Neurino
e-neuron documentation

Introduction :

e-Neurons are open-source analog electronic circuits that operate similarly to biological neurons, that is by generating and transmitting electrical impulses called action potentials, or spikes. In combination with e-synapses, e-neurons can be assembled into networks covering a wide range of applications, like biomimetic robots and artificial intelligence.

Bio background:

Neurons are specialized cells found in the nervous system of every animal on the planet and assume, despite some variations, a typical morphology. Neurons have a small (typically 15-50 microns) cell body from which extend thin processes, or neurites, through which they can contact their neighbors. These contacts, called synapses, allow communication in a directed manner, from one neuron to the other.

The most important functional feature of neurons is that they are electrically excitable, meaning that some processes inside them are coupled together via an electric potential existing across the cell membrane. Like all cells, neurons possess a membrane which separates the intracellular medium from the outside. Because cells actively maintain a differential repartition of charged species between the intracellular and extracellular compartments, there is an electric potential difference, or voltage, across the membrane. At rest, it sits at about -65mV. However the membrane potential is constantly modulated by transient ionic currents across the membrane, controlled by the opening of ion channels present in the membrane.

Different effectors can open these channels, including neurotransmitters released by other neurons, external factors (such as light, odorant molecules, mechanical forces), or even the membrane potential itself. The fact that the membrane potential depends on voltage-gated channels allows positive and negative feedback loops, which are key to a fundamental mechanism taking place in almost all neurons : the action potential, or spike.

Spikes are electrochemical impulsion consisting in depolarization, repolarization and hyperpolarization of the membrane : when the membrane potential increases to a threshold value of about -50 mV, voltage-gated sodium channels open and sodium rushes into the cell following its electrochemical potential. Since sodium ions are charged positively, the inward flow depolarizes the membrane even more, which triggers the opening of adjacent channels and creates a strong depolarisation in all the neurons. The depolarisation stops rapidly as sodium channels spontaneously enter into an inactive state. In parallel, this depolarization induces the opening of voltage-gated potassium channels, albeit with a small delay. Following their electrochemical potentials, potassium ions quickly diffuse out of the cell. This outward flow of positive charges repolarizes the membrane. However, because the potassium channels do not close immediately after the membrane has returned to its resting potential, a transient hyper-polarization, or overshoot, can be observed. Back to the resting potential, the inactivated sodium channels become excitable again and another action potential is therefore permitted.

Spikes trigger important processes inside the neuron, most notably, the secretion of neurotransmitters at synapses. They are therefore key to the modality of neuronal communication and processing. Neuron and spikes have several properties that are important for their functions :

Resting potential : It is the value of the membrane potential when the neuron is inactive.

Membrane time constant : It tells how much time it takes for the membrane potential to reach a new equilibrium when current is injected through the membrane. A short time constant means the neuron responds quickly to injected currents.

Spike Threshold : It is the membrane potential at which spikes are initiated. If the threshold is set lower than the « virtual » rest potential, the neuron spikes by itself and becomes a pacemaker neuron.

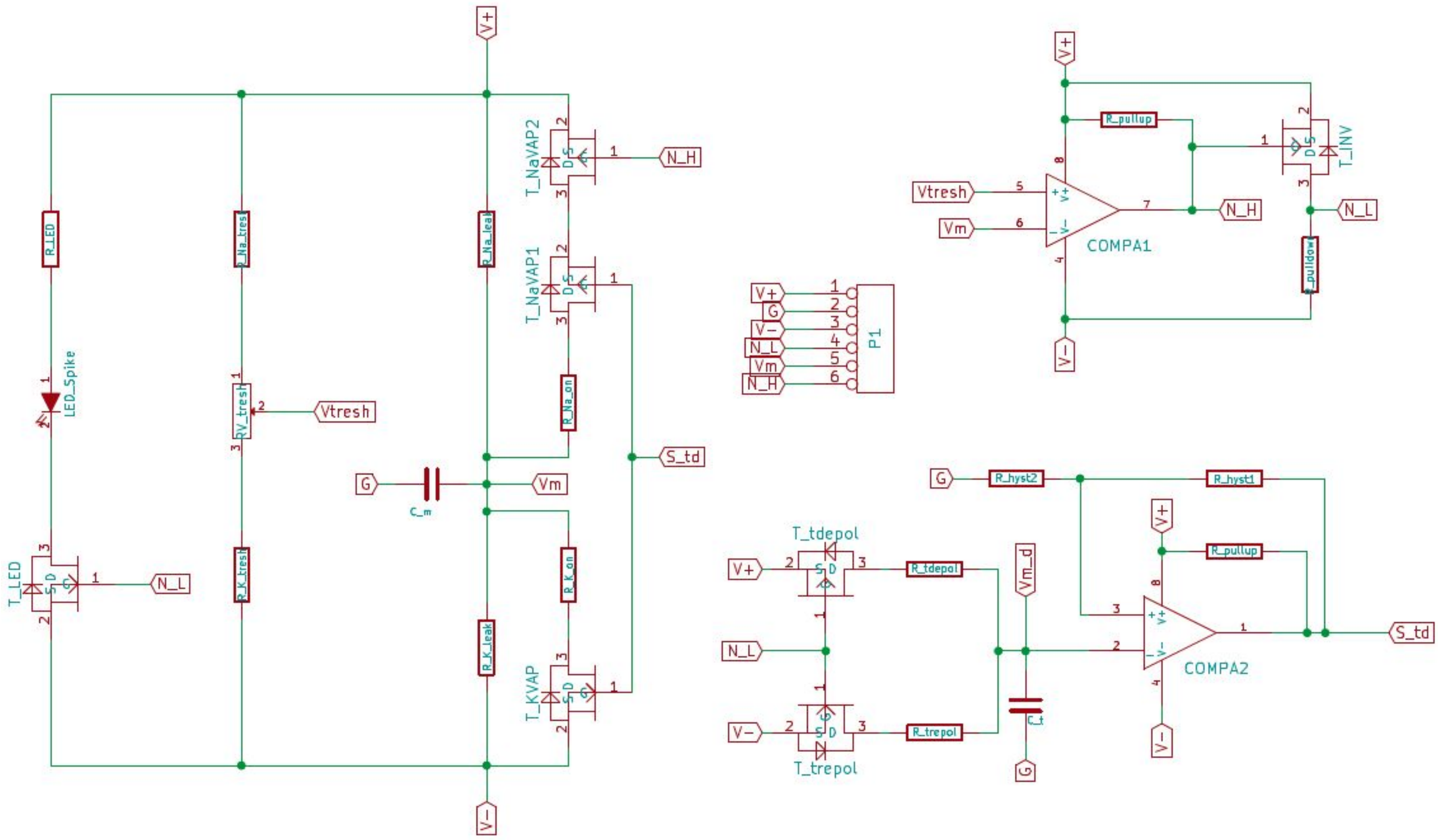
Spike Duration : It can be defined as the time spent above the threshold during a spike.

Spike Overshoot : It is the hyperpolarization occuring after each spike. The overshoot makes it harder for a neuron to be excited again immediately after a spike.

Schematics and Parameters :

The e-Neuron is an analog neuromorphic chip, meaning the different physical entities allowing the functioning of biological neurons are replaced by other physical entities that together work in an analogous way (see table below).

Physical entity in biological neurons	Analogous entity in electronic neurons
Ions	Electrons
E_{Na+} (Na^+ electrochemical gradient)	Positive power supply V+
E_{K+} (K^+ electrochemical gradient)	Negative power supply V-
Membrane	Capacitor
Leak channels	Resistors
Na and K voltage gated Ion channels	Transistors
Voltage sensing domain of Ion Channels	Reference voltage and Comparator



The names of the component in the schematic above are explicit. The membrane components are gathered in the left part of the schematic. The bottom-right part of the schematics is a timer controlling the duration of spikes depolarisation and hyperpolarization.

The different components can be chosen to tune the different properties mentioned in the previous part. Neurino offers different presets.

Type A		
Component	Value/Type	INSERT CURVES HERE
R_Na_tresh	500 kΩ	
R_K_tresh	500 kΩ	
RV_tresh	100 kΩ	
R_Na_leak	100 kΩ	
R_K_leak	100 kΩ	
R_Na_on	10 kΩ	
R_K_on	10 kΩ	
C_m	1 μF	
T_KVAP	n-mosfet	
T_NaVAP1	p-mosfet	
T_NaVAP2	p-mosfet	
R_tdepol	10 kΩ	
R_trepol	47 kΩ	
C_t	0.1 μF	
T_tdepol	p-mosfet	
T_trepol	n-mosfet	

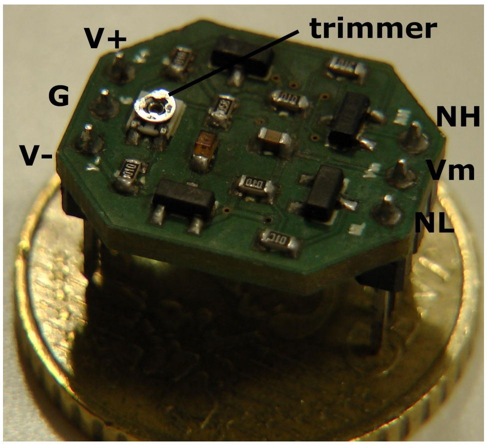
R_hyst1	/	
R_hyst2	10 kΩ	
R_pullup	10 kΩ	
R_pulldown	10 kΩ	
T_INV	p-mosfet	
R_LED	1 kΩ	
T_LED	n-mosfet	
COMPA1	Open collector	
COMPA2	Open collector	

Usage :

e-Neurons have a 6-pin interface :

V+ : Positive power supply
V- : Negative power supply
G : Ground
Vm : Membrane potential
NL : Normally Low (V-) switch
NH : Normally High (V+) switch

The spike threshold can be adjusted using the trimmer.



The symmetrical power supply can be generated from a single 9V battery using a buffered voltage divider or a rail splitter like TLE2426.

Vm is the input pin corresponding to the « membrane » potential of the neuron, through which current can be injected or drawn to elicit or inhibit spikes.

NL and NH are two output signal lines switching between V- and V+ during a spike. They can be used to control transistors to inject currents into other neurons or actuators. For instance, a p-channel mosfet transistor with source V+ and gated by NH can be used to create a simple excitatory synapse, and a n-channel mosfet driven by V- and NL can be used to create an inhibitory synapse. More complex circuits can be used. Neurino's e-Synapses include different properties of biological synapses, like facilitation, short term depression, and plasticity. For more information see documentation for e-Synapses.

e-Neurons can also be inserted into bases to facilitate networks assemblies. Each base provides 4 connectors (6 ways JST-SH) to easily connect neurons togethers via e-synapses using the same kind of connectors. Bases can additionally be stacked to increase the number of connections.