Computer based experiments for off-campus teaching and learning of AC electricity

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***Abstract**: In this work, we show the implementation of a computer based Digital Storage Oscilloscope (DSO) and Signal Generator (SG), using the computers soundcard for off-campus AC electronics experiments. The microphone input is used for the DSO, and the speaker jack is used as the SG. In an effort to reduce the cost of implementing the experiment, we examine software available for free online. A small number of applications were compared in terms of their interface and functionality, for both the DSO and SG. With the choice of a suitable app for both the input and the output, simple AC experiments were completed using the computer based DSO.*

Introduction

Experimental work is an essential component of an undergraduate education in engineering and physical science. This usually takes place on campus in a laboratory with specialist equipment. However, over the last two decades there has been increasing financial pressure to reduce the laboratory component which require small student to staff ratios and significant resources to supply and maintain the laboratory. In a recent survey by Sharma, et al. (2005), Australian university physics departments reported the ability to upgrade/upkeep laboratories and laboratory staff was a major challenge. In addition to this, student contact time in laboratories has decreased over the same period of time, and this is most evident for large first year classes.

Previous work by Mendez, et al. (2005) has shown that there are some excellent experiments from physics for off-campus students. In the face of decreasing contact time in laboratories, introducing some off-campus experimental work would be an ideal way to maintain the practical portion of the course for on-campus students, as well as providing a laboratory component for off-campus students. We are of the view that even some experiments that normally use bulky and expensive specialist equipment could be performed by students at home. Specifically in undergraduate electronics courses, experiments typically involve the use of Digital Storage Oscilloscopes (DSOs) and Signal Generators (SGs). These relatively expensive and bulky pieces of bench top equipment make it prohibitive for external, distance, or off-campus students to be involved, without attending a residential school. With a strong laboratory program in the Applied Physics course at Edith Cowan University (ECU), there has been a reluctance to offer all but the simplest of subjects with laboratory components, to off-campus students. However, there is a growing demand, particularly from the Engineering sector, for courses to be more available remotely. To that end, ECU is investigating the possibility of remote laboratory programmes, which can be completed by off-campus students to ensure their Applied Physics or Engineering knowledge is balanced by experimental experience.

The goal of this work is to use freely downloadable software to turn a PC into a DSO and SG to enable students to investigate AC electronics. We demonstrate how students might conduct experiments at home using the microphone and speaker jacks of the PC soundcard for input and output, respectively. This is done using some fundamental experiments on AC electricity and electronics. AC electricity and analogue electronics are an integral part of applied physics and engineering, hence, the experiments are an ideal choice for students to complete at home. The work is similar to that of Magno et al. (2007). However, we use the advanced functionality of the chosen software to more efficiently analyse all the circuits considered. The work of Magno et al. only considered a RLC circuit. In this work, we investigate RC, RL, and RLC circuits.

Software

Digital Storage Oscilloscope

There are a small number of freely downloadable soundcard based oscilloscopes. These include Zelscope, BIP Electronics Lab Oscilloscope, Virtins Sound Card Oscilloscope, xoscope (for Linux), and Soundcard Oscilloscope. The license for these varies from program to program, some are free, others require a license but have free trials, and others have optional licenses. For an external program either a free or licensed program will be required, however, the cost associated with licensing these is low, such that an individual student, or the institution would be able to cover (Zelscope for example has a site license of $99.95, one could discuss use of a site license to cover all external students).

Signal Generator

In addition to the oscilloscopes, there are also a number of freely downloadable soundcard based function generators; these include Virtins Sound Card Signal Generator, Test Tone Generator, and Tone Generator. In addition to these, Soundcard Oscilloscope has its own built-in signal generator. As with the oscilloscope software, various license options exist with the signal generator applications.

Software Choice

Several of these oscilloscope applications were tested for the purpose of comparison (Oswald, 2009). This involved looking at the ability of the application to measure the frequency of standing waves in pipes. The applications were not tested for accuracy, but for usability. This work assessed, comparatively, how easy it was to perform a pre-existing laboratory session, using the computer based oscilloscope in place of the bench top DSO. The conclusion of this work was that the Soundcard Oscilloscope, with its real looking interface, the frequency analysis functionality, and the built in signal generator, was the best choice. The wonderful by-product of this is that Soundcard Oscilloscope is free for public education purposes. Figure 1 shows screen shots of the Soundcard Oscilloscope, for both the oscilloscope function (left) and the signal generator function (right).

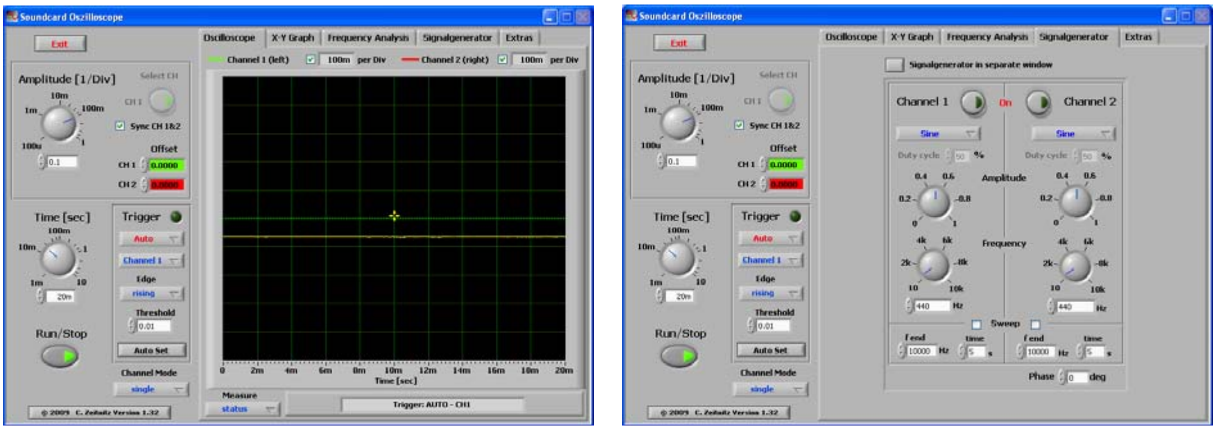

Figure 1: Screen shot of the Soundcard Oscilloscope (left), and the signal generator (right).

Theory

For completeness, we include the basic theory of the undergraduate experimental work considered in this paper. There are three main circuits in AC electricity, the RC, RL, and RLC circuits. Here, R is a resistor, C is a capacitor, and L is an inductor. These components can be connected in series (as seen in Figure 2), parallel, or a combination. In this work we will only consider basic series AC circuits.

Frequency Response

In a series circuit, the capacitor acts as a high pass filter, and an inductor acts as a low pass filter, due to the frequency dependence of its impedance. The most important point in the frequency response is called the cut-off frequency, which is the half power point. For an RC circuit is given as,

$$f_c = 1 / (2 \pi R C). \quad (1)$$

For an RL circuit, the cut-off frequency is given as,

$$f_c = R / (2 \pi L). \quad (2)$$

With the combination of the high pass and low pass filter, an RLC circuit acts like a band pass filter. This then has a peak resonant frequency (f), and a bandwidth (Δf), given as,

$$f = 1 / [2 \pi \sqrt{(C L)}], \quad (3)$$

and,

$$\Delta f = R / (2 \pi L). \quad (4)$$

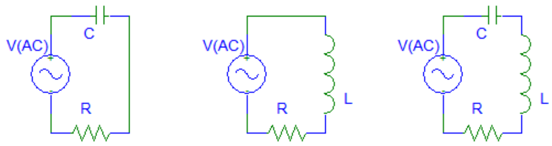

Figure 2: AC series circuits, RC, RL, and RLC.

Phase Response

Like the voltage, the phase angle relative to the input AC signal also depends of frequency. The phase angle between the source voltage and the current flow for a series RLC circuit can be expressed as,

$$\phi = \arctan [(2\pi f L - 1 / [2\pi f C]) / R]. \quad (10)$$

For an RC circuit, the inductor term can ignored, and similarly, for an RL circuit, the capacitor term can be ignored.

Method

The components required for the experiment are fairly inexpensive, even when utilizing several different resistors, capacitors, and inductors. What are required are cables to go from the headphone and microphone jack, to the components. In this work, we have utilized a commercial jack to banana plug cable. These are not too complicated to fabricate. However, it would also be simple to supply the components and cables directly to the students. Equipment is mailed to students in our Introduction to Physics unit. By supplying the equipment to students, the materials required to perform DC electricity experiments could be supplied; including a digital multimeter, and a breadboard.

Frequency Response

In the traditional on-campus experiments, only a simple SG and DSO are available for students. This means that students must manually set the frequency on the SG, and measure the amplitude of the input and output signals on the DSO. The advantage of the PC based system, is that the software has a built-in frequency analysis component, and the SG component can be used to sweep the frequency. This is similar to the functionality of a spectrum analyser, which would be available in higher level electronics laboratories. This means that with the PC based equipment, the student can examine the frequency response of the AC circuits using the SG to sweep the frequency range of interest, and capture the data using the frequency analysis component, with the peak hold option checked. Figure 3 shows the frequency analysis component.

Phase Response

A desktop spectrum analyser is capable of not only looking at the frequency response; they can usually look at the phase response. However, the frequency analysis component of the software used is not able to do this. Although there are some spectrum analysis programs available, none of these are freely available, and we have not investigated if they can perform a suitable phase analysis.

The simplest method to investigate the phase response is then to utilize the traditional laboratory based method. That is, manually varying the signal frequency, comparing the input signal to the output signal, and measuring the phase shift visually. By utilizing the frequency sweep option of the SG with the time based signal on the DSO, the student will be able to qualitatively see the output signals amplitude and phase change as the input signal is swept. From here, students can step through several frequencies and quantitatively analyse the phase change, comparing to the predicted angle from the theory (Serway and Jewett, 2008).

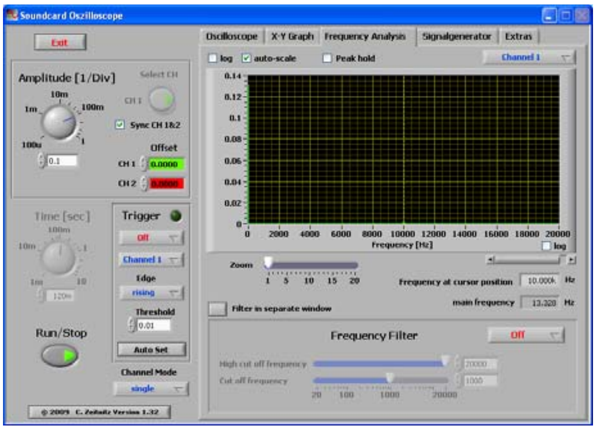

Figure 3: Screen shot of the frequency analysis function.

Results

Frequency Measurements

To obtain the results of the frequency response, the output of the speaker port was used in place of the AC voltage source in Figure 2, which was also connected to channel 1 of the microphone port, while channel 2 was connected across the resistor. The two ports of the DSO are possible because the microphone port used had a stereo input (left and right).

Figure 4 (left) shows the frequency sweep of channel 2, from 10Hz, to 10kHz of the sample RC circuit (R = 1kΩ and C = 0.2μF). Here, the theoretical value for the cut-off frequency is 796Hz. Taking into account the uncertainty in the resistor and the capacitor, both with a 10% tolerance, this value agrees with the measured value of approximately 860Hz.

Figure 4 (right) shows the frequency sweep from channel 2, from 10Hz, to 10kHz of the sample RL circuit (R = 1kΩ and L = 100mH). Here, the theoretical value for the cut-off frequency is 1.59kHz. Taking into account the uncertainty in the resistor and the inductor, with tolerances of 10% and 5% respectively, this value agrees with the measured value of approximately 1.60Hz.

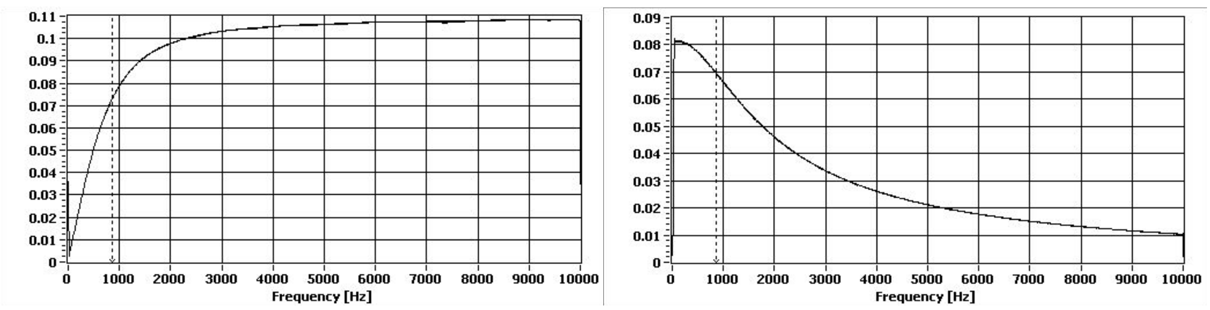

Figure 4: Frequency sweep of (left) the RC circuit, and (right) RL circuit.

Figure 5 shows the frequency sweeps (again from 10Hz, to 10kHz) of the two sample RLC circuits. In Figure 5 (left), the values of the components used were 100Ω, 4.7mH, and 0.2μF. This gives a resonant frequency of 4.95kHz, with a bandwidth of 3.4kHz. In Figure 5 (right), the inductance was increased to 47mH, while the capacitance was reduced to 22nF. This resulted in the same resonant frequency, but a reduced bandwidth of 340Hz. In these figures a small amount of noise can be seen, particularly around the resonant frequency. This noise is digital error from the stepping of the frequency sweep. That is, the frequency sweep functionality of the SG, since it is from a computer, is discrete. This means that the signal switches from frequency to frequency in discrete steps. This is in contrast to an analogue frequency sweep, which would sweep through all frequencies in the spectrum.

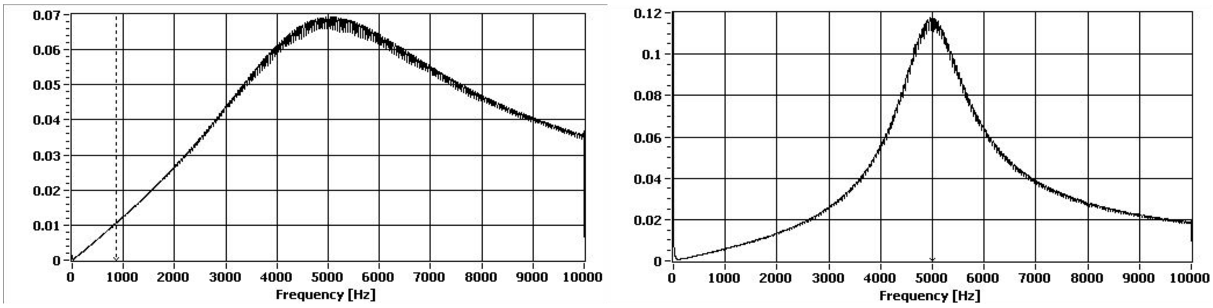

Figure 5: Frequency sweep of the RLC circuits, (left) using 100Ω, 4.7mH, and 0.2μF, and (right) using 100Ω, 47mH, and 22nF.

Phase Measurements

Table 1 show the result of the phase angle dependence on the frequency for the RLC circuit, using the 100Ω, 47mH, and 0.02nF components. We see a combined result of the RC and RL circuits. That is, at low frequencies the circuit is capacitive so the current is ahead of the voltage source in terms of the phase angle. At resonance, the circuit becomes resistive so the phase angle between the current and source voltage is zero. Also, at high frequencies, when the circuit is inductive, the current lags behind the voltage in terms of the phase angle. The same applies for the analysis of either the RC or RL circuits.

An alternative method of determining the phase angle is to use Lissajous curves. That is, plotting channel 1 against channel 2, this can be done using one of the functions of the soundcard oscilloscope software. If the phase angle is zero, the figure will be a straight line. If the phase angle is 180 degrees, then the figure will be a perfect oval. For angles in between, the figure will be an oval on an angle, and the horizontal axis value can be used to determine the actual value.

Table 1 Phase angle frequency dependence of RLC circuit.

Frequency (Hz)	Phase Divisions	Divisions for 360^o	Phase Angle (Degrees)
3000	5	20	~90
4500	2	14	~50
4800	0	-	0
5150	2	13	~55
8000	3.5	15	~85

Discussion

There are two primary benefits to the computer based system developed. The first is in terms of the enhancement to learning by students at the undergraduate level, where the knowledge learnt by off-campus students can be significantly improved with the use of practical experimental work. Secondly, a by-product of this work is a system that can be used in the secondary education system to enhance year 11 and 12 Physics programs. High school classes tend to lack practical work, making them less appealing to students, which has a flow through effect to undergraduate courses, such as Engineering and Physics. As such, this method of investigating circuits using a PC soundcard is well suited to high school level electricity, especially due to the low cost of the method. In addition, the proposed changes to the high school physics syllabus could see the inclusion of a lot more in the way of electricity and electronics (ACARA, 2010). This means that experimental courses will be needed for these aspects, to enhance the learning of the students.

Findings

Overall, the software was simple and effective to use. Looking at the signals in the time domain on the standard oscilloscope gives the student an understanding of how the circuits affect the voltage signals qualitatively. The use of the spectrum analyser function will enable the students to quantitatively analyse the frequency response of the circuits, while being able to see the frequency sweep, when utilising that functionality of the SG. By varying the values of the components used (the resistors, capacitors, and inductors), the students will easily be able to compare the affect. This is a significant improvement over the laboratory based experiments where the data collection can take a significant amount of the allocated in-class time. At home, students will have the opportunity to take their time, and when confident in the use of the software, the amount of time required for the collection of the data will be minimal. This means that students can focus on the effect of varying component parameters. Just looking at the time domain signals, the off-campus students will be able to reproduce the results of the on-campus experiments for the phase aspects of the experiments.

The ideal option for this method of delivery of experiments is to supply small experimental kits. This way the availability of components to students in different locations can be controlled. The off-campus students will have access to the same materials used on-campus. The cost of implanting this sort of program should be minimal, with the most expensive component being the cable from the headphone jack to banana connector or alligator clip for the circuit. As previously mentioned, the other advantage of this method is the ability to include the components required for DC circuit experiments, which could also include a stop watch to investigate transient affects in RC and RL circuits.

Future Work

Although the software (Soundcard Oscilloscope) has proven to be very effective, with all the required functionalities necessary to undertake this work, other software is required. Ideally, we would like to look at the ability to use Labview (which was used to develop the Soundcard Oscilloscope software) to develop in-house software. The primary motivation of this would be to ensure the software interface is identical to the on-campus DSOs and SG. This would mean that if students have learned to use the soundcard based equipment, they should effortlessly be able to change to the laboratory based equipment. Also, this would mean that the software is always available and maintained, keeping it up to date, and more importantly free to use, if the license for Soundcard Oscilloscope was to change. This would make an ideal project for a Physics/Computer Science student.

Finally, it would also be advantageous if other AC circuits could be analysed using the soundcard based DSO and SG. This would include circuits that make use of electronic devices, such as diodes and transistors. Currently the only problem is that the microphone input includes a DC offset which is used to power microphone devices, if required. We will look at possible solutions to this using the soundcard, but it is likely that we will need to go to something like a USB interface. This will, however, result in additional costs, with a basic USB interface valued at approximately $30 AUD. Alternatively, the work of Dimitrov (2010) could be used to control the DC off-set present on the microphone input. This work could also be directly applied to use the soundcard for DC signals, enabling DC circuits to be analysed.

Conclusions

We have successfully demonstrated the use of a soundcard based oscilloscope and signal generator for off-campus AC electricity experiments. These experiments were equivalent to those conducted within a teaching laboratory setting. This work will make it possible for both on-campus and off-campus (distance learning) students to actively participate in quantitative experimental work without the need to be present on-campus. The results of this work show that the PC based software actually offered some advantages over the conventional laboratory based approach, specifically in terms of functionality resulting in improved teaching and learning opportunities, to aid in the understanding of the material, quantitatively, and allowing students additional time to work on the practical component.

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