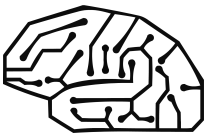
Neurino
e-synapse documentation



Introduction :

e-synapses are open-source electronic circuits that mimic natural synapses, and are designed to be used easily with e-neurons. By choosing the different components appropriately, different synaptic properties can be set so as to reproduce many types of synapses found in biological brains.

Bio background:

A synapse is a contact between two cells, often specialized in the transmission of molecules from one cell to the other.

In the case of neurons, there are two main types of synapses. In the first one, ion channels connect the two cells directly, granting an electrical continuity between them. These synapses are hence called « electrical synapses ». They are very fast, and are usually found in reflex circuitry and in simpler animals. However, they cannot do much computation besides propagating an action potential (AP) from one cell to the other.

In the second type, there is no direct electrical coupling. The presynaptic neuron releases instead special molecules, or neurotransmitters, in the small cleft between the two cells. The neurotransmitters bind onto specific receptors on the postsynaptic neuron. These receptors are usually ion-channels which open upon binding of neurotransmitters. The resulting ionic currents depolarize or hyper-polarize the membrane of the postsynaptic neurons possibly eliciting or inhibiting action potentials. Such synapses are called « chemical synapses » because of this indirect coupling, and are the most common types of synapses in the nervous system of animals. Although slower than electrical synapses, they allow a huge deal of modulation in the transmission of information, allowing more complex computation.

Chemical synapses are often classified depending on the properties of the postsynaptic currents (PSC) they elicit after the presynaptic neuron fires.

Sign : The first property is the sign of the PSC. Positive PSC means that positive charges are injected into the postsynaptic neuron, resulting in a depolarization. They are called excitatory PSC, or EPSC. Reversely, negative PSC are called inhibitory PSC, or IPSC, and hyperpolarize the membrane.

Rise time : Since the processes of neurotransmitter secretion and binding are not instantaneous, the PSC increases from 0 to a maximum value over a duration called rise time.

Fall time : Unbiding, diffusion and recapture of neurotransmitters by the presynaptic neuron, brings the PSC back to 0 with a time constant called fall time. It is generally far greater than the rise time. In some cases, the fall time of PSCs is large enough for a synapse to be reactivated before the complete recapture of previously released

neurotransmitters. In this case, neurotransmitters accumulate in the synaptic cleft, and the average resulting PSC increases.

Amplitude : The amplitude of an isolated PSC is its maximum value. Neurophysiologists usually refer to this maximum value as the strength of the synapse.

Fatigue : These important synaptic properties cannot be observed in isolated PSC curves. Synaptic fatigue occurs due to the finite replenishment rate of neurotransmitters in the presynaptic neuron. This leads to a progressive decrease in the amount of neurotransmitters released when the synapse is often solicited, for instance during a train of AP. The full potential of the synapse is restored after a recovery period.

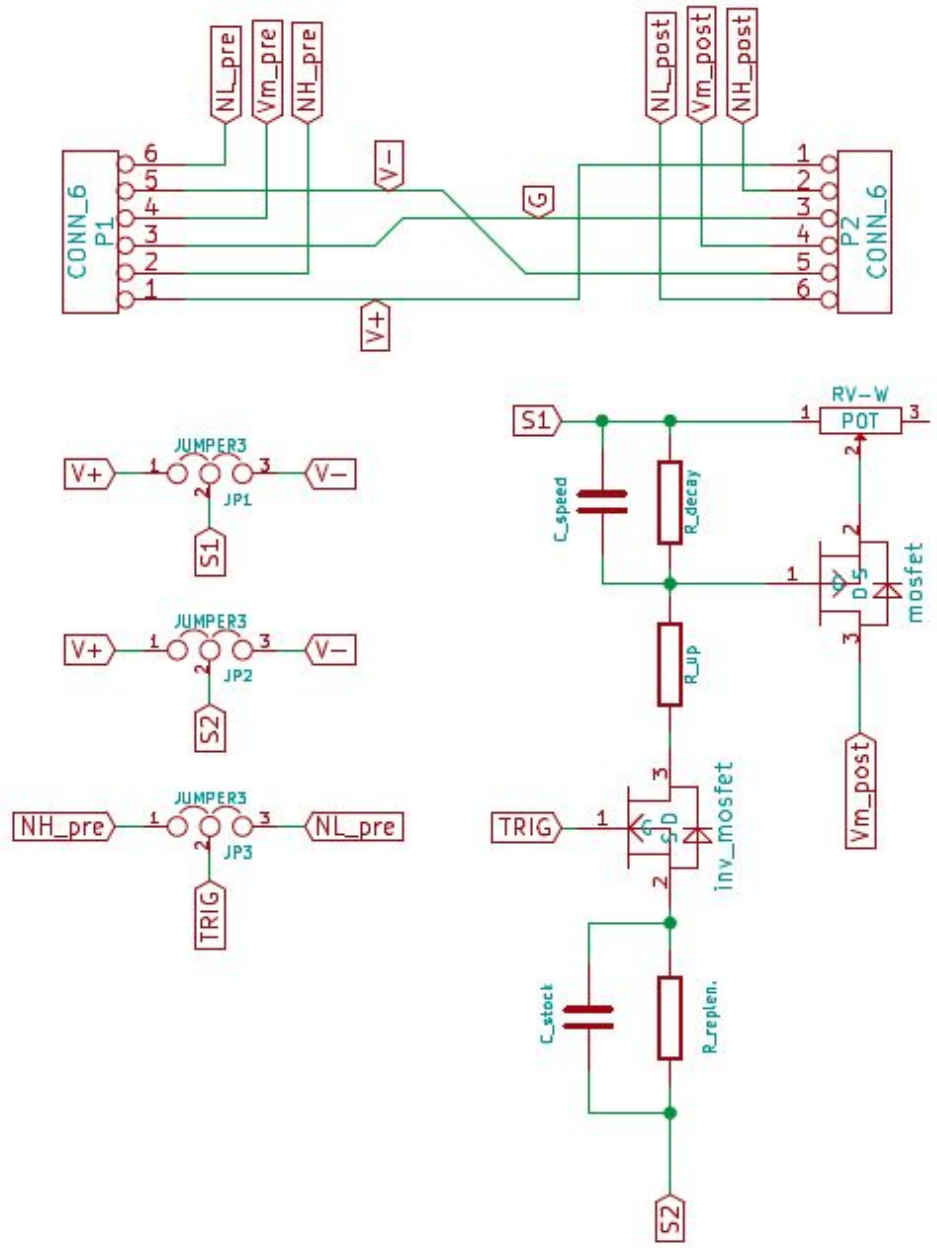
Facilitation : When the amplitudes of individual PSC peaks increase after each synaptic activation, we talk instead of facilitation. This increase in the PSC amplitude is different from the increase due to the accumulation of neurotransmitters in the cleft.

Plasticity : It is the ability of a synapse to change its strength (the amplitude of isolated PSC) either positively (potentiation) or negatively (depression). Fatigue and facilitation can be seen as short term depression and potentiation, respectively. Other mechanisms can affect synaptic strength at longer time-scales. Long-term potentiation (LTP) and long-term depression (LTD) are the basis for memory formation in the brain. This property is only accessible in plastic e-synapses.

Those different properties, in combination with those of neurons themselves, can combine into subtle yet powerful computation.

Schematics and Parameters :

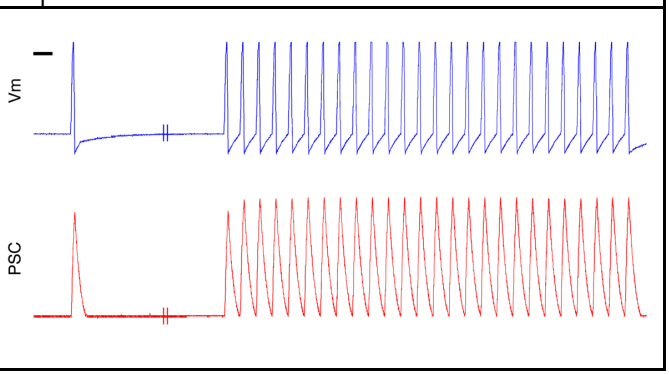
The circuit has two stages. The first stage generates a voltage with the shape of the desired postsynaptic currents (PSC). The second one converts this voltage into the actual PSC injected in the postsynaptic neuron. The second stage has a trimmer to adjust the amplitude of the PSC while maintaining its shape. This configuration allows easy parameterization of the e-synapse.

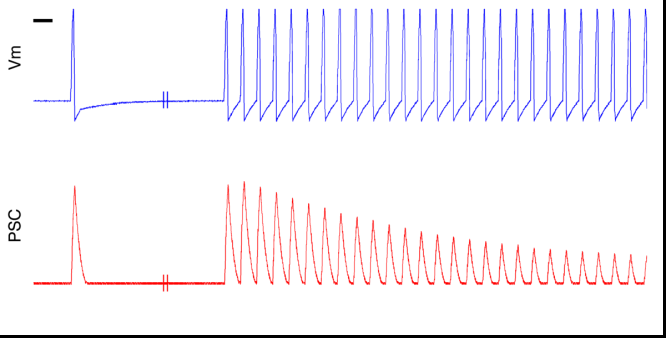


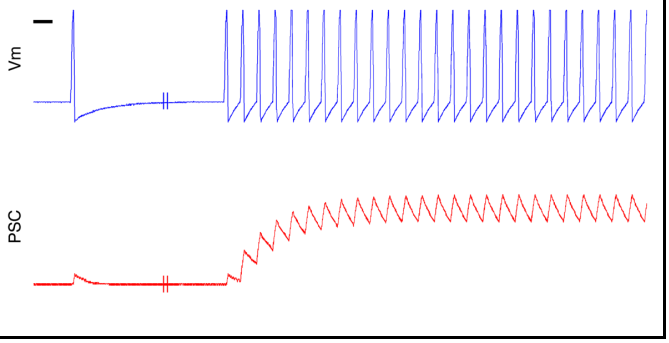
The circuit can be adapted to create either excitatory or inhibitory synapses. The PCB versions distributed by Neurino have solder jumpers to wire the circuit appropriately.

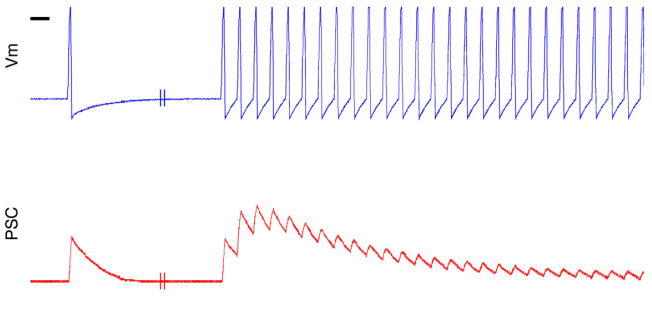
Variable	Excitatory value	Inhibitory value
S1	V+	V-
S2	V-	V+
Trig	NL_pre	NH_pre
mosfet	P-chan	N-chan
inv_mosfet	N-chan	P-chan

The different components can be chosen to configure the e-synapse. You can see a couple of configurations showing the different sets of components and the resulting PSC shapes. In blue is the membrane potential of the presynaptic neuron, in red are the PSC traces. Scale bar is 0.1 s.

Type A : Basic synapse with constant PSCs.		
Component	Value	
C_stock	none	
R_replen	0Ω	
R_up	50kΩ	
Rdecay	100kΩ	
C_ speed	100nF	

Type B : Synapse with short-term depression (fatigue).		
Component	Value	
C_stock	1µF	
R_replen	500kΩ	
R_up	50kΩ	
Rdecay	100kΩ	
C_ speed	100nF	

Type C : Synapse with accumulation.		
Component	Value	
C_stock	none	
R_replen	0Ω	
R_up	20kΩ	
Rdecay	100kΩ	
C_ speed	1µF	

Type D : Synapse with accumulation and short-term depression.		
Component	Value	
C_stock	1µF	
R_replen	500kΩ	
R_up	10kΩ	
Rdecay	100kΩ	
C_ speed	1µF	