Neuronal networks with Cobra4 Xpert-Link (Item No.: P4010964)

Curricular Relevance

Area of Expertise: Biology
Education Level: University
Topic: Neurobiology
Subtopic: Nerve Cell - Functions, Interactions and Networks
Experiment: Neuronal networks with Cobra4 Xpert-Link

Difficulty	Preparation Time	Execution Time	Recommended Group Size
Difficult	10 Minutes	2 Hours	2 Students

Additional Requirements:

- PC

Experiment Variations:

Keywords:

Transient (phasic) responses, Neuronal oscillator (body clock), Short-term memory, Special anatomical circuits, Unilateral inhibition, Self-calibration of paired sensory channels

Task and equipment

Introduction

First, perform the experiments "The nerve cell with Cobra4 Xpert-Link" (P4010764) and "Nerve cell interactions with Cobra4 Xpert-Link" (P4010864).

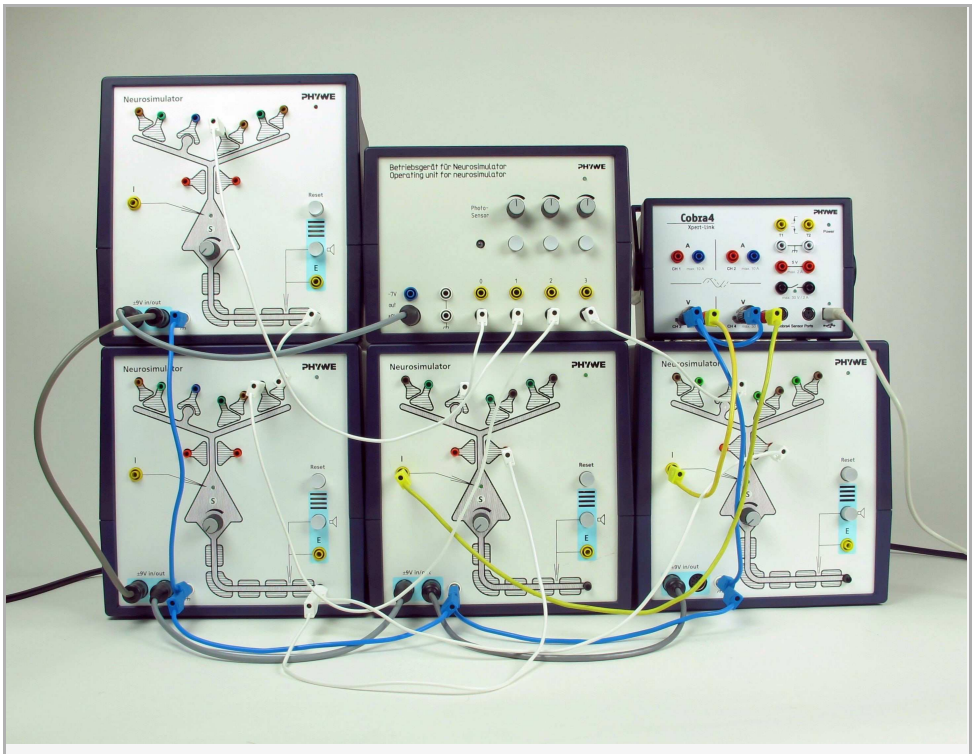

Fig. 1

Function and Applications

The neuron unit Neurosimulator simulates a generalised nerve cell with an apical dendrite and its synaptic contacts, a cell body (soma) and a nerve fibre (axon) with myelin sheathes and a Ranvier's ring.
The operating unit comprises the power supply of up to four neuron units, three touch simulators with a variable stimulating intensity and an optic sensor.
The Cobra4 Xpert-Link is the perfect measurement device for all experiments. Up to 4 values can be measured: 2 values using the two internal voltage channels and 2 values via the Cobra4 Sensor Ports. (To use the sensor ports, a Cobra4 Sensor-Unit Electricity (12644-00) and a Cobra4 Xpert-Connect (12625-01) for each sensor port are needed additionally.)

Benefits

- The dendrite comprises exciting, inhibiting, presynaptic and Hebbian synapses which are marked by the corresponding colours of the sockets
- here the axons end in presynaptic buttons
- these are represented together with a part of the (afferent) fibre providing the signal
- the connection between the (efferent) axon of a neuron unit which leads away or the stimulus output socket of the operating unit and a synapse is established by means of a white cable which is inserted into the desired synapse socket
- the yellow sockets serve for the derivation of the state of excitement of the simulated neuron
- they must be connected to suitable measuring instruments (e.g.oscilloscope) or a computer interface
- the action potentials can be made audible with the aid of the integrated acoustic monitor
- the turning knob "S" serves for setting the "firingthreshold" of the neuron.

Equipment

Position No.	Material	Order No.	Quantity
1	Cobra4 Xpert-Link	12625-99	1
2	Neuro-simulator	65963-00	4
3	Neuro-simulator, power supply	65963-93	1
4	Software measureLAB	14580-61	1
5	Adapter, BNC-plug/socket 4 mm	07542-26	2

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Transient (phasic) responses: focus on visual sense

Introduction

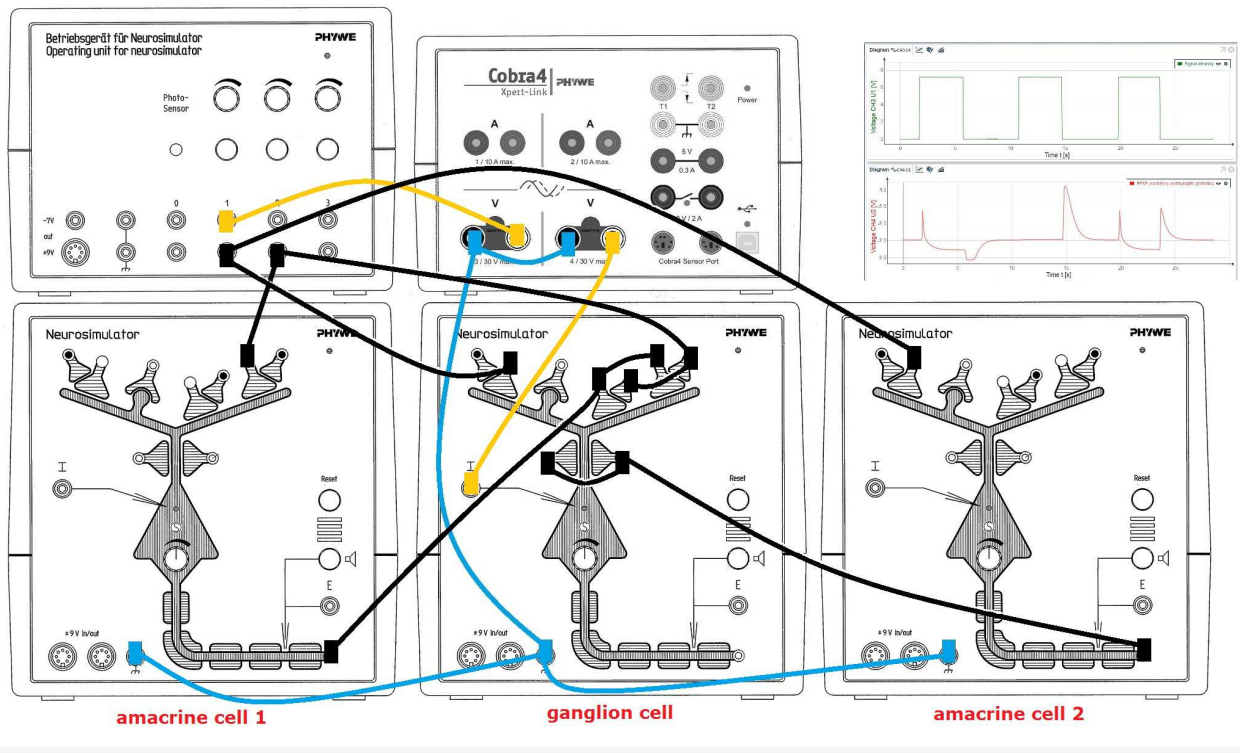


Fig. 2

One type of neurons reacts only to stimulation changes, not ongoing stimulations. These are called ON and OFF neurons. They only respond to the start and/or disappearance of a stimulus with an activation that is mostly brief, and the more intense the stronger the stimulus change.
These two types of neurons act on other neurons, e.g. on ganglion neurons of the visual sense system. In addition, such neurons can be found in the touch and olfactory sense systems.
The circuit in this experiment – an example in the visual system – can be used to show the circuitry of the retinal ganglion cells with amacrine cells. In the retina, visual cells come into contact with bipolar cells, of which mostly several are connected to one ganglion cell at a time. In addition, the visual cells are interconnected with each other via horizontal cells and the ganglion cells via the amacrine cells. Each nerve cell so receives signals from several sense cells, and each sense cell leads signals to several nerve cells. Receptor potential builds up on the bipolar, horizontal and amacrine cells, but action potentials are first formed on the ganglion cells.

Set-up and procedure

Connect the Xpert-Link to the PC.

1. Transient responses

The experiment is set up as per Fig.3.
Two BNC-adapters (plug/socket 4 mm) are needed for voltage measurement.

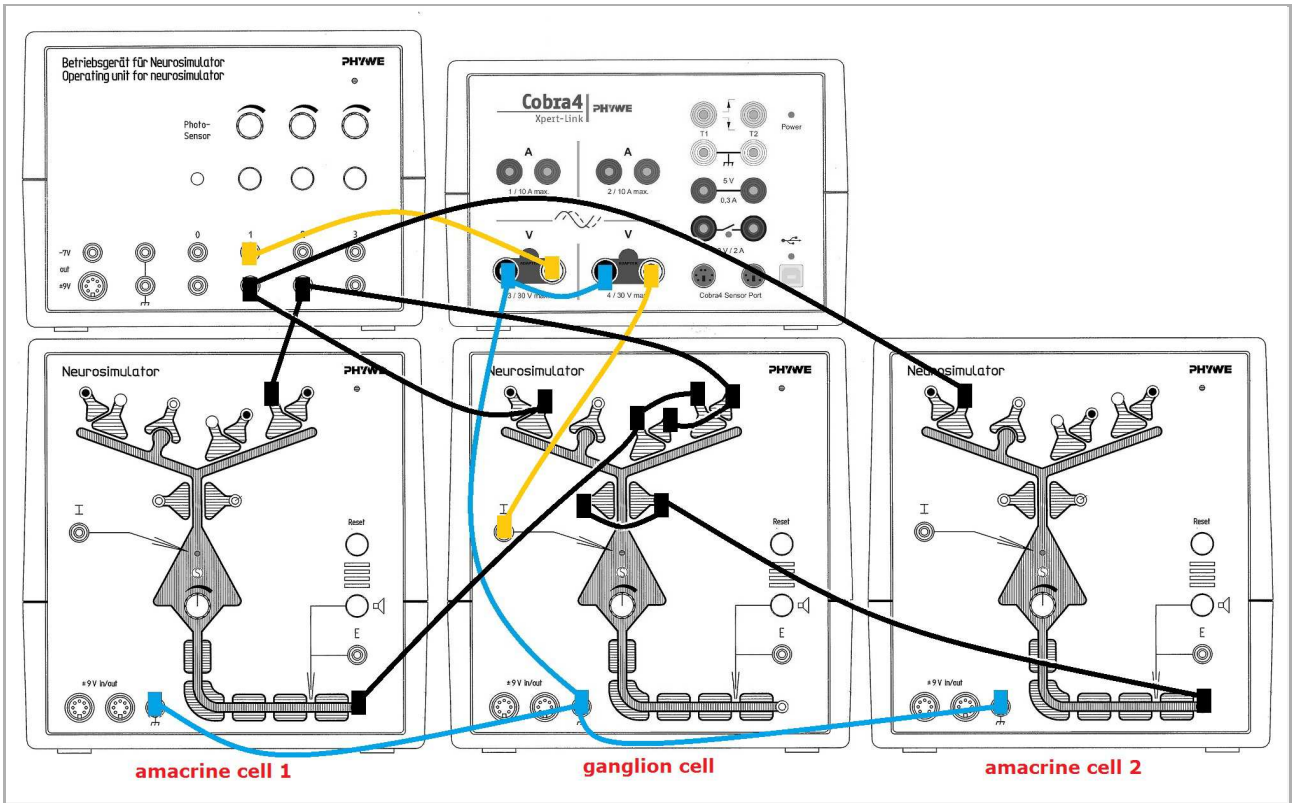
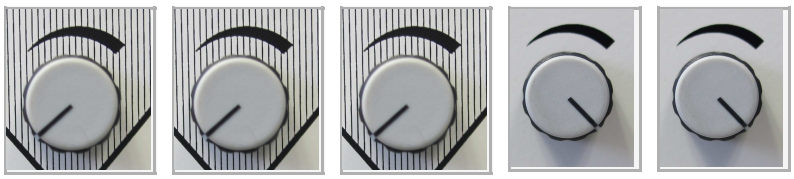


Fig. 3

- Neurosimulator 1, knob threshold: 0%
- Neurosimulator 2, knob threshold: 0%
- Neurosimulator 3, knob threshold: 0%
- Operating unit, knob stimulation intensity 1 (stimulus for ON): 100%
- Operating unit, knob stimulation intensity 2 (stimulus for OFF): 100%



- Start measurement in the measurement window.
- Press the stimulation button 1 for approximately 5 seconds. Wait until the voltage has reached the initial value.
- Plug the yellow cable into the black socket of channel 2 (red arrow, Fig. 4).

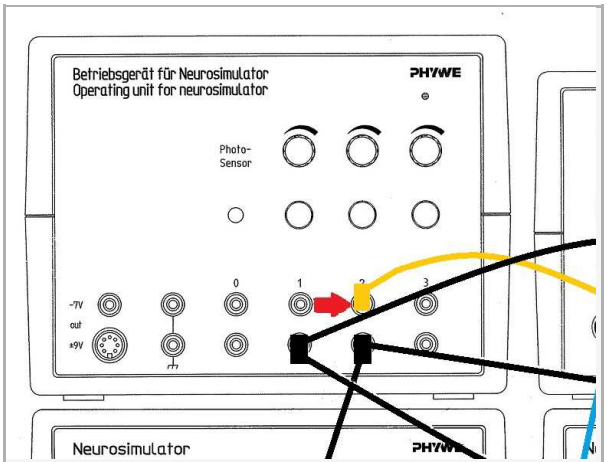


Fig. 4

- Press the stimulation button 2 for approximately 5 seconds. Wait until the voltage has reached the initial value.
- Press the stimulation buttons 1 and 2 for approximately 5 seconds. Wait until the voltage has reached the initial value.
- Finish the measurement as soon as the voltage has reached the initial value.
- Save and evaluate the results.

Results and evaluation

Results:

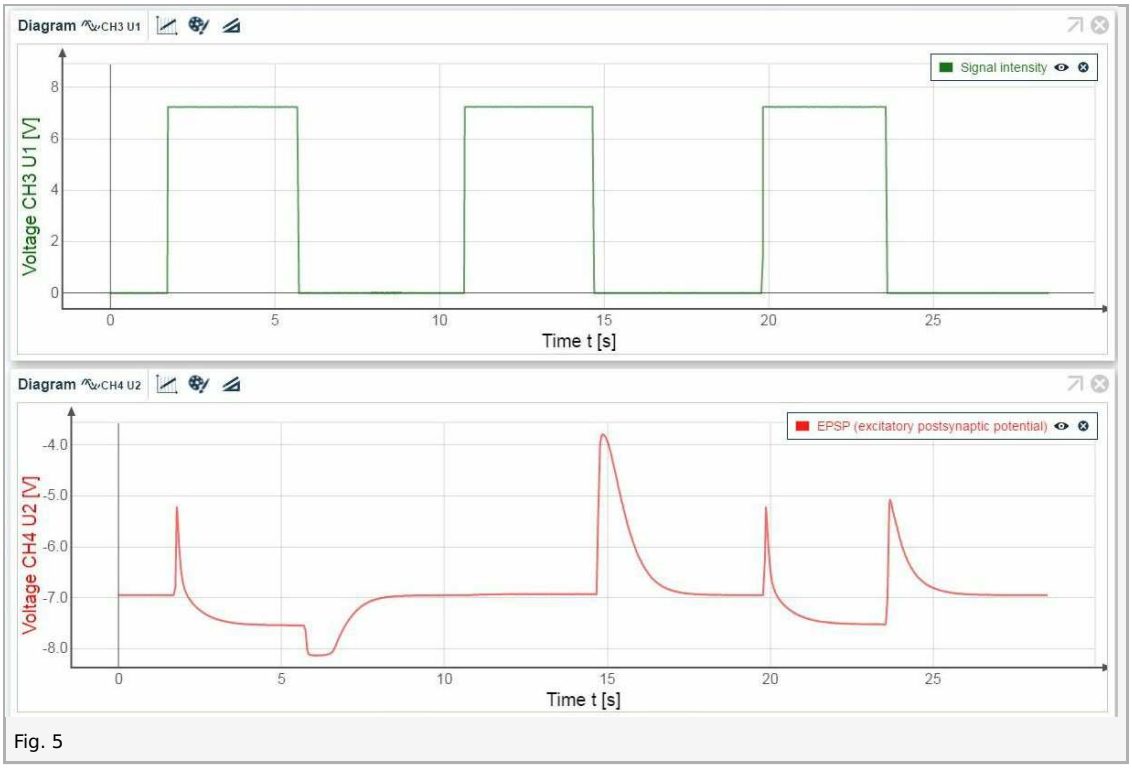


Fig. 5

Explanation:

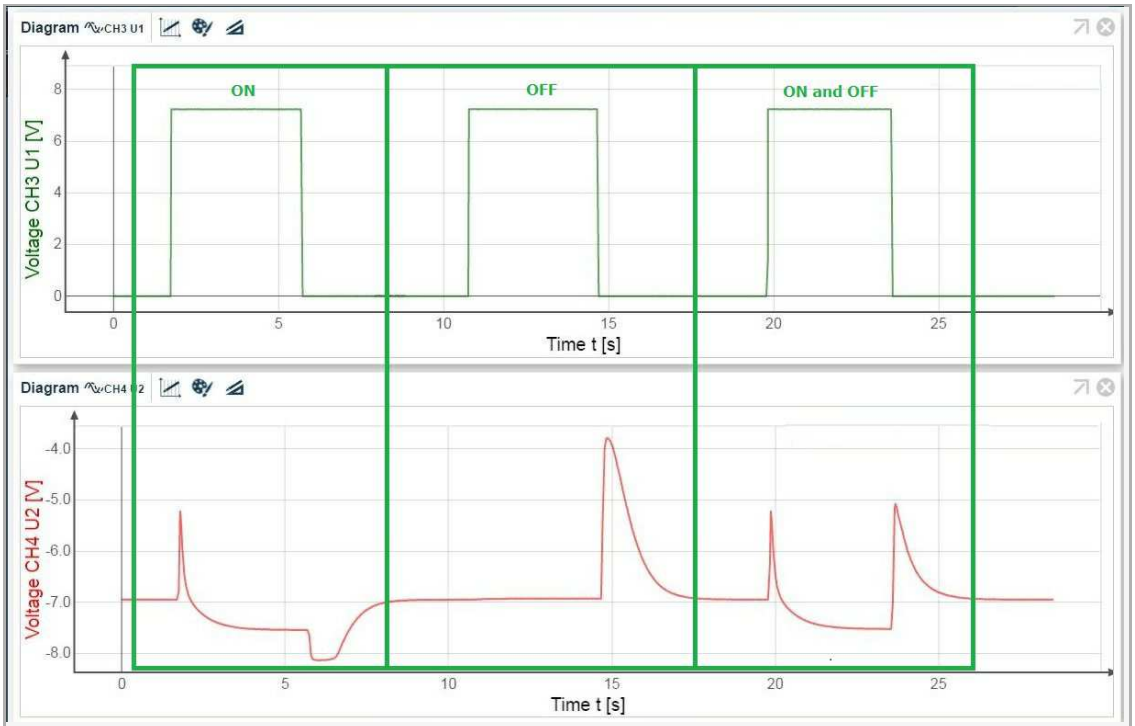


Diagram CH3 U1
ON
OFF
ON and OFF
Voltage CH3 U1 [V]
Time t [s]
Diagram CH4 U2
Voltage CH4 U2 [V]
Time t [s]

Fig. 6

Neuronal oscillator (body clock)

Introduction

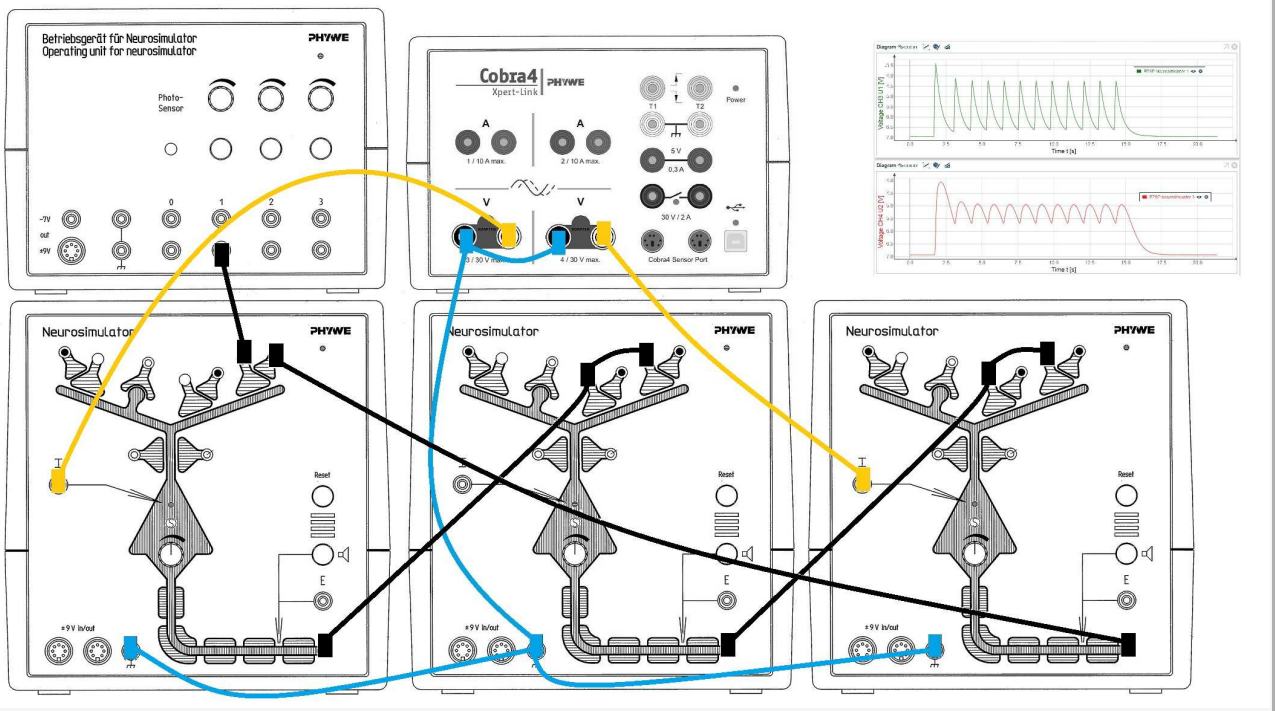


Fig. 7

Many animal and human modes of behavior exhibit rhythmic characteristics. The periodicity of such rhythmicity that is created in the central nervous system can extend over months (e.g. seasonal rhythm), days (e.g. hormonal rhythm), hours (e.g. sleep-wake cycle) or seconds (e.g. the rhythmic movement of many animals).
In each case, neural oscillators are necessary as timing generator for such behavior. The circuit example shows how individual neurons can be brought to oscillating behavior when grouped.
The rhythmic behavior of this neural network is based on the time-delayed negative feedback across a veto synapse. Through this, the input signal is switched off at regular time intervals. Because of the membrane time constant of the neuronal module (due to its capacitative properties), there is not an abrupt signal drop-off. With a time delay that is essentially determined by the signal strength, the small excitement at the veto synapse also again leads to such a small inhibition that the stimulation signal can again be effective. I.e. the inhibition at the veto synapse becomes so weak after some time of increasing inhibitory strength that it cannot inhibit the excitatory synapse any more.

Set-up and procedure

Connect the Xpert-Link to the PC.

1. Transient responses

The experiment is set up as per Fig. 8.
Two BNC-adapters (plug/socket 4 mm) are needed for voltage measurement.

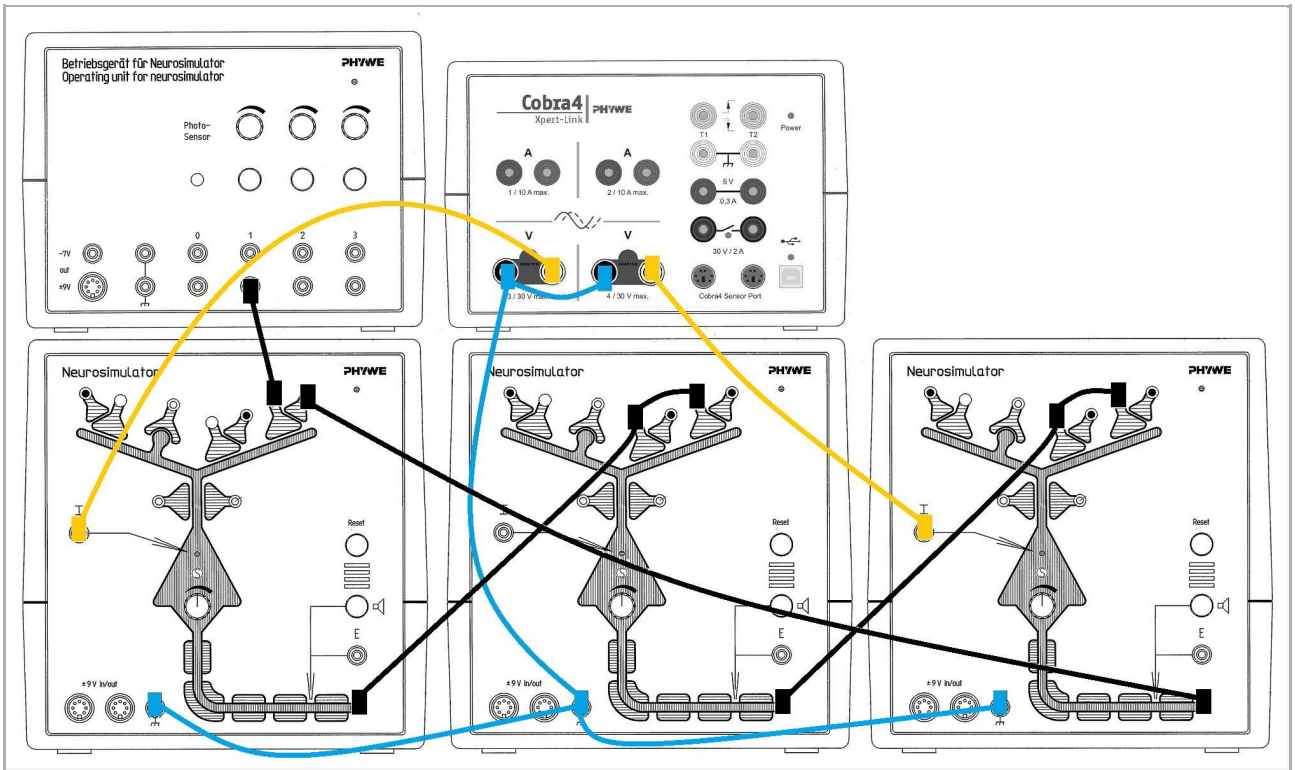
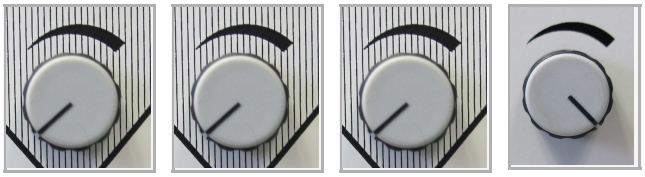


Fig. 8

- Neurosimulator 1, knob threshold: 0%
- Neurosimulator 2, knob threshold: 0%
- Neurosimulator 3, knob threshold: 0%
- Operating unit, knob stimulation intensity 1: 100%



- Start measurement in the measurement window.
- Press the stimulation button 1 for approximately 15 seconds.
- Finish the measurement as soon as the voltage has reached the initial value.
- Save and evaluate the results.

2. Transient responses with different threshold on Neurosimulator 1

Change the oscillation by different settings of the threshold knob on Neurosimulator 1 (Fig. 9).

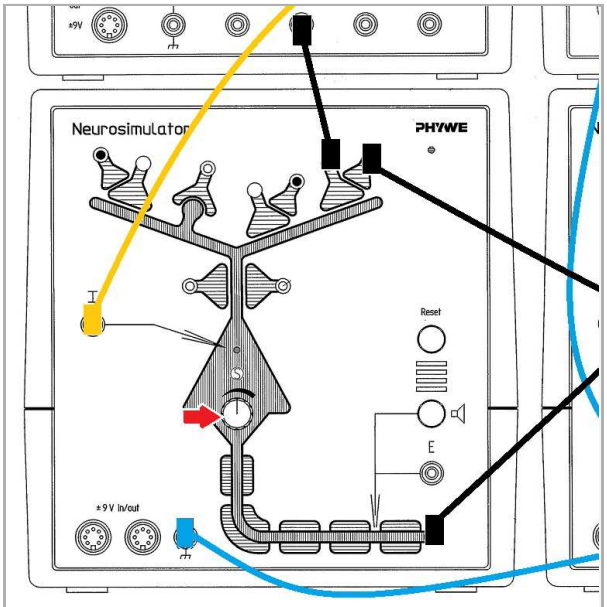
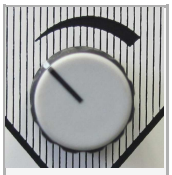


Fig. 9

Settings of the threshold:


0%


16%


33%


50%


66%


84%

- Start measurement in the measurement window.

1. Start with threshold knob on 0%. Press the stimulation button 1 for approximately 5 seconds. Wait until the voltage has reached the initial value.
2. Turn the threshold knob on 16%. Press the stimulation button 1 for approximately 5 seconds. Wait until the voltage has reached the initial value.
3. Turn the threshold knob on 33%. Press the stimulation button 1 for approximately 5 seconds. Wait until the voltage has reached the initial value.
4. Turn the threshold knob on 50%. Press the stimulation button 1 for approximately 5 seconds. Wait until the voltage has reached the initial value.
5. Turn the threshold knob on 66%. Press the stimulation button 1 for approximately 5 seconds. Wait until the voltage has reached the initial value.
6. Turn the threshold knob on 84%. Press the stimulation button 1 for approximately 5 seconds. Wait until the voltage has reached the initial value.

- Finish the measurement, save and evaluate the results.

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Results and evaluation

1. Transient responses

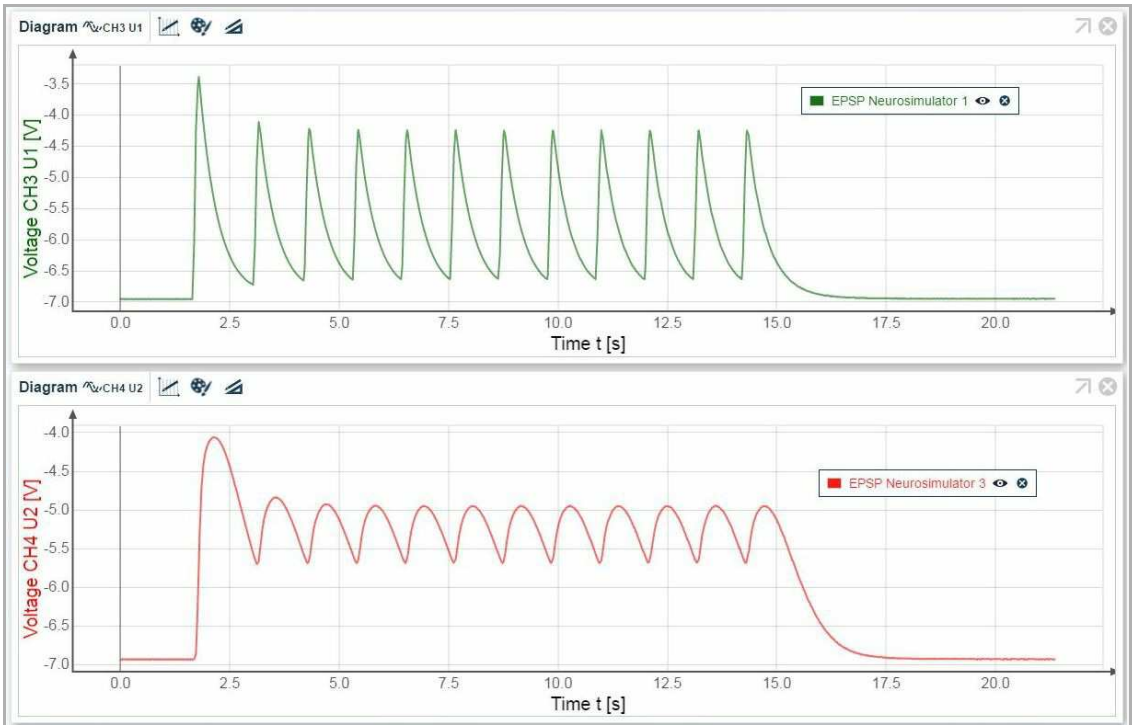

Fig. 10

2. Transient responses with different threshold on Neurosimulator 1

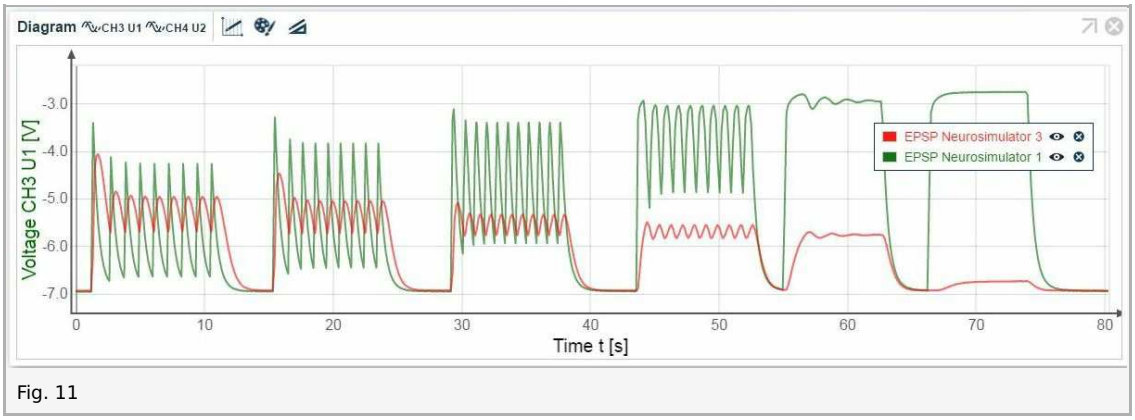

Fig. 11

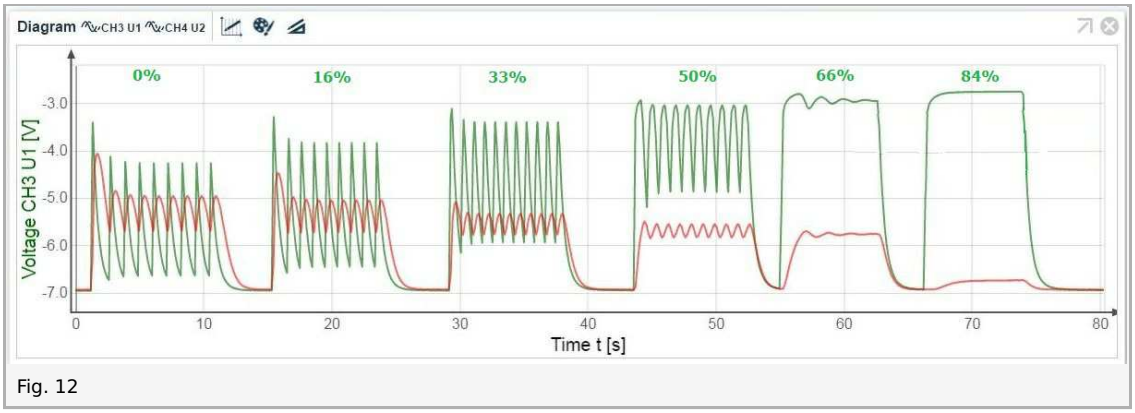

Fig. 12

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Rotating excitation (short-term memory)

Introduction

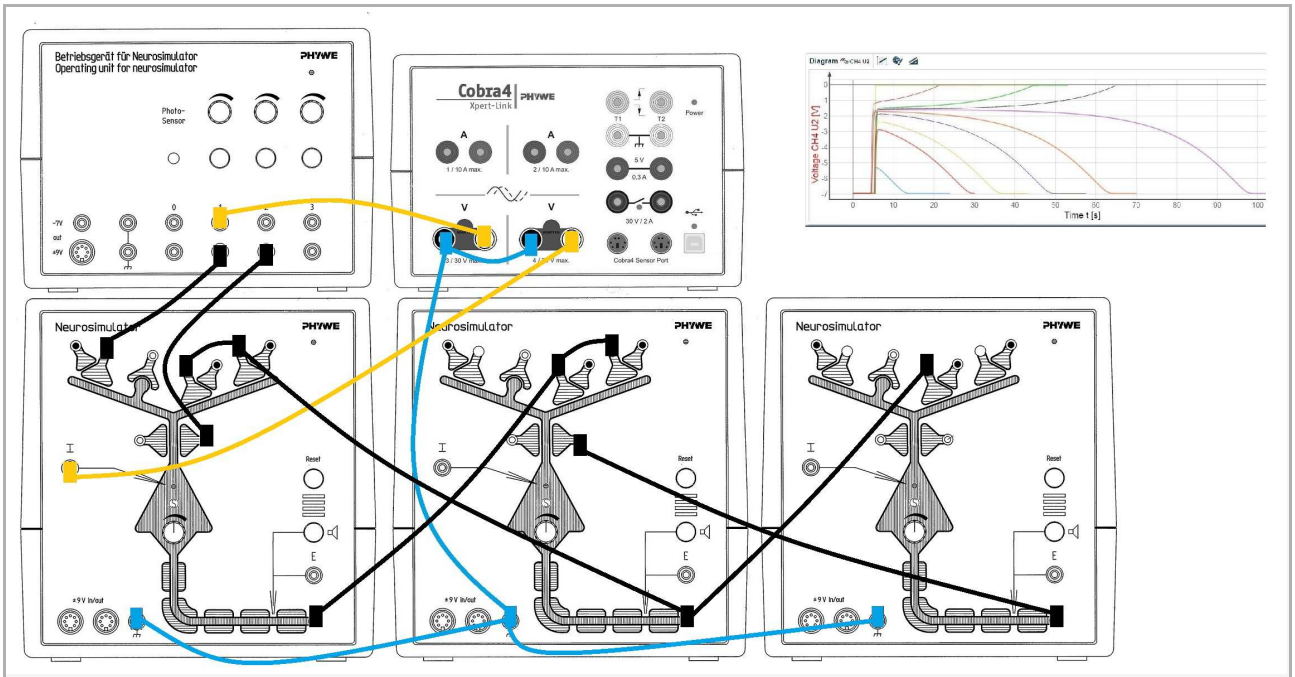


Fig. 13

This self-preserving excitation within a neural network is exemplary for short-term memory, because a stimulus is retained for some time within this network.
Neurosimulators 1 (on the left) and 2 (in the middle) form a positive feedback loop, i.e. once a short stimulus has been inititated, the signal keeps being transmitted. The third Neurosimulator (on the right) acts as an inhibiting interneuron for Neurosimulator 2.
This setup permits studying several variations, by changing stimulus intensity and threshold levels of neurons 1 or 2 and the inhibiting interneuron.

Set-up and procedure

Notes: Each person presses the button specificly. To get similar signal duration, all parts of this experiment should be performed by the same person.

1. Rotating excitation variation: variation of stimulus duration

The experiment is set up as per Fig. 14.
Two BNC-adapters (plug/socket 4 mm) are needed for voltage measurement.

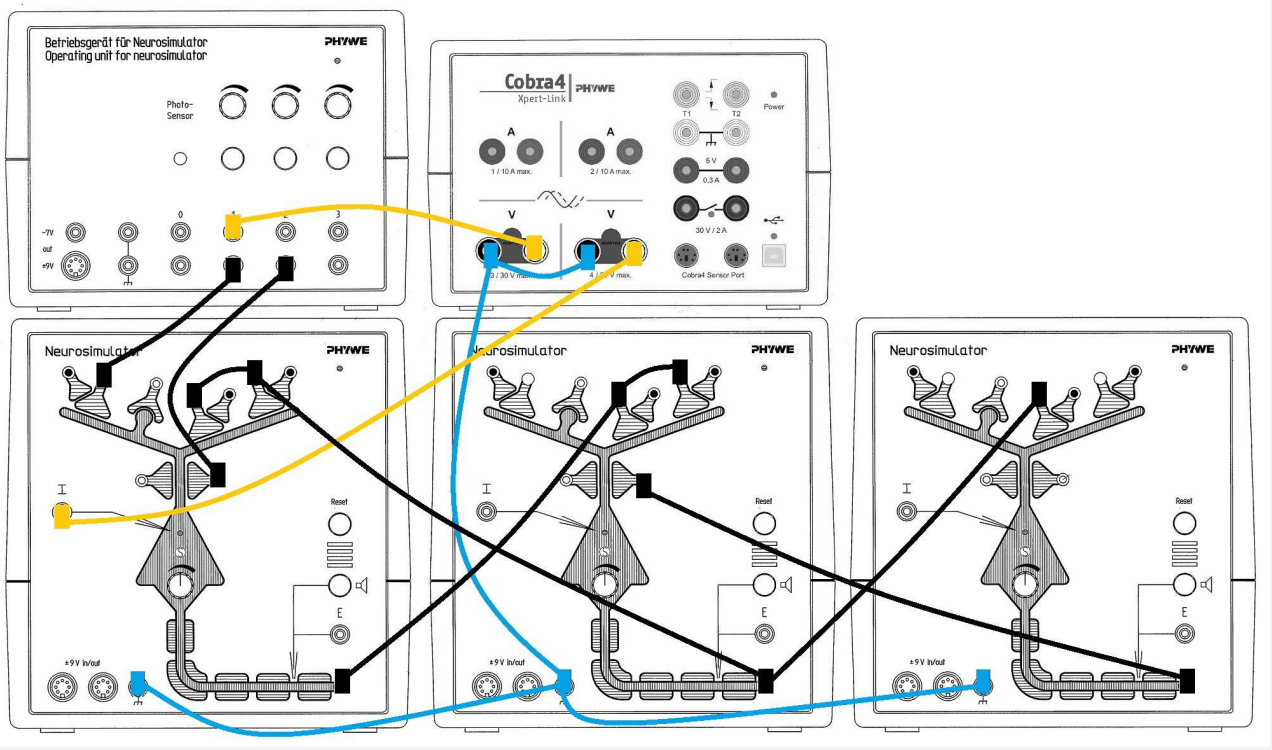
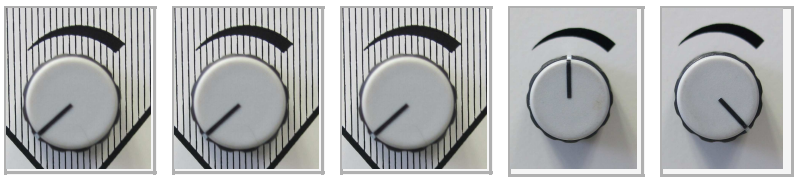


Fig. 14

- Neurosimulator 1, knob threshold: 0%
- Neurosimulator 2, knob threshold: 0%
- Neurosimulator 3, knob threshold: 0%
- Operating unit, knob stimulation intensity 1: 50%
- Operating unit, knob stimulation intensity 2: 100%



1.1. Convulsive excitation

- Start measurement in the measurement window.
- Press the stimulation button 1 approximately one second.
- Finish the measurement as soon as the voltage has reached the initial value.
- Stop the convulsive excitation by pressing the stimulation button 2.
- Save and evaluate the results.

1.2. Dampening

- Start measurement in the measurement window.
- Press the stimulation button 1 less than a second (very short tap, like on a hot stove).

- Finish the measurement as soon as the voltage has reached the initial value.
- Save and evaluate the results.

2. Rotating excitation variation: variation of stimulus intensity

- Start measurement in the measurement window.
- Press the stimulation button 1 less than a second (very short tap, like on a hot stove).
- Finish the measurement as soon as the voltage has reached the initial value. Save the results.
- Repeat the measurement several times. Change minimal the signal intensity for each mesurement: turn minimal the knob for stimulation intensity 1, both directions are possible. Aim is to get diagrams with convulsive excitation and with dampening.
- Save every time the results and evaluate them. Before each measurement stop the convulsive excitation by pressing the stimulation button 2.

3. Rotating excitation variation: variation of threshold, equilibrium

Change settings of the threshold knob at the Neurosimulator 3 on 16% (Fig. 15). Neurosimulator 3 is equivalent to inhibitory neuron.

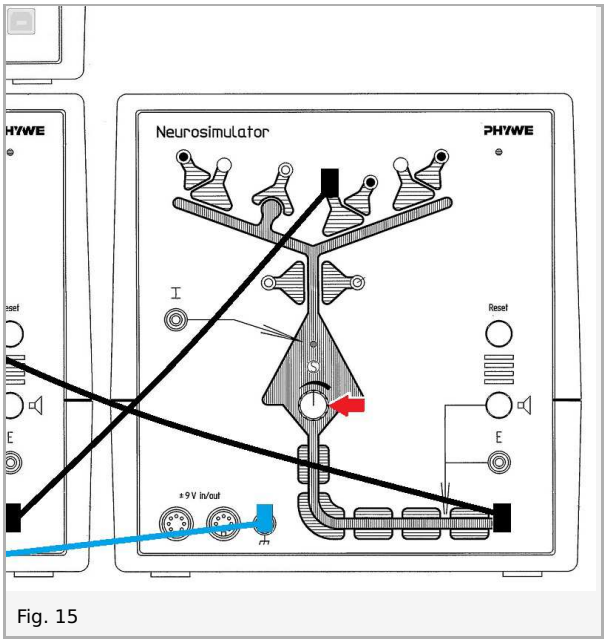
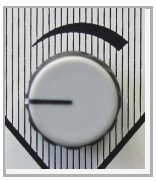


Fig. 15



- Start measurement in the measurement window.
- Press the stimulation button 1 less than a second (very short tap, like on a hot stove).
- By modifying the firing threshold of the inhibitory interneuron (Neurosimulator 3) during the measurement, an equilibrium between the effects of the positive feedback of the neuron-neuron cycle (Neurosimulators 1 and 2) and the negative feedback of the interneuron can be retained (see results).
- Finish the measurement and save the results.

Results and evaluation

1. Rotating excitation variation: variation of stimulus duration

1.1. Convulsive excitation

First example for convulsive excitation:

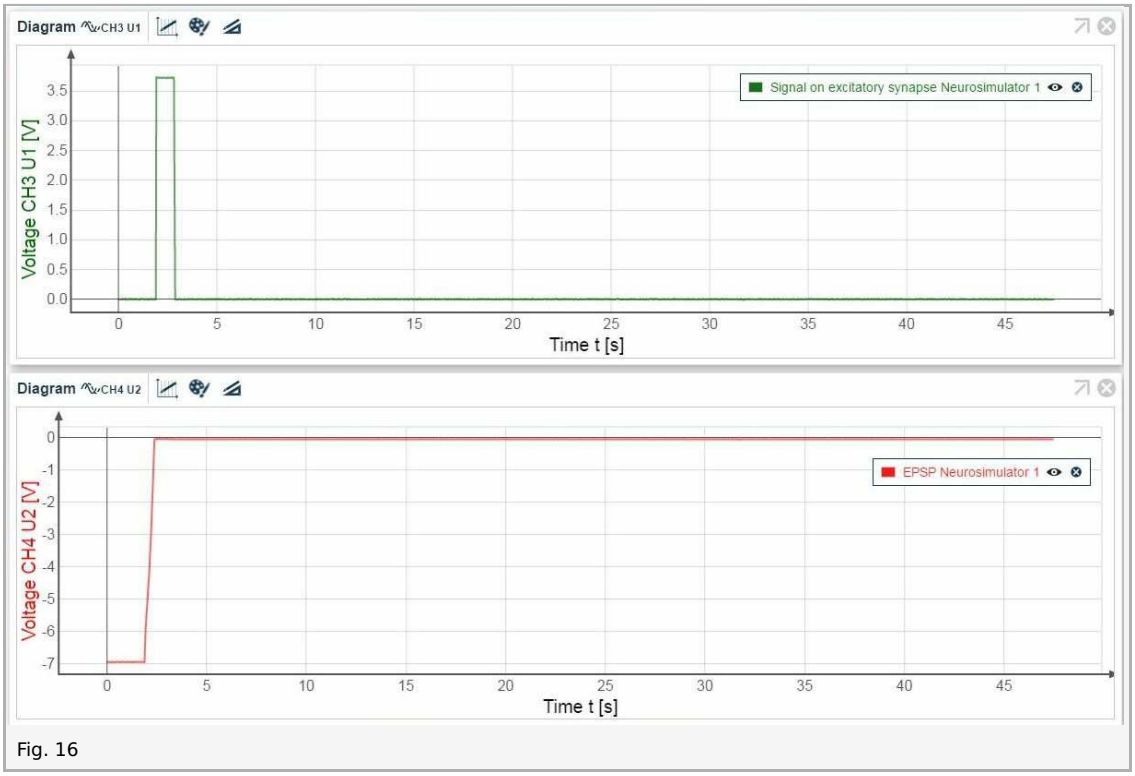


Fig. 16

Second example for convulsive excitation:

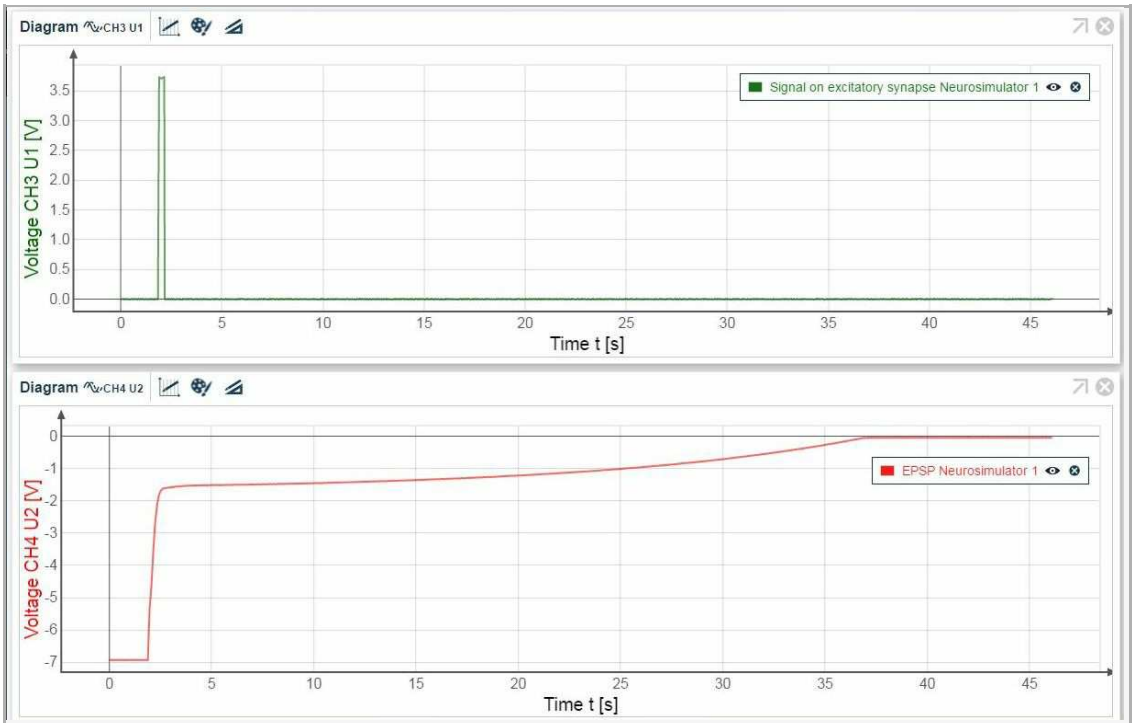


Fig. 17

1.2. Dampening

Example for dampening:

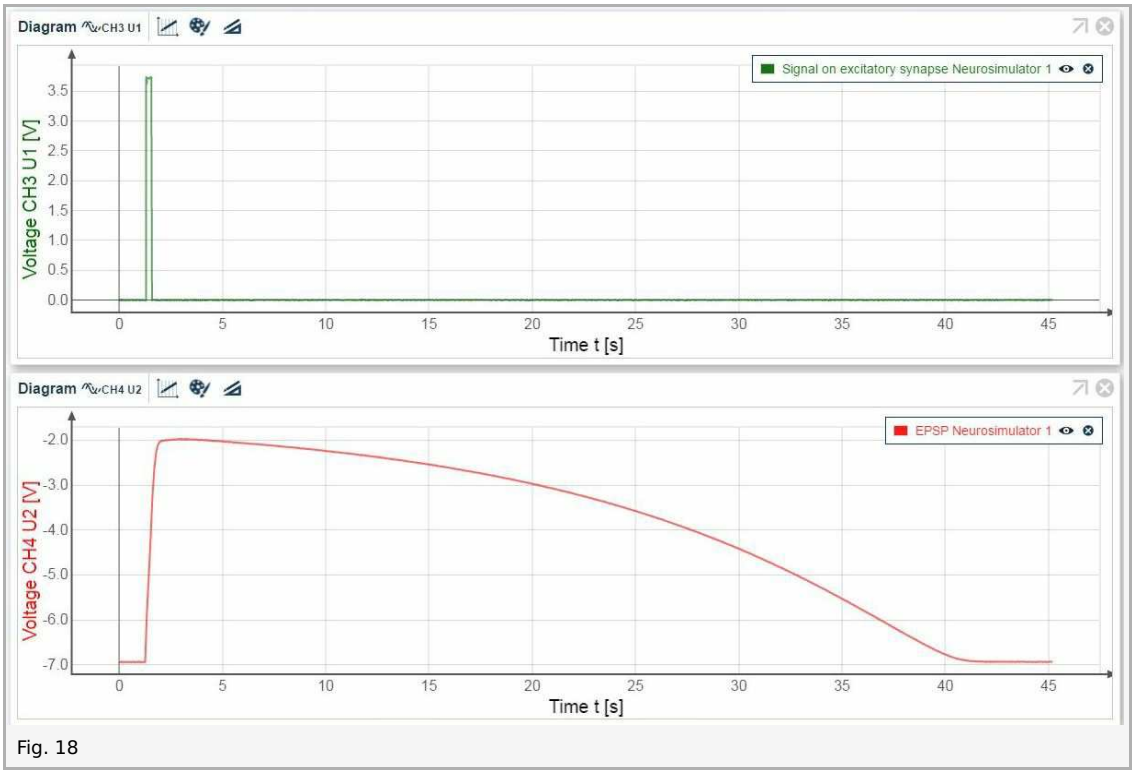


Fig. 18

2. Rotating excitation variation: variation of stimulus intensity

Examples of convulsive excitation and dampening using different stimulus intensity.
Hint: The most convenient way to read the values (signal intensity U_{max} and duration $t = t_2 - t_1$) is when you use the mouse pointer. Move the mouse pointer along the graph line, as shown in Fig. 17.

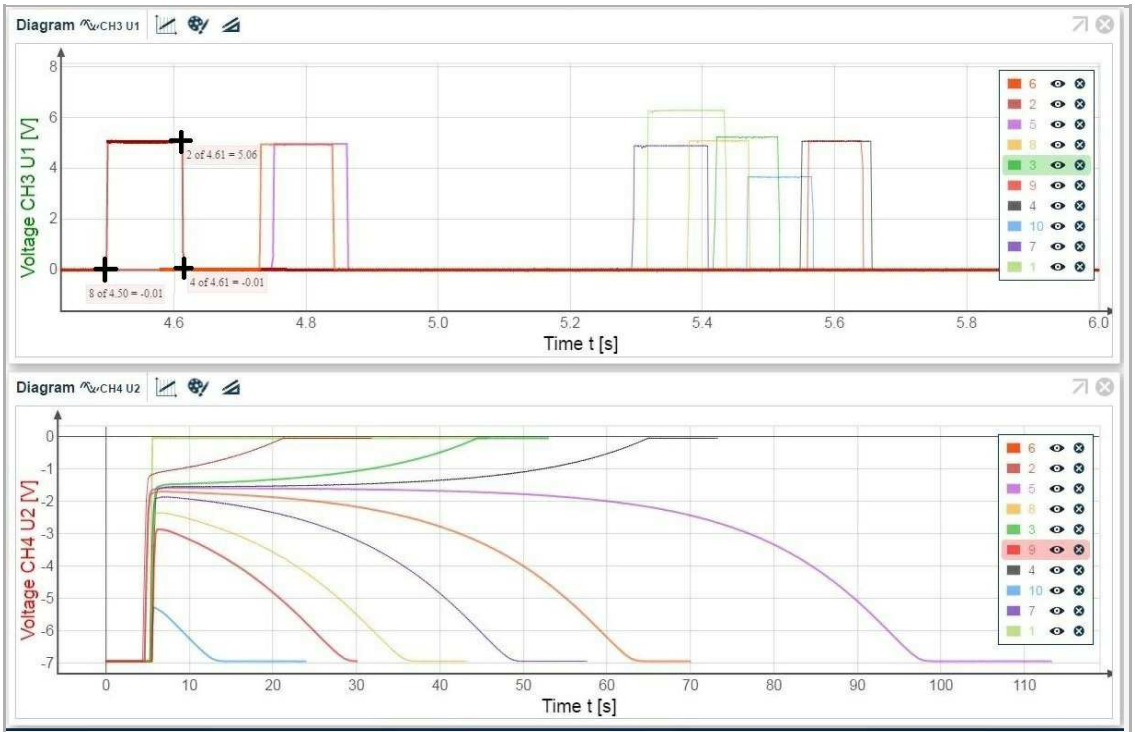


Fig. 19

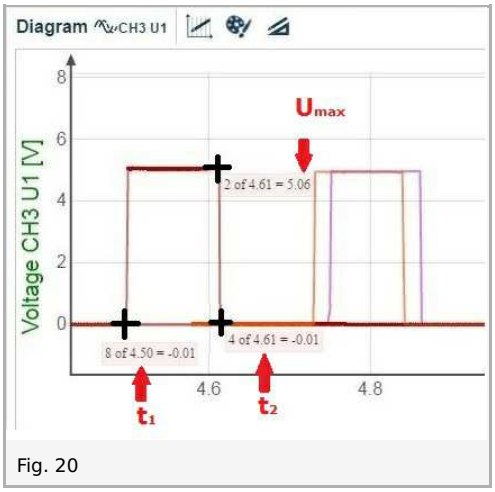


Fig. 20

Examples of different rotating excitation depending on signal intensity and duration:

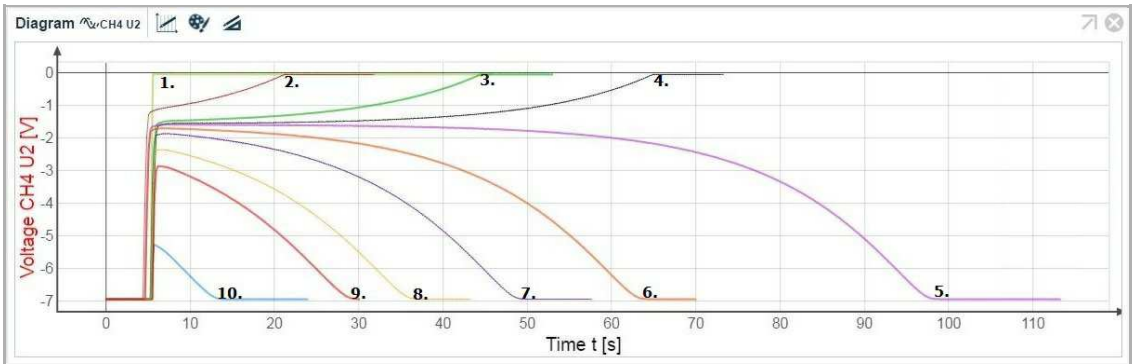


Fig. 21

Number	signal intensity U_{max}	signal duration $t_2 - t_1$	convulsive excitation	dampening
1.	6.28	0.12	x	
2.	5.05	0.11	x	
3.	5.24	0.10	x	
4.	5.09	0.11	x	
5.	4.96	0.11		x
6.	4.95	0.11		x
7.	4.89	0.11		x
8.	5.08	0.09		x
9.	5.09	0.08		x
10.	3.65	0.10		x

3. Rotating excitation variation: variation of threshold, equilibrium

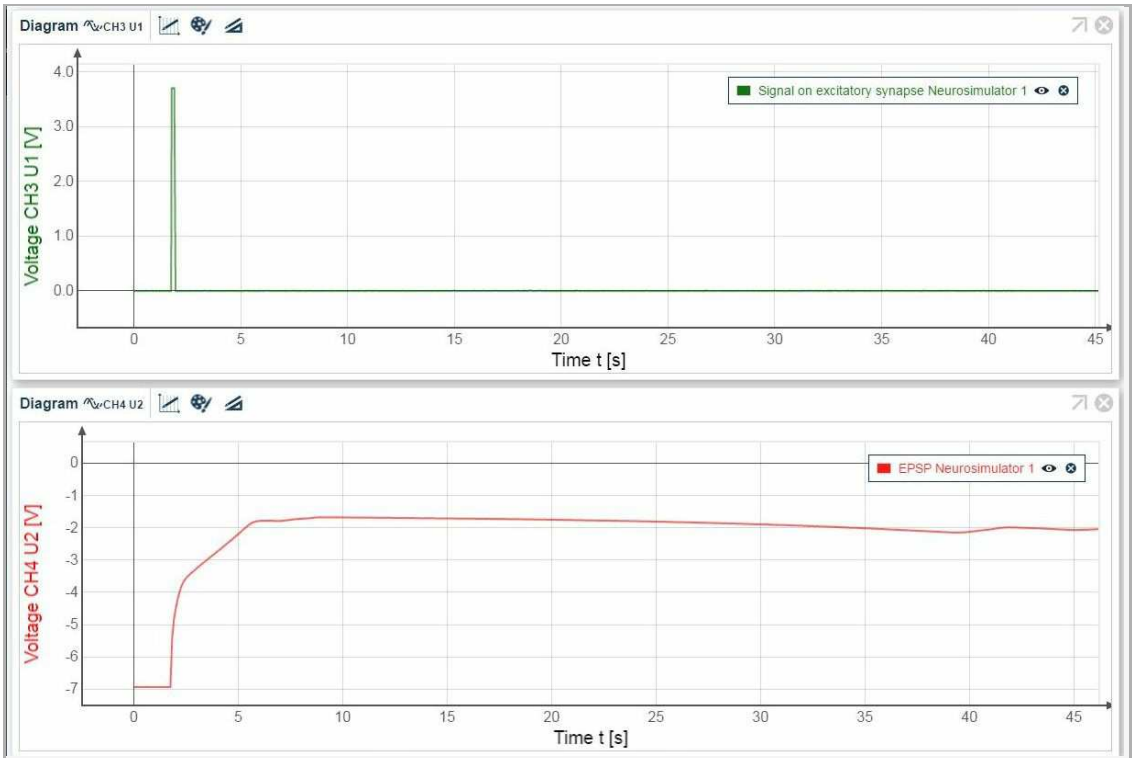


Diagram CH3 U1
Signal on excitatory synapse Neurosimulator 1
Voltage CH3 U1 [V]
4.0
3.0
2.0
1.0
0.0
0
5
10
15
20
25
30
35
40
45
Time t [s]
Diagram CH4 U2
EPSP Neurosimulator 1
Voltage CH4 U2 [V]
0
-1
-2
-3
-4
-5
-6
-7
0
5
10
15
20
25
30
35
40
45
Time t [s]

Fig. 22

Cerebral cortex and sensoric learning

Introduction

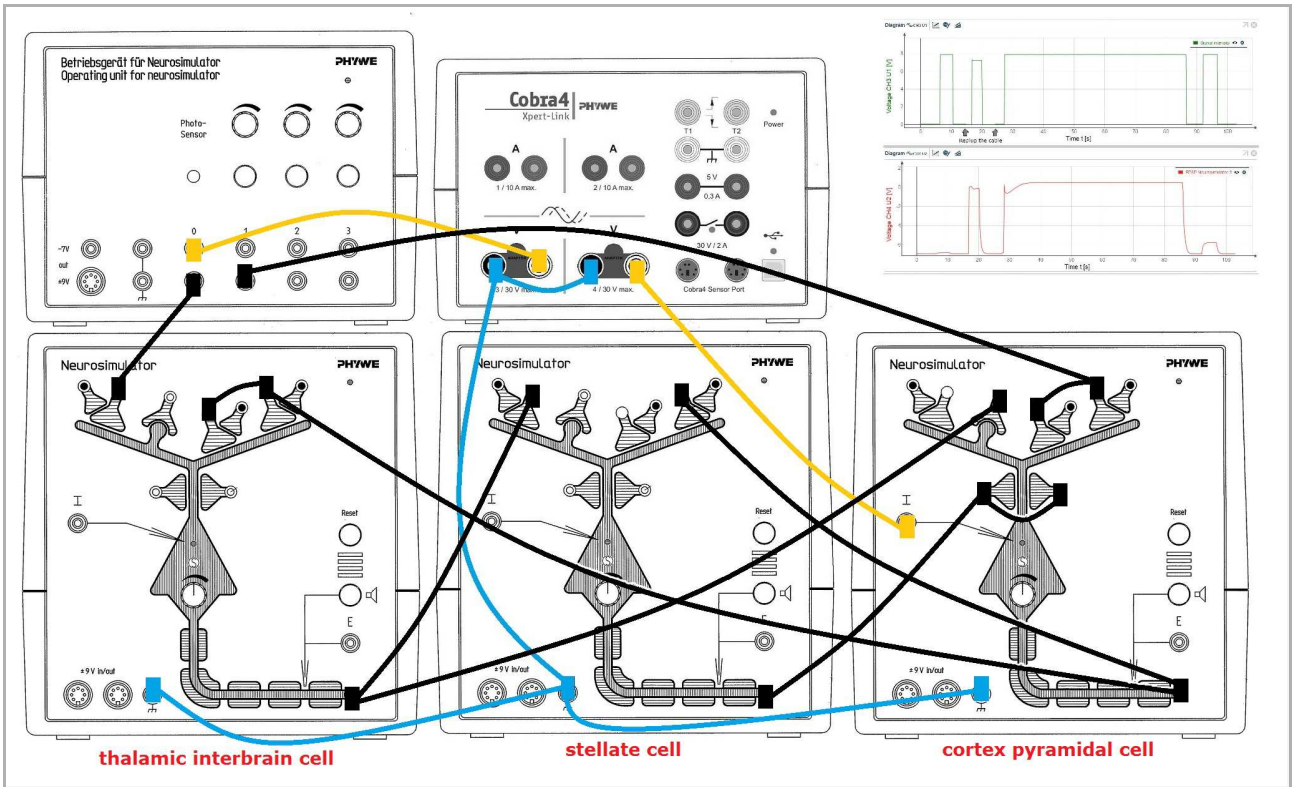


Fig. 23

This experiment shows that a cortex pyramidal cell can only then respond stimulus-specifically, when it has learned this by means of a preceding correlation of the sensory signal with a non-specific alerting signal. In this way only important signals are stored and processed, and "overloading" of the cerebral cortex is avoided.

The optical channel (photosensor) provides the specific signal of a sense organ which excites a thalamic interbrain cell, which in turn excites the Hebbian synapse of a cortex pyramidal cell. The cortex pyramidal cell is also stimutalated by an unspecific stimulus (channel 1). At the same time a stellate cell inhibits the pyramidal cell. These three cell types make up the triad.

The processing of sensory signals and their association to motoric programmes occurs in the cerebral cortex of mammals. In addition, the storing of experience takes place here. In an early stage of development, the cerebral cortex is in a diffuse, unformed condition, in which signal processing does not function with the precision that it does in the adult organism. This ability is only slowly acquired in active involvement with the environment. Stimulus processing is also a result of plastic adaption. Coincidence between different stimulations is always necessary hereby, to reach a cortical pyrimidal cell and to stabilize synapses of Hebb’s type there by sustained potentiation.

Set-up and procedure

The experiment is set up as per Fig. 24. Two BNC-adapters (plug/socket 4 mm) are needed for voltage measurement.

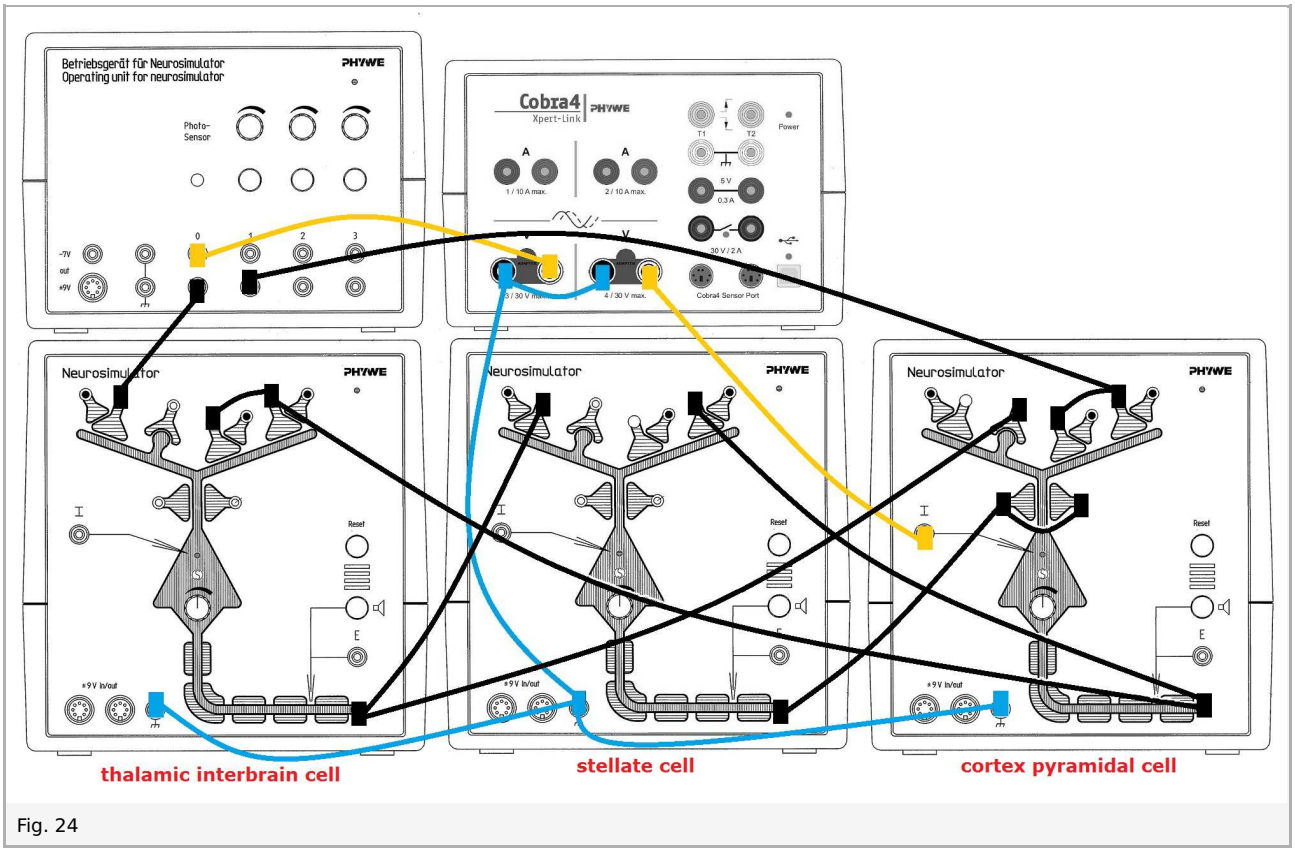
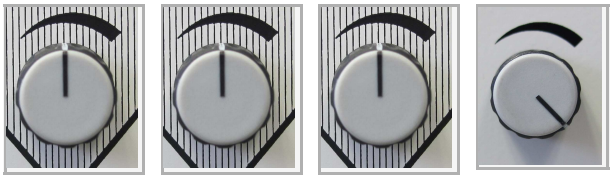


Fig. 24

- Neurosimulator 1, knob threshold: 50%
- Neurosimulator 2, knob threshold: 50%
- Neurosimulator 3, knob threshold: 50%
- Operating unit, knob stimulation intensity 1: 100%



- To set Hebbian synapse to default, press the reset button on Neurosimulator 3 (cortex pyramidal cell).
- Start measurement in the measurement window.
- Cover the photosensor for 3 second. Wait until the voltage has reached the initial value.
- Replug the yellow cable on chanel 1 (red arrow, Fig. 25).

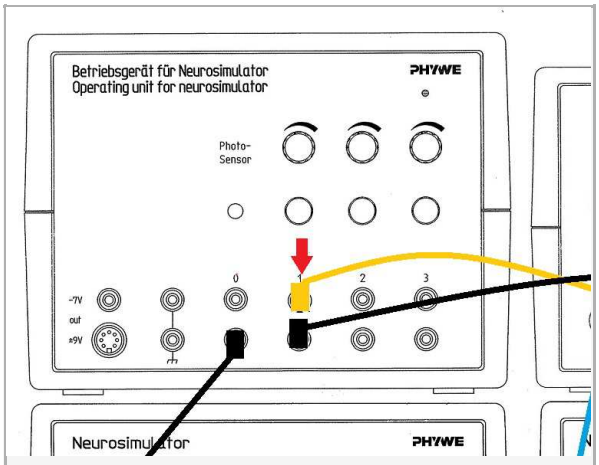


Fig. 25

- Press the stimulation button 1 for 3 seconds. Wait until the voltage has reached the initial value.
- Replug the yellow cable on photosensor (red arrow, Fig. 26).

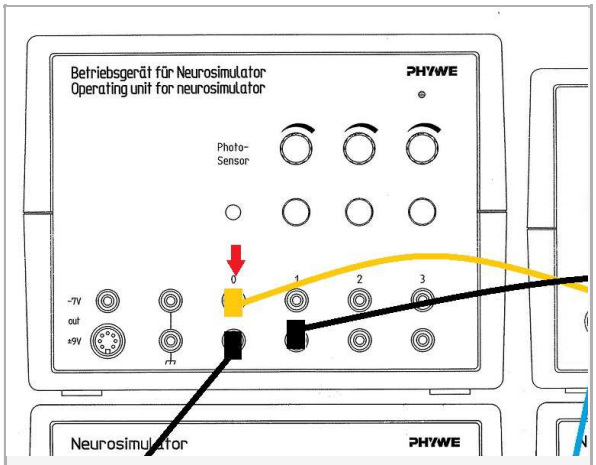


Fig. 26

- Cover the photosensor and press the stimulation button 1 (simultaneously) for 60 seconds. Wait until the voltage has reached the initial value.
- Cover the photosensor for 3 second. Wait until the voltage has reached the initial value.
- Finish the measurement, save and evaluate the results.
- To set Hebbian synapse to default, press the reset button on Neurosimulator 3 (cortex pyramidal cell).

Results and evaluation

The course of the graph for signal intensity depends on the brightness in the room:

- Example 1: It is cloudy outside.
- Example 2: It is sunny outside.
- Example 3: Photosensor is illuminated with flashlight.

The results for EPSP are the same.

Example 1: It is cloudy outside.

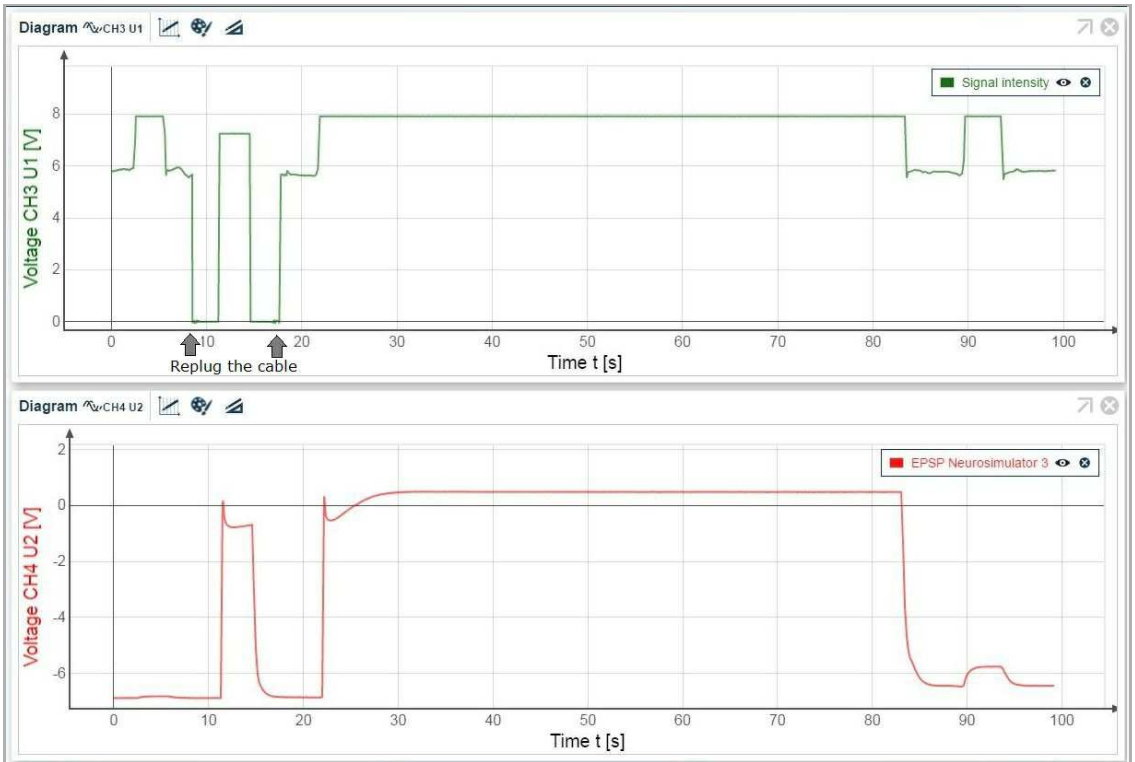


Fig. 27

Example 2: It is sunny outside.

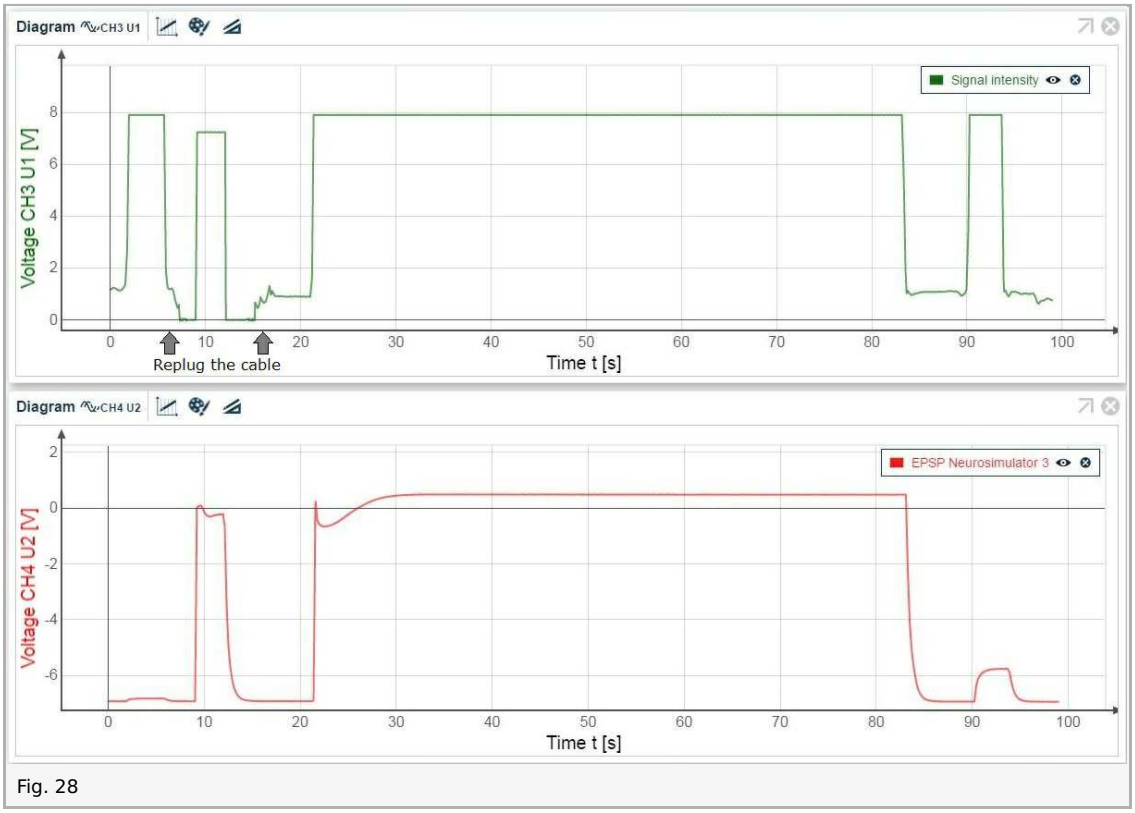


Fig. 28

Example 3: Photosensor is illuminated with flashlight.

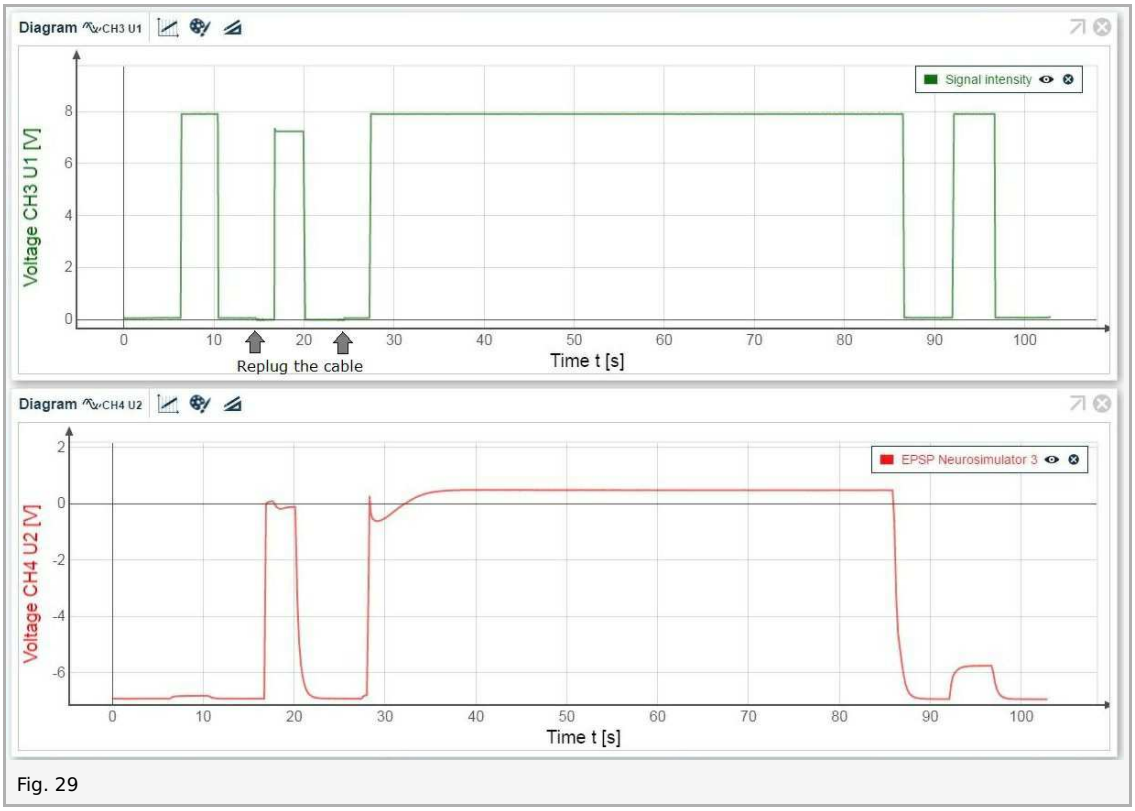


Fig. 29

In all cases, the results are the same:
A cortex pyramidal cell (Fig. 30, area 1.) can only then respond stimulus-specifically (area 4.), when it has learned this by means of a preceding correlation of the sensory signal with a non-specific alerting signal (area 3.).

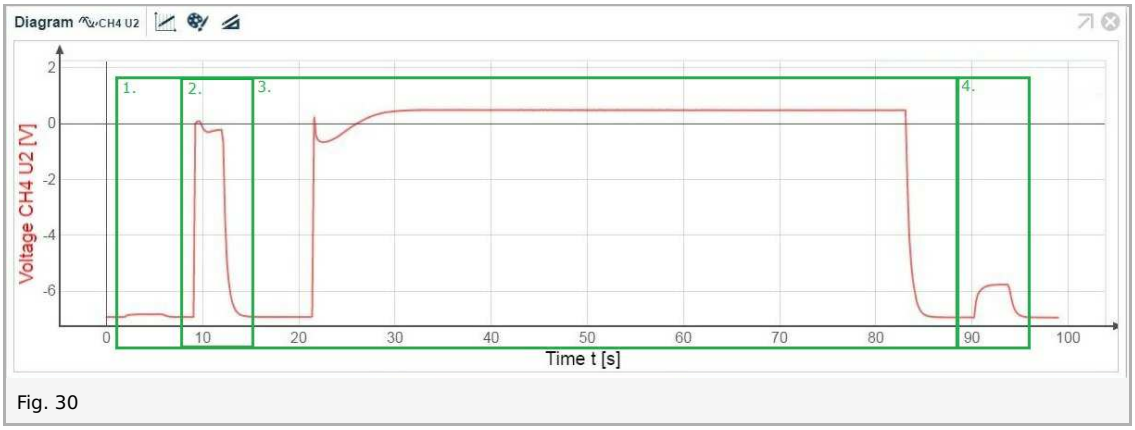


Fig. 30

Direction selectivity by unilateral inhibition

Introduction

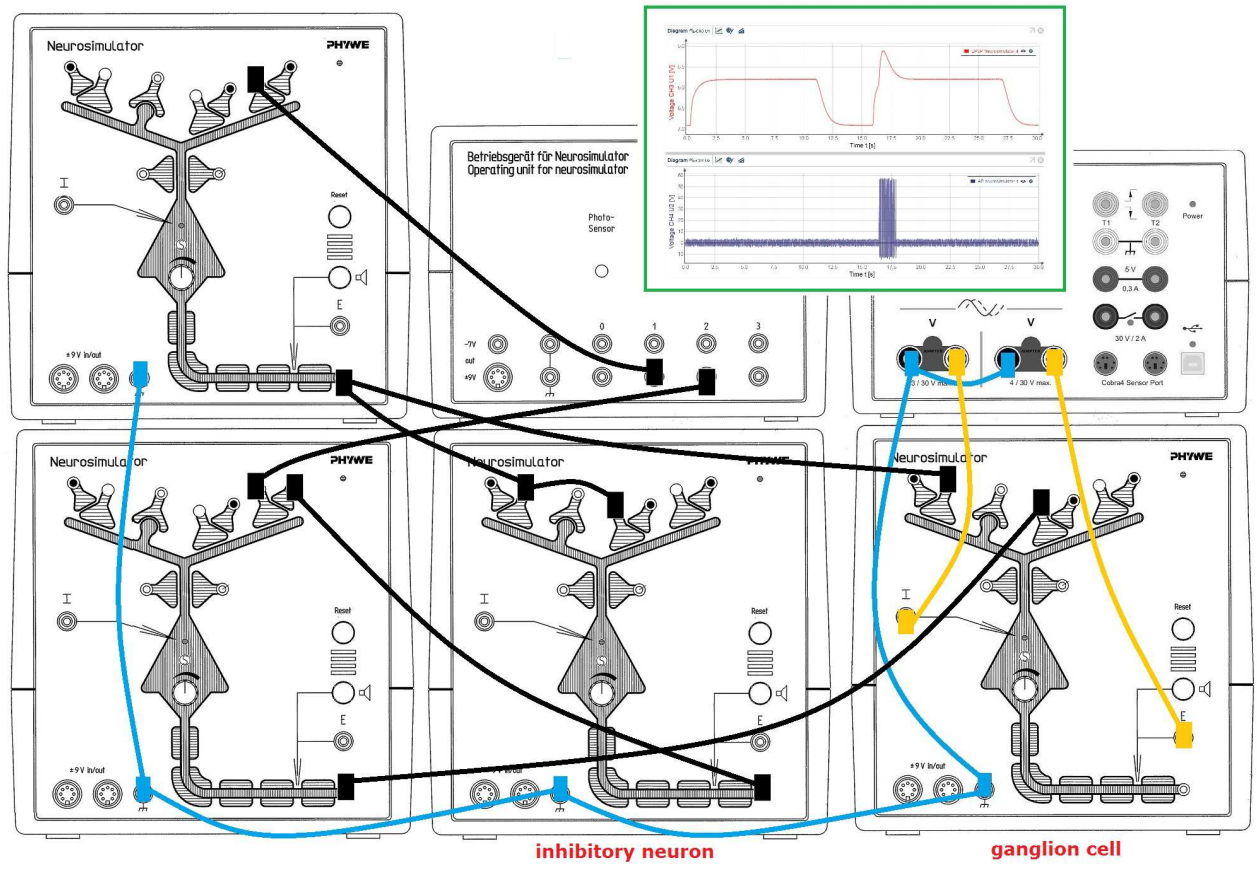


Fig. 31

Examples: many nerve cells in sensory systems are direction-selective. E.g., certain ganglion cells in the retina respond only when a light stimulus moves in a certain direction but not, however, by movements in the reverse direction. Similar behavior is also known for the sense of touch.
This neuronal circuit can be simulated using a circuit with unilateral inhibition between two stimulus channels which are activated successively.

Local projection sense organs, e.g. the retina of the eye or the body surface with its touch receptors, are basically capable of coding movements (changes in position in time). One correspondingly also actually finds, in these sense channels, neurons that selectively address stimulus movements (see also On-off response). Some of these cells do not simply react to any movement, but respond only to certain movement directions, while other directions remain unanswered. Their response intensity is as a rule a function of the rate of movement, the direction of movement and - mostly to a low extent - the intensity of the moved stimulus.
Such cells are to be found already in the retina of most vertebrates, but only in a few of them on a higher processing level (e.g. anthropoidea).

Set-up and procedure

The experiment is set up as per Fig. 32. Two BNC-adapters (plug/socket 4 mm) are needed for voltage measurement.

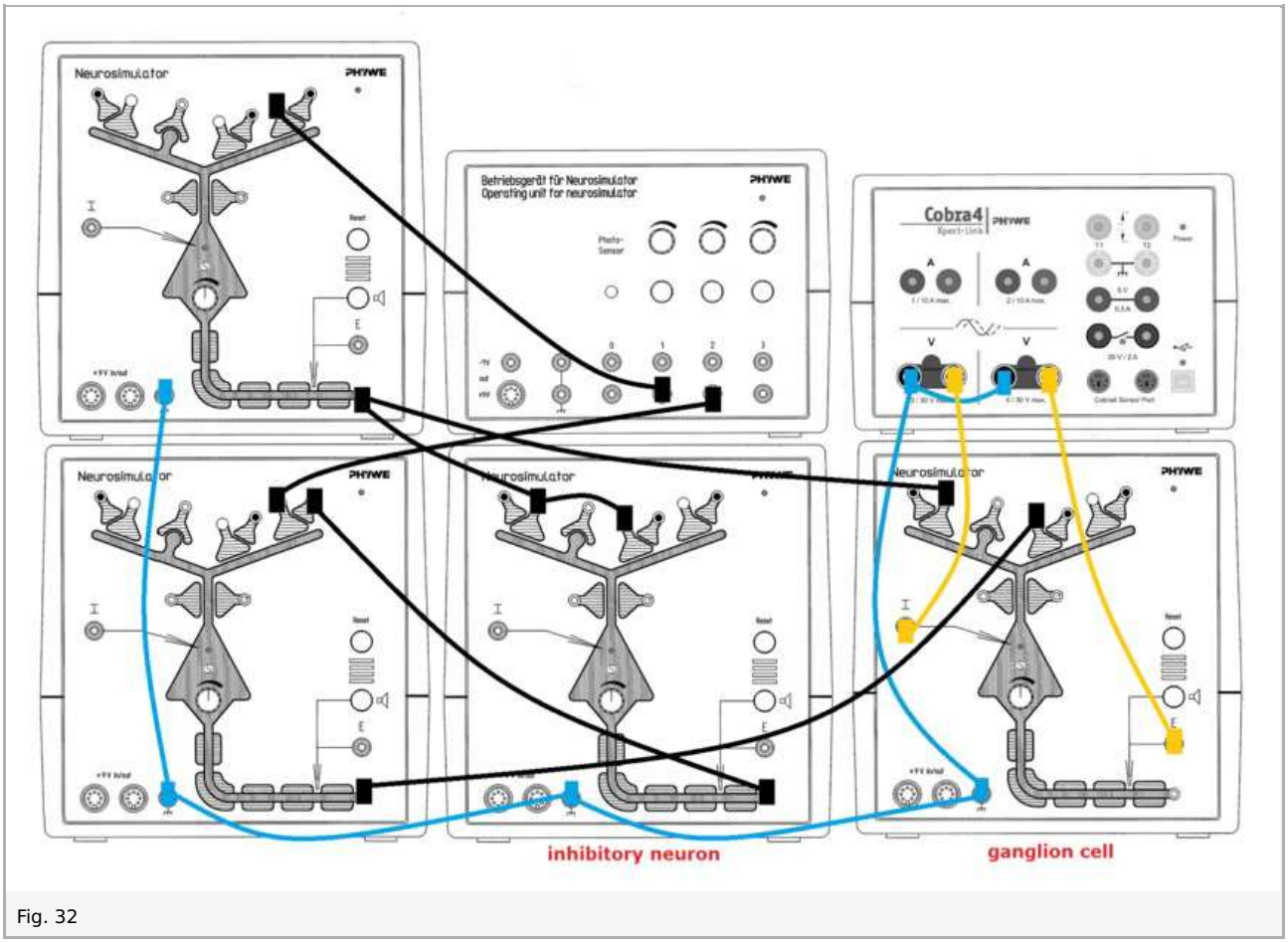
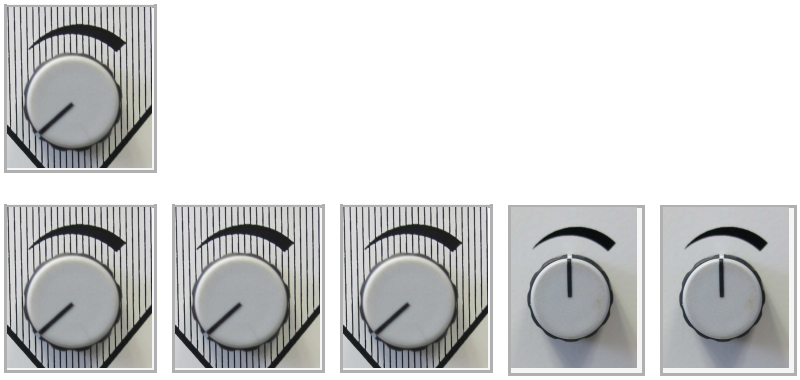
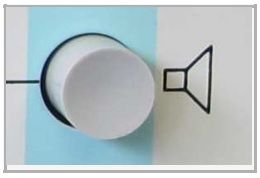


Fig. 32

- Neurosimulator 1, knob threshold: 0%
- Neurosimulator 2, knob threshold: 0%
- Neurosimulator 3, knob threshold: 0%
- Neurosimulator 4, knob threshold: 0%
- Operating unit, knob stimulation intensity 1: 50%
- Operating unit, knob stimulation intensity 2: 50%



- Only acoustic monitor of ganglion cell (Neurosimulator 4) is switched on.



- Next, by sending a stimulus only from stimulus channel 1, increase threshold level of the ganglion cell so that no action potential is audible (acoustic monitor of ganglion cell). Check if action potential is audible when stimulus channel 2 is activated. There should not be an acoustic signal as well.

Part 1.

- Start measurement in the measurement window.
- Press the stimulation **button 1** and immediately after that (nearly simultaneous) press the stimulation button 2.
- Finish the measurement. Save and evaluate the results.

Part 2.

- Start measurement in the measurement window.
- Press the stimulation **button 2** and immediately after that (nearly simultaneous) press the stimulation button 1.
- Finish the measurement. Save and evaluate the results.

Results and evaluation

Results

Part 1.

No action potential (AP) is generated.

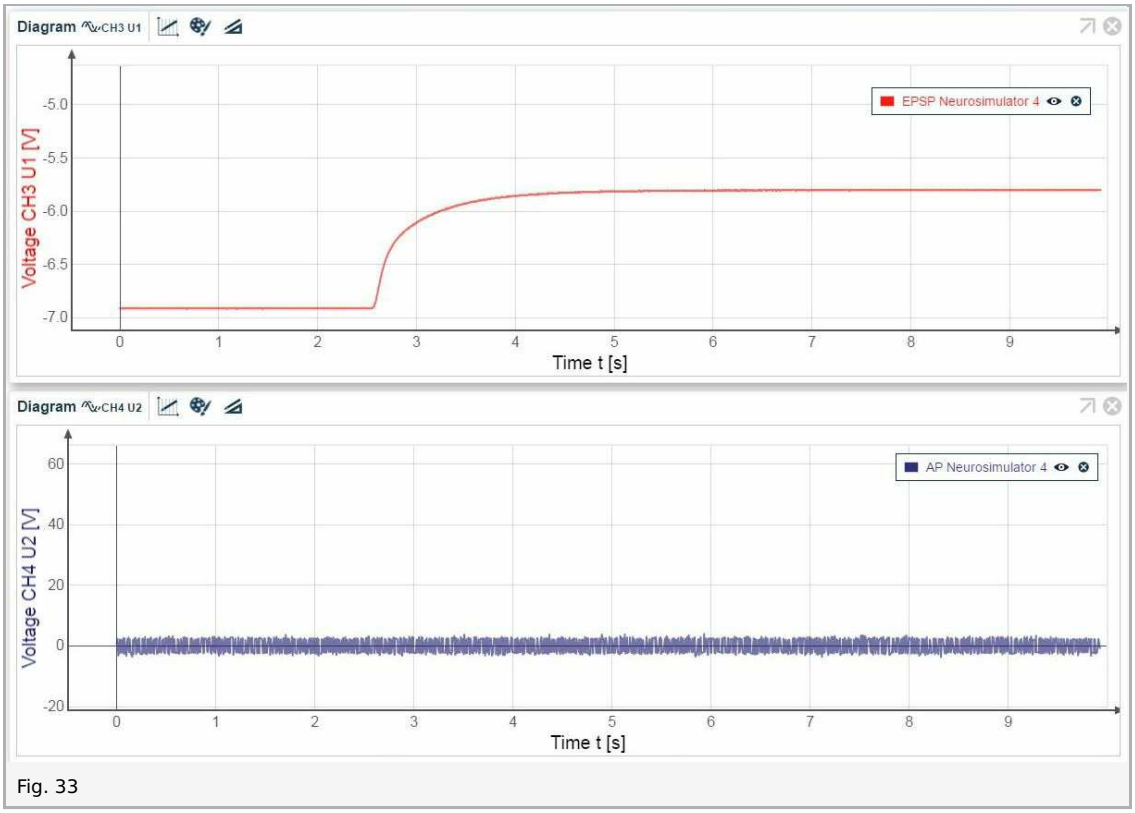


Fig. 33

Part 2.

Action potential (AP) is generated.

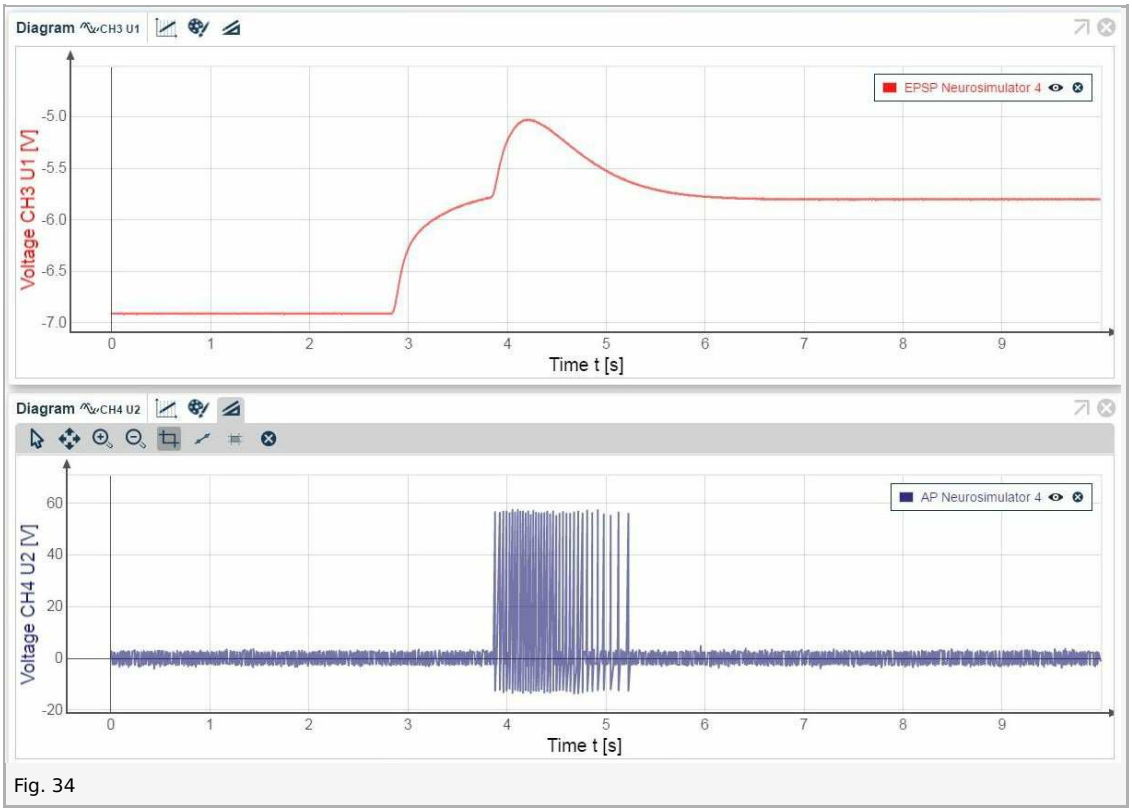


Fig. 34

Results at different settings

Different settings in measureLAB can be used depending on the used computer. The result is always clear, but the quality of the diagram depends on the settings.

1. Example 3: Measurement at 10 kHz (low quality)
2. Example 3: Measurement at 50 kHz
3. Example 3: Measurement at 100 kHz (high quality)

Example 1: Measurement at 10 kHz.

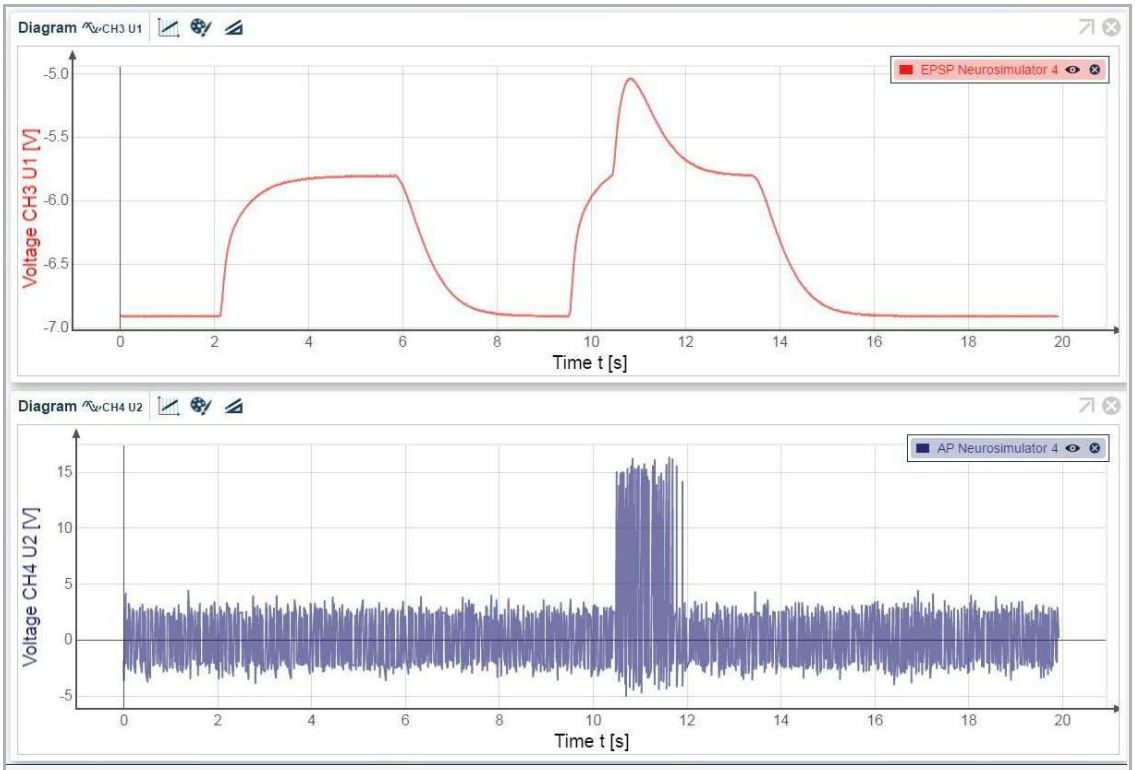


Fig. 35

Example 2: Measurement at 50 kHz.

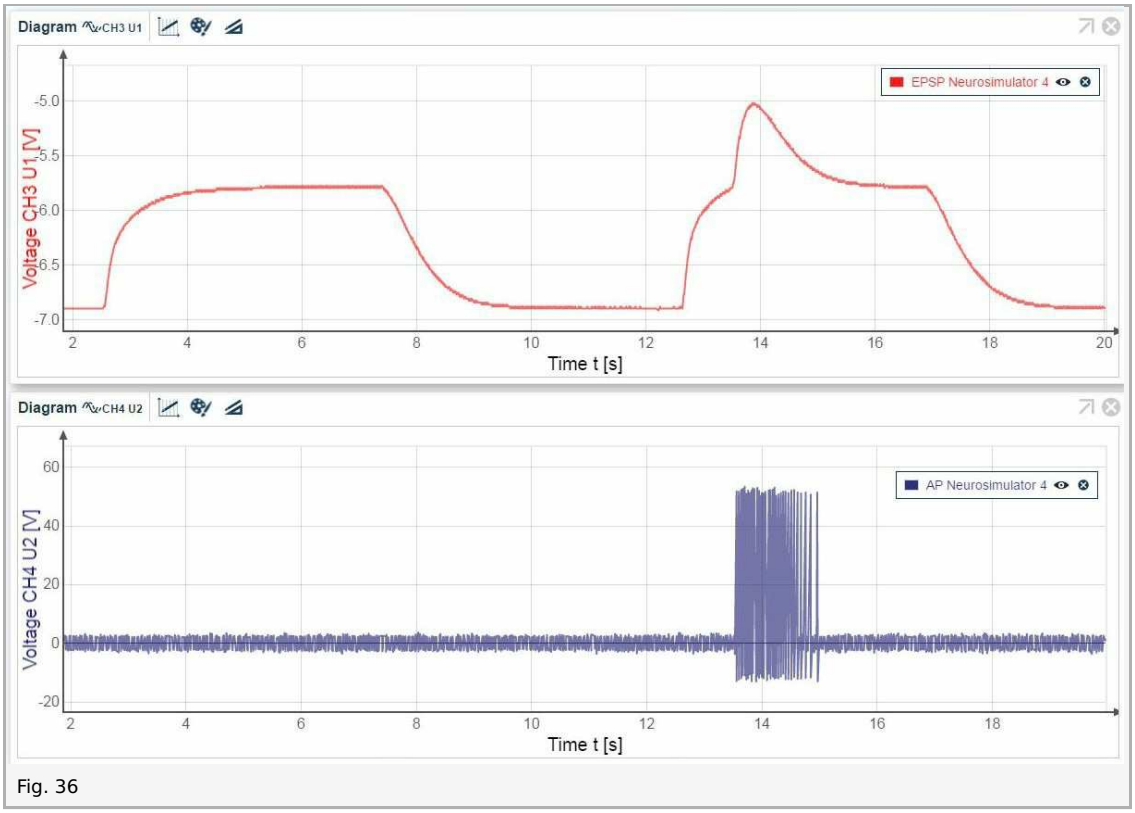


Fig. 36

Example 3: Measurement at 100 kHz.

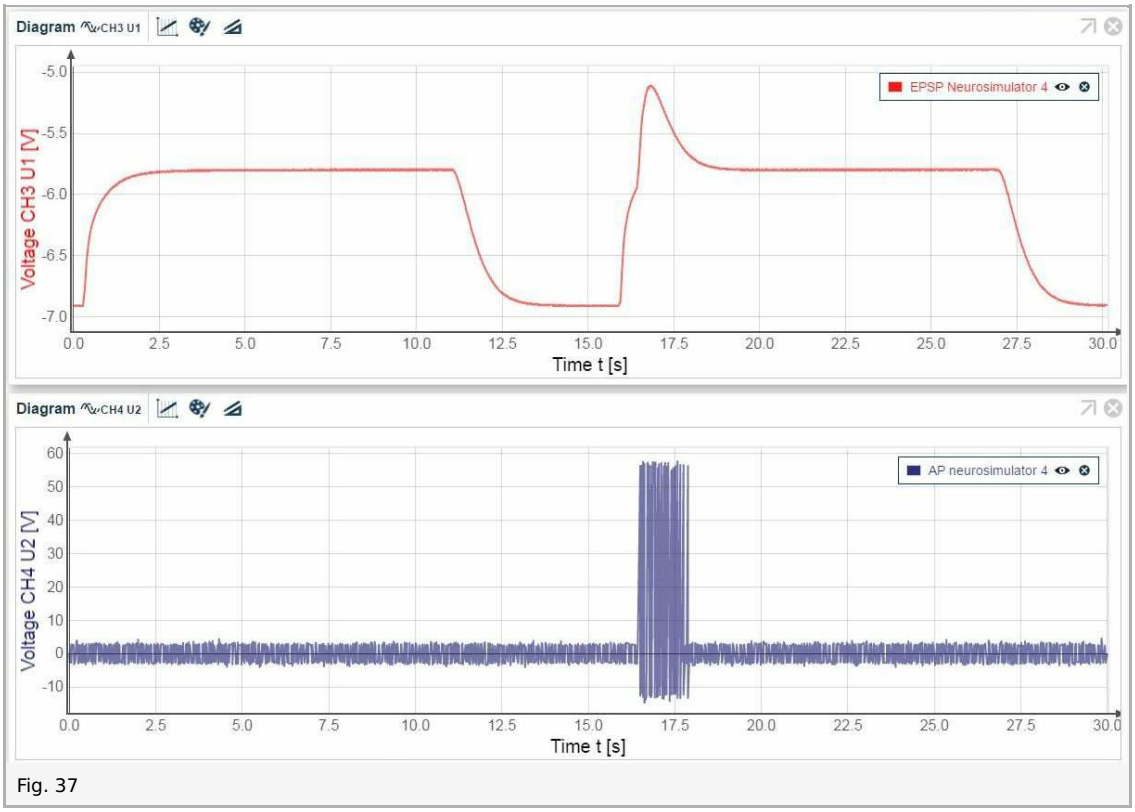


Fig. 37

Measurement at 100 kHz: enlarged area of AP.

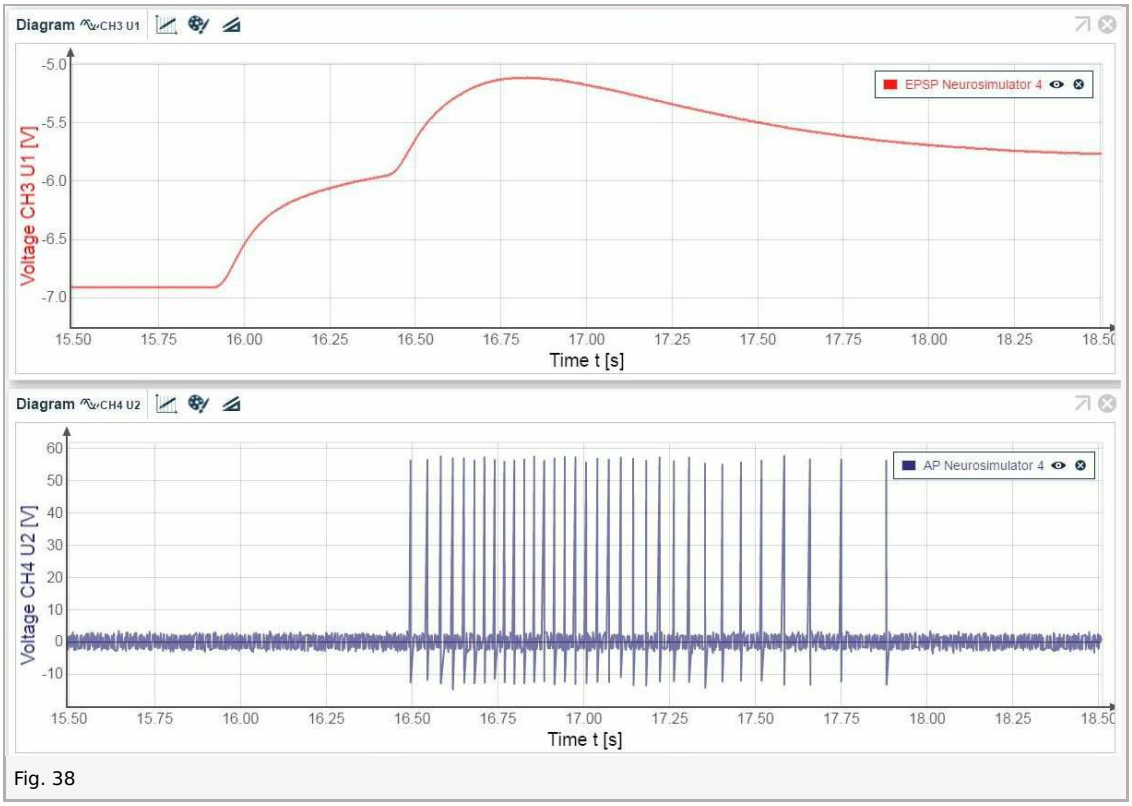


Fig. 38

Self-calibration of paired sensory channels

Introduction

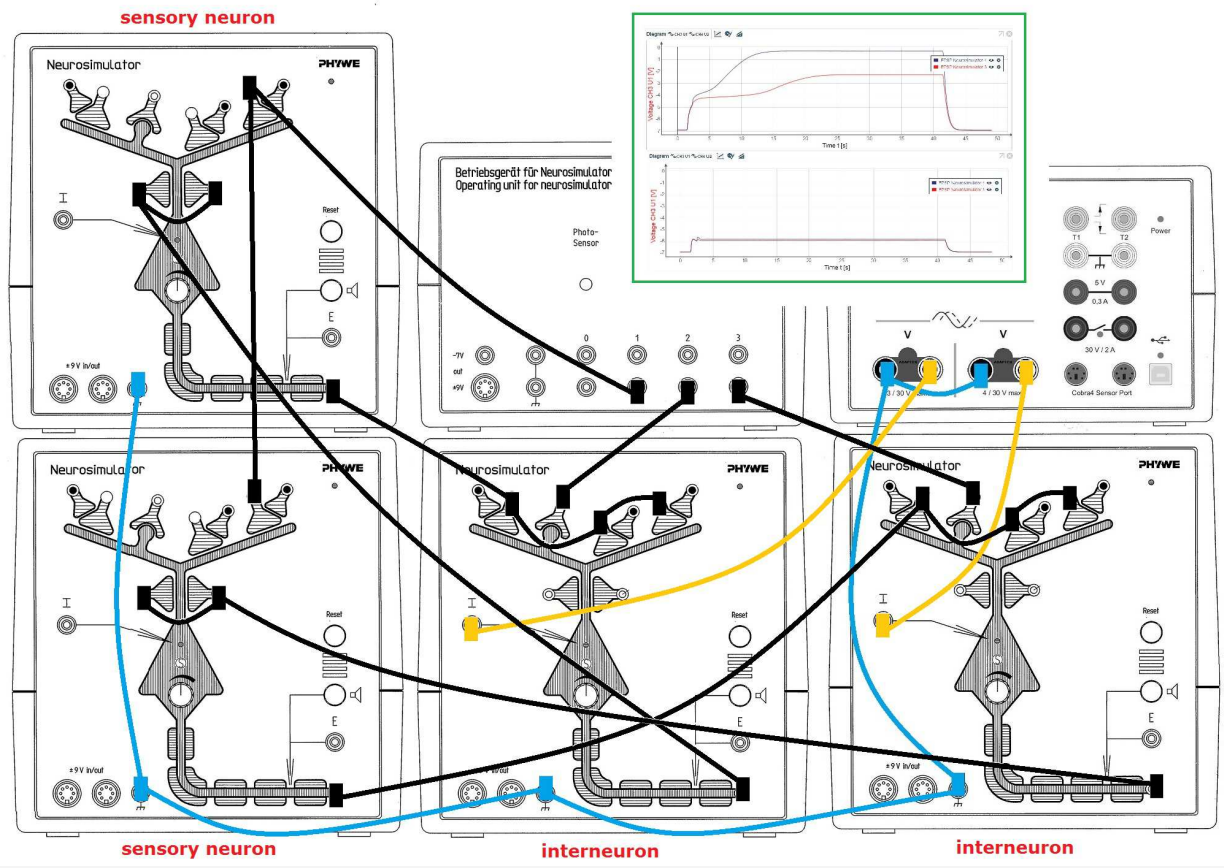


Fig. 39

Example: embryonal formation of axis-symmetrical species is not perfect, resulting in slight irregularities of the symmetry. Irregularities of sensory epithelia, e.g. in the equilibrium organ, can be compensated by the nerve system: Hebbian principle offers the possibility to adjust the output signals so that they are symmetrical when the sensory organs are asymmetrical.

Experimental setup: There are two sensory neurons and two interneurons (two sensory neuron-interneuron pairs). Asymmetric signals are sent to the Hebbian synapses of the two sensory neurons. A signal generated by the photosensor of the operating unit is sent to the two interneurons, which forward the signal through their efferent axon to their sensory neuron partner where the signal is amplified by branching the signal. Both sensory neurons inhibit their own interneurons.

Set-up and procedure

No self-calibration of paired sensory channels

The experiment is set up as per Fig. 40.
Two BNC-adapters (plug/socket 4 mm) are needed for voltage measurement.
Leave two cable unplugged (red arrows).

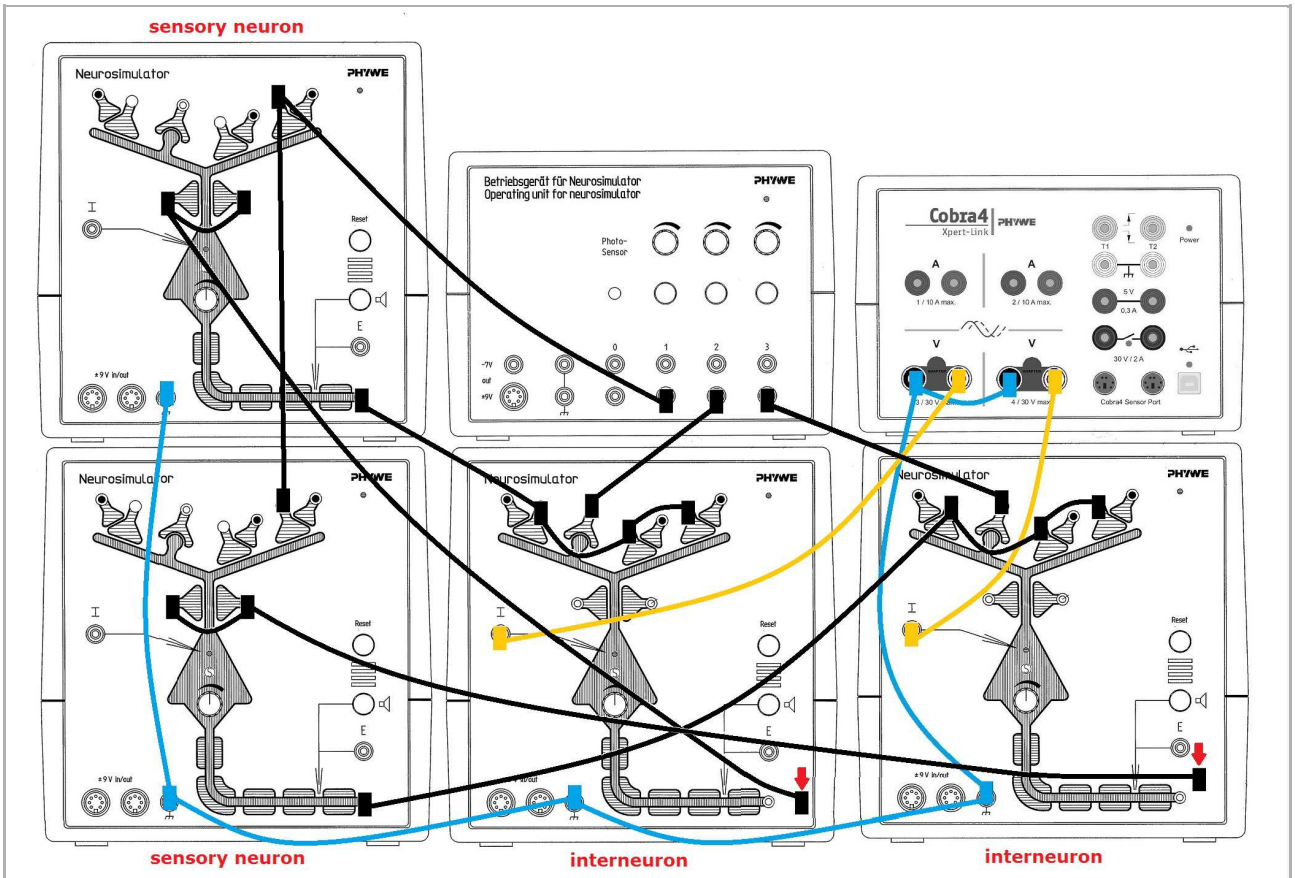
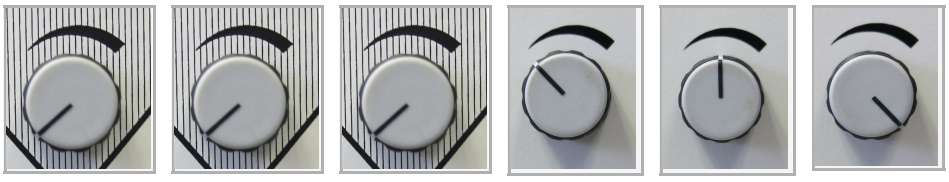


Fig. 40

- Neurosimulator 1, knob threshold: 0%
- Neurosimulator 2, knob threshold: 0%
- Neurosimulator 3, knob threshold: 0%
- Neurosimulator 4, knob threshold: 0%
- Operating unit, knob stimulation intensity 1: 33%
- Operating unit, knob stimulation intensity 1: 50%
- Operating unit, knob stimulation intensity 1: 100%



- Start measurement in the measurement window.
- Press the stimulation button 1, wait for 1-2 seconds and press additionally simultaneously buttons 2 and 3.
- Keep the three buttons pressed for approximately 40 seconds.
- Finish the measurement if the voltage has reached the initial value.

- Save and evaluate the results.

Self-calibration of paired sensory channels

Plug one loose cable back into the black socket (red arrows, Fig. 41).

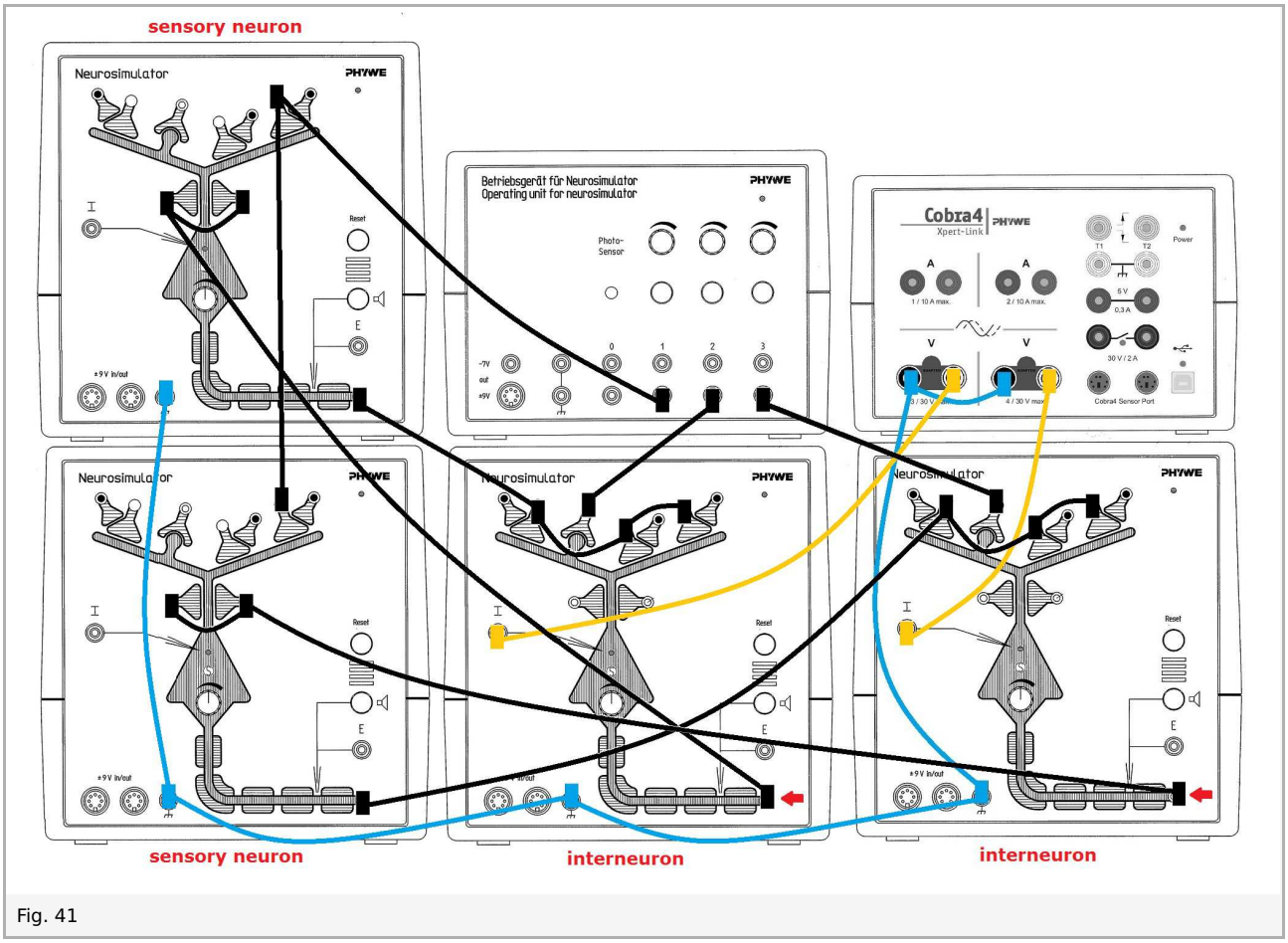


Fig. 41

- Start measurement in the measurement window.
- Press the stimulation button 1, wait for 1-2 seconds and press additionally simultaneously buttons 2 and 3.
- Keep the three buttons pressed for approximately 40 seconds.
- Finish the measurement if the voltage has reached the initial value.
- Save and evaluate the results.

Results and evaluation

No self-calibration of paired sensory channels

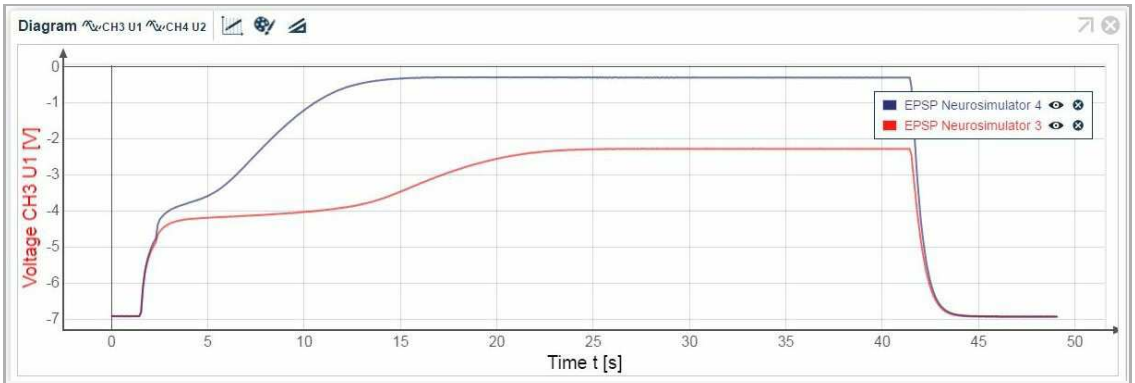


Fig. 42

Self-calibration of paired sensory channels

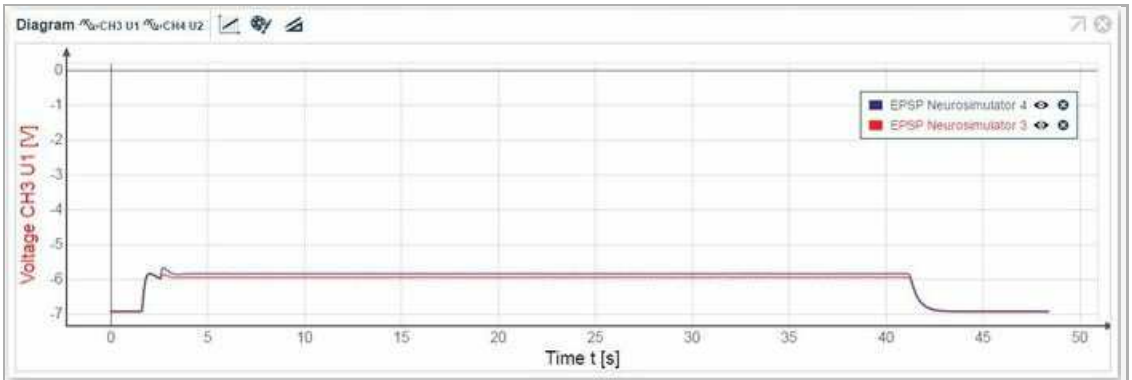


Fig. 43

Enlarged section: beginning of self-calibration.

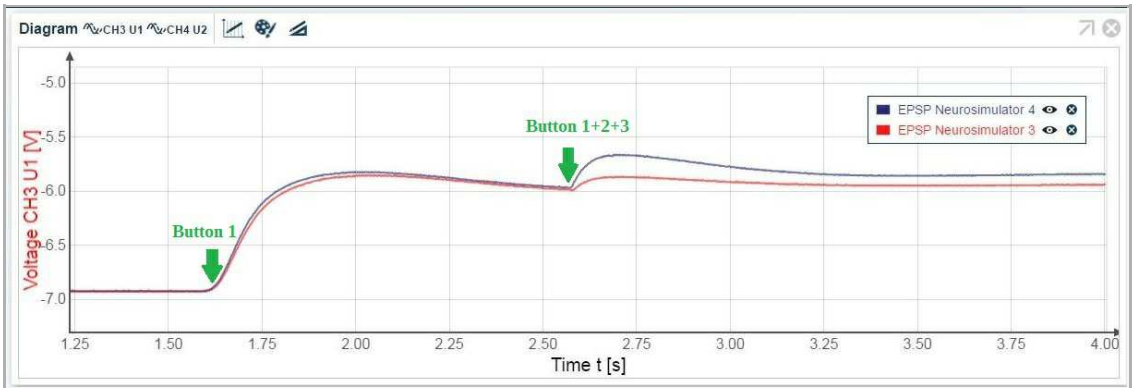


Diagram
CH3 U1
CH4 U2
EPSP Neurosimulator 4
EPSP Neurosimulator 3
Button 1
Button 1+2+3
Voltage CH3 U1 [V]
-5.0
-5.5
-6.0
-6.5
-7.0
1.25
1.50
1.75
2.00
2.25
2.50
2.75
3.00
3.25
3.50
3.75
4.00
Time t [s]

Fig. 44