Young's Fringes of Sound Waves

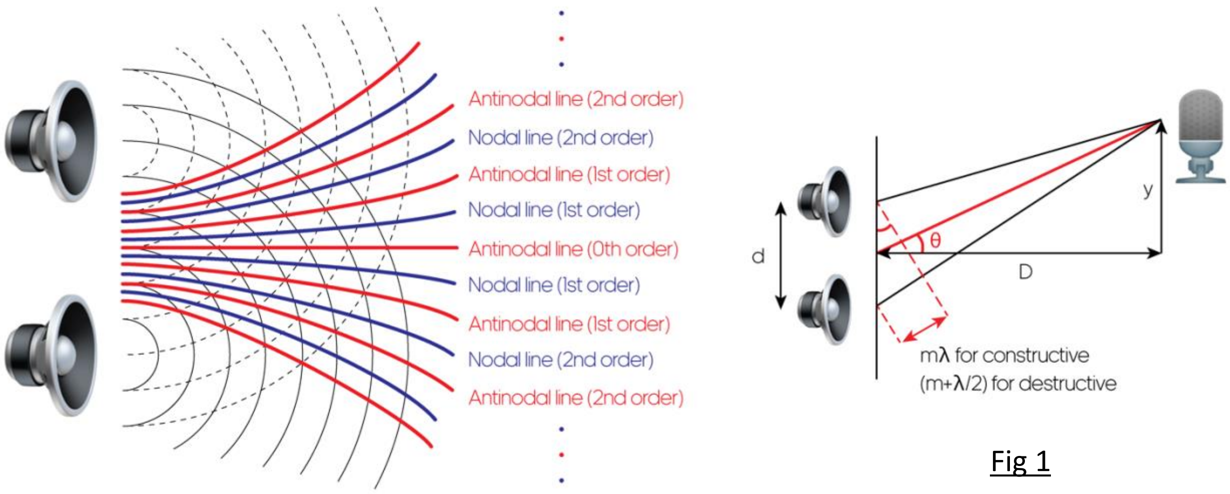

Fig 1

Purpose

Using mobile devices as sound generators and sound analyzer to observe the interference pattern of two homogeneous sound waves, determine their wavelengths and hence the speed of sound waves in air.

Theory

- Waves share some common properties – **interference**, **reflection**, **refraction** and **diffraction**. In this experiment, the properties of interference will be utilized to find the wavelength and speed of sound wave.
- The principle of superposition states that superposing waves result in their vector sum at different points in space.
- For two point sources that generate homogeneous sound waves, those waves propagate and interfere with each other in space. This gives a "fringe" pattern with alternating maximum and minimum amplitude when constructive and destructive interference occurs on the plane.
- As illustrated in Fig 1, the **antinodes** appear when the resultant wave is at maximum and those points constitute antinodal lines. The **nodes** appear when the resultant wave is at minimum and those points constitute nodal lines.
- Let us go through some mathematics of Young's fringes occurred due to interference. The interference pattern on a screen produced by two sources is illustrated in Fig 1. *d* refers to the separation of two sources, *D* refers to the perpendicular distance of the "screen" from the sources, both in the unit of meter (m).
- Path difference refers to the length difference of which the two waves travel in specific paths. Antinodes are found when the path difference is equal to $m\lambda$ (the two waves are "in phase"

that they fortify each other). Nodes are found when the path difference is equal to $(m+1/2)\lambda$ where m = 0, ±1, ±2,… (the two waves are "out of phase" that they cancel each other).

- Using approximation for small angle θ,

$$\tan\theta \approx \sin\theta \approx \theta = \frac{y}{D}$$

- Resolving the geometry in Fig 1, y gives the positions of fringes from center at different orders.

For constructive interference (antinodes)

$$d\sin\theta = \pm m\lambda$$

$$\Rightarrow d\,\frac{y}{D} = \pm m\lambda$$

$$\Rightarrow y = \pm\frac{m\lambda D}{d}$$

For destructive interference (nodes)

$$d\sin\theta = \pm(m+1/2)\lambda$$

$$\Rightarrow d\,\frac{y}{D} = \pm(m+1/2)\lambda$$

$$\Rightarrow y = \pm\frac{(m+1/2)\lambda D}{d}$$

where m = 0, ±1, ±2,… for 0^{th}, 1^{st}, 2^{nd},… orders of antinodes and 1^{st}, 2^{nd}, 3^{rd},… order of nodes.

- Homogeneous sound waves at desired frequency f are generated by the Sound Generator of "AP-Sensor" app in 2 mobile devices. If available, amplifiers should be used instead of built-in speakers of devices in order to amplify the sound and make the result more observable. The center of the surface of sound generator is assumed to be the point source the generate circular wavefronts.
- The distance between successive antinodes and successive nodes is $\frac{\lambda D}{d}$. The positions of antinodes and nodes are determined by moving the Sound Analyzer of the "AP-Sensor" app on the 3^{rd} mobile device along the "screen". With known value of D and d, the wavelength λ can be found.
- The velocity of a traveling wave v is then determined by one wavelength λ (unit in m) divided by one period T (time taken for the wave to travel one wavelength, unit in s). The reciprocal of period is frequency f (unit in Hz). The wave formula is therefore given by

$$v = \frac{\lambda}{T} = f\lambda$$

where v = velocity of wave; f = frequency of wave; λ = wavelength of wave.

- The speed of sound can be deduced using the wave formula. Its theoretical value is given by $340ms^{-1}$ in HKDSE syllabus.

Apparatus

- 2 mobile devices with "AP-Sensor" app
- an amplifier with 2 speakers (if applicable)
- A meter ruler
- An earphone with microphone and 3.5mm audio jack (if applicable)

Setup

As in Fig 1. Reminder: This experiment should be conducted in a room with good sound insulation and trivial amount of feedback from the walls.

Procedure

Set up the Experiment (Fig 1 & 2)

1. Set one mobile devices with Sound Generator of the "AP-Sensor" app opened. Connect it to the speakers. The centers of speakers (amplifiers if available) are kept 0.5m away from each other, facing the same direction.
2. Set a mobile device with Sound Analyzer of the "AP-Sensor" app 1.0m away from the mid-point of center of drum surface of the two speakers. Its microphone should be pointed perpendicularly to the plane of the speakers. If available, an external microphone with 3.5mm audio jack connection can be used for better data quality.

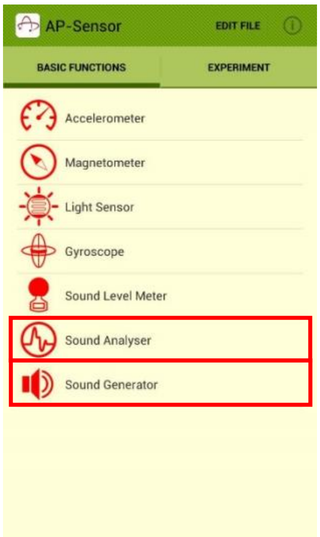

Fig 2

Fig 3

Find Positions of Nodes and Antinodes

3. In the Sound Generator, set the frequency to 2000Hz and press "Gen" to generate the sound wave (Fig 3).
4. In the sound analyzer, press the button "Waveform" to display waveform of detected wave. Sweep the graph with two fingers to zoom the graph to a scale suitable for observation (Fig 4).
5. Move the microphone slowly along the "screen" as indicated in Fig 1. At nodes, the amplitude of waveform will be minimum. At antinodes, the amplitude of waveform will be maximum. Measure and record all the positions of the nodes and antinodes *y* for both sides in Table 1.
6. Obtain the average distance between successive nodes/antinodes. Determine the wavelength λ using the formula $y = \frac{\lambda D}{d}$, and thus the speed of sound wave using the wave formula.
7. Optional: Repeat the experiment with different frequencies f, distance between two speakers *d*, and distance between speakers and screen *D*.

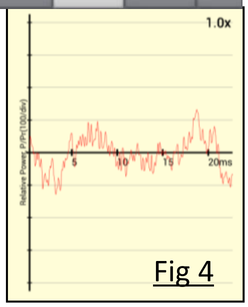

Fig 4

Data

Frequencies f = ______________Hz

Distance between two speakers d: ______________m

Distance between speakers and screen D: ______________m

Table 1: Positions of nodes and antinodes for different harmonics

Order	Positions of Antinodes from Center (m)		Positions of Nodes from Center (m)	
0th order	0		0	
1st order				
2nd order				
3rd order				
4th order				
5th order				
Average distance Δy between adjacent antinodes from 0th to 5th order (m)				
Wavelength of the sound wave $\boldsymbol{\lambda} = \frac{\boldsymbol{D}}{\boldsymbol{d\Delta y}}$ (m)				
Speed of sound wave $\boldsymbol{v} = \frac{\boldsymbol{\lambda}}{\boldsymbol{T}} = \boldsymbol{f\lambda}$ (ms^{-1})				

Discussion

1. As the sound analyzer is moved along the "screen", what did you observe?
2. At nodes, the waveform recorded is non-zero, what is the reason? Is it significant to the experiment? Share your point of view.
3. Observing higher orders of antinode are challenging, what are the reasons?
4. In Table 1, how is the precision of separation between adjacent nodes/antinodes for different orders in the experiment?
5. In Table 1, there are other possible ways to determine the average distance Δy, such as taking average from the 0th to 1st, 2nd, 3rd or 4th orders. Will there be any significance using different approaches? Why is the 5th order preferred in Table 1?
6. How are the experimental values of speed of sound in air obtained in Table 1 compared to the literature value ($340ms^{-1}$ for HKDSE syllabus)? What are the possible errors or limitations of the experiment?
7. Optional: If the experiment is repeated with different frequencies f, distance between two speakers d, and distance between speakers and screen D, are the results of wavelength and speed of sound consistent with the theory? What would happen if f, d, D goes extremely large or small?
8. Optional: What would happen if the frequencies of two sound generators are different?