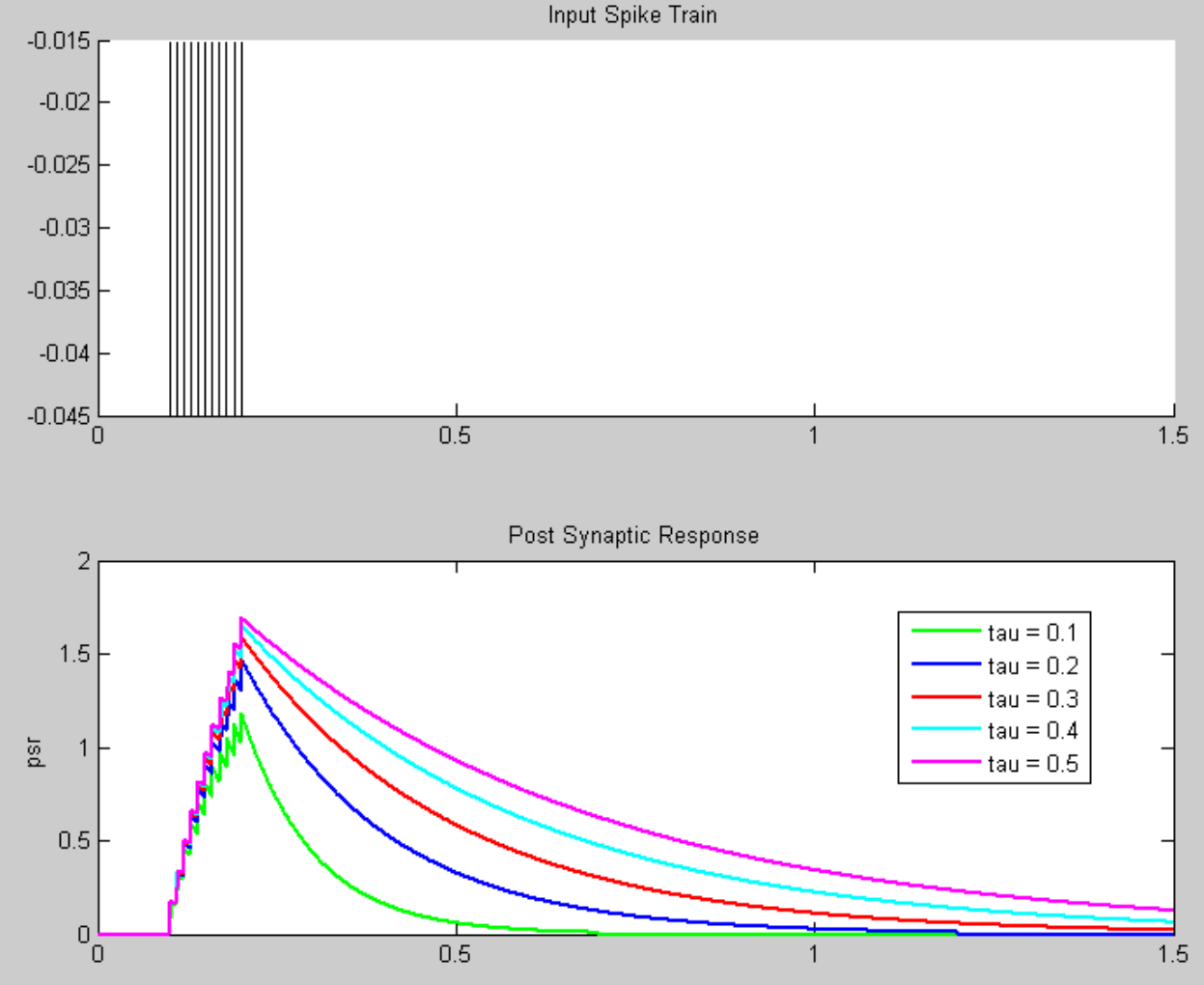

Figure 7: This figure shows post synaptic potential in response to a spike train with different tau values in seconds.

Parameters:
w = 0.17
Time = seconds

Inhibitory Synapses:

So far we have only considered excitatory synapses with different '*tau*' values. In figures 8 and 9, inhibitory synapses were modelled with the values similar to hardware model but different *tau* values in milliseconds scale.

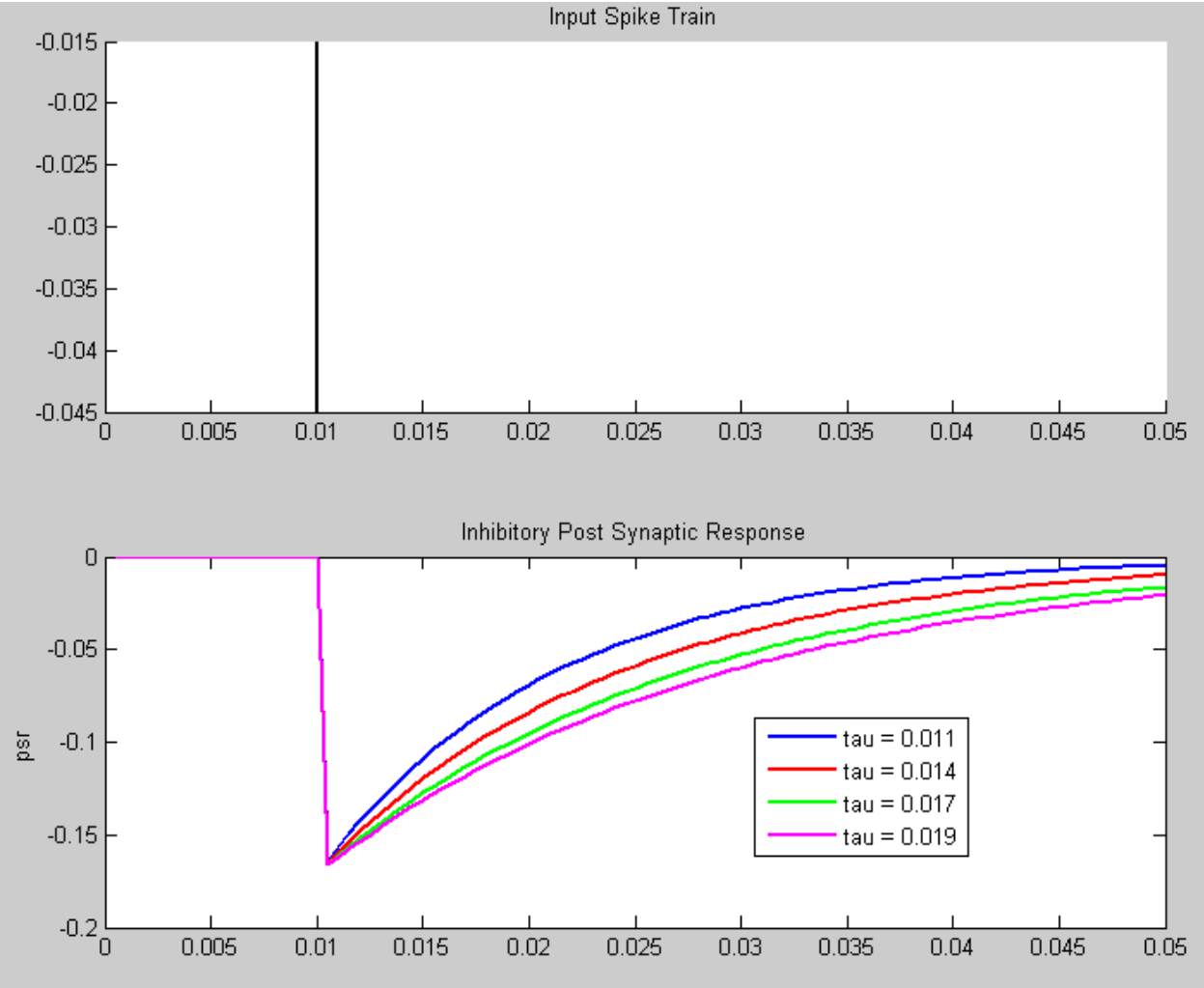

Figure 8: This figure shows a response of an inhibitory synapse to a single spike with different tau values. (w = - 0.17)

Parameters:

w = - 0.17

Time = milliseconds

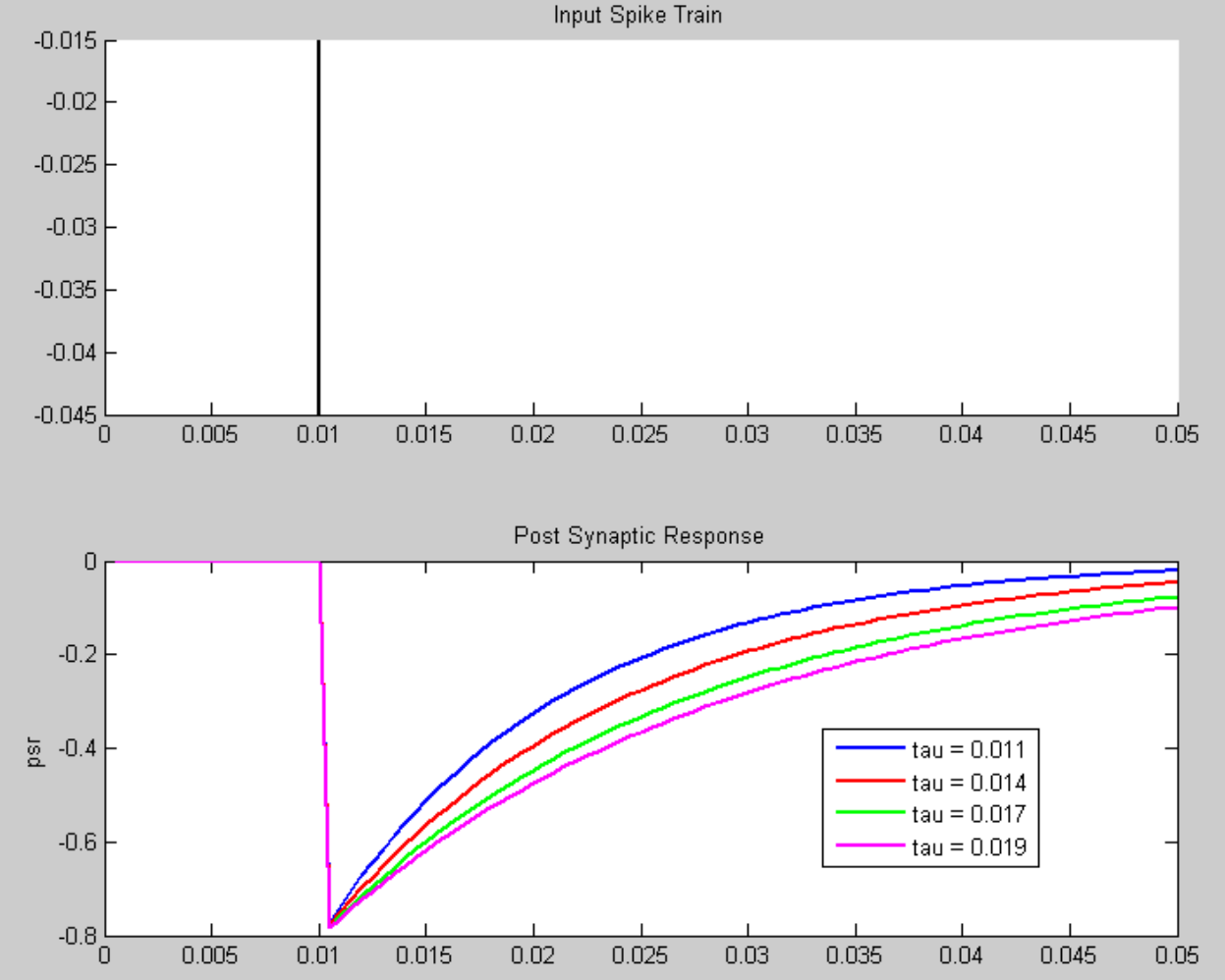

Figure 9: This figure shows an inhibitory synapse with maximum postsynaptic potential (- 0.8 volts), similar to the data measured on chip with different tau values.

Dynamic Synapses:

So far we have only considered static synapses and presumed that the synaptic weight value '*w*' will be changed only during learning. In contrast, the weight of a biological synapse is strongly dependent on the inputs X_i *(t – tau)* that this synapse has received from the pre-synaptic neuron '*i*' at previous time step '*t – tau*'. This can be shown as a model of the form (Varela et al, 1997).

$W_i(t) = W_i \,.\, D(t).\ (1+ F(t))$

With a constant 'W_i'a depression term '*D (t)*' and a facilitation term '*F (t) > 0*' can be fitted remarkably well to experimental data for synaptic dynamics (Varela et al, 1997).

In the following simulations, the time varying state 'X*(t)*' of the synapse is increased by 'W · r · u' when a pre-synaptic spike hits the synapse and decays exponentially with corresponding time constant 'tau',

otherwise, '*u*' and '*r*' model the current state of facilitation and depression. The following parameters were used to model a dynamic synapse and results are shown in figure 10.

U : The use parameter of the dynamic synapse
D (sec) : The time constant of the depression of the dynamic synapse
F (sec) : The time constant of the facilitation of the dynamic synapse
tau (sec) : The synaptic time constant
W : The weight (maximal amplitude) of the synapse
delay (sec) : The synaptic transmission delay

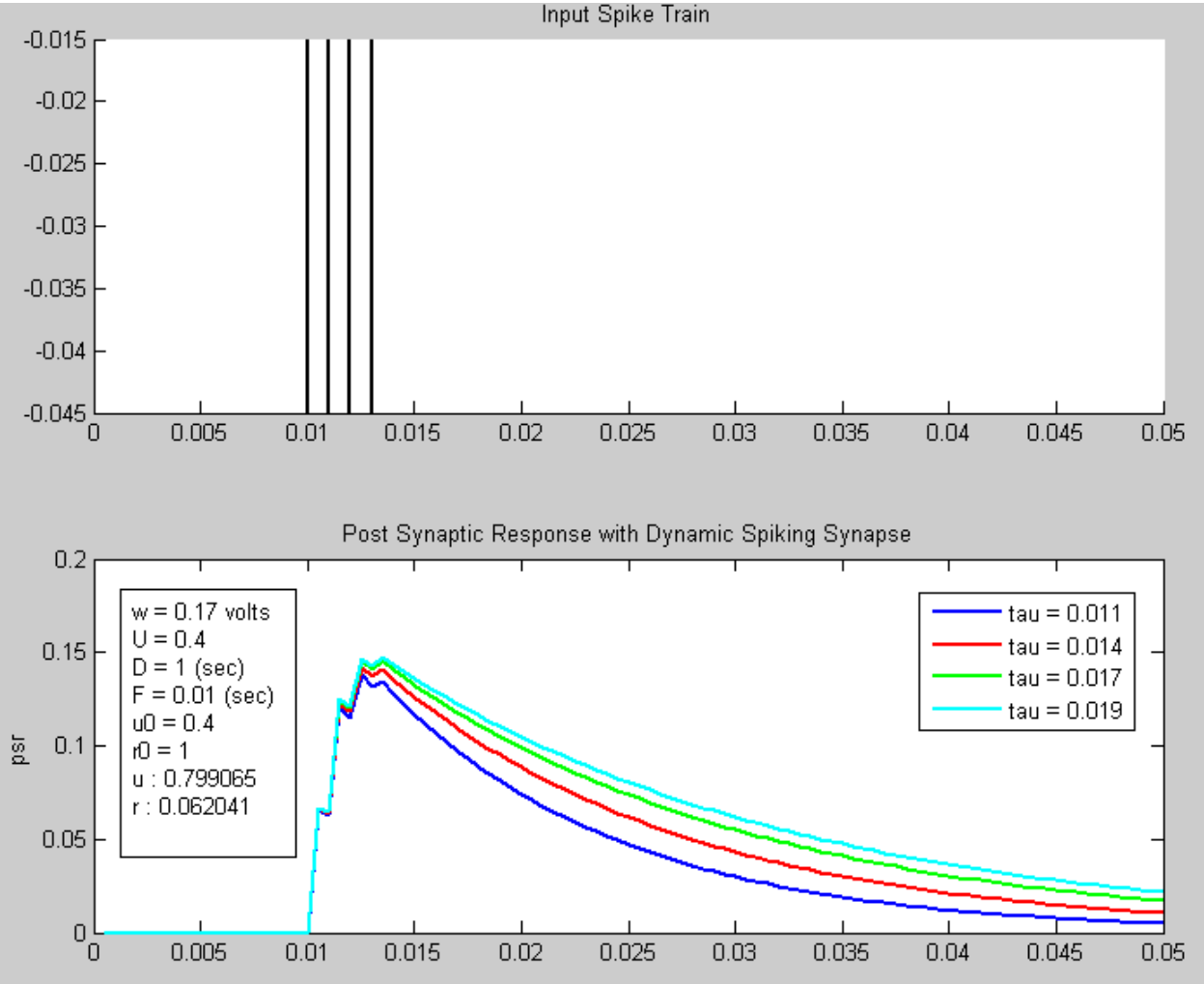

Figure 10: This figure shows a response of a dynamic spiking synapse simulated with different tau values. It is shown that in biological synapses, the postsynaptic response is not a linear sum of incoming spikes as shown previously.

Biological parameters:

In order to have an insight into the biological domain, different papers were surveyed to collect realistic biological data sets. It is important for us to know our limitations in terms of hardware and the values required to develop a biologically plausible SNN platform to emulate systems as close as possible to biology. These parameters have also been widely used in computing related tasks and the details are provided in (Maass et al, 2002, Neurocomputing Journal), (Varela et al, 1997) and (Markram et al., 1998). In figures 11 and 12, postsynaptic responses were modelled in response to a single input spike and spike train at a biological scale.

Biological neuron parameters:
Membrane time constant = 30ms
Absolute refractory period = 3ms (excitatory neurons)
Absolute refractory period = 2ms (inhibitory neurons)
Membrane inside potential = 30 mV
Membrane outside potential = 100 mV
Resting potential = -70 mV
Difference in membrane potential = 70 mV
Threshold = 15mV (for a resting membrane potential assumed to be 0)
Reset voltage = 13.5mV
Constant nonspecific background noise (current Ib) =13.5nA
Input resistance = 1 M ohms

Biological synaptic parameters:
Input projecting onto an excitatory neuron = 18 nA
Input projecting onto an inhibitory neuron = 9 nA
A uniform transmission delay between neurons = 1.5 ms
Initial conditions of each LIF neuron (membrane voltage at time t = 0) = [13.5 mV – 15.0 mV]
Tau (excitatory) = 3ms
Tau (inhibitory) = 6 ms

Biological parameters used for these simulations:
Tau = 3ms - for excitatory synapse
Tau = 6 ms - for inhibitory synapse
I(t) = 18 nA - for excitatory neuron
I(t) = 9 nA - for inhibitory neuron
Membrane time constant = 30 ms
Absolute refractory period = 3 ms
Threshold = 15 mV
Resting potential = 0
Reset voltage = 13.5 mV
Non-specific background current (I_b) = 13.5 nA
Input resistance = 1 Mohms
Transmission delay between circuit neurons = 1.5 ms
Transmission delay for other connections = 0.8 seconds
V= IR
Excitatory voltage drop = $18 \times 10^{-9} \times 1 \times 10^{6} = 0.018$ (18 mV) = V_{PSP}

Inhibitory voltage drop = $9 \times 10^{-9} \times 1 \times 10^{6} = 0.009$ (9 mV) = V_{PSP}

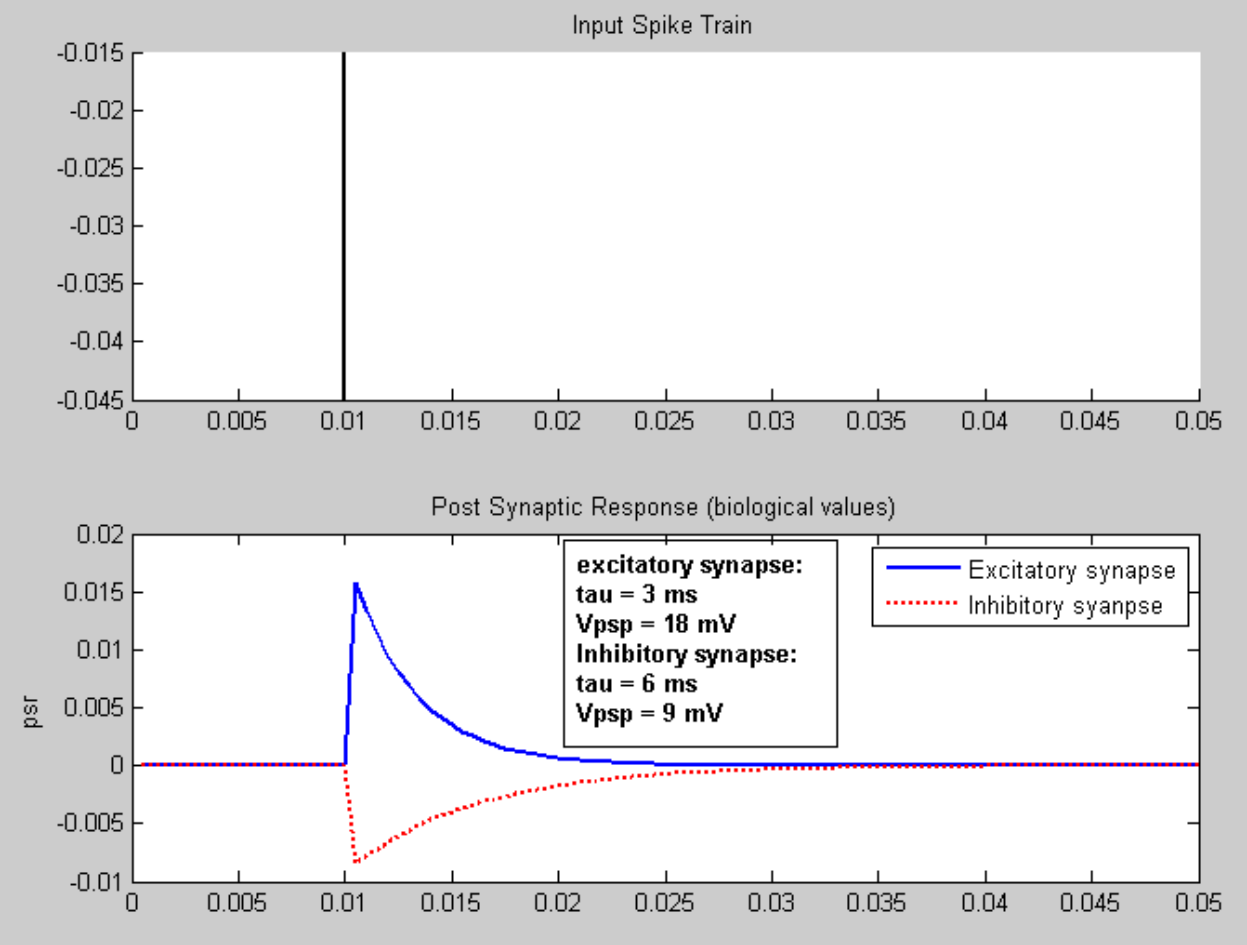

Figure 11: This figure shows the simulation of an excitatory and inhibitory postsynaptic potential simulated with biological parameters in response to a single spike in milliseconds time scale.

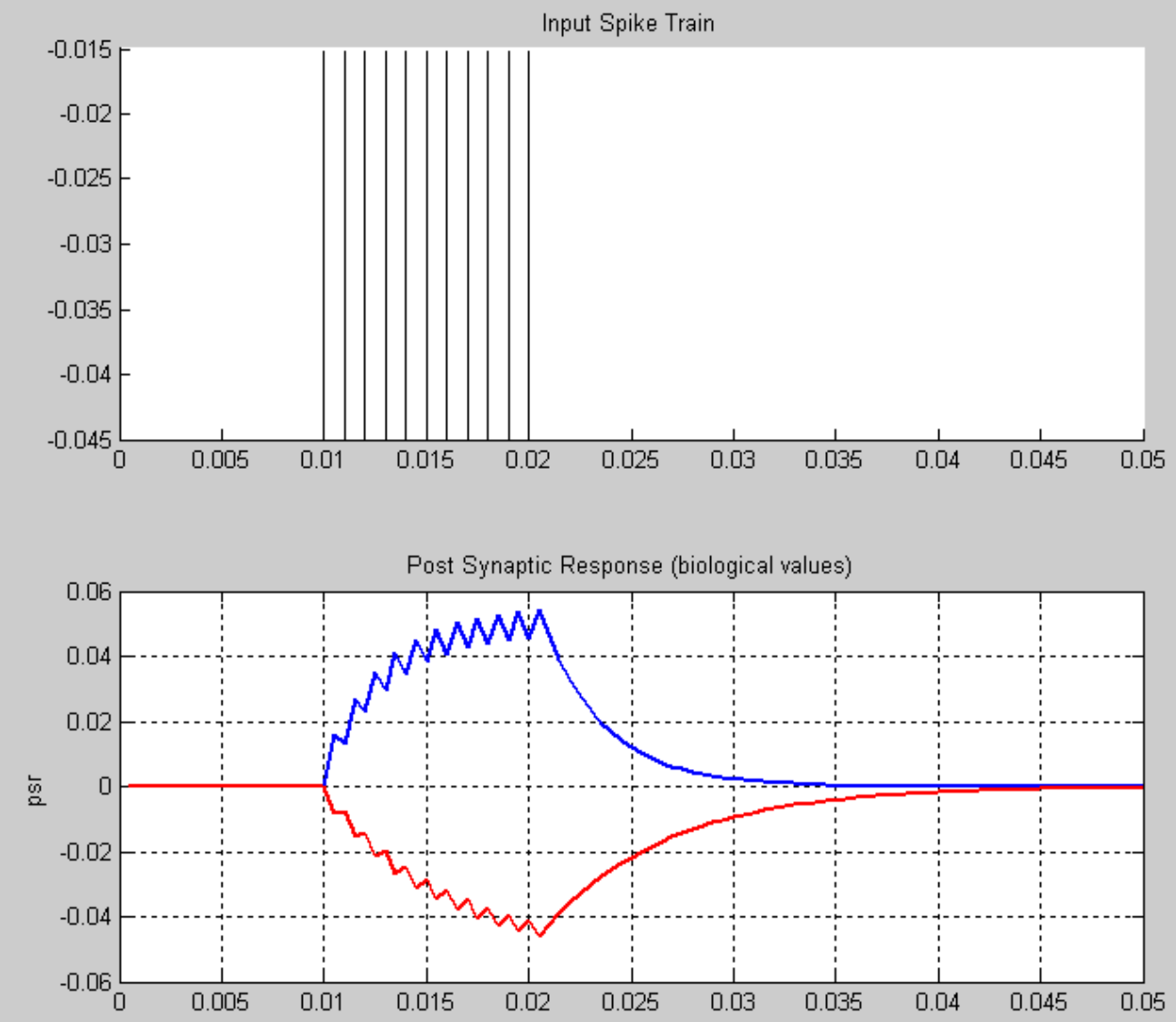

Figure 12: This figure shows postsynaptic simulations in response to an input spike train with biological parameters.