Speed of Sound Using Two Microphones

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General: Most traditional high school physics experiments measuring the speed of sound in air utilize standing waves in air columns. While the equipment is fairly simple and the theory is straightforward, students often find it difficult to locate the point of resonance by ear. It would be far simpler for the student to measure the time and distance for a sound pulse and then to calculate speed from distance divided by time. This becomes possible in a typical classroom lab if one uses a computer sound card oscilloscope, such as the one developed by C. Zeitnitz. Two small microphones can be placed a measured distance apart and be used to detect a single sound pulse, such as a clap of the hands. Using the oscilloscope, one can determine the time between the pulse detections by inspection of the two channels and calculate the speed. Furthermore, if one has access to a means of producing a single frequency sound (such as a signal generator), a second method to determine the speed of sound can also be used. By moving one of the microphones until the sound waves are in phase, the wavelength can be determined by examining the locations of the microphones. The frequency can be measured from the oscilloscope, and the speed calculated from the wave equation, $v = f\lambda$.

Problem: To determine the speed of sound in air by:

1) measuring the distance and time for a traveling sound pulse
2) measuring the wavelength and frequency of a pure tone sound

Procedure

1. Equipment – a computer with a sound card, Soundcard Oscilloscope, two small microphone assemblies with connecting cables, two 9-volt batteries, a meter stick, two optical bench support feet, two optical bench screen supports, a periodic single frequency sound source
2. Speed of sound from measurements of distance and time
    a. Place the meter stick in the two optical bench screen supports.
    b. Mount each of the microphone assemblies on an optical bench screen support. The microphone jack should be connected to the "line in" port on the computer sound card.
    c. Place the screen supports on a meter stick and determine the distance between them. Distances greater than 0.50 m work better.
    d. Start the Soundcard Oscilloscope. The computer settings have to be changed to accept input for the microphones. In the oscilloscope window, click the "settings" tab, then click "input" under Audio Mixer, select "line in" while de-selecting "microphone. "Line in" is used because it includes a stereo arrangement that can be displayed on the two channels of the oscilloscope.
    e. Adjust the oscilloscope settings. Set the amplitude to about 0.300 and the time (ms) to about 10. The trigger should be set to "normal" on "channel 1" (the microphone closer to the sound source) with a "threshold" of 0.10 and "edge" to rising. The threshold may be adjusted by clicking the up or down indicators next to the threshold box or by using the white cross-shaped cursor to move the yellow

cross up or down. The threshold may have to be adjusted slightly up or down. If the threshold is set too low, the microphones will pick too much of the ambient sound and the scope will trigger continuously. The threshold should be high enough so that only the sound of a handclap or a finger snap will trigger the scope. If the threshold is too high, the scope will only trigger on very loud sounds. The offset for channel 1 can be set at about 0.100 and the offset for channel 2 can be set at about -0.100. The offsets are not critical because they only separate the signals from the two channels vertically on the scope. These can be adjusted individually so that the two signals are not overlapping too much.

f. Produce a sound pulse near one of the microphones. This could be a finger-snap or a handclap. The waveform will be displayed on both channels with an obvious time separation. It will be a fairly complicated looking waveform. The waveforms will appear similar but not identical. There is some attenuation because the second microphone is farther away from the source than the first microphone. Since the distance between the two microphones is arbitrarily chosen, it is likely that the waveforms will also be out of phase to some degree.
g. Activate the cursor to show time values by clicking the cursor button and selecting "time." Two vertical dashed blue lines should appear. The time between the lines is displayed in the "dT" box to the right of the cursor button. These blue lines may be moved by placing the white cross-shaped cursor on the blue "X" on the blue line, clicking, and then dragging the cursor.
h. Move one of the blue lines to the starting point of the waveform signal on channel 1. Then move the other blue line to the corresponding position on channel 2. The time difference can be read from the "dT" box. This is the tricky step. Remember, the waveforms are similar but not identical. In placing the blue lines, it is usually better to try to place them at the beginning point of the signal. While it should be possible to match similar locations on the two waveforms to measure the time difference, attenuation and phase differences may alter the appearance of the second waveform so it is advisable to use the starting point of the sound pulses.
i. Compute the speed of sound from the separation distance divided by the "dT" value. An accepted value for speed of sound in air can be obtained from the empirical formula v = 331 + 0.61 x (temperature in Celsius). Values between 340 m/s and 350 m/s would be expected for typical room temperatures. Values within 15% are routinely obtainable. The major difficulty with this method is setting the time cursor markers (blue lines) to the beginning of the waveforms.

3. Speed of sound from measurements of wavelength and frequency
   a. Place the meter stick in the two optical bench screen supports.
   b. Mount each of the microphone assemblies on an optical bench screen support. The microphone jack should be connected to the "line in" port on the computer sound card.
   c. Place the screen supports on a meter stick. Tilt the microphone cards so one card does not block the other.
   d. Place the single frequency sound source near the end of the meter stick and about 0.30 m from the microphones. If the microphones are too close to the source, the

individual amplitudes can be quite different, and it is difficult to match the phase of the waveforms by inspection.

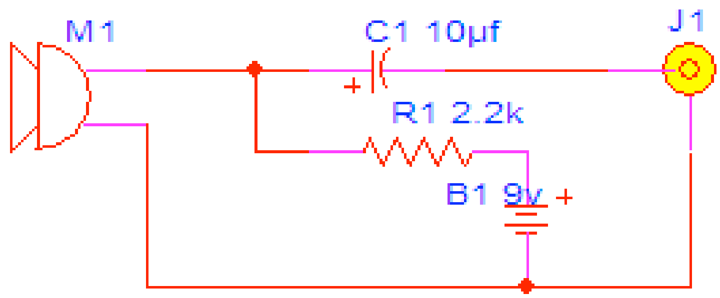
e. Adjust the oscilloscope settings. Set the amplitude to about 0.200 and the time (ms) to about 3. The trigger should be set to “normal” on “channel 1” (the microphone closer to the sound source) with a “threshold” of 0.0003 and “edge” to rising. The threshold may be adjusted by clicking the up or down indicators next to the threshold box or by using the white cross-shaped cursor to move the yellow cross up or down. The threshold may have to be adjusted slightly up or down depending on the sound source. The offsets should be adjusted so that the two waveforms are at approximately the same vertical level to make it easier to see if the waves are in phase.
f. Turn on the source and adjust it to produce a frequency between 2000 Hz and 3000 Hz (this results a in wave with a wavelength that is not too long. Make sure that the scope is triggering. Two almost identical waveforms should be visible. The amplitude, time, and/or trigger may have to be adjusted depending on the source. Note: increasing the amplitude value on the scope increases the vertical scale, which results in a decrease in the amplitude of the waveform visible on the scope. If the waveform is not a smooth sine curve, the speaker may be producing harmonics. Click on the “frequency analysis” tab, set the “frequency filter” to “band pass” pass, and adjust to pass the desired frequency.
g. Start with the channel 2 microphone just behind the channel 1 microphone. The waves should be slightly out of phase. Keep the channel 1 microphone stationary. Move the channel 2 microphone away from the channel 1 microphone. Watch the wave pattern on the scope. When the two waves are in phase (peaks and troughs match up), the microphones should be one wavelength apart.
h. Turn on the cursor to “time” and the two blue lines should appear. Move the blue lines so that they are on two consecutive peaks. (Any two corresponding points would work, but peaks are easy to use.)
i. Record the frequency from the “f” box to the right of the “dT” box.
j. Measure the distance between the two microphones to determine the wavelength.
k. Calculate the speed of sound from $v = f\lambda$. An accepted value can be calculated as in step 2h. Again, values within 15% are routinely obtainable. The major difficulty with this method is setting the time cursor markers (blue lines) to the peaks of the waveforms. A smooth waveform from a single frequency source is desirable.

Additional Information

1. The Soundcard Oscilloscope is freeware. It can be downloaded from www.zeitnitz.de/Christian/Scope/Scope_en.html (note: there is an underline in the space between the “e” in the second “Scope” and the “e” in “en”). If a “The page cannot be found” message appears, just click on the “Go” button. This usually gets to the correct web page.
2. Constructing microphone assemblies
    a. Materials – an Electret microphone (this is a condenser microphone with an FET preamplifier) a 10 microfarad electrolytic capacitor, a 2.2 kilo-ohm carbon resistor (1/8 watt), a 9-volt battery clip, IC PC board (Radio Shack 276-159), 1/8

inch stereo plug, stranded speaker wire (solid wire will work but is more likely to break with use)

b. Schematic



Extensions

1. The phase adjustments in Procedure step 3 can also be done with Lissajou figures. Change the Soundcard Oscilloscope from "oscilloscope" to "X-Y Graph." Again, start with the channel 2 microphone just behind the channel 1 microphone. The waves should be slightly out of phase. Keep the channel 1 microphone stationary. Move the channel 2 microphone away from the channel 1 microphone. Watch the wave pattern on the X-Y Graph. When the two waves are in phase, the pattern should be a diagonal line with a positive slope. The distance between the microphones would be one wavelength. The pattern on the X-Y Graph will be circular when the phase difference is 90^0. This is fairly easy to do when dealing with a single frequency source. If the source is a buzzer emitting a continuous sound composed of several frequencies, the pattern will not form a single line. Instead, a highly eccentric elliptical pattern appears due to the multiple frequencies. In this case, one has to produce the narrowest ellipse. After adjusting the distance between the two microphones, switch the screen back to the oscilloscope and move the blue cursor lines to consecutive peaks. The wavelength will be the distance between the microphones and the frequency can be read off the oscilloscope.

2. Phase variations with distance (related to human hearing)
   a. Place the two microphones about 80 cm apart and facing each other.
   b. Adjust the oscilloscope settings. Set the amplitude to about 0.400 and the time (ms) to about 10. The trigger should be set to "normal" on "channel 1" (the microphone closer to the sound source) with a "threshold" of -0.05 and "edge" to rising. The offset for channel 1 can be set at about 0.100 and the offset for channel 2 can be set at about 0.030. The threshold should be high enough so that only the sound of a handclap or a finger snap will trigger the scope.
   c. Produce a sound (handclap or finger snap) at the approximate midpoint and observe the waveforms on the two channels. Produce a sound nearer to one of the microphones and compare the two channels. The waveform should appear earlier

on the nearer microphone. Continue producing sounds at different locations and note the waveforms.

3. Speed of sound in different gaseous mediums