Hardware for hard-up schools?

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Hardware for hard-up schools?

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Abstract

The purpose of this work was to investigate ways in which everyday computers can be used in schools to fulfil several of the roles of more expensive, specialized laboratory equipment for teaching and learning purposes. The brief adopted was to keep things as straightforward as possible so that any school science department with a few basic tools can copy the ideas presented. The project has so far produced a simple, safe input device to enable use of a computer as an oscilloscope and the conversion of external speakers into a signal generator. They are not without their limitations, but the intention is that they may provide opportunities for hands-on learning in schools where budgets are very limited. Several teaching ideas are outlined, with pointers for further development. It is hoped that interest in the project may generate further application of the ideas to the teaching of high school physics.

Educational science equipment has always been notoriously expensive. In the wake of the 'credit crunch' most school science departments in the UK have had their budgets slashed. Many have little left to spend after essentials like exercise books and photocopying have been paid for. With this in mind (and also being a rather tight individual!) I have been working on some ways for schools to avoid costly equipment purchases while still being able to offer ways to significantly improve upon a purely theoretical approach to some areas of school physics. This work has been carried out with generous assistance from the Anthony Waterhouse Fellowship.

Approach

These days most schools in the UK, while not necessarily possessing much specialist science equipment, usually have a fair number of computers. Therefore I have looked into a number of ways to (safely) adapt existing equipment so that it can be put to good use in physics lessons, without upsetting ICT staff or those responsible for portable appliance testing (PAT). For those who are really serious tinkerers there is perhaps little here that is new, but for people who do not have the time or inclination to spend hours trawling the internet I hope that these ideas will be of benefit. Aspects of this work have been covered previously by Hunt and Dingley [1] and Ganci [2], but it is my hope that, by pulling several strands together and giving greater focus on the 'how to', their ideas and others might become more widely accepted and used.

Your computer as an oscilloscope

The cathode ray oscilloscope (CRO) is one of those pieces of equipment that students might see once or twice prior to the completion of pre-16 studies (perhaps in the context of sound with 13 year olds or ac electricity for 14–16 year olds). Basic units cost in the region of £250 (the Philip Harris 'budget' model). Pico Technology produce a range of USB-based oscilloscopes—

 0031-9120/12/010106+06$33.00

these have many advantages, notably the ability to easily display the waveform via a data projector (and even a modest computer monitor is a big improvement over the size of most CRO screens). They are not cheap, though (£125 for the most basic model), and few schools could afford a set of these, even before the recent financial woes. However, most school computers come equipped with a decent analogue-to-digital converter in the form of a soundcard. Even the most basic units have a sampling rate of 44 kHz and many these days are capable of sampling at around 100 kHz.[1] This is no threat to the typical 20 MHz CRO, or, indeed, the most basic picoscope, but for a wide range of teaching and learning purposes it is more than sufficient. There are a number of freeware and shareware programs available that can take soundcard signals and display them on a 'virtual oscilloscope' on the computer screen. Although it has limitations I have found Christian Zeitnitz's Scope software [3] to be very useful in this regard. It is not freeware in the full sense but it is free for personal/educational use, and its author was keen to assure me that he would be delighted if it was used in schools and colleges. Simply plug in a microphone—or some light headphones if you are really stuck!—and you can 'see' your speech or singing as you would on a traditional CRO, but without any cost and with minimal setup time. This particular software has an FFT algorithm[2] built in so that, as well as comparing different waveform shapes, you can also look at the frequency spectrum of the sound being made. When playing my Irish tin whistle into it, for instance, the fundamental note is clear, as are five or six harmonics that are also present[3]. The screenshots show the changes in the frequency spectrum when 'overblowing' (figures 1 and 2). Most of the students in lower school classes have found this sort of activity interesting, while those with more musical leanings find it quite

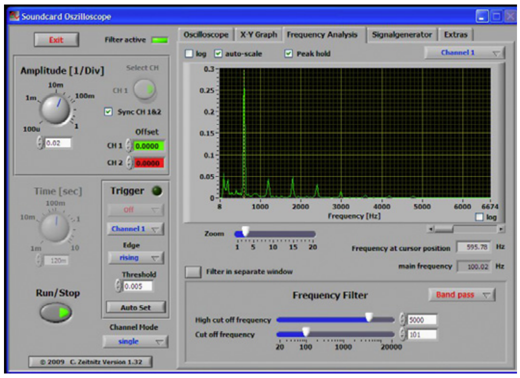

Figure 1. Zeitnitz's 'Scope' software being used for frequency analysis.

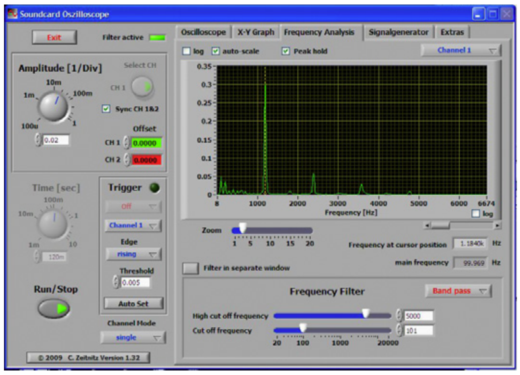

Figure 2. 'Overblowing' eliminates the fundamental (∼600 Hz) so the main frequency heard is then around 1200 Hz (one octave higher).

intellectually satisfying. However, this is only the beginning of its usefulness.

The question then arises: if I have an oscilloscope at my disposal on the computer, can I use it with inputs other than a simple microphone? Well, there are a range of things that can be done using sound files/CDs/MP3s, such as studying waveform shapes or analysing the range of frequencies present. However, I was particularly interested in the prospect of using it in a similar way to a CRO, particularly bearing in mind that, for the time being, we need to teach about CROs and AC signals at GCSE. Despite being a bit rusty at practical electronics (since our exam board closed down that little avenue of pleasure as a post-16 physics option), I knew that connecting anything greater than ±1 V to the line input was probably bad for the soundcard, possibly fatal. So I set about finding a way to protect the soundcard's inputs from signal

[1] The Nyquist sampling theorem dictates that in order to sample a signal of frequency f, a sampling rate of $2f$ is required, so a 'bog-standard' 44 kHz card can only sample signals up to around 22 kHz—perfectly good for audio waveforms.

[2] Fast Fourier transform—a mathematical process that transforms a waveform into the components of its frequency spectrum.

[3] Overblowing eliminates the fundamental, revealing the second harmonic as the new main frequency present, demonstrating that the one octave shift in the sound of the note is the result of hearing the frequency of the main sound double.

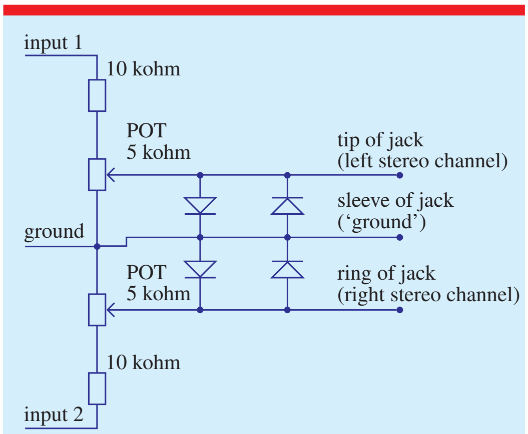

Figure 3. Circuit diagram for the soundcard input device.

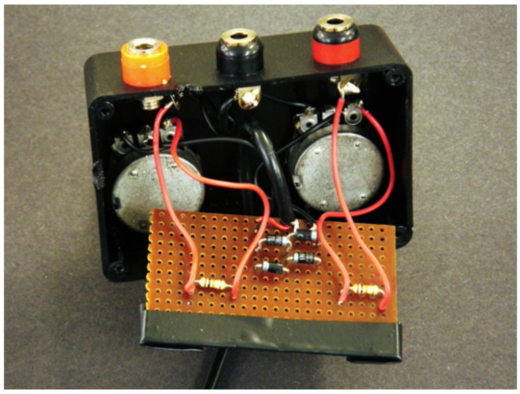

Figure 4. Soundcard input device, showing back-to-back diodes.

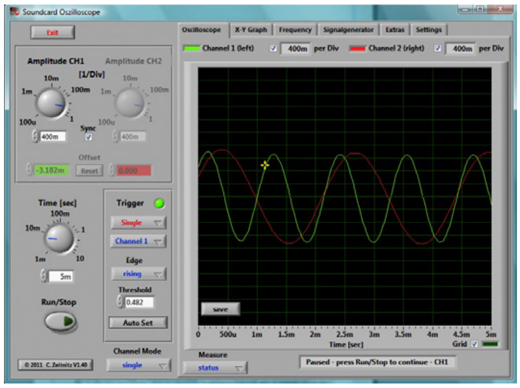

Figure 5. 'Scope' software in use as a dual-beam oscilloscope.

overload, certain that someone 'out there' had already solved the problem. Trawling around various forums revealed a number of promising ways to achieve this. The brief was to make it safe, but simple, so this excluded a good number of hobbyist circuits involving multiple op amps, and so forth. I also wanted to find a circuit that could be built by anyone with minimal soldering skills, such as my own! My final choice of circuit was modified from one given on the website of a Swiss researcher, Peter Luethi [4], and uses a pair of potential dividers and four diodes to achieve dual-channel input (figure 3). The input stage uses the 5 kΩ potentiometers to 'tap off' a fraction of the input signal and the diodes limit the size of this to ± 0.7 V (extra diodes can be used in series with each of those shown if ± 1.4 V is required). A 3.5 mm stereo jack lead was attached to the output stage (figure 4) such that the sleeve is ground, the tip is L and the ring is R. If connected to a soundcard's stereo line-in socket this means that the Scope software turns your computer into a 'dual-beam oscilloscope' (figure 5).

Some caveats

At this stage you may well be thinking that this is too good to be true—turning a PC into a dual-beam oscilloscope for £10 worth of components and less than an hour's construction time?! Well, yes, it does come with a few warnings.

- The very nature of the input device means that voltage measurements are uncalibrated, so you can only measure relative signal sizes.
- Many soundcard inputs are capacitor-coupled, so will only work with ac signals of $f > 10$ Hz. (Mind you, if you want to measure dc signals you can buy a decent multimeter for around £5 these days!)
- Many different makes and types of soundcard exist. I have tested several different ones (home PC, school laptop, classroom PC $\times 3$) but cannot promise that this will work on *your* computer. It ought to, though.

Signal generator

Another mainstay of physics laboratory equipment is the trusty signal generator (typical price ~£100+). In its familiar form, connected to a speaker, it has now been thoroughly eclipsed by any computer that has speakers. A wide variety of free software exists for generating tones of a range of frequencies, including the excellent freeware program Audacity [5]. Zeitnitz's Scope software also has a signal generator built in which not only generates sine wave, square and sawtooth tones at the click of a button, but will also perform frequency sweeps between pairs of values over a determined period of time. However, in order to drive items other than speakers (such as vibration generators and the like) the signal generator might seem like the only option, and an expensive one at that. Emboldened by success with my soundcard input device, I started to wonder if there was a way to buffer the output from the computer so that external coils, and so forth, could be driven without fear of damage. This brought to mind various op amp based circuits that we used to build, and I started to wonder if I was getting beyond my depth. I have to acknowledge here the wise intervention of Charles Tracy, who pointed out (without the deserving sarcasm) that a set of powered external speakers was exactly what I wanted! What is more, they can be had for very little money; the pair I eventually bought cost less than £10. Having splashed out on this new set of speakers I then set about them with screwdriver, craft knife and snips and removed the speaker cones. I kept the cones safe, as they were very good quality considering the price I paid! I then mounted a pair of 4 mm 'banana plug' sockets on each speaker case. Bingo! A dual-channel 4 Ω signal generator for under a tenner, plus about 20 min drilling/soldering (figure 6). Once again this idea does not come without a few warnings: first, having carefully modified my speakers I noticed that I had mounted a pair of output sockets on a plastic box into which a 240 V mains lead entered. I have received mixed reports on the legality of this, but it is probably not wise—if my soldering was poor enough I could feasibly have left wires dangling in danger of touching the 240 V live wire. An immediate workaround would be to remove the sockets from the unit containing the 240 V transformer and use only those on the second speaker, since there is no mains connection to this one. Only a single-channel signal generator, but still not bad for the money! A better solution, and one with which the PAT testers in your institution would be much happier, would be to use speakers that run off a wall-socket dc adaptor, so that only low voltage is present in the speaker boxes. Although the modification I have shown is specific to my pair of

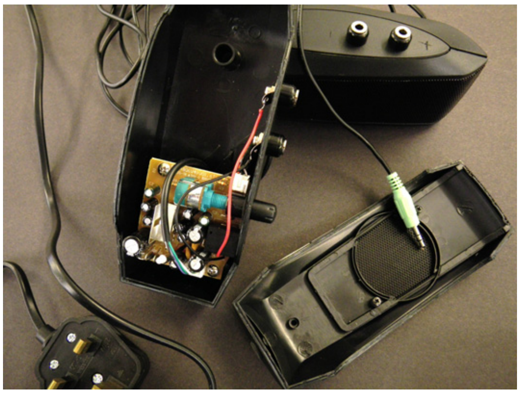

Figure 6. Loudspeaker-turned-signal-generator.

speakers, the basic idea is the same for any: open the case, de-solder the speaker cones and remove them. Then drill a pair of holes in the side of the case, fit a pair of 4 mm sockets, solder the speaker connecting wires to the sockets, remembering to keep the wires to the same configuration for both pairs of terminals (so you do not inadvertently invert one of the outputs).

A couple more caveats

Do not short out the terminals—the amplifier probably will not like having 0 Ω connected across its outputs. Mind you, the same goes for expensive standalone signal generator units—several years ago one of my 17 year olds did this and it cost the school over £100 to get it repaired. At least if it happens to me again then I will only be £10 down on the deal!

Make a note of the speaker impedance when you remove the cones (mine are 4 Ω) as this gives an indication of what you can successfully attach.

Since the amplifier inside the speaker unit is essentially an audio amplifier—designed to reproduce speech and music in the audio spectrum—do not expect anything amazing outside of the 20 Hz–20 kHz range.

What can I do with it?

So far I have only tried a handful of experiments:

- This first idea does not even require you to build any kit! (Ideal, perhaps, if the software and general ideas have taken your fancy, but you do not feel ready to start soldering yet.) Just get a 3.5 mm stereo jack-to-jack lead.

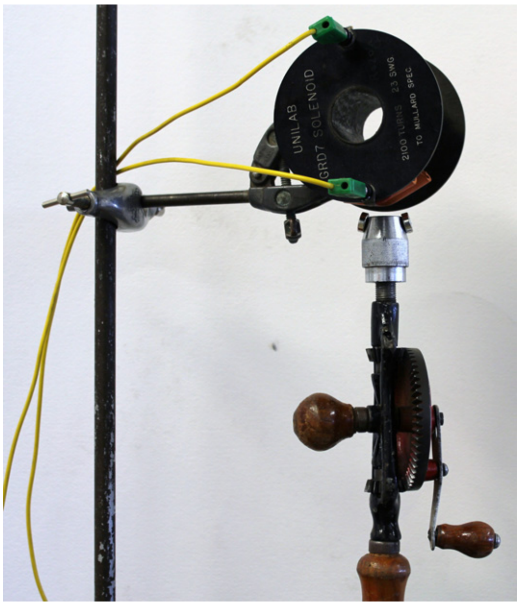

Figure 7. Dynamo demonstration.

Link the line-out of one computer's soundcard to the line-in of another. One is used in signal generator mode, the other as an oscilloscope. Students work in groups paired together, creating waveforms and getting the other group to work out period and frequency.

- Demonstrate how a generator works: simply attach a coil of wire (hand-turned is better, so that they can see it is just wire) to the soundcard input device (it does not have a name yet!), then spin a magnet close to it and observe the waveform on the computer screen. We used an old hand-drill mounted in a vice as the mount for the magnet(s) (figure 7) because that was what we had to hand, but I am sure there must be a more elegant solution!
- Demonstrate wireless energy transfer! (Or to show how a transformer works, and why having a core is a good idea.) Drive a coil of wire from the signal generator, attaching a second coil to the computer using the input device (figure 8). Placing the coils near to each other it is relatively simple to show that energy is being transferred from one coil to the other without wires. Putting a piece of iron bar through the coils immediately causes an increase in amplitude, as would be expected, and a discussion can then be had about why transformers need big iron cores when they run at 50 Hz. The recent changes to GCSE physics have seen 'switch mode' power supplies appear on the syllabus. They achieve weight savings by converting the 50 Hz input to much higher frequencies, so that much smaller cores (often made of ferrite) can be used. Using the 'frequency sweep' function on the signal generator it becomes apparent that the amplitude of the signal on the oscilloscope is greater at higher frequencies. It should be possible to carry out the experiment outlined by Luczak and Baker [5] with this apparatus (plus a small capacitor) to determine the resonant frequency. This could be further developed into explanations about radio waves and tuning.

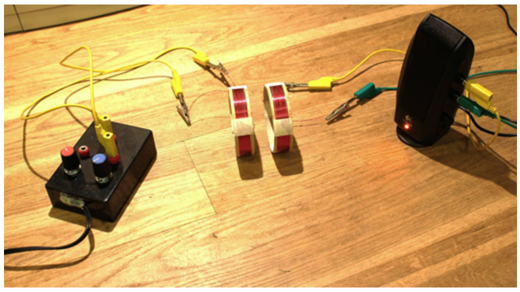

Figure 8. Demonstrating wireless energy transfer.

Where next?

This is where you, the reader, come into your own. I am hoping to set out some of the ideas above in much greater detail at http://www.practicalphysics.org. In the longer term I think that online collaboration is the way forward. As a long-time user of the PTNC e-mail forum[4] I have watched with interest how quickly an initial

[4] PTNC, run by the Institute of Physics, is found at http://networks.iop.org: 'PTNC is Physics Teaching News and Comment, a discussion list open to all with a professional interest in the teaching and learning of physics. E-mails you send go to all list members and are archived. It has many subscribers, leading to a reasonable pool of wisdom for tapping into, a sensible receptacle for your tips and tricks, a source of data collection when faced with benchmarking and a useful virtual soapbox for your opinions. Please be polite, constructive and focused'. At the time of writing it has 897 subscribers. TalkPhysics, perhaps the 'Web 2.0' natural successor to PTNC, has just celebrated its first anniversary and now boasts around 4000 subscribers.

idea is seized upon and improved by nothing more than a bunch of helpful physics teachers. Ideally a collection of well-documented experiments could be built up, with each teacher tweaking and refining them for the benefit of the whole physics education community. The term ‘Big Society’ may be a current political fad in the UK, but the reality of it is well established among teachers. I am indebted to those who have shared their ideas with me over the years, both in print and in person. I hope that the ideas presented in this article can be of use to others.

Acknowledgments

I am grateful for the generous financial assistance from the Anthony Waterhouse Fellowship awarded by the Institute of Physics from the Trust set up in Anthony’s name. I would like to extend my thanks to the Trust and the Institute for this opportunity, which allowed me to spend time on developing these ideas. I also grateful for the personal encouragement of Charles Tracy and Ian Lawrence. The assistance of my laboratory technician, Lucy Meadley, has also been much appreciated, as have the comments and encouragement of all at the QEGS Science Department.

A note from Helen Parsons about the fellowship

My father Vincent Waterhouse was first a physics lecturer at Ludlow Grammar and then a physics lecturer at Furzedown Teacher Training College. He passed on his love of science to my brother Anthony who went up to Cambridge (Trinity) to read Electrical Engineering, on an industrial scholarship. In 1969 he visited South Africa with the Dryden drama group as ‘props man’. While up Table Mountain he missed the last cable car and took a path down the mountain which he had been told was easy. Tragically the path was not clear and he fell and was killed. My parents and I never got over his loss and this is why I am giving this money in memory of him.

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