Physics demonstration of sound waves using Visual Analyser

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(Received 22 September 2012, accepted 5 February 2013)

Abstract

This article describes several possible physics demonstrations of sound waves using Visual Analyser (VA). The suggested demonstrations are suitable for physics classroom during teaching and learning process in the subtopic of sound waves at secondary and tertiary education levels. VA is a freeware which offers alternative solution with the functions of more than just an oscilloscope. By integrating the VA and easily available material, specific physics concept can be demonstrated. We suggest five physics demonstrations for sound waves by assembling pipes, speakers, and microphones with VA-installed computer. These physics demonstration aims for the concept of resonance, interference, standing wave and others related to the sound waves.

Keywords: Visual Analyser, sound waves, physics demonstration.

Resumen

Este artículo describe varias demostraciones físicas posibles de las ondas de sonido utilizando el Analizador Visual (AV). Las demostraciones sugeridas son adecuadas para el aula física durante el proceso de enseñanza y aprendizaje en el subtema de las ondas de sonido en los niveles de educación secundaria y terciaria. El AV es un programa gratuito que ofrece una solución alternativa con las funciones de algo más que un osciloscopio. Al integrar el material de AV y fácilmente disponible, se pueden demostrar conceptos específicos de física. Sugerimos cinco demostraciones de física de las ondas sonoras mediante montaje de tuberías, altavoces y micrófonos con el AV-instalado en la computadora. Estas demostraciones físicas apuntan a la idea de resonancia, interferencia, ondas estacionarias y otros relacionados con ondas sonoras.

Palabras clave: Analizador Visual, ondas sonoras, demostración física.

PACS: 01.40.gb, 43.58.Dj **ISSN 1870-9095**

I. INTRODUCTION

Many physical quantities need special instrument to measure or quantify such as current, air pressure, and frequency. Some instruments are expensive to be afforded by schools and colleges, for example oscilloscope, signal generator and spectrum analyzer. Consequently, important physics concepts remain unproven to students during classroom. A utilization of Visual Analyzer (VA) in physics demonstration offers solution to this problem. Demonstration is one of the teaching approaches which plays an important role to improve students' in-depth understanding in the fundamental principles of physics and enhances students´ practical and scientific reasoning skills e. g, to see, analyze and assess the results. Demonstration-laboratory allows students to make observations through demonstration rather than through hands-on laboratory in order to overcome time and resources constraint [1].

VA is a freeware which is not only a true oscilloscope, but also can be operated as a spectrum analyzer, frequency meter, voltmeter, and function generator [2]. We will describe briefly five physics demonstration sets to demonstrate the physical properties of sound waves. These demonstrations are easy to set up and conduct in the physics classroom by teacher and instructors. VA is compatible to windows-based computers. The systematic and effective use of computers also enables teachers to teach problem solving. Teachers who use computers are truly talented individuals since these additional capabilities must be learnt and relearned to for them to be good with it [3].

II. EXPERIMENT

All demonstrations described in this article were constructed from easily available materials at low cost including pipes or tubes, speakers, and microphones. The VA is downloaded from the developer website (http://www.sillanumsoft.org) and installed in Windows-based Computer. In the large classroom, a projector can be used to display the measurement window on the wall.

The microphone, either built-in or external one, plays an importance role as a sound wave sensor. The microphone detects variation in the air pressure at the surface of its active element; diaphragm. High signal output implies high air pressure. For the case of standing wave of sound in an air column, the volume of rarefactions and compression of molecules are established along the air column. Rarefactions refer to the high molecules density which causes the air pressure to decrease. In other hand, compression refers to the low molecules density which causes the air pressure to increase. Therefore, the point of anti-node for molecules displacement is the point of node for air pressure and vice versa.

The spectra display covers the frequency range from 0 Hz to 2970 Hz. The amplitude of the spectra is arbitrary value, but represents the strength of air pressure as previously mentioned. It is worth noted that the speed of sound in air at room temperature is 343 m/s [4]. This value is a reference value for the demonstration described in this article.

A. Harmonic series of sound waves in a one-end-closed tube

The objective of this demonstration is to show that multiple resonances of sound waves can occur in an air column of various lengths. Different frequencies of sound or so called harmonics are produced when a one-end-closed tube is knocked by a rod, as illustrated in Fig. 1.

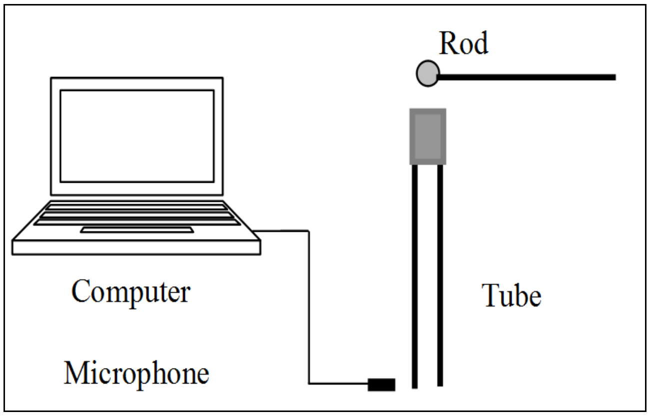
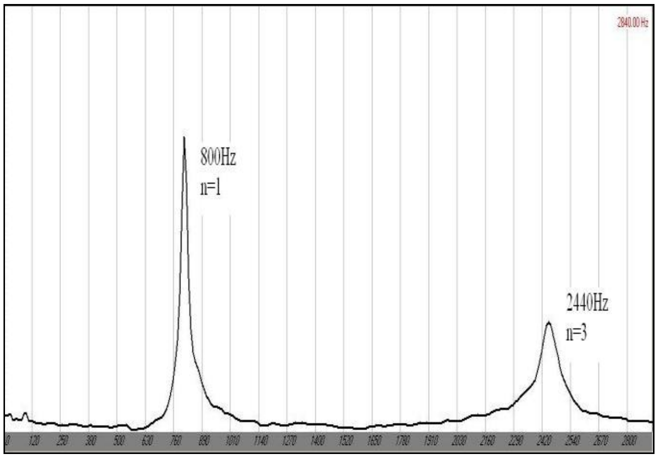


FIGURE 1. Demonstration of the harmonic series of standing waves in a tube closed at one end.

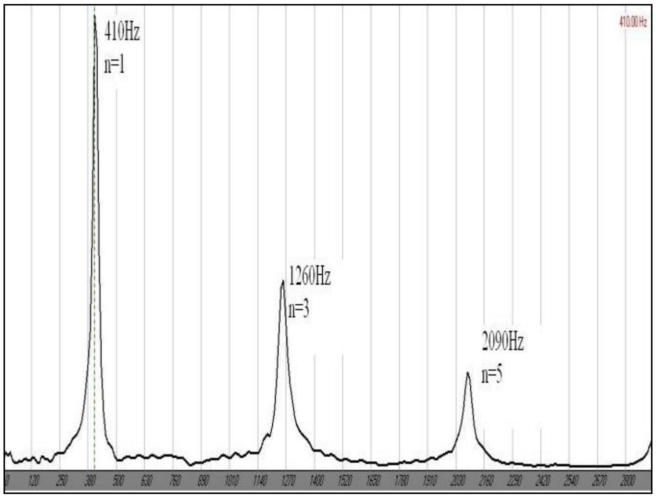
Our ear cannot differentiate between these harmonics. By setting VA for spectrum analyzer, the harmonic series can be demonstrated clearly. Figure 2 shows VA snapshot for the tube with the length of 10 cm, 15 cm, 20 cm, and 25 cm. In a closed-tube, the relationship between length of the tube, L and wavelength is $l = (4/n)L$ where $n = 1,3,5...$ The corresponding harmonics is $f_n = nf_o$ where $n = 1,3,5...$ and f_0 is the fundamental resonance. From the snapshot, we can clearly see that higher harmonics are in the multiple integer of fundamental frequency ($n = 1,3,5...$) and the values in the harmonic series depends on the tube length. During demonstrations, the teacher can ask student to verify this relationship by doing simple calculation and confirm the standing profile in Fig. 2(d).

B. Resonance of sound waves in a one-end-closed tube with variable length

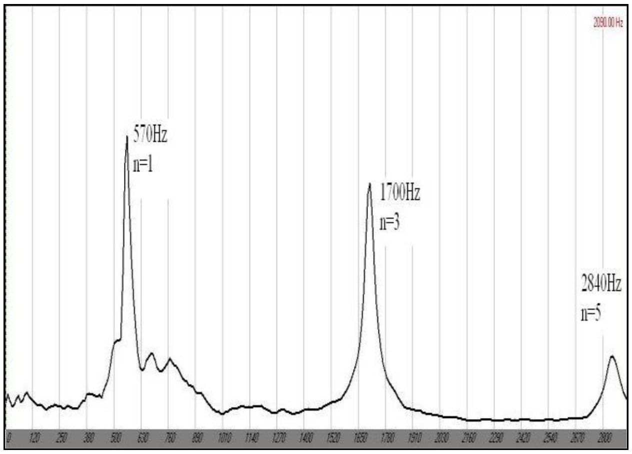
This demonstration shows that a single frequency of sound wave can establish resonance condition at various length of a one-end-close tube. 1 m tube with adjustable piston is used to establish the air column with variable length. VA is capable to be used as signal generator and detector simultaneously. A speaker is placed at the open end to generate sound wave. A microphone can be placed anywhere close to the tube to detect the resulted resonance.



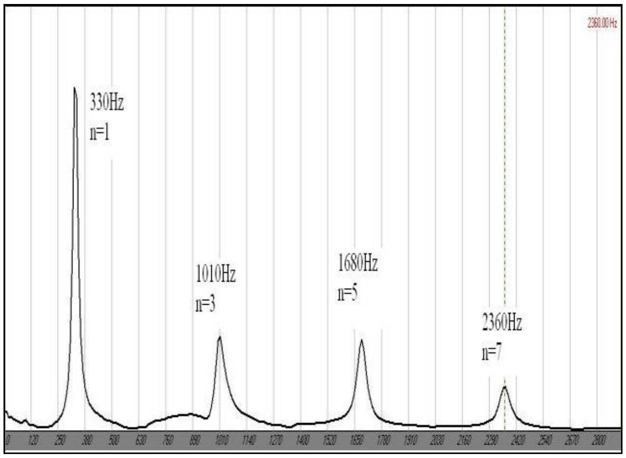
a) 10 cm



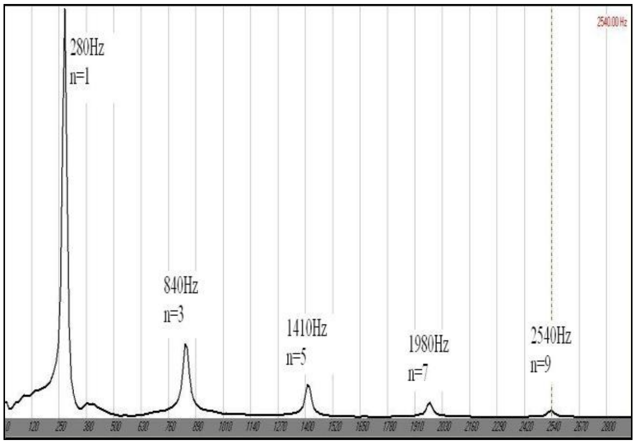
b) 15 cm



c) 20 cm



d) 25 cm



e) 30 cm

FIGURE 2. VA snapshots of the harmonic series in the one-end-closed tube for the tube length of (a) 10 cm, (b) 15 cm, (c) 20 cm, (d) 25 cm and (e) 30 cm.

To begin the demonstration, the VA signal generator's frequency is set at the initial value of f_o, let say 600 Hz. The loudness of the speaker should be set at appropriate level. The microphone also detects the frequency 600 Hz even the resonance condition is not achieved yet due to the scattered sound waves from the speaker. Then, the piston was moved away from the speaker until the 600 Hz peak is at its highest in the spectrum analyzer window of the VA windows, as shown in Figure 4 (a).

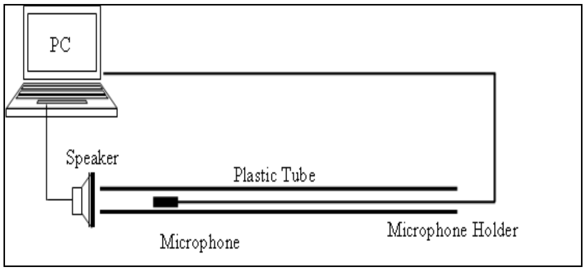


FIGURE 3. Schematic diagram of a closed tube experimental set-up.

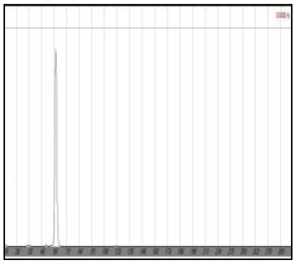
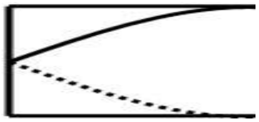
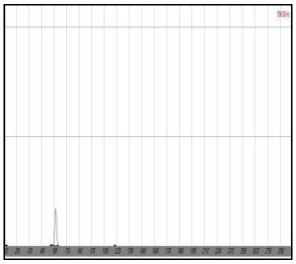
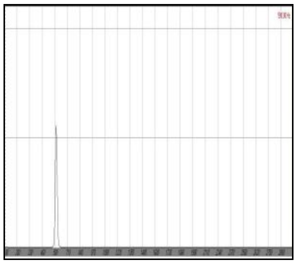
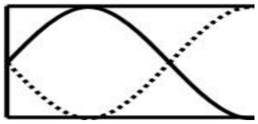
 (a) 13.4 cm	$\frac{1}{4}wave$  $v = f\lambda$ $v = (600\text{ Hz})(4L)$ $v = (600\text{ Hz}) \times (4 \times 0.134\text{ m})$ $v = 322\text{ ms}^{-1}$
 (b) 20 cm	Resonance is not achieved at this position
 (c) 40 cm	$\frac{3}{4}wave$  $v = f\lambda$ $v = (600\text{ Hz})\left(\frac{4}{3}L\right)$ $v = (600\text{ Hz})(4/3 \times 0.40\text{ m})$ $v = 320\text{ ms}^{-1}$

FIGURE 4. The VA snapshots for the sound wave frequency of 600 Hz at 3 piston locations, relative to the open end. (a) 13.4 cm, (b) 20 cm and (c) 40 cm.

The piston position relative to the open-end is recorded as the air column length for the resonant condition. One can also hear that at this position the speaker loudness is high; indicated that resonance is achieved. When the piston is moved further than 600 Hz, amplitude decreases to the background level, as shown in Figure 4(b). At position 43 cm, the resonant condition is achieved again as shown in Figure 4(c). Calculations in Fig. 4 confirmed that Fig. 4(a) represents first fundamental mode for *L*=13.4 cm and Fig. 4(b) represent the first overtone mode for *L*=40 cm.

In the above demonstration, the wave frequency is fixed while the air column length is change to search resonance condition. For more variation, one can fixed the air column length and adjust the wave frequency. By this way, student can observe the series of harmonics in a fixed length of an air column.

C. Harmonic series of sound waves in an open tube

Section 2.1 and 2.2 describe the demonstration for sound waves resonance in a one-open-end tube. The resonance can also be achieved in an open tube. For that purpose, a computer is use to generate sound waves at certain frequency by a speaker and detect the pressure amplitude of sound wave by a microphone. The microphone is placed closed to the tube as shown in Fig. 5.

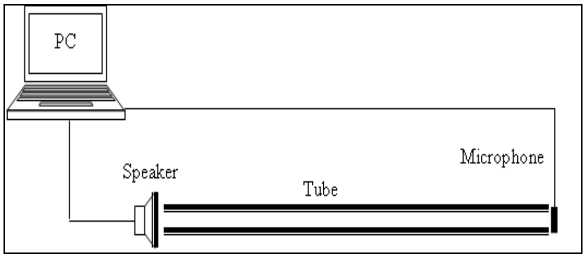


FIGURE 5. Demonstration of the harmonic series of sound waves in an open tube.

The frequency of the generated sound is adjusted staring from low frequency until the first highest peak is observed in the VA spectrum analyzer. This is the fundamental frequency of the standing wave in the open tube. Qualitatively, one can hear high loudness at this frequency. When the frequency of the generated sound is further increased, the next frequency peaks can be observed at periodical frequency interval. These are the overtones of the standing waves.

Figure 6 shows the snapshots of the resonances in a 1 m open tube. The fundamental resonance is observed at 166 Hz and the next overtones happen in an interval of about 169 Hz. The standing wave profile is shown at the right side of the respective snapshot.

For verification, the instructor can repeat demonstration in Section 2.1 by replacing the one-end closed tube with the open tube. A series of harmonics in a VA snap shot is expected to be observed in the open tube.

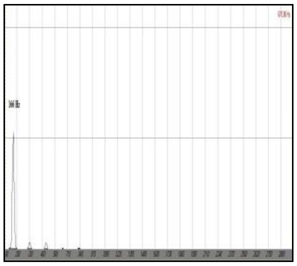
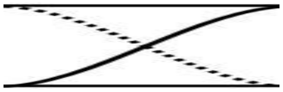
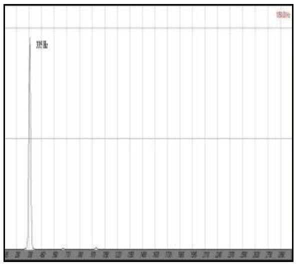
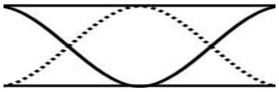
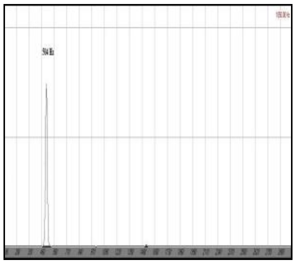
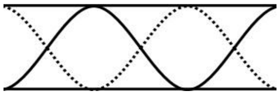
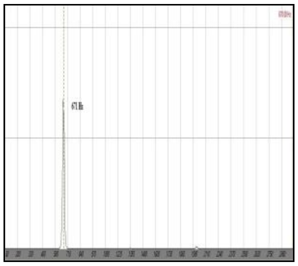
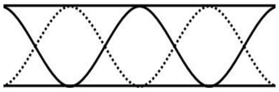
 (a) 166 Hz	 $v = f\lambda$ $v = (166\text{ Hz})\left(2L\right)$ $v = (166\text{ Hz})\times(2\times 1.0\text{ m})$ $v = 332\text{ ms}^{-1}$
 (b) 335 Hz	 $v = f\lambda$ $v = (335\text{ Hz})\left(L\right)$ $v = (335\text{ Hz})(1.0\text{ m})$ $v = 335\text{ ms}^{-1}$
 (c) 504 Hz	 $v = f\lambda$ $v = (504\text{Hz})\left(\frac{2}{3}L\right)$ $v = (504\text{ Hz})(\frac{2}{3}\times 1.0\text{ m})$ $v = 336\text{ ms}^{-1}$
 (d) 671 Hz	 $v = f\lambda$ $v = (671\text{ Hz})\left(\frac{L}{2}\right)$ $v = (671\text{ Hz})(\frac{1.0\text{m}}{2})$ $v = 336\text{ ms}^{-1}$

FIGURE 6. The VA snapshots for the resonance condition in 1 m open tube is achieved at (a) 166 Hz, (b) 335 Hz, (c) 504 Hz and (d) 671 Hz.

D. Node and anti-node of Standing wave in an open tube

In this section, one can show the location of node and anti-node in the tube. The microphone position can be adjusted inside an open tube as shown in Fig. 7. The pressure node and anti-node is searched by moving the microphone along the tube while the frequency of sound wave is fixed.

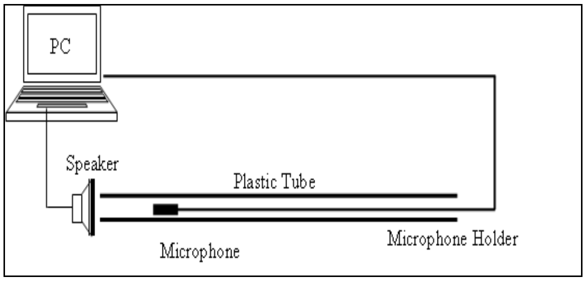


FIGURE 7. The demonstration of node and anti-node position in an open tube.

Figure 8 shows the VA snapshots for the wave frequency of 500 Hz in 1m open tube. By using open tube relation, $v = f\lambda$ and $n\lambda = 2L$ with $n = 1,2,3..$, it is estimated that the wavelength of the standing wave is 0.667 m and $n = 3$, which implies that the second overtone is established.

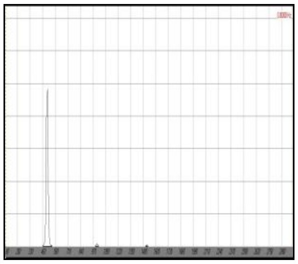
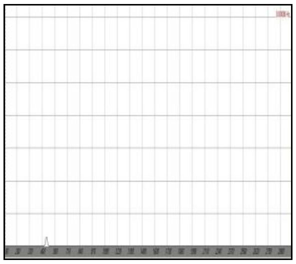
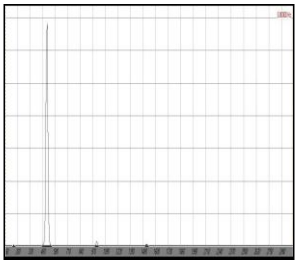
 (a) 15 cm	First pressure anti-node position.
 (b) 33 cm	The pressure decreases at the position others than anti-node
 (c) 49.5 cm	Second pressure anti-node $v = f\lambda$ $v = (500\text{ Hz})(2L)$ $v = (500\text{ Hz}) \times (2 \times (0.495 - 0.17)\text{ m})$ $v = 325\text{ ms}^{-1}$

FIGURE 8. The VA snapshots for the sound wave frequency of 500 Hz in 1 m open tube at 3 microphone locations. (a) 15cm, (b) 33 cm and (c) 49.5 cm.

At position 17cm [Fig. 8 (a)], the pressure amplitude is maximum which is recognized as the first pressure anti-node. The value is equivalent to quarter wavelength. At position 51cm [Fig. 8(c)], second anti-node is reached with an equivalent of third quarter wavelength. If the microphone is further moved, the third pressure anti-node is expected to be at around 85cm. At other position other that the pressure anti-node, the pressure amplitude is lower for example at position 25cm [Fig. 8(b)].

For more exciting activity, demonstrator can ask student to plot the peak amplitude versus positing along the tube to see the pressure amplitude profile of a standing wave along an open tube. Student can investigate the pressure amplitude profile at any other sound frequency and tube length.

E. Beats of sound wave

Beats are the periodic and repeating fluctuations heard in the intensity of a sound when two sound waves of very similar frequencies interfere with one another. A beat pattern is characterized by a wave whose amplitude is changing at a regular rate.

When constructive interference occurs between two crests or two troughs, a loud sound is heard. This corresponds to a peak on the beat pattern. When destructive interference between a crest and a trough occurs, no sound is heard. This corresponds to a point of no displacement on the beat pattern. Since there is a clear relationship between the amplitude and the loudness, this beat pattern would be consistent with a wave that varies in volume at a regular rate.

The beat frequency refers to the rate at which the volume is heard to be oscillating from high to low volume. If ten complete cycles of high and low volumes are heard every second, the beat frequency is 10 Hz. The beat frequency is always equal to the difference in frequency of the two notes that interfere to produce the beats. So, if two sound waves with frequencies of 1000 Hz and 1100 Hz are played simultaneously, a beat frequency of 100 Hz will be detected and measured at time domain window of VA.

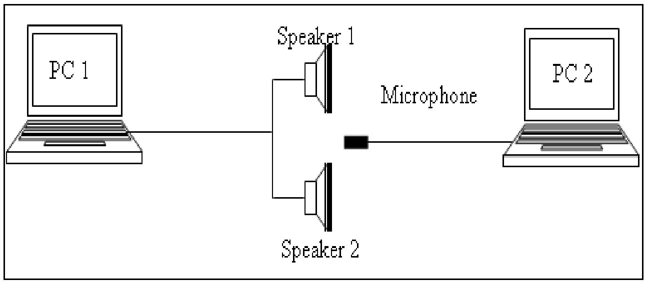


FIGURE 9. The demonstration of beats.

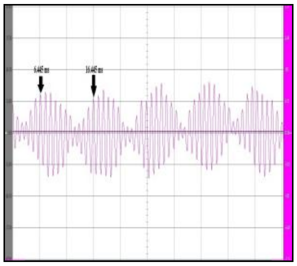
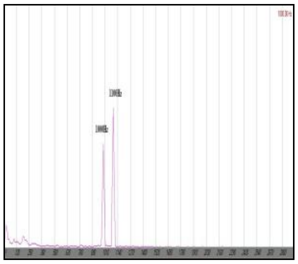
 (a) time domain graph	$f = \frac{1}{T}$ $f = \frac{1}{(16.445\,\text{ms} - 6.445\,\text{ms})}$ $f = \frac{1}{10\,\text{ms}}$ $f = 100\,\text{Hz}$
 (b) frequency domain graph	$f = 1100\,\text{Hz} - 1000\,\text{Hz}$ $f = 100\,\text{Hz}$

FIGURE 10. The VA snapshots for the beats conditions at (a) time domain graph and (b) frequency domain graph.

VI. CONCLUSIONS

We described 5 demonstrations of sound waves using the freeware called Visual Analyser (VA). The demonstrations use simple devices such as; speakers, microphone and plastic tube. All the demonstrations presented above are not only inexpensive, but also very easy to perform and can be utilised in a large classroom. All the results obtained from demonstrated observation are comparable to the standard or calculated values of sound waves velocity and frequency.

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