

Calibration documentation

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1 Introduction

The aim of this document is to describe each step of the calibration that is done in the cake module. Please note that this document is unfinished and may change at any time. Also note that some of the features described here might not be implemented yet. ALSO note that until now, only LIF parameters are supported.

The result of the presented calibration are equalized potentials, i.e. membrane and synaptic potentials, for each denmem. Membrane and synaptic time constants are not calibrated to a specific value but chosen such that the effect of synaptic input, i.e. PSPs, is maximized.

2 Parameter types

Since the hardware has different types of parameters, we need to define different parameter spaces and transformations. The aim of a calibration is to accurately determine

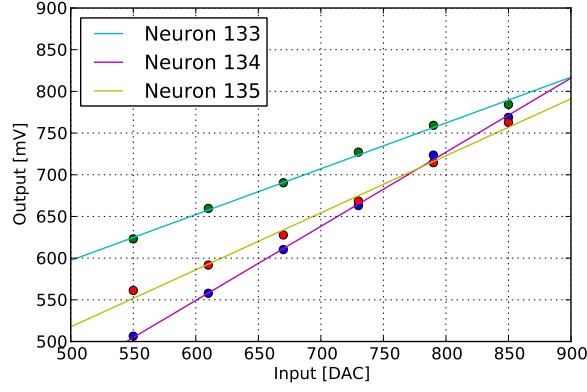


Figure 1: Calibration example.

these transformations.

We concluded that we should define four different parameter spaces (note that the two examples given for each parameter space are corresponding):

- Biological parameters (Bio)
 - pyNN parameters, for example V_{rest} or τ_m .
- Hardware parameters (HW)
 - Parameters that are measured on the hardware, for example E_l or g_l
- Hardware control parameters (HC)
 - Parameters that control the hardware, for example E_l or I_{gl}
 - Found in `pyhalbe.HICANN.neuron_parameters` and `..shared_parameters`
- Floating gate values (DAC)
 - Discreet floating gate values between 0 and 1023.
 - Voltages are calculated by $DAC * \frac{1800 \text{ mV}}{1023}$
 - Currents are calculated by $DAC * \frac{2500 \text{ nA}}{1023}$

Calibration should be applied as the **last** step (to DAC values) in order to make it independent on the type of user input. Until now, calibtic only supports this last step and it does not properly support transformations between each of these parameter spaces.

3 Calibration

Calibration steps are listed in the order in which they should be run. For each parameter, you will find a description of what it does, how it is measured, what the calibration does to it and everything else that is worth noting.

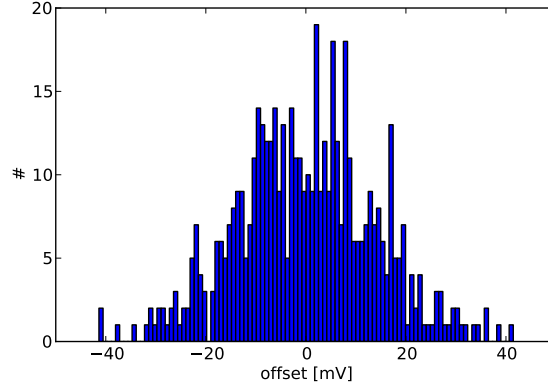


Figure 2: Offset of analog readout buffer.

The `run_calibration` tool in the `pycake/bin/` folder will calibrate all working parameters. To configure the calibration, you have to edit `parameters.py` to match whatever you want to calibrate or measure. There you can edit the calibrated ranges, step length and number of repetitions (which will increase accuracy but also linearly increase experiment time). After calibration of a parameter, you should keep that variable within the range in which you calibrated – outside of the range, the accuracy can decrease.

3.1 Readout shift (21st parameter)

The neuron is connected to the readout amplifier via an operational amplifier. This amplifier has a different offset for each neuron, which has to be measured in the first step. For this purpose, we make use of the fact that one value of V_{reset} is applied to a whole block of neurons, so that there should be no variation between this block.

Measurement

First, V_{reset} is measured for all neurons and averaged over each blocks. This mean V_{reset} is considered to be the "real" V_{reset} . The readout shift is then calculated by taking each neuron's mean variation from that "real" value. This shift is stored in `calibtic` as the 21st parameter.

3.2 Reset Potential (V_{reset})

After a spike, the membrane potential is set to V_{reset} . This parameter corresponds to the `pyNN` parameter V_{reset} .

Since this parameter is a shared parameter, it can not be set for each neuron individually but only for blocks of 128 neurons. In this case, the calibration reduces block-to-block variation.

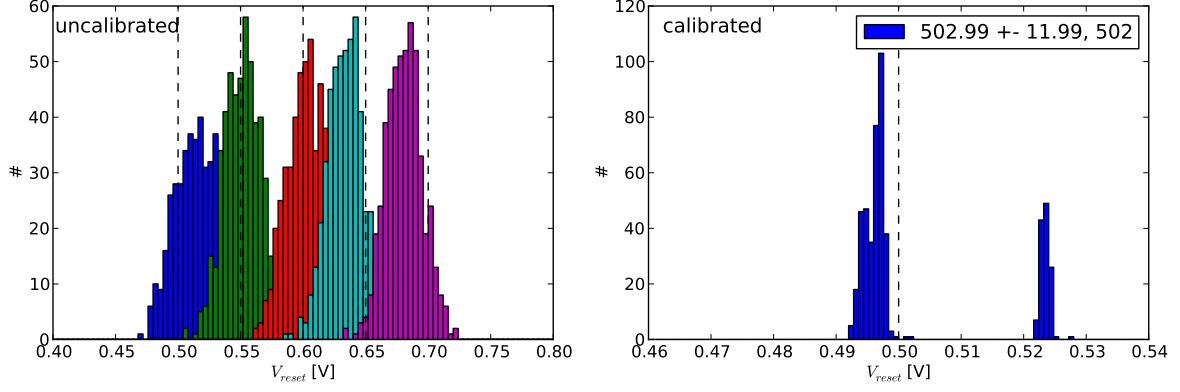


Figure 3: Uncalibrated (left) and calibrated (right) V_{reset} .

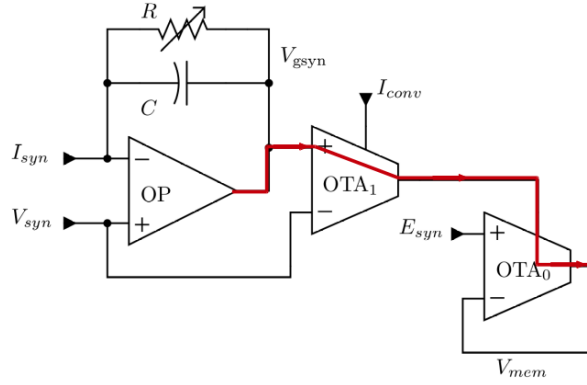


Figure 4: Synapse circuit. $E_{\text{synx/i}}$ is applied to OTA0

Measurement

V_{reset} is measured by choosing a long τ_{ref} time. Then, the neuron is set to be always spiking. The value of the membrane during the refractory period is averaged.

3.3 Reversal Potentials (E_{syni} and E_{synx})

E_{syni} and E_{synx} are the synaptic reversal potentials. These voltages are applied at the OTA_0 in the synaptic input circuit (see fig. 4). Their pyNN-counterparts are `e_rev_I` and `e_rev_E`.

Measurement

The synaptic reversal potentials are measured using leakage currents of the synaptic input circuit. Since inhibitory and excitatory input circuits are identical, I will only describe the measurement once.

Ideally, when no spike input is present, there should be no leakage current through OTA_0 . However, due to imperfections in the manufacturing process, these leakages

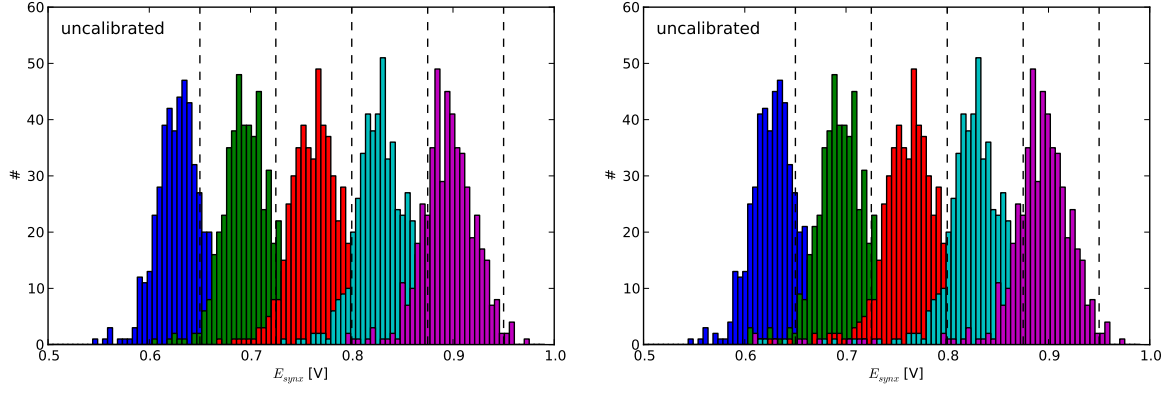


Figure 5: $E_{\text{synx}/i}$ calibration. Without (left) and with (right) inclusion of neurons flagged as not responsive to calibration protocol.

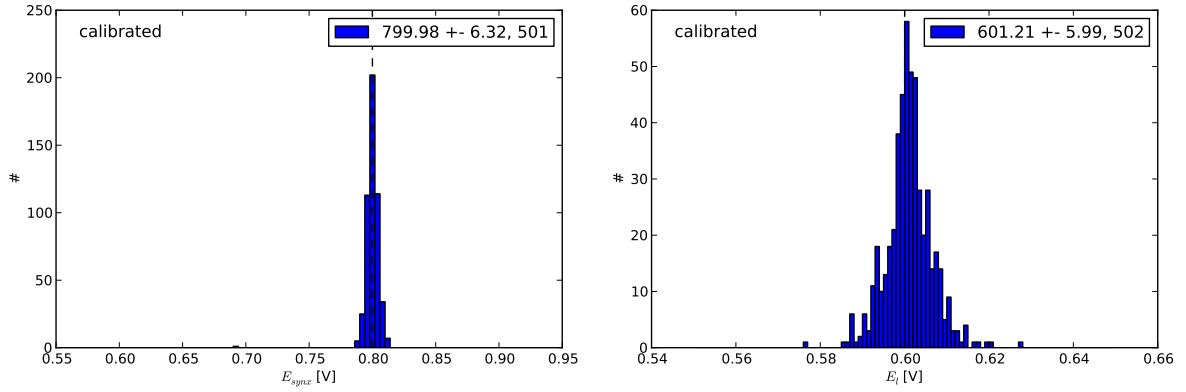


Figure 6: E_{synx} and E_{syni} after calibration.

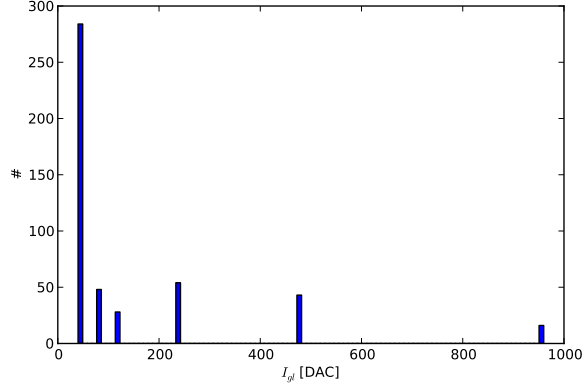


Figure 7: I_{g1}

cannot be avoided. Here, we make use of them by turning off all other conductances in the neuron circuit. With the synaptic input being the only remaining conductance, the membrane potential will approach the synaptic reversal potential. This can easily be measured with the ADC, thus giving an approximation of the reversal potential.

In addition, the background generators are used as input...

3.4 Leak Conductance (I_{g1})

Ideally, the leakage conductance is used to control the membrane time constant. However, to maximize the effect of synaptic input, a small conductance is beneficial. Therefore, a two dimensional scan of I_{g1} and E_1 is performed that finds the smallest I_{g1} for which the target membrane potential can be reached.

3.5 Synaptic Time Constant ($V_{\text{syn}cx/i}$)

The value of the synaptic time constant has a strong effect on the PSP height. Only in a small window, synaptic input can be observed at all, see fig. 8.

Measurement

The standard deviation, i.e. the spread, of the voltage trace is used as a proxy for the PSP height. The value of synaptic time constant that maximizes the spread is picked.

3.6 Resting Potential (E_1)

E_1 is the membrane leakage potential that determines where the membrane potential should stay when no input is given at all. It is applied at the leakage OTA (see fig. 4). The corresponding pyNN parameter is the resting potential V_{rest} .

While calibrating, the synaptic reversal potentials are fixed and typically set symmetrically around the target E_1 with a distance of 100 mV.

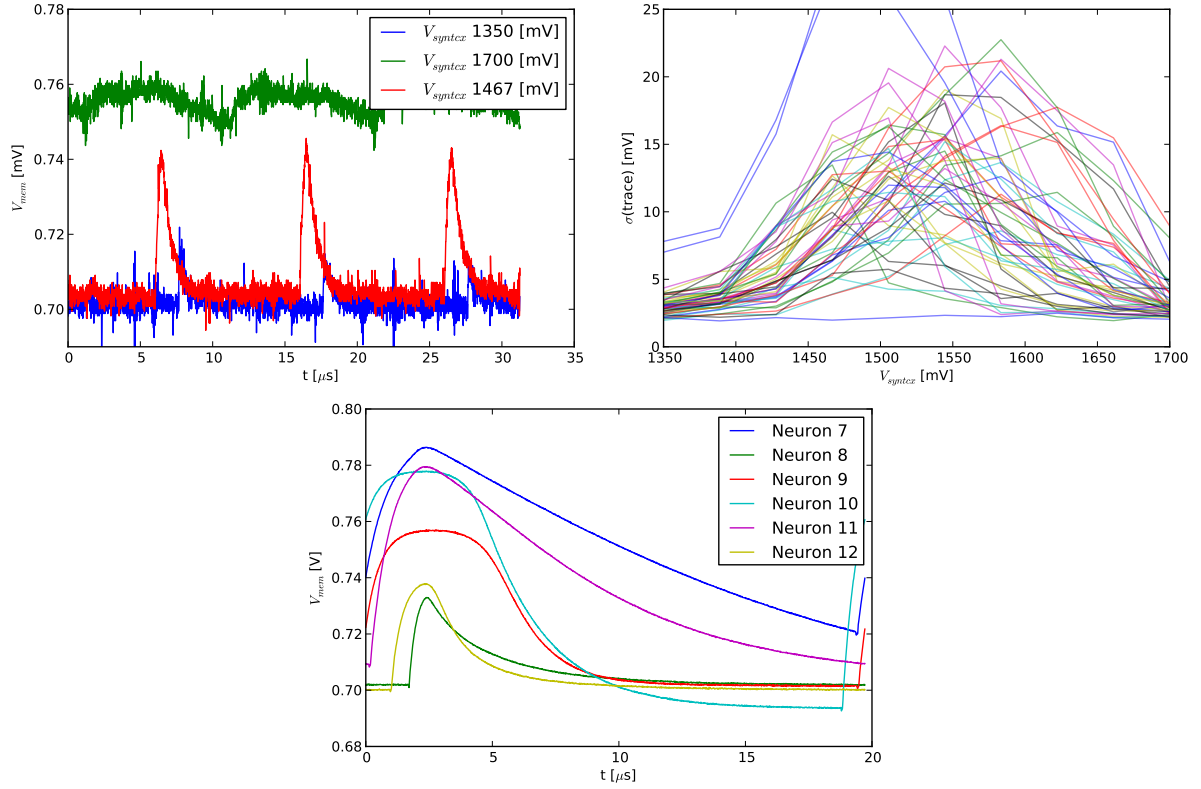


Figure 8: $V_{syntcx/i}$ calibration. Traces for different V_{syntcx} settings demonstrating the small range of operation. PSP heights as function of V_{syntcx} . PSP shapes after picking the V_{syntcx} that maximizes the height.

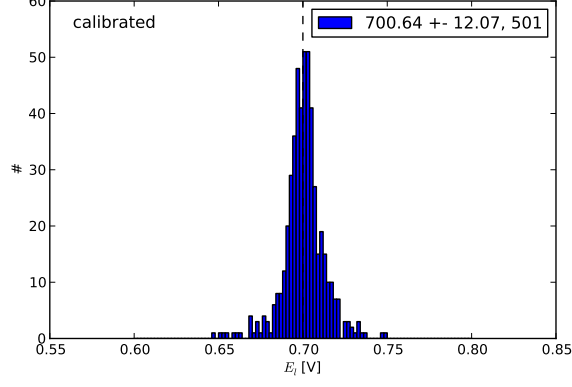


Figure 9: E_l after calibration.

Measurement

E_l is measured by turning on all conductances that will later be turned on while experiments are run. That way, it is ensured that we calibrate an effective resting potential that balances the unwanted leakage currents. Then, without any input, the membrane potential approaches a value which will be considered as E_l .

3.7 Threshold Potential (V_t)

V_t is the voltage at which a spike is initiated. This voltage corresponds to the pyNN parameter V_{thresh} in a LIF model.

Measurement

To measure V_t , the resting potential E_l is set above the threshold so that the neuron is spiking all the time. Then, the peaks of the trace are found and averaged, see fig. 10. This might underestimate the threshold because the ADC might sample too early or too late. However, relying on e.g. the maximum of the full trace results in larger variations.

3.8 Refractory Period (I_{pl})

The refractory period τ_{ref} determines how long a neuron stays at V_{reset} after it elicited a spike, see fig. 11.

Measurement

τ_{ref} depends $\propto \frac{1}{I_{pl}}$. First, I_{pl} is set very high to achieve an approximately vanishing refractory period. With this setting, the spike to spike time Δs is determined. Assuming no change in the spike to spike time, Δs serves as reference that is subtracted for runs with increased τ_{ref} (decreased I_{pl}).

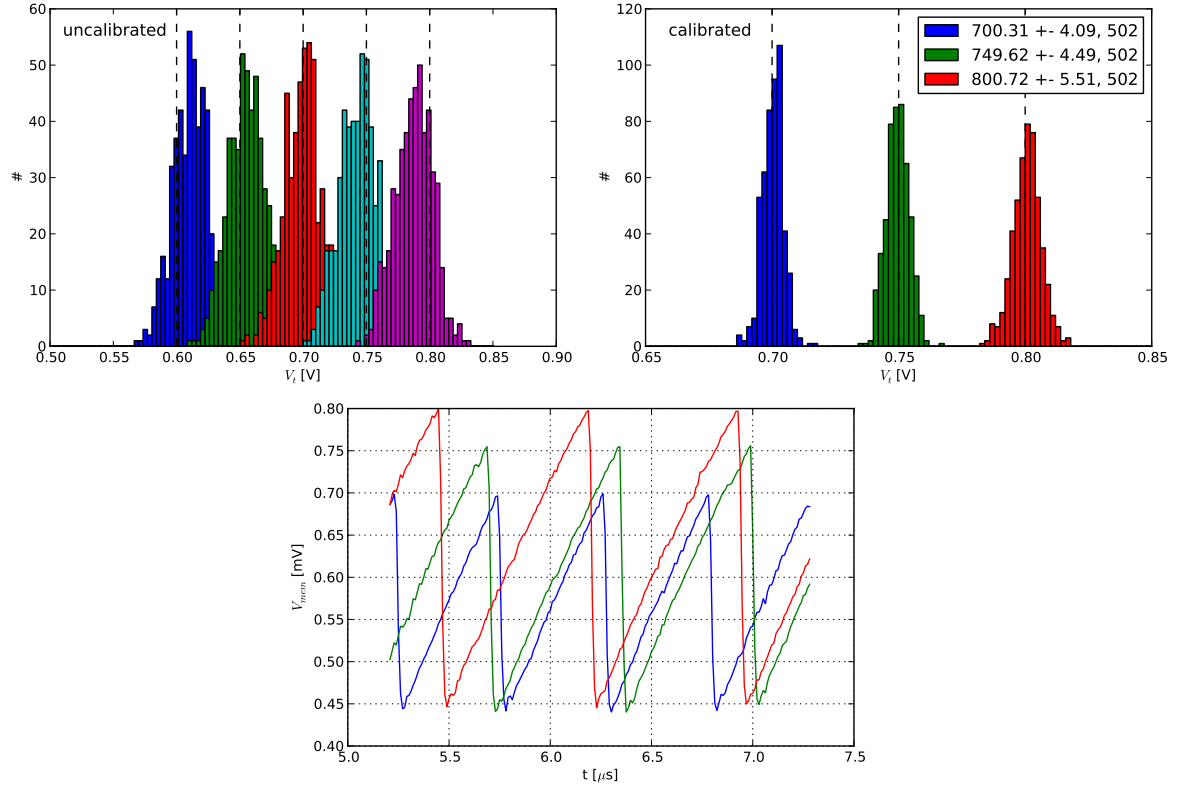


Figure 10: V_t before (left) and after (right) calibration.

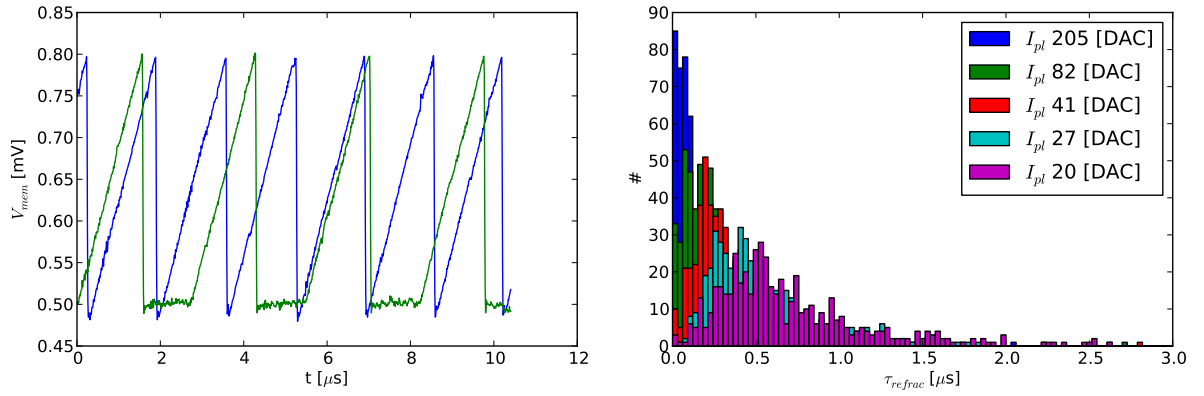


Figure 11: I_{pl} calibration.