Harmonic series experiments in three-in-one resonance tube with audacity software

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Abstract. In this study, we utilized Audacity Open Source Software (OSS) to perform the harmonic series experiments in three-in-one resonance tube. Three-in-one resonance tube was configured as both-closed-end (BCE), one-closed-end (OCE) and both-open-end (BOE) tubes while Audacity was utilized to measure their resonance frequencies. The harmonic series experiments were performed to determine the speed of sound in air, \( v \), in five different lengths of BCE, OCE and BOE tubes (15, 20, 25, 30 and 35 cm). The experimental values of \( v \) were calculated from the slope of \( f_n \) versus \( n \) graphs for all types of resonance tubes. Findings showed that the experimental values of \( v \) are less than 5.00% errors compared to the reference values. It indicated that Audacity can be an alternative for oscilloscope as it provides the accurate peak values of frequency spectrum within the audible ranges.

1. Introduction
Hands on activities, especially demonstration and experiment are important in developing students’ understanding in the fundamental principles of Physics and enhancing students’ scientific reasoning skills [1–4]. However, several experiments in schools and colleges could not be performed due to lack of appropriate instruments such as oscilloscope, spectrum analyzer and signal generator. Therefore, freeware and Open Source Software (OSS) such as Visual Analyser (VA) [2, 4–5] and Tracker [6–9] can be used as alternatives to the basic instruments which are required to perform specific Physics experiments.

In 2017, Jaafar, et al. employed VA freeware to study the harmonic series in BCE, OCE and BOE tubes [4]. However, the operators require special training sessions to learn its operation procedures as it has multiple functions and can be operated as a spectrum analyzer, frequency meter, voltmeter, and function generator [2, 5]. In addition, the peak values of frequency spectrum could not be accurately measured as the displayed values refer to the position of cursor. Audacity is an OSS for recording, editing and analyzing the direct recording or saved audio files. Hence, it can be easily operated by the novice users compared to VA freeware. Besides, it is able to measure accurately the peak values of frequency spectrum within the audible ranges. Thus, previous researches utilized Audacity to study several Physics concepts such as gravitational acceleration [10–11], Doppler Effect [12], electromagnetic induction [13] and kinematics of uniform circular motion [14].

In this study, we employed Audacity OSS to carry out the harmonic series experiments in three different types of resonance tubes; BCE, OCE and BOE tubes. All types of resonance tubes are...
configured from the customized three-in-one resonance tube. Five different lengths of three-in-one resonance tubes are used to determine the speed of sound in air, \( v \) from the harmonic series experiment. The experimental values of \( v \) are calculated from the slope of \( f_n \) versus \( n \) graphs for all types of resonance tubes. Then, the experimental values of \( v \) are compared with the reference values to determine the compatibility of Audacity in replacing oscilloscope for sound wave experiment.

2. Materials & Methods

2.1 Three-in-one resonance tube

Three-in-one resonance tube for this study is adapted from the special resonance tube which was designed and constructed by Jaafar, et al. (2017). It consists of PVC conduit of 2.5 cm diameter with a rectangular hole of \( 2 \times 3 \text{ cm}^2 \), hollow rubber tube, rubber stopper and rubber stopper with embedded microphone as shown in figure 1. In this study, five different lengths of three-in-one resonance tubes (15, 20, 25, 30 and 35 cm) are configured as BCE, OCE and BOE tubes. BCE tube is configured by fixing the hollow rubber tube at the rectangular hole, the rubber stopper at one end and the rubber stopper with embedded microphone at the opposite end. The resonance tube is configured as OCE tube by removing the rubber stopper at its end. Meanwhile, BOE tube is configured by removing rubber stoppers at both ends and placing the rubber stopper with embedded microphone near the PVC conduit during the experiment.

![Figure 1. Components of three-in-one resonance tube.](image)

2.2 Harmonic Series Experiment

In this study, the harmonic series experiment is performed using three-in-one resonance tube and Audacity OSS as shown in figure 2 (a). The rubber tube at the rectangular hole of three-in-one resonance tube is flicked once to produce sound wave in the resonance tube and it is detected by the microphone. Then, the wave is displayed and analyzed on the computer with preinstalled Audacity OSS. There are four important elements on Audacity interface to record and measure the resonance frequencies for the harmonic series experiment; RECORD button (R) or press R on the computer keypad, STOP button (S) or press space bar on the computer keypad, TRIM button (T) and Analyze menu (A). The detected wave is displayed on Audacity interface [Figure 2 (b)] as the RECORD button is pressed to start the recording of the wave until the STOP button is pressed to stop the recording.
Figure 2. (a) Schematic diagram of the harmonic series experiment and (b) the detected wave is displayed on Audacity interface.

The displayed signal is trimmed by highlighting the appropriate signal to be analyzed using mouse and pressing the TRIM button. The trimmed signal is displayed as shown in figure 3(a). Then, the frequency domain of trimmed signal is plotted by clicking “Analyze” menu and choosing “plot spectrum” from dropdown menu [Figure 3 (b)]. As the cursor is positioned at each peak of the plotted spectrum and clicked, the value of each peak which represents the resonance frequency is displayed in the peak column (circle) as shown in figure 3(c).
3. Results & Discussions

Figure 4 shows the $f_n$ versus $n$ graphs for five different lengths of BCE, OCE and BOE tubes. According to figure 4, the slopes of the graphs decreased as the length of tube increased for all BCE, OCE and BOE tubes. It proved that short resonance tubes have higher resonance frequencies compared to long tubes [4–5]. However, BCE and BOE tubes produced all harmonic series while OCE tubes only produced the odd harmonic series in the tubes [3–4]. Therefore, the slopes of the $f_n$ versus $n$ graphs for BCE and BOE tubes were approximately twice compared to the slopes of the $f_n$ versus $n$ graphs for OCE tubes.

Figure 3. Steps to analyze the displayed signal using Audacity.
The values of \( f_n \) are plotted against the values of \( n \) to determine the speed of sound in air, \( v \), for BCE, OCE and BOE tubes. However, the end correction, \( e \), should be considered to calculate the values of \( v \) in OCE and BOE tubes to improve the accuracy of experimental results since both tubes consist of open ends \([3–4]\). The value of \( e \) for OCE tube was calculated from its diameter, \( D \), using equation, \( e = 0.33D \) and its value was 0.0073 m \([4]\). Meanwhile, the value of \( e \) for BOE tube was calculated from its diameter, \( D \), using equation, \( e = 2 \times 0.33D \) and its value was 0.0145 m \([4]\).

The values of \( f_n \) for BCE, OCE and BOE tubes can be determined using the corresponding equations: \( \frac{nv}{2L} \), \( \frac{nv}{4(L + e)} \) and \( \frac{nv}{2(L + e)} \). Thus, the slopes of \( f_n \) versus \( n \) graphs represent \( \frac{v}{2L} \), \( \frac{v}{4(L + e)} \) and \( \frac{v}{2(L + e)} \) for BCE, OCE and BOE tubes, respectively. Therefore, the experimental values of \( v \) for each length of resonance tubes were calculated from the slopes of \( f_n \) versus \( n \) graphs and compared with the reference values of \( v \), 346 m s\(^{-1}\) \([3–5, 15–16]\) to determine the compatibility of
Audacity as an oscilloscope. Table 1 summarizes the comparison between the experimental and reference values of $v$ for three different types of resonance tubes.

Table 1. Comparison between the experimental and reference values of $v$ for BCE, OCE and BOE tubes.

| $L$ (m) | BCE $m$ (Hz) | $v_{exp}$ (ms$^{-1}$) | % | OCE $m$ (Hz) | $v_{exp}$ (ms$^{-1}$) | % | BOE $m$ (Hz) | $v_{exp}$ (ms$^{-1}$) | % |
|---|---|---|---|---|---|---|---|---|---|
| 0.15 | 1131.60 | 339.48 | 1.88 | 522.97 | 329.05 | 4.90 | 1079.70 | 355.22 | 2.67 |
| 0.20 | 822.29 | 328.92 | 4.94 | 404.86 | 335.71 | 2.97 | 818.23 | 351.02 | 1.45 |
| 0.25 | 681.81 | 340.91 | 1.47 | 332.24 | 341.94 | 1.17 | 665.55 | 352.08 | 1.76 |
| 0.30 | 554.68 | 332.81 | 3.81 | 276.34 | 339.68 | 1.83 | 557.46 | 350.64 | 1.34 |
| 0.35 | 490.99 | 343.69 | 0.67 | 246.17 | 351.83 | 1.68 | 479.38 | 349.47 | 1.00 |

According to Table 1, the experimental values of $v$ are within 4.94%, 4.90% and 2.67% compared to the reference values for BCE, OCE and BOE tubes, respectively. Since the end corrections have been considered to determine the values of $v$ in OCE and BOE tubes, the percentage error for both resonance tubes was smaller compared to BCE tube. Therefore, the errors were probably caused by the temperature variation inside the tube [3–4, 16]. However, the small percentage errors prove that Audacity is compatible to be used as an oscilloscope for sound wave experiment.

4. Conclusion

We have successfully determined the speed of sound in air in both-closed-end (BCE), one-closed-end (OCE) and both-open-end (BOE) tubes by performing the harmonic series experiments using Audacity Open Source Software (OSS) in this study. Audacity was employed as an oscilloscope to measure the resonance frequencies for BCE, OCE and BOE tubes. The experimental values of $v$ were calculated from the slope of $\frac{v}{m}$ versus $m$ graphs for five different lengths of BCE, OCE and BOE tubes. The experiments produced results within 4.94% errors, indicated that Audacity can be utilized as an oscilloscope in sound wave experiments. However, a further study should be carried out to explore other functions of Audacity OSS in Physics experiments.

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