Inexpensive Electronics for the Teaching Lab

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AMPLIFIER & ELECTRODE

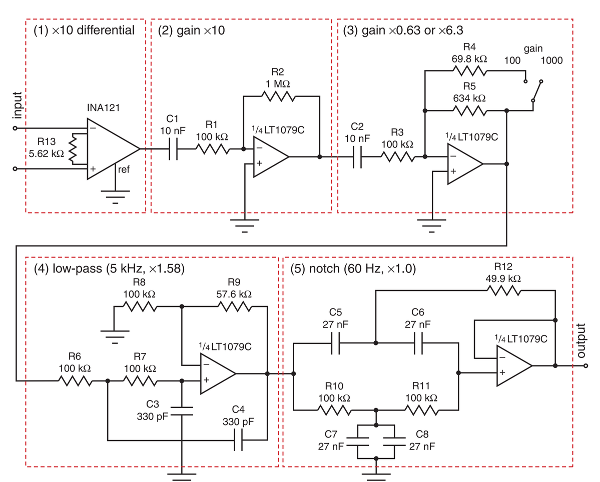
An extracellular amplifier for use in the student laboratory should have the following characteristics: (1) gains of 100 and 1000; (2) good frequency response from 300 Hz to 5 kHz, matching the bandwidth of nerve and muscle spikes; (3) 60 Hz or 50 Hz notch filter to reduce interference from line voltage; (4) good common-mode rejection, permitting use in electrically noisy environments; (5) low internal noise; (6) high input impedance to permit use with a variety of electrode types; and (7) low power requirements to allow battery operation for extended periods. To be a practical alternative to commercial units, a home-made amplifier must also be significantly less expensive, straightforwardly constructed with few components, and require no adjustments for optimal performance.

1. Design & Construction

Amplifier

The amplifier is in five sections: an input stage, two amplification stages, and two filtering stages. Gains of the sections are 10, 10, 0.63 or 6.3, 1.58, and 1.0, for a total of 100 or 1000. The first stage subtracts the two input voltages, removing noise common to both inputs. This section uses one integrated circuit. Sections 2-5 use the four op-amps of one quad integrated circuit. Section 2 gives a fixed AC-coupled gain of 10. Section 3 gives an AC-coupled gain of 0.63 or 6.3. Section 4 is a low-pass filter designed for a flat response below 5 kHz, with a gain of 1.58. Section 5 is a 60 Hz notch filter.

The circuit uses two integrated circuits and fits on a 2x3 inch board in a 4×2.25×2.25 inch metal enclosure. The total cost of parts is about $40. Power comes from two standard 9V batteries.



Burr-Brown instrumentation amp INA121 [1]
Linear Technologies quad op amp LT1079 [1]
10 nF capacitor [2; C1-2]
330 pF capacitor [2; C3-4]
27 nF 5% cap (33 nF for 50 Hz notch) [4; C5-8]
100 kΩ resistor [7; R1, R3, R6-8, R10-11]
1 MΩ resistor [1, R2]
69.8 kΩ 1% resistor [1; R4]
634 kΩ 1% resistor [1; R5]
57.6 kΩ 1% resistor [1; R9]
49.9 kΩ 1% resistor [1; R12]
5.62 kΩ 1% resistor [1; R13]
14 pin DIP socket for LT1079 [1]
8 pin DIP socket for INA121 [1]
9V battery [2]
9V battery clip with leads [2]
BNC jack for output [1]
binding post, red, for + input [1]
binding post, black, for– input [1]
binding post, green, for ground input [1]
SPST switches for gain and filter [2]
DPST switch for power [1]
1.5 inch aluminum stand-offs with screws [2]
2×3 inch printed circuit board or perfboard [1]
Metal enclosure at least 4×2.25×2.25 inches [1]

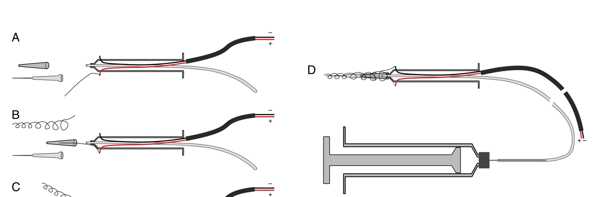
Electrode

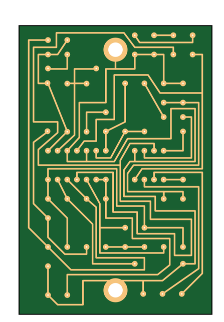
The suction electrode consists of a replacable gel-loading pipette tip (which contacts the nerve), a 1 cc syringe (which fits in a manipulator), and a 10 cc syringe (to provide suction). The main advantage of this design over others is that the tip is flexible, need not be hand-made, and is easily replaced, unlike the usual glass tip.

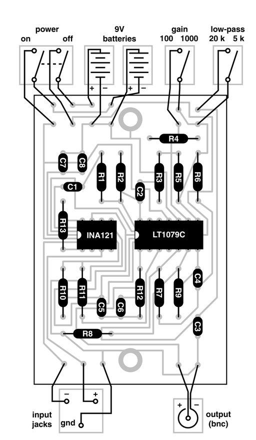
For More Information

Complete descriptions of the construction and performance of the amplifier and electrode can be found in Land, B.R., Wyttenbach, R.A., and B.R. Johnson (2001) Tools for physiology labs: An inexpensive high-performance amplifier and electrode for extracellular recording. J. Neurosci. Methods 106:47-55. Pdf files of that paper and the printed circuit board, and a parts list with sources, are available from www.crawdad.cornell.edu/downloads.html.

1 cc plastic disposable syringe, plunger discarded
10 cc plastic disposable syringe
18-gauge syringe needle, tip filed blunt
microbore tubing to fit 18-gauge needle
stainless steel wire, uninsulated, approx. 0.25 mm diameter
two-conductor cable, shielded if possible, any desired length
200 ml pipette tip
ultra micro gel-loading pipette tip (0.2 mm diameter)
fast-setting glue (hot glue gun works best)







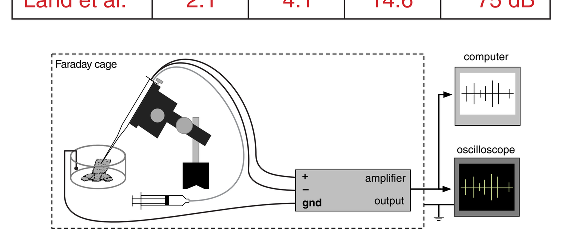
2. Performance

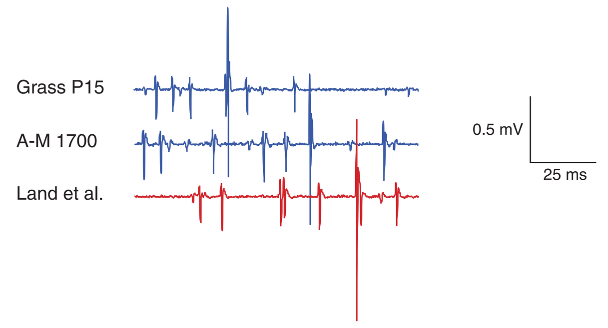
The amplifier's input impedance is high enough to use with a range of electrode types, including suction, pins, hooks, nerve chambers, ane electromyography wires. We test it here with the suction electrode shown above.

We compared our amplifier with two commercial ones often used in teaching labs, the A-M Systems Model 1700 and the Grass P15. (1) Internal noise was determined by measuring output with a resistance of 0 Ω, 100 kΩ, or 1 MΩ across the inputs. Ideally, this should be 0 V. (2) Common-mode rejection ratio (CMRR) is the ratio of output to input with a 1 V 60 Hz sine wave applied to both inputs (notch filter off). A low ratio (high dB attenuation) is desirable. (3) We used all three amplifiers with the same preparation and suction electrode to record spontaneous activity in a crayfish motor nerve.

Internal noise of our amplifier is comparable to that of the A-M 1700. CMRR is not quite as good as the others but it still eliminates between 99.9 and 99.99% of noise common to both inputs. There is no obvious difference in the quality of the three crayfish nerve recordings, so the higher internal noise and lower CMRR of our amplifier do not compromise recording quality. The traces demonstrate the quality of recording typical of our suction electrode.

Amplifier	Internal Noise (μV RMS) 0 Ω	100 kΩ	1 MΩ	CMRR at 60 Hz
Grass P15	1.4	3.6	7.0	>80 dB
A-M 1700	2.5	4.0	15.0	>100 dB
Land et al.	2.1	4.1	14.6	75 dB





STIMULUS ISOLATION UNIT

An electronic stimulator or computer-generated stimulus can bring noise into a recording, add a large DC offset, and add a large stimulus artifact that can obscure the biological response. Much of this noise results from stimulus current traveling through the ground of the recording electrode.

A stimulus isolation unit (SIU) isolates the stimulus ground from the equipment ground, causing most of the stimulus current to travel directly from the positive pole of the stimulator, through the tissue to be stimulated, to the negative pole of the stimulator without going through the ground of the recording electrode.

An SIU for the teaching lab should have the following characteristics: (1) isolation over 1 GΩ and capacitative coupling under 20 pF, (2) variable output of 0-100 V, and (3) output of about 1 Watt power (10 mA at 100 V). Ideally, it should not require battery power, due to the high demands of daily use and students unfamiliar with equipment. Thus power must be supplied across the galvanic isolation. The design presented here is a practical alternative to commercial units, requiring few components of low cost. We estimate that the components for a 90 V SIU cost about $50.

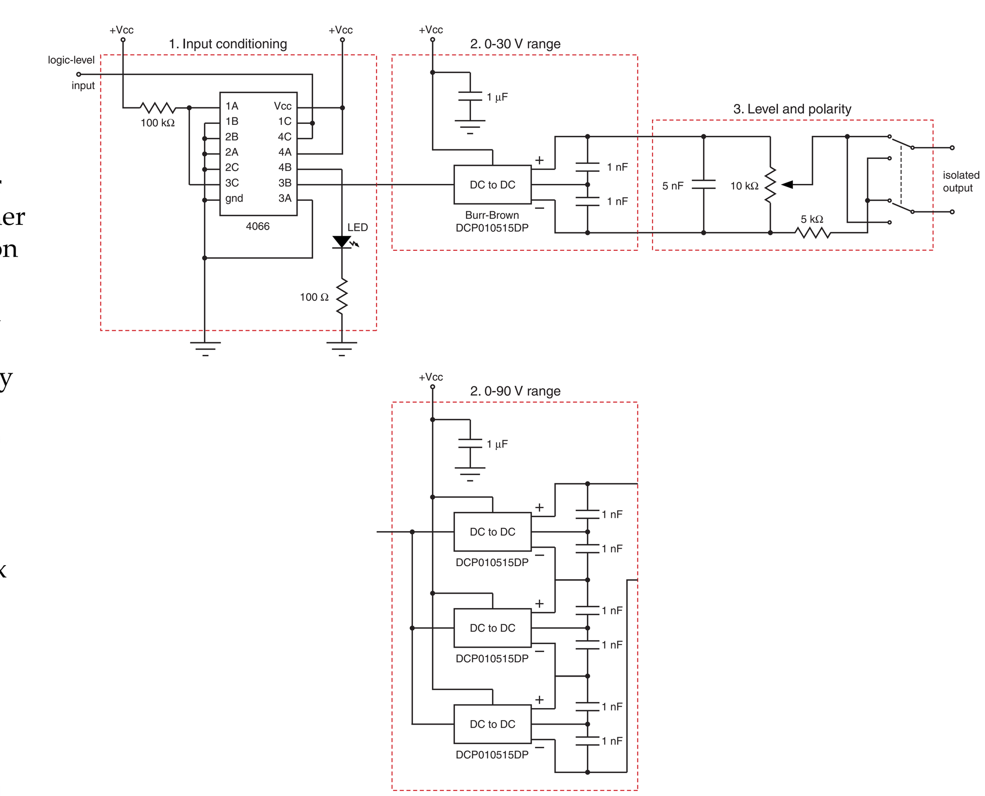
1. Design & Construction

The SIU consists of three sections: (1) input conditioning, (2) isolation and voltage increase, and (3) level and polarity control.

The second section uses one or more DC-to-DC converters to produce the stimulus voltage. Each converter produces 30 V with a 5 V power supply; several can be ganged together for higher voltages, as shown. The converters are turned on when their input is grounded. The first section uses the input logic level (+5V) pulse to ground the input of the converters and provides visual feedback with a LED. The third section is simply a voltage divider to set the output level and a switch to set polarity. The 5 nF capacitor and 10 kΩ resistor act as a low-pass filter to remove some of the 400 kHz noise produced by the converters.

The SIU should be built in a non-metallic box to reduce capacitative coupling to ground. The 4066 should be kept away from the converter outputs for the same reason. Keep the 1 nF capacitors as close as possible to the converter outputs. Power comes from a 5 V 300 mA regulated supply.

See www.nbb.cornell.edu/neurobio/land/projects/siu/ for more information.



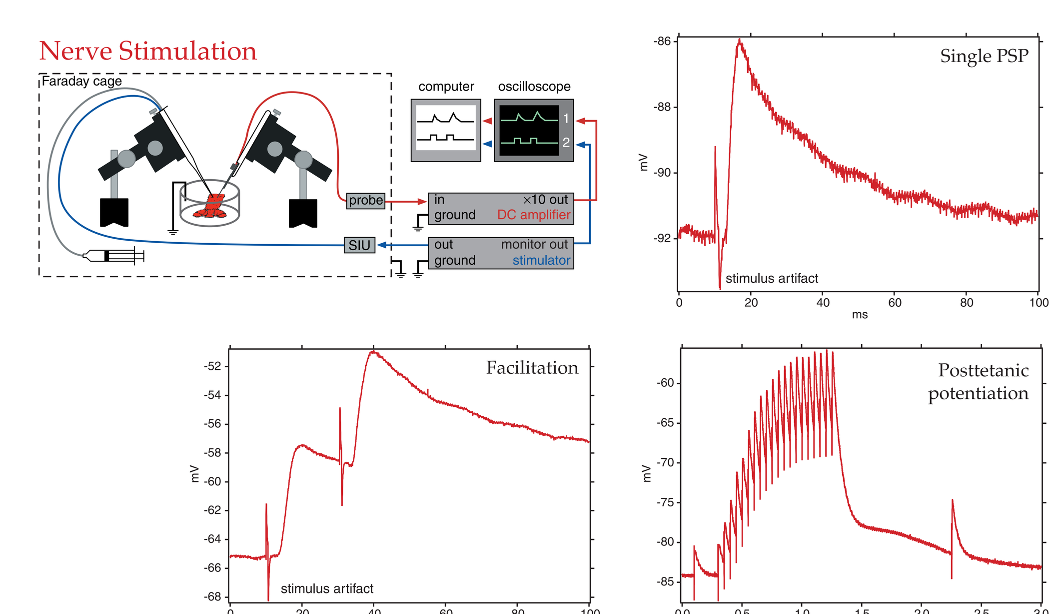
2. Performance

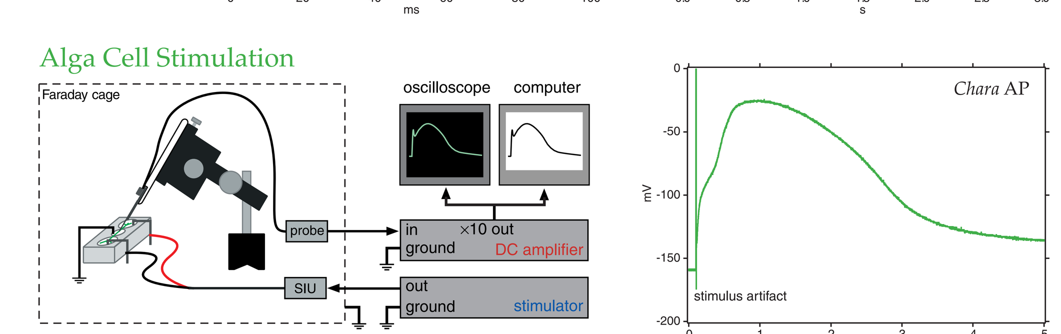
We have used a prototype of this SIU in our teaching lab for 2-3 years now. Here, we present examples of its use in two of our teaching preparations, a crayfish nerve and a large alga cell (see www.crawdad.cornell.edu, labs 7 and 9).

Nerve 3 of the crayfish abdominal ganglia innervates the superficial flexor muscle. We recorded intracellularly from the muscle while using our SIU to stimulate the neve through the suction electrode described before. Traces show postsynaptic potentials recorded in the muscle. Some stimulus artifact is unavoidable even with commercial SIUs.

The alga *Chara corallina* consists of a series of large cells (≥ 1mm diameter, up to 10 cm long) that fire large slow action potentials when electrically stimulated. The cell is placed in a chamber and stimulated across its length through wires placed in the water.

Lastly, we measured DC offset of the SIU by placing stimulating and recording electrodes in crayfish saline without a preparation. Below 5V, the offset was unmeasurable; it was 1 mV at 5 V, 2 mV at 10 V, 8 mV at 50 V, and 14 mV at 100 V stimulus.





STIMULUS CONTROL

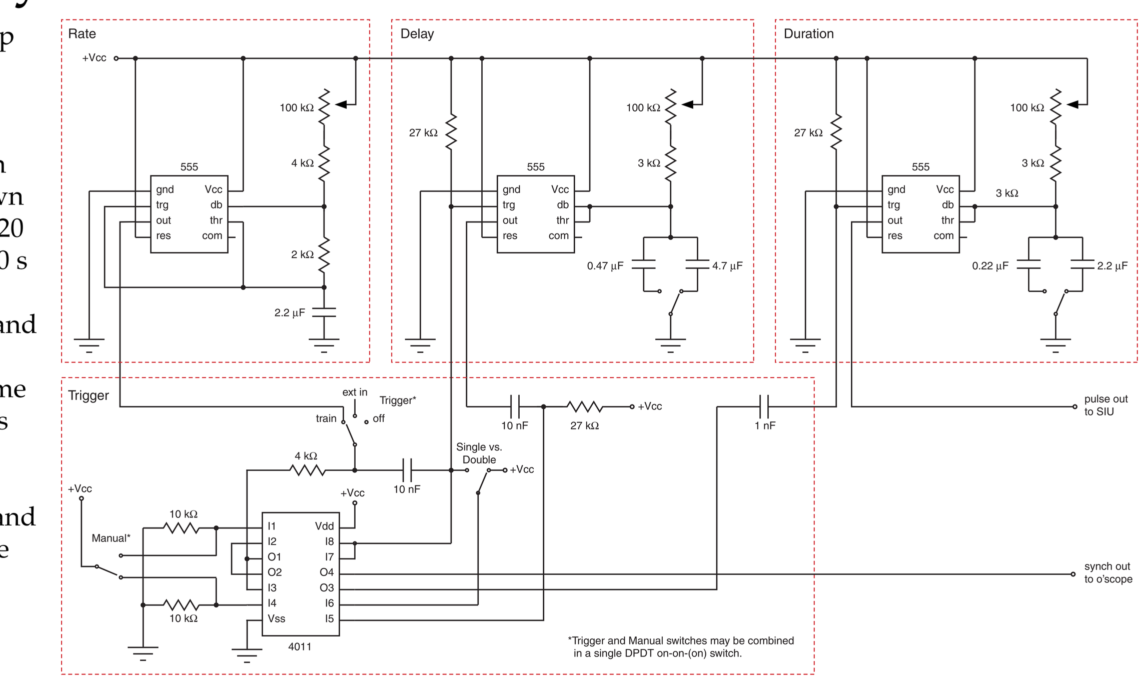
The SIU described here must be controlled by another device that produces a logic-level pulse with the desired timing. A stimulator for the teaching lab should have the following features: (1) ease of use; (2) ability to produce single pulses, pairs of pulses, or trains of pulses; (3) a wide range of pulse rates and durations; (4) variable delay for single pulses; and (5) a manual single-pulse button.

Traditionally, a stimulator combined analog timing circuitry with a battery-powered SIU. Nowadays, a digital circuit or computer software may be more convenient and less expensive. We present three options here, any of which could be used with our SIU design. All are simple and can be constructed inexpensively; which is preferable depends on the intended use.

1. Analog Circuitry

This circuit uses a 555 timer chip in each of three sections to control pulse rate, delay, and duration. Timing is determined by the capacitors and variable resistors in each section. With the values shown here, the stimulator has ranges of 20 to 220 ms pulse period, 0 ms to 470 s delay, and 0 to 220 ms duration. A fourth section handles triggering and produces a synch output for an oscilloscope. Power (+5 V) can come from the same source that supplies the SIU.

Parts for this stimulator would cost about $35, with the switches and variable resistors being most of the cost.



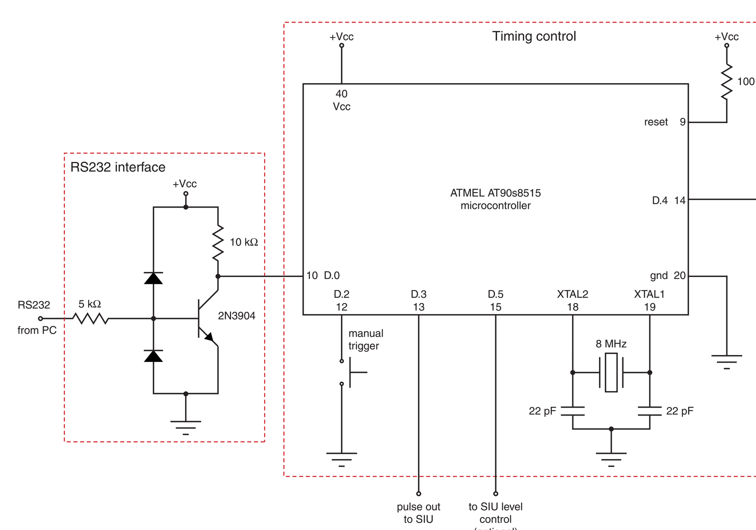
2. Computer Control

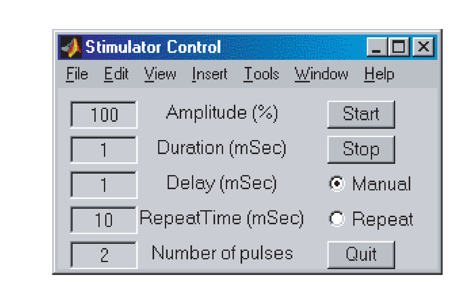
This circuit is controlled by serial port output of a PC running MatLab. The circuit consists of an RS232 interface (to work with the computer), AVR microcontroller (sets stimulus timing in response to commands from the computer), and an optional CMOS switch (to set stimulus level). There is a pushbutton for manual triggering and a synch pulse to trigger an oscilloscope. To avoid noise from the microcontroller, put the SIU and control circuitry on separate boards in separate boxes, and keep the SIU near the preparation. Power (+5 V) can come from the same source that supplies the SIU.

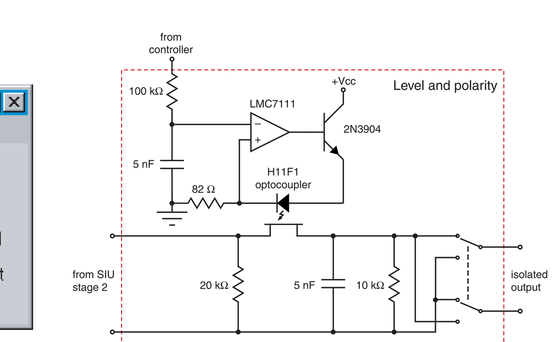
Stimulus amplitude can be set manually by the variable resistor in part 3 of the SIU circuit, or by software. For computer control, replace part 3 of the SIU with the circuit shown at the lower right.

Parts for this stimulator would cost about $20; construction is simpler than the analog version because fewer parts are involved.

See www.nbb.cornell.edu/neurobio/land/projects/stimulator2/ for more information, including AVR code and the MatLab interface.







3. Stand-Alone Digital

We are working on a stimulator based on the above design, but with the addition of a 16-button keypad and 4-line LCD display for use without a computer. Again, an Atmel AVR microcontroller times pulses and sets their amplitude. In this version, timing parameters are set by the keypad via a UART.

See www.nbb.cornell.edu/neurobio/land/projects/stimulator/ for more information and updates as the project progresses.

CONCLUSIONS

The cost of electronics can be a barrier to setting up teaching labs in neurophysiology. In an ongoing effort to promote neuroscience teaching (www.crawdad.cornell.edu), we are developing inexpensive and easily constructed equipment.

This poster describes an amplifier, electrode, stimulator, and stimulus isolation unit suitable for extracellular recording and stimulation in a variety of teaching and research preparations.

The cost of components for each of these pieces is under $50, and all are simple enough to be built by faculty, students, or support staff with basic knowledge of circuit construction.

It is our hope that publishing these plans will make it possible for more students to be exposed to laboratory exercises in neuroscience, in introductory or general courses as well as in specialized neurophysiology courses.

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