

Lab Exercise 1: Acoustic Waves

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Objective

To examine experimentally the characteristics of acoustic waves.

General concepts to be covered:

- Interference
- Speed of sound in air
- Spherical waves
- Spreading factor
- Traveling waves

1-1 PRE-LAB ASSIGNMENT

1-1.1 **Read** Sections 1-4, 1-5, and 1-6 of the text.

1-1.2 **To be entered into your lab notebook prior to coming to lab:**

Summarize the experimental procedure (1 paragraph per section) of:

- (a) Section 1-5.1: Traveling Waves
- (b) Section 1-5.2: Interference
- (c) Section 1-5.3: Speed Of Sound

1-2 FORMAT AND COMMENTS

The following format for instructions pertaining to the three instruments (network analyzer, oscilloscope, and RF signal source) has been adopted:

- All instructions pertaining to the instruments are boxed
- A key given in the form KEY refers to one of the keys on the front panel of the instrument. These are sometimes referred to as “hard keys” in the instrument documentation.
- A “softkey” refers to one of the keys located on the side or below the display screen. The functions of these keys are displayed on the screen, and change according to the other keys that have been pressed. The name of a softkey appears in **bold** typeface.

1-3 INTRODUCTION

In the first lab exercise, you explored the phenomenon of waves using one and two dimensional water waves. In this lab exercise, you will be using acoustic waves to explore the same phenomenon. Acoustic waves are three dimensional waves. The wavefronts for these waves are spheres, whereas in the case of linear and circular waves, the wavefronts were planes and circles, respectively.

1-3.1 Spreading Factor: Spherical Waves

Three dimensional waves, like sound waves, which have point sources have phase fronts which are spheres. In the absence of attenuation, the amplitudes must decrease with the radius, to compensate for the increasing area of the spheres over which the phase front is distributed as time progresses. The form for a spherical wave with a source at the origin is

$$f_{\text{sph}(r,t)} = A_{\text{sph}} \frac{e^{-\alpha r}}{r} \cos \left(2\pi \left(\frac{t}{T} - \frac{r}{\lambda} \right) + \phi_{\text{sph}} \right) \quad (1.1)$$

where the attenuation is included. The spreading factor is $1/r$ for the spherical waves.

For spherical waves (as was the case for circular waves), the expressions for the amplitude at the origin approaches infinity. There is no such thing as a true point sources, so the expressions must be considered approximate. They are valid as long as the point of observation is “far” from the source. A good rule of thumb to know if a point of observation is far enough from a point source is if the distance to the source is larger than $2D^2/\lambda$, where D is the largest dimension of the source and λ is the wavelength.

1-3.2 Interference In 3-D

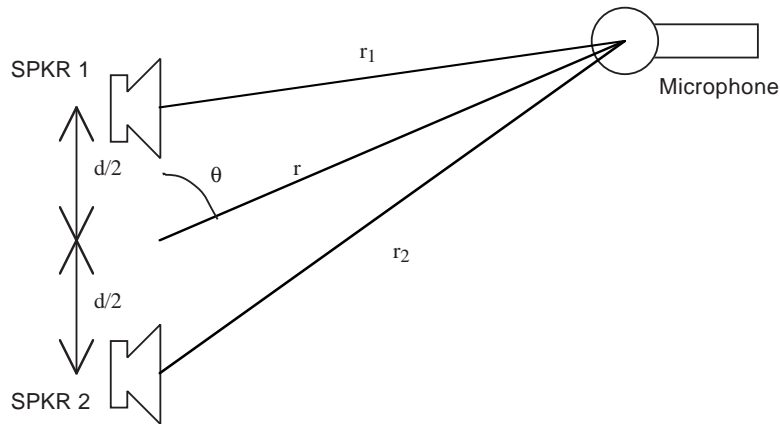


Figure 1-1: Geometry for an Acoustic Experiment

Like the standing waves which are generated by two water waves traveling in opposite directions, multi-dimensional waves can also generate interference patterns. As an example of this phenomenon, let us analyze the acoustic setup in Fig. 1-1. Two isotropic (directionless) speakers are set up a distance d apart. Each of them produces a harmonic acoustic wave with a wavelength λ . For the first speaker, the pressure wave can be described as

$$f_1(r_1, t) = \frac{A_1}{r_1} e^{-\alpha r_1} \cos \left(2\pi \left(\frac{t}{T} - \frac{r_1}{\lambda} \right) + \phi_1 \right) \quad (1.2)$$

and the second speaker's pressure wave is given by

$$f_2(r_2, t) = \frac{A_2}{r_2} e^{-\alpha r_2} \cos \left(2\pi \left(\frac{t}{T} - \frac{r_2}{\lambda} \right) + \phi_2 \right) \quad (1.3)$$

where α is the attenuation constant and r_1 and r_2 are the distances between the speakers and the observation point (microphone). For each of these speakers alone, ϕ doesn't matter, and the microphone will measure the same signal as long as the range remains constant.

But if both are turned on at the same time, the microphone will be picking up the sum of their signals:

$$f_s(r_1, r_2, t) = f_1(r_1, t) + f_2(r_2, t) \quad (1.4)$$

Let's assume that the speakers are driven with a common reference phase, so that $\phi_1 = \phi_2$. Then, if $r_1 = r_2$, that is, if the distance from speaker 1 to the microphone is the same as the distance from speaker 2 to the microphone, then constructive interference occurs and the microphone measures twice the amplitude as from one speaker only. This is also true if the difference between r_1 and r_2 is zero or even multiple of $\lambda/2$. On the other hand, if the difference between r_1 and r_2 is an odd multiple of $\lambda/2$, destructive interference occurs and the microphone will pick up hardly any signal. Simply adding an additional speaker does not increase the volume of sound everywhere. In fact, in some places, the use of two speakers instead of one will reduce the volume of sound!

1-4 EQUIPMENT

Item	Part #
Audio component Box	—
Connecting cable	WA-9305
Digital function generator	Pasco PI-9587C
Microphones (2)	—
Microphone pre-amplifier box	—
Oscilloscope	HP54645A
Speaker (2)	Pasco WA-9303
Speaker box	—
Ultrasonic receiver	—
Ultrasonic transmitter	—
Various cables & connectors	—

1-5 EXPERIMENT

1-5.1 Traveling Waves

In this section of the lab, you will measure the traveling wave characteristics of sound waves. Unlike water waves, which may be one or two-dimensional, sound waves in air are three-dimensional. The amplitude of the waves changes with respect to the distance from the source, yet the waves are not attenuating: they are merely spreading out.

Setup

This experiment uses the microphone pre-amplifier box, speaker box, oscilloscope, digital function generator, speaker, omnidirectional microphone, two banana cables, and two BNC cables.

Setup the experiment as shown in Fig. 1-3:

- Connect the power cord of the microphone pre-amplifier box to the power supply. Be sure to observe polarity (see Fig. 1-2).

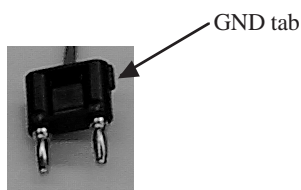


Figure 1-2: Ground tab for identifying the polarity of the speakers.

- Set the voltage on the power supply to 5 volts.
- Connect the high impedance output of the digital function generator to the rear panel of the speaker box using the two banana cables.
- Plug a speaker into the top panel of the speaker box.

- Plug the unidirectional microphone (the one with the plastic cone) into the input jack on the top panel of the microphone pre-amp box and feed the amplified output signal into channel 2 of the oscilloscope.
- Feed a signal from the high impedance output of the digital function generator directly into channel 1 of the oscilloscope.

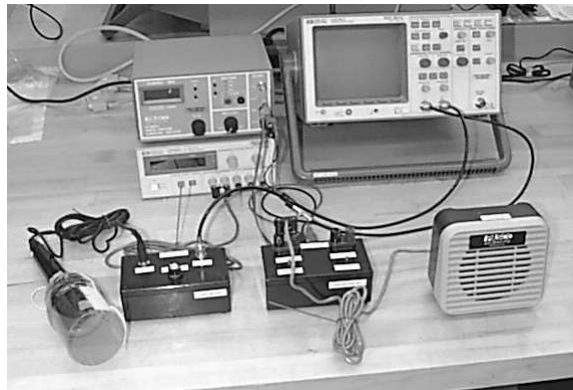


Figure 1-3: Setup for the traveling wave experiment

Procedure

1. Set the speaker on the workbench facing out. You want to make sure that the speaker is the front edge of the workbench to minimize interference.
2. Configure the oscilloscope to send output to the printer.

- Press **POWER** to turn on the oscilloscope. Wait for the oscilloscope to perform its self check.
- Press **Print/Utility**
- Press the **Hardcopy Menu** softkey
- Press the **Format** softkey until *DJ mono* is displayed
- Press the **Destination** softkey until *Parallel* is selected
- Press the **Printer Setup** softkey
- Press the **Factors** softkey until *On* is selected
- Press the **Grey scale** softkey until *Off* is selected
- Set the printer switch box to output channel **A**

3. Turn the amplitude of the digital function generator to its minimum setting. Adjust the gain of the microphone pre-amp to the 12 o'clock position.
4. Set frequency of the digital function generator to 2 kHz. Slowly adjust the amplitude of the digital function generator to display a strong signal on the oscilloscope while keeping the noise level tolerable (\approx 9 or 10 o'clock position).
5. Adjust the distance between the microphone and the speaker by moving the microphone away from the speaker until the sine wave on channel 1 is "in-phase" with that on channel 2. Use the metal ruler to measure the distance from the speaker. Record the peak-to-peak amplitude of the wave on channel 2. Estimate the uncertainty in the position and amplitude. Record these values. **Print the display.**

To measure the phase difference between channel 1 and channel 2:

- Press **TIME**
- Press the **Next Menu** softkey until the **Define Thresholds** softkey is displayed on the far left of the screen.
- Press the **Measure Phase** softkey

To measure voltage:

- Press **VOLTAGE**
- Press the **Clear Meas** softkey to clear the last measurement
- Press the **Source** softkey until channel 1 is selected
- Press the **Next Menu** softkey until the **V_{AMP}** softkey is displayed
- Press the **V_{AMP}** softkey to display the amplitude of the waveform
- Repeat for channel 2 (Don't clear the last measurement)

6. Move the microphone further or closer to the speaker until the signals on the scope are again "in-phase". Record the distance between the speaker and the microphone and the amplitude of the wave on channel 2.
7. Repeat the previous step until you have at least 3 measurements at different distances, each of which satisfies the "in-phase" condition. (This is a measurement of the wavelength of the sound waves: When the two signals are "in-phase" on the

oscilloscope, their signal paths are an integer number of wavelengths apart from each other. Changing the distance between the speaker and the microphone from one “in-phase” location to the next “in-phase” location results in that signal’s path length change being equal to one wavelength).

- Change the frequency to 4 kHz and increase the the amplitude of the digital function generator as necessary (\approx 1-2 o’clock position). Repeat the experiment.

Measured Data

Copy the following chart into your lab book and fill in the measured data. If you are missing any data, please repeat the necessary parts of this experiment before proceeding to the analysis section.

In-Phase Location	Frequency	Position	V_{AMP}
Position #1	2 kHz		
Position #2			
Position #3			
Position #4			
Position #5			
Position #1	4 kHz		
Position #2			
Position #3			
Position #4			
Position #5			

Position uncertainty _____ (cm)

Amplitude uncertainty _____ (mV)

Analysis

- For the two frequencies, calculate the wavelength and its uncertainty from the distance measurements.
- For the two frequencies, calculate the velocity of sound in air, and its uncertainty.
- Determine the experimental relationship between spreading factor and distance, by applying a power fit to your data. Since the sound waves are 3D waves, the amplitude should decay as: $A(r) = A_0 r^{-1.0}$. If the sound wave was behaving as a 2D, or a 1D wave, the spreading factor would be different. Compare the fit with the theoretical prediction. Record the fit equation in your report. Remember that the spreading factor is valid only at ranges sufficiently far from the source.

Questions

1. How does the velocity of sound depend on the frequency?
2. How is the spreading factor different for three-dimensional waves from that of two- or one-dimensional waves?

1-5.2 Interference

In this experiment you will measure the interference pattern of two outward facing speakers.

Setup

This experiment uses the microphone pre-amplifier box, speaker box, oscilloscope, digital function generator, speaker, omnidirectional microphone, and two BNC cables.

Setup the experiment:

- Without changing the frequency of the digital function generator, turn the amplitude to its minimum setting.
- Attach the second speaker to the audio component box. Be sure to observe the polarity of the speakers (see Fig. 1-2).

Procedure

1. Make sure the frequency of the digital function generator is set to 4 kHz.
2. Set the two speakers near the edge of the workbench in the configuration shown in Fig. 1-4. Set the distance between the speakers such that the center of the speakers are separated by 34 cm. Place the protractor between the speakers such that the center of the protractor falls in the middle directly between the two speakers, and the straight edge of the protractor is in line with the two speakers.



Figure 1-4: Configuration for finding the standing wave pattern in front of the two speakers.

3. Put the omnidirectional microphone at $r \approx 50$ cm and $\theta = 90^\circ$. Use the string and protractor as measurement aides.

4. Set the amplitude of the digital function generator to give you a strong signal on channel 1 of the oscilloscope .
5. Measure the peak-to-peak amplitude of the signal on channel 2 from $\theta = 60^\circ$ to $\theta = 120^\circ$ in steps of 5° . Record both the amplitude and the angle.

Measured Data

Copy the following charts into your lab book and fill in the measured data. If you are missing any data, please repeat the necessary parts of this experiment before proceeding.

Angle ($^\circ$)	V _{amp}
60	
65	
70	
75	
80	
85	
90	

Angle ($^\circ$)	V _{amp}
95	
100	
105	
110	
115	
120	

Angular uncertainty _____ ($^\circ$)

Amplitude uncertainty _____ (mV)

Analysis

1. Plot the measurements of the interference pattern of the two speakers which were facing out as a function of θ . Don't forget the error bars.
2. Derive the upper envelope of the interference pattern of the two speakers, $+|f_e(r_1, r_2)|$. Assume the speakers are driven with equal amplitudes ($A_1 = A_2$), are in-phase ($\phi_1 = \phi_2$) and that the attenuation in the air is negligible ($\alpha = 0$). State any simplifying assumptions you make and please justify their validity.
(Note: we're not asking for $+|f_e(\theta)|$. Don't further complicate the derivation.)
3. On the **same graph** from step 1, plot the derivation of the upper envelope of the interference pattern of the two speakers, $+|f_e(r_1, r_2)|$ derived in the previous step, as a function of θ onto the plot of these measurements. Please ensure that the plot of $+|f_e|$ is smooth and adequately represented, (i.e. use $\Delta\theta \leq 1^\circ$).
 - (a) Consult with your lab partners to make sure you agree on your derivations. If you decide to use a derivation other than your own, state whose derivation you are using in your lab notebook.
 - (b) The upper envelope $+|f_e|$ is in terms of r_1 and r_2 , variables which were not measured. Use the following relationships to convert them to r , θ and d , all of

which were measured:

$$r_1 = \sqrt{r^2 + (d/2)^2 - 2r(d/2)\cos\theta} \quad (1.5)$$

$$r_2 = \sqrt{r^2 + (d/2)^2 + 2r(d/2)\cos\theta} \quad (1.6)$$

(c) You may have to re-normalize your set of calculations, that is, pick a value of the amplitude A , to see the fit of your data to the pattern. Do this by picking a value of A which makes $|f_e|$ at 90° agree with your measurement data at 90° .

4. Find the spacing between the nulls (minimums in the interference pattern) along the measured arc. *Hint:* the distance along an arc is $r\theta$, where r is the radius and θ is the angle *between* two points, in radians.

Questions

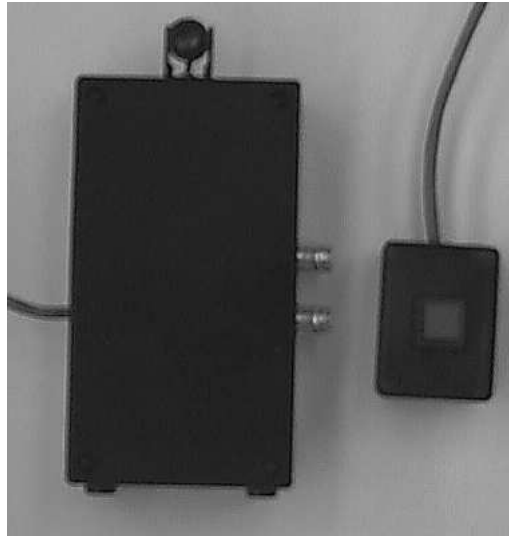
1. What is the meaning of the upper envelope of the interference pattern $|f_e|$? In other words, how does the envelope relate to the time domain expression for the sum of the two waves?
2. Explain the shape of the interference pattern in front of the two speakers.
3. How would $|f_e|$ change if the speakers were 180° out of phase?
4. Along what radial line from the center of the speakers should a person listen for maximum reception?

1-5.3 Speed Of Sound

In this experiment you will measure the speed of sound in air by determining the propagation time of sound waves over a known distance.

In order to make these measurements, you will need to use ultrasonic (sonar) transmitters and receivers. Why can't you use sound in the audible range? The answer is interference. When trying to determine when a response was received, you have to be able to clearly identify the start of the received signal. If you were to use a frequency of 1 kHz, your receiver would pick up not only your transmitted signal, but also the ambient noise in the room from people talking, walking around, etc. By using the ultrasonic transducers (which operate at 40 kHz), you are not sensitive to most of the ambient signals in the room, so your noise level is greatly reduced, allowing you to clearly identify the received signal.

The ultrasonic transmitter and receiver used in this experiment are shown in Fig. 1-5. The transmitter has two BNC jacks, one for the input from the function generator and one to the oscilloscope. The receiver has one BNC jack to connect it to the oscilloscope. The transmitter has a momentary contact push button switch attached to it. When the button is pressed, the signal from the function generator is allowed to pass to the ultrasonic transmitter. This results in the transmission of a very short pulse. When the receiver detects this signal, the output of the ultrasonic receiver is displayed on the oscilloscope after being amplified.



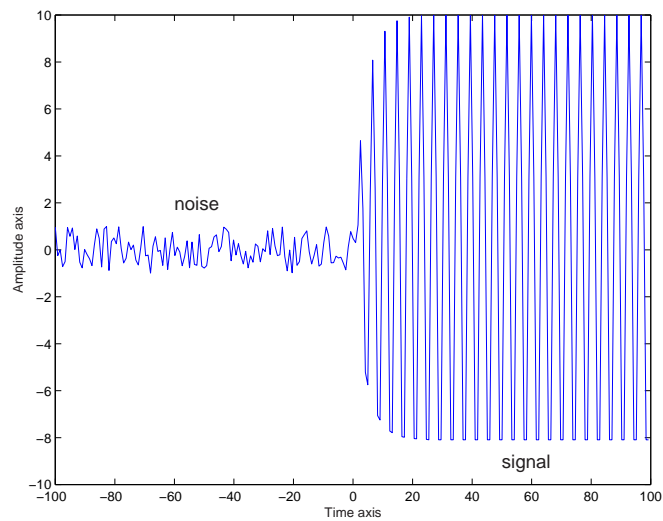
(a) Transmitter



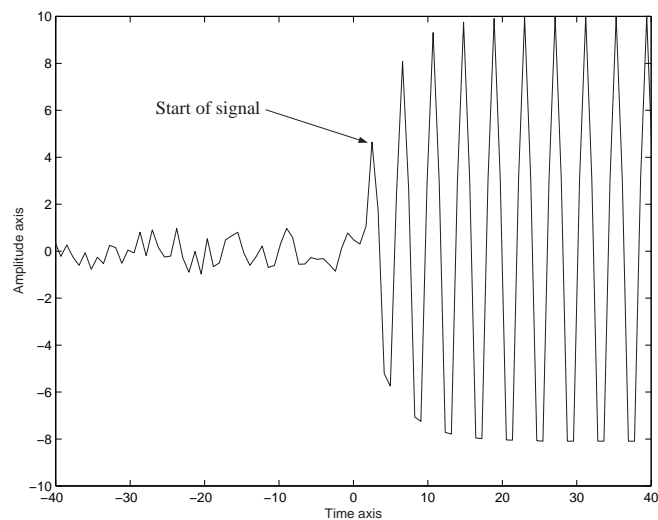
(b) Receiver

Figure 1-5: Ultrasonic transmitter and receiver units used in this experiment

In order to determine the speed of sound, you measure the delay between the transmitted and received signal over a known distance. Due to the nature of the sensors, it may be difficult to determine where the received signal actually begins. Figure 1-6 shows a simulated waveform from the receiver. As shown in the figure, the point in time where the signal is received is defined where the signal is first distinguishable from the noise floor.



(a) Full view



(b) Start of signal

Figure 1-6: Simulation of received signal showing the received signal as a function of time.

Setup

This experiment uses the digital function generator, oscilloscope, ultrasonic transmitter and receiver, two 24'' BNC cables, one 180'' BNC cable, and one BNC to banana plug adaptor.

Setup the experiment as shown in Fig. 1-7:

- Connect the high impedance output of the digital function generator to the input port of the ultrasonic transmitter using a 24'' BNC cable and the BNC to alligator adaptor.
- Connect the output port of the ultrasonic transmitter to Channel 1 of the oscilloscope using the 180'' BNC cable.
- Connect the output port of the ultrasonic receiver to Channel 2 of the oscilloscope using the 24'' BNC cable.



Figure 1-7: Setup for the speed of sound experiment.

Procedure

1. Separate the transmitter and receiver by 40 cm.
2. Configure the function generator.

- Select the Sine wave output
- Set the frequency to 40 kHz
- Turn the amplitude knob to the 10 o'clock position

3. Configure the oscilloscope.

- Set the volts per division setting for Channel 1 to 5.00 V/div.
- Set the volts per division setting for Channel 2 to 1.0 V/div.
- Set the time base to 1.00 ms/div.
- Set the trigger source to Channel 2.
 - Press **Source**
 - Press the **2** softkey
- Set the trigger mode to normal
 - Press **Mode Coupling**
 - Press the **Normal** softkey
- Press **Single**

4. Press the red button attached to the transmitter to transmit a short pulse.

5. Measure the delay between the start of the transmitted signal and the start of the received signal.

- Press **Cursors**
- Press the **t₁** softkey
- Use the entry knob to move the cursor to the start of the transmitted signal.
- Press the **t₂** softkey
- Use the entry knob to move the cursor to the start of the received signal.

Note: By decreasing the time base, you may improve the accuracy of your measurements.

6. Record the Δt value displayed on the oscilloscope. Print the display.
7. Press **Single** and take another measurement. Record the Δt value.
8. Repeat step 7 four more times so that you have five measurements for the 40 cm separation distance.
9. Repeat the experiment for separation distances of 60, 80, and 100 cm.

Measured Data

Copy the following charts into your lab book and fill in the measured data. If you are missing any data, please repeat the necessary parts of this experiment before proceeding.

Separation (cm)	Δt_1 (ms)	Δt_2 (ms)	Δt_3 (ms)	Δt_4 (ms)	Δt_5 (ms)
40					
60					
80					
100					

Analysis

1. For each separation distance, compute the average Δt value. Record these values.
2. Using the average Δt values for each separation distance, compute the measured speed of sound in air. Record these values.
3. Compute the average speed of sound in air by averaging the computed speed of sound at each of the separation distances. Record this value.
4. Plot your measurements with distance on the vertical axis and time on the horizontal axis. Apply a linear fit to your data. Compare the slope of the fit line to your calculated velocity from step 3.

5. Look up the accepted value of the speed of sound in air (available in any physics book). Compare the accepted value to the value that you computed in this experiment. Comment on your results.

Questions

1. Steps 3 and 4 of the analysis compute the average velocity through different methods. Which method should yield a more accurate estimate of the velocity and why?
2. In this experiment, we have claimed to measure the speed of sound in air. To do this, we used a frequency of 40 kHz. Why can we claim that the speed of sound will be the same at 4 kHz?
Hint: Consider how the sound wave propagates through air.
3. When computing the delay time between the transmitted and received signal, you did not take into account the added delay due to the BNC cable. Why?
4. If we were to do this experiment on the moon (in the open), would it have worked? Why or why not?

1-6 LAB WRITE-UP

For each section of the lab, include the following items in your write-up:

- (a) Overview of the procedure and analysis.
- (b) Measured data where asked for.
- (c) Calculations (show your work!).
- (d) Any tables, plots and printouts.
- (e) Comparisons and comments on results.
- (f) A summary paragraph describing what you learned from this lab.