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# TECHNOLOGY REVIEW
# Data Acquisition and Display for Electrophysiology: PC Oscilloscopes

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The PC oscilloscope, an external data acquisition unit connected to a laptop computer, is an option worth considering for neuroscience teaching labs that include electrophysiology. This article describes the available technology and reviews products on the market as of mid-2006.

*Key words: digital oscilloscope; A/D conversion; USB devices*

## INTRODUCTION
A new generation of devices now makes it technically easy and reasonably inexpensive to outfit neuroscience teaching lab electrophysiology setups with storage and display functions more powerful than those of expensive digital storage oscilloscopes. These devices, called PC oscilloscopes, are small digitizing units connected to computers, ideally laptops, using a USB interface. Accompanying software provides oscilloscope-like displays of electrical activity. Having the electrophysiological data in the computer allows students to do more powerful data analysis after the experiment is over than is feasible with stand-alone digital storage oscilloscopes.

## HISTORY
In recent decades, the venerable oscilloscope has gradually been supplemented, or even replaced, in electrophysiology labs by computers equipped for analog-to-digital (A/D) conversion and display of electrical signals from neurons. Initially, specialized A/D function boards were available for installation in expansion slots in desktop computers. Most were expensive multi-function boards having more input channels than needed for teaching purposes. Desktop computers and monitors located near electrophysiological preparations also generated unwanted electrical noise. Standard oscilloscope features such as external triggering were often challenging to implement. At the high end of this technology, research labs had access to specialized data loggers designed specifically for electrophysiology, but these systems have been too expensive for most teaching labs with multiple setups.

For the past few years, external PC oscilloscope devices that connect to a computer's parallel port have been available. Most recently, models using a USB connection instead of the parallel port have been introduced. These have the advantage that the PC oscilloscope unit is powered through the USB connection, rather than requiring an external power supply with its associated 60 Hz noise. An electrophysiological setup with a USB-interfaced PC oscilloscope connected to a laptop running on its battery has fewer wires, less 60 Hz noise, and less weight and volume of equipment than previous ways of doing electrophysiology in student labs.

## DESIGN CHARACTERISTICS
PC oscilloscopes require several features in order to meet the needs of neuroscience teaching labs involving electrophysiology. At the time this review was prepared in mid-2006, the cheapest PC oscilloscope units costing $200 to $500 lacked some of these features, but several units costing just above $500 were satisfactory. Here are four characteristics prospective buyers should consider.

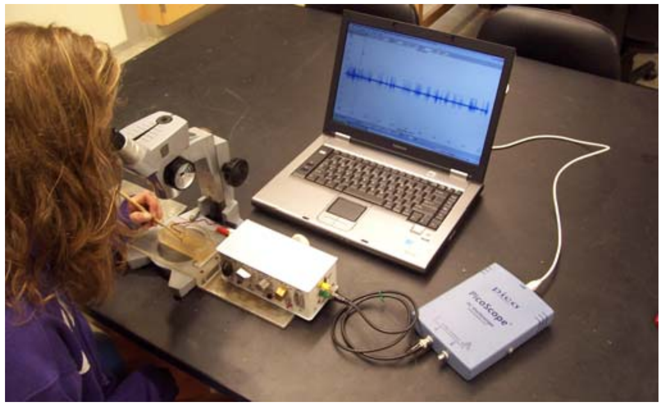

*Figure 1.* Simplified electrophysiology. Cockroach tibial spine preparation, with preamplifier, PC oscilloscope, and laptop for display and analysis. Preparations using AC-powered devices such as audio monitor, electrical stimulator, or illumination may require additional shielding or grounding.

### Voltage sensitivity
The system must be able to detect, digitize, and display the smallest signals in any of the planned experiments. For example, impulses from a cockroach tibial spine recorded with insect pins in the leg can be around 100 microvolts; after amplification at a gain of 100 these will be 10 millivolt spikes. (Many amplifiers can be set to provide higher gains, but under some recording conditions gains above 100 can be associated with high noise and intermittent saturation of the amplifier, so a conservative choice is a gain of 100.) Thus, a PC oscilloscope with adequate sensitivity needs its most sensitive full-scale vertical setting to be at least as low as ±20 mV. The cheapest units lack this level of sensitivity, but some in the $500-$800 range have it.

### A/D conversion capacity
The A/D converter changes an analog voltage from the nerve preparation into digital levels. The number of levels spanning the full scale of the device is described as the bit capacity of the A/D converter, which in currently available

units is usually 8, 12, or 16 bits. The integer 2 raised to these powers shows the number of voltage levels that can be discriminated across the full scale of the data acquisition unit. Thus an 8-bit device can distinguish 256 levels, a 12-bit device 4096 levels, and a 16-bit device around 65,000 levels. Some products provide enhanced detection when the signal is periodic, i.e. perfectly repetitive. However, this is not applicable to most electrophysiological signals, so the raw number of bits for a single occurrence is important. In my experience with a few of these units, those with 8-bit converters turn the familiar smooth waveform of an extracellularly recorded nerve impulse into something like the profile of a multi-layered wedding cake, which is inadequate even for student lab use. Units featuring 12-bit conversion are satisfactory, although not as smooth as analog oscilloscope displays. The 16-bit models are expensive, so they may not be within budgets for multiple lab setups, but they do reproduce analog neural signals beautifully.

**Buffer size, also called buffer depth**

The PC oscilloscope makes multiple A/D conversions and sends them to the attached computer. In order to display a nerve spike lasting 1 msec with good fidelity, including detecting the peak fairly accurately, the unit should sample the signal at least 10 times within 1 msec. This corresponds to a sampling interval of 0.1 msec or a sampling frequency of 10 kHz. Even the cheapest models can sample at higher rates than this, so sampling frequency is not an issue. However, performance is limited by how much data the unit's memory buffer can hold, given the length of time one wants to record. For example, one might wish to record and display two seconds of data when bending a cockroach tibial spine or changing the load on a crayfish stretch receptor. A buffer size of 20,000 would be needed to hold two sec of data at a sampling frequency of 10 kHz; higher sampling frequencies or longer recording times of course would require even larger buffer capacity.

**External trigger**

Analog oscilloscopes have an external trigger input that synchronizes the oscilloscope sweep to an electrical stimulus applied to a biological preparation. Some cheaper PC oscilloscopes lack this feature, which is a crucial feature for electrophysiology. Units with external trigger capability typically have a second input channel, which can be used either as a second data trace or as a trigger. When the second channel is selected as a trigger, the software monitors it and, when a threshold is reached, starts recording data entering the first input channel.

Figure 2*A* shows cockroach tibial spine spikes produced in response to bending the spine with an insulated probe, recorded over 1 second at a sampling frequency of 10 kHz. Figure 2*B* shows similar responses from the same spine sampled at 2 kHz, corresponding to a sampling interval of 0.5 msec. Note the degradation, as expected, of spike amplitude and waveform at this low sampling frequency. Figure 2*C* shows an expanded segment of an 0.1 sec portion the trace in 2*A*, indicated by the bar, as an example of the PC oscilloscope's capability for later off-line data analysis and display.

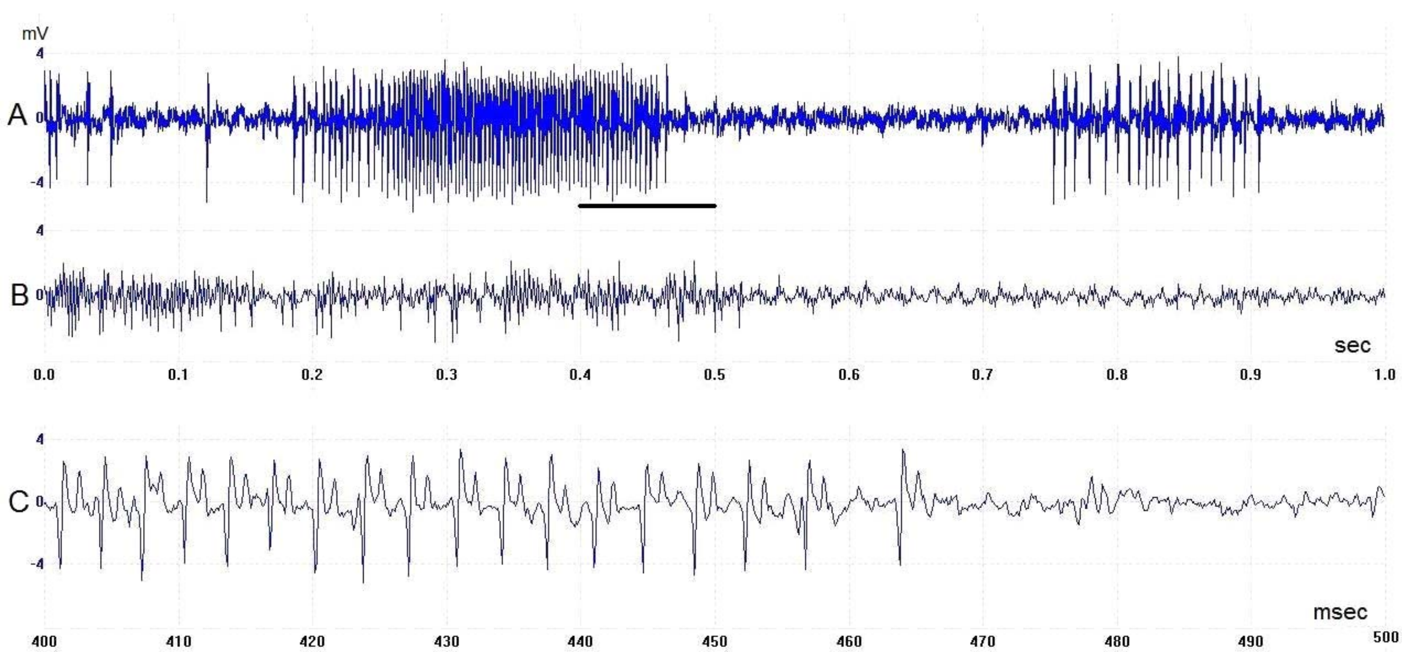


*Figure 2.* Cockroach tibial spine responses recorded using a PicoScope 3224 PC oscilloscope. *A*: Sampled at 10 kHz for 1 sec. *B*: Similar responses sampled at 2 kHz showing effects of low bandwidth. *C*: Expansion of data in trace in *A* between 0.4 and 0.5 sec.

| Product | Max. Sensitivity | A/D bits | Buffer | Trigger | Cost |
|---|---|---|---|---|---|
| USB Instruments Stingray DS1M12 | ±50 mV | 8 | 32 kS | Y | $199 |
| Data Translation DT9812-2.5 | ±152 mV | 12 | 32 kS | Y | $229 |
| Picoscope 2202 | ±50 mV | 8 | 32 kS | N | $309 |
| Keithley KUSB-3100 | ±1250 mV | 12 | 2 kS | Y[1] | $349 |
| Velleman PCSU1000 | ±50 mV | 8 | 4 kS | Y | $356 |
| **Bitscope 310** | **±10 mV** | **12** | **64 kS** | **Y** | **$545** |
| **Picoscope 3224** | **±20 mV** | **12** | **512 kS** | **Y** | **$595** |
| Link Instruments DSO-2102M | ±200 mV | 8 | 32 kS | Y | $725 |
| TiePie Handyscope HS3-5 MHz | ±200 mV | 12 | 128 kS | Y | $770 |
| Keithley KUSB-3108 | ±20 mV | 16 | 2 kS | Y[1] | $1045 |
| **ADInstruments Powerlab 4/25** | **±2 mV** | **16** | **[2]** | **Y** | **$2000** |

*Table 1.* Characteristics of selected PC oscilloscope models. Three units shown in bold are described in detail in the text.
[1]External trigger input must conform to “TTL” specifications rather than allowing for user-selected trigger characteristics
[2]No actual buffer: works by writing data directly to computer hard disk, like a data logger

| Product | Internet Resource |
|---|---|
| USB Instruments Stingray DS1M12 | http://www.easysync-ltd.com/index.html?lang=en-uk&target=d16.html |
| Data Translation DT9812-2.5 | http://www.datatranslation.com/econ/prod_dt9812.htm |
| Picoscope 2202 | http://www.swangate.com/Pico/Oscopes/200/PS2202.htm |
| Keithley KUSB-3100 | http://www.keithley.com/products/dataacqmodules/?mn=KUSB-3100 |
| Velleman PCSU1000 | http://www.vellemanusa.com/us/enu/product/view/?id=522377 |
| Bitscope 310: | http://www.bitscope.com/product/BS310/ |
| Picoscope 3224 | http://www.swangate.com/Pico/Oscopes/PS3000_12/picoscope_3224.htm |
| Instruments DSO-2102M | http://www.linkinstruments.com/oscilloscope21.htm |
| TiePie Handyscope HS3-5, 5 MHz | http://www.tiepie.nl/uk/products/External_Instruments/USB_Oscilloscope/ |
| Keithley KUSB-3108 | http://www.keithley.com/products/dataacqmodules/?mn=KUSB-3108 |
| ADInstruments Powerlab 4/25 | http://adinstruments.com/products/hardware/education/product/ML845/ |

*Table 2.* Internet resources. Products reviewed are listed with internet locations.

## PRODUCT REVIEWS

Table 1 lists the above features and cost, as of mid-2006, of a sample of PC oscilloscopes that work via USB connections. If some listed products seem expensive based on the characteristics listed, it is usually because the units have other advanced features not needed for student electrophysiology, such as large numbers of input channels, analog and/or digital output lines, or very high sampling frequencies. Costs are for a single item; discounts may be available for multiple purchases.

Three products in the table meet the four criteria discussed above: at least 12-bit conversion, at least 20 mV maximum voltage sensitivity, at least 20,000 buffer size, and having external trigger capability. All can interface with both Macintosh and PC computers.

**Bitscope 310.** This unit has the features one would need, in an attractive and sturdy physical package and at a reasonable price. It has two disadvantages. First, the manufacturer is in Australia and does not sell through dealers in other parts of the world, so units must be shipped from Australia and must pass through customs. Second, the software does not appear to allow the user to set the digitizing rate. Instead, the rate is automatically adjusted depending on the duration of digitizing to make full use of buffer capacity. While this feature may be desirable in some contexts, it results in effectively different bandwidths of the recorded waveforms depending on the duration one selects, which does not seem ideal.

**Picoscope 3224.** This is the system chosen for neuroscience teaching labs at Amherst College. Maximum voltage sensitivity is only just adequate, but the smallest signals we expect to record (approximately 10 millivolt spikes after preamplification) display well (see Figure 2). The price is reasonable, and the software is full-featured and intuitive, allowing the user full control of digitizing rate and all display functions. Records can be saved in data format for later off-line work such as displaying an expanded portion of part of the trace; alternatively, screen images can be saved for printing. Picoscope is manufactured in the United Kingdom, but sold through several U.S. suppliers. We found Swangate International, Inc. easy to deal with, helpfully sending a trial unit for evaluation.

**ADInstruments Powerlab 4/25**. ADInstruments is entirely devoted to research and teaching physiology, including neurophysiology, unlike other companies that provide general-purpose data acquisition systems. Product support includes pre-written lab protocols, accessories for many different kinds of physiology, and responsive staff who are available by telephone and who are knowledgeable about teaching physiology labs. Although the Powerlab 4/25 is this company's lowest-cost data acquisition unit, it is very powerful, with higher sensitivity than all other units reviewed, 16-bit A/D conversion, hardware filters, and analog output so it can be used as a stimulator. Software is superb, allowing students to edit, analyze, and print their data. Obviously, the issue with this item is price: the Powerlab 4/25 costs almost four times as much as other PC oscilloscopes that are adequate for neurophysiology teaching labs. Pricing is also not always easy to understand: the price for multiple Powerlab 4/25 units was quoted as $2,500 per unit in mid-2006, but if one agreed to "bundle" it with other physiology accessories not useful in a neuroscience lab, the price of the whole bundle dropped to $2,000.

For more information about any of these products, see the internet resources listed in Table 2.

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