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The tin-can telephone: An example of sound propagation and communication for Project Listen Up

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3eED9. The tin-can telephone: An example of sound propagation and communication for Project Listen Up

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The tin-can telephone can be used to illustrate the basic concepts of sound waves and sound-structure interaction. It can also be used to illustrate advanced concepts of frequency response and speech intelligibility in acoustic communications. For the proposed demonstration, students will construct a tin-can telephone from household materials and observe its performance from a variety of acoustic tests. Students will observe sound transmission and discover that some sounds are transmitted with greater clarity than others. A measured frequency response function for several tin-can telephones constructed from different materials will be provided to the student to illustrate the concept of frequency response and speech intelligibility.

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1. Introduction

The use of hands-on demonstrations is an effective way to teach acoustical physics. The tin-can telephone, consisting of two cans connected by a tensioned string, is one such demonstration. It is well suited for classroom instruction because the materials are inexpensive and it is easy to construct. It is also well suited to experimental exploration since there is an almost endless combination of possible configurations.

2. Construction and operation

This section describes the procedure used to construct a tin-can telephone. The materials required to construct a tin-can telephone include

- 2 cans (they can be any shape, size, and material (not necessarily metal), but must have one open end and one closed end)
- 1 piece of string (can be any type, e.g. thread, yarn, twine, kite string, bailing wire, fishing line, nylon wire, etc.)
- 2 fasteners to prevent the string from pulling through the holes in the cans (e.g. buttons, toothpicks, tape, hot glue, etc.)

To begin, create a small hole in the center of the bottom of one can. The hole can be drilled or punched and should be large enough to allow the string to pass through. Feed one end of the string through the hole in the can and use a fastener inside the can to prevent the string from pulling back through the hole. For example, if a button is used as the fastener, tie the end of the string to the button. Repeat the steps with the other can and the other end of the string.

To operate the tin-can telephone, instruct two students to each hold a can and walk away from each other until the string is taut. It is important to maintain tension in the string when using the telephone; it will not work with slack in the string (why?). Have one person put the can to their mouth and speak while the other person holds the can to their ear to listen. It works best if the listener turns their head while keeping the axis of the can aligned with the string instead of keeping their head stationary and turning the can. If the string is too short or the speaker is too loud, you may need to instruct the listener to concentrate on the sound that is coming through the can and not the sound that is traveling through the air and arriving at the other ear. It may be worthwhile to use an earplug to mitigate the flanking path for the listener or to use a door or window to provide an acoustic barrier between the speaker and listener.

The ease of construction and operation of the tin-can telephone is one of the qualities that suit it for classroom use. A wide variety of construction materials (can, string, and fastener sizes and types) could be investigated. Several construction methods could also be investigated (e.g. What happens if the hole is drilled off center? What happens if the hole is drilled in the side of the can instead of the bottom?). Because of its adaptability, students can begin to discover how and why different elements of the telephone can affect its acoustic behavior. This allows students to postulate and instructors to illustrate various principles of acoustics.

3. How it works

The basic operation of a tin-can telephone is depicted in Figure 1. The numbered processes shown in the figure are explained below.

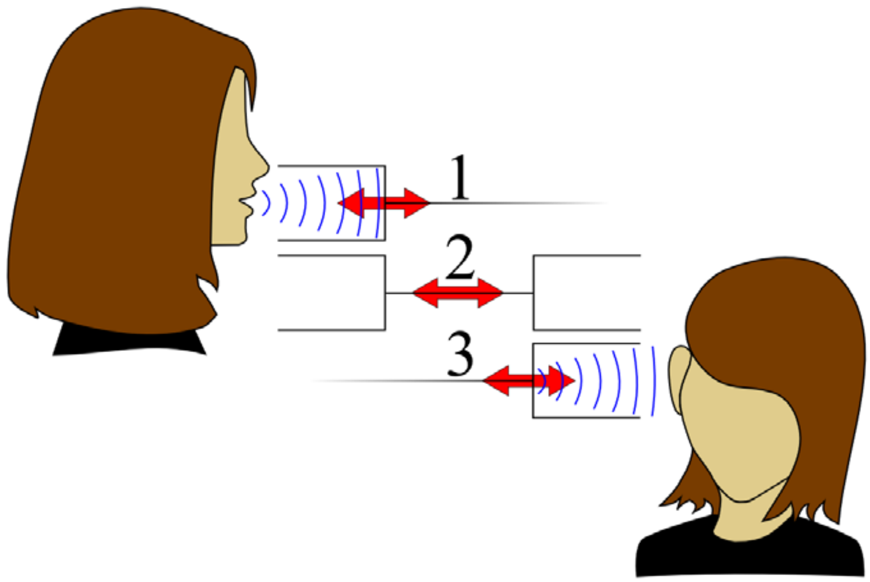

Figure 1. Basic operation of a tin-can telephone.

1. The sound pressure from the speaker's mouth exerts a force on the bottom of the can. This force excites a transverse flexural wave on the bottom of the can and causes it to vibrate back and forth.
2. The vibration from the bottom of the can is transmitted down the taut string as a compressional wave. The compressional wave motion is similar to a disturbance propagating along a stretched spring. The arrow represents a particle on the string which vibrates back and forth as the compressional wave propagates down the string.
3. When the compressional wave in the string reaches the listener's can, it excites a transverse flexural wave on the bottom of the listener's can. This motion creates sound pressure that is detected by the listener's ear. This process is similar to the production of sound that occurs when a guitar string causes a sounding board to vibrate.

4. Frequency analysis

The acoustic response of the tin-can telephone depends strongly on frequency. The tin-can telephone demonstration gives students an opportunity to learn about frequency and frequency spectra. Many sounds (including speech) are made up of several individual frequencies with different amplitudes.

To help understand the frequency content of a sound, consider the operation of a piano. Each key on a piano has a different fundamental frequency; some keys create low-pitched notes and other keys create high-pitched notes. For example, the key of Middle C has a frequency of 261.6

Hz and the highest key on the piano has a frequency of 4186 Hz. (Hertz is the unit of frequency (cycles per second) and is abbreviated Hz). Each key on the piano can be played with a different amplitude (or loudness). When multiple keys are played at the same time, the resulting sound depends on the amplitudes of the keys relative to one another. Unique sounds can be made with the same keys by playing them with different amplitudes. Although everyday sounds (e.g. speech, traffic noise, etc.) are not produced by playing piano keys, the sounds that we hear typically contain multiple frequencies of various amplitudes.

A graph of amplitude vs. frequency is called a frequency spectrum. An example of a frequency spectrum is shown in Figure 2. In this graph, frequency is shown on the horizontal axis and amplitude is shown on the vertical axis. A piano keyboard is shown below the spectrum to help the student visualize the meaning of the frequency axis (note that a fictitious spectrum is shown—it is not intended to represent the spectrum of an actual piano).

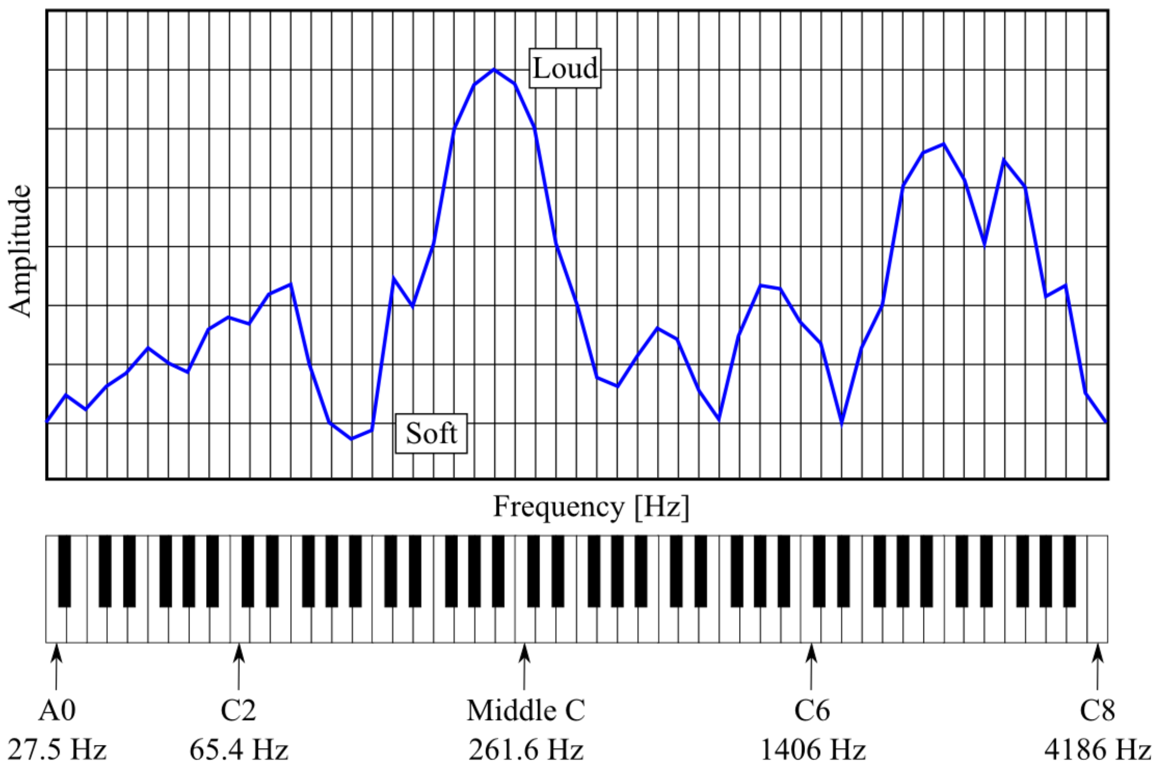

Figure 2. Example of a frequency spectrum.

5. The experiment

The frequency response function (FRF) is an important quantity in acoustics that relates the output of a linear system to the input as a function of frequency. FRFs are important in the design and analysis of acoustic systems and in experimental measurements. The tin-can telephone provides an opportunity to learn about FRFs.

FRFs contain two pieces of information: the amplitude ratio (the output amplitude divided by the input amplitude) and the phase delay (how much the output lags behind the input in time). For simplicity, we will only discuss the amplitude ratio of the tin-can telephone in this manuscript. For the purpose of illustration, an experiment was undertaken to measure the FRFs of four different tin-can telephones.

The objective of this experiment was to determine the magnitude of the FRF of a tin-can telephone. A second objective of this experiment was to observe how the FRF changed when different construction materials were used. For this experiment, two different can sizes and two different can types were used: a small tin-can, a large tin-can, a small paper cup, and a large paper cup. The relative sizes of the cans are shown in Figure 3.

Figure 3. Relative sizes of the cans used in the experiment.

The procedure for constructing each telephone for the purpose of the measurement is now discussed. A 15 m piece of lightweight fishing line was fed through the bottom of each can and then tied to a small plastic button so that the end of the line would not pull back through the hole. A 1.27 cm hole was then drilled into the side of the source can, 5 cm from the open end of the can. The purpose of the hole was to allow a 0.635 cm condenser microphone to pass through the side wall of the can and measure the interior sound field. A 0.635 cm inside diameter rubber grommet was inserted into the hole to provide a tight seal between the side wall of the can and the microphone body. Care was taken to position the tip of the microphone so that it was located on the center axis of the source can. No modifications were made to the receiving can.

The procedure for measuring the FRF of each telephone is now discussed. In order to reject ambient noise and to provide consistent tensioning of the fishing line, two plywood baffles were constructed to aid the measurement process as shown in Figure 4. The source can was attached to one baffle, which had a 7.6 cm diameter loudspeaker mounted in it. The receiving can was also attached to a plywood baffle with a small hole drilled in it for the receiving microphone. The receiving microphone was positioned so that it extended 5 cm into the receiving can. A uniform tension in the fishing line was achieved by using a 2.2 kg mass and a pulley system as shown. A repeating broadband chirp was played through the loudspeaker and recordings were simultaneously made at each of the microphones. The magnitude of the FRF (the output amplitude divided by the input amplitude) was determined by comparing the sound recorded at the source microphone to the sound recorded at the receiving microphone. A frequency analyzer was used to make this measurement.

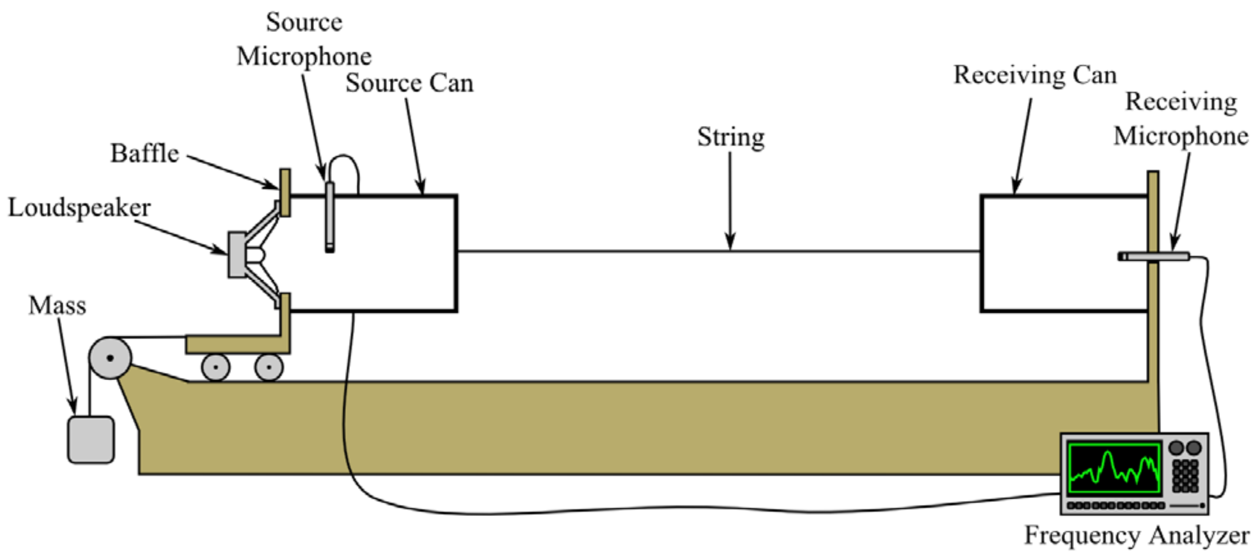

Figure 4. Experimental setup.

6. Results

The magnitudes of the measured FRFs are shown in Figure 5. The horizontal axis plots frequencies from 0 Hz to 5,000 Hz and the vertical axis plots the pressure amplitude ratio (output pressure amplitude divided by input pressure amplitude). The scale of the vertical axis is logarithmic, meaning that each major grid line is 10 times larger than the one below it (e.g. 1.000, 0.100, 0.010, etc.). Each plot has been normalized so that it has a maximum amplitude of unity. Doing this provides a way to look at the relative amplitudes of individual frequencies across different can types and sizes.

The FRFs have some similarities and some differences:

Similarities:
- Multiple peaks and valleys in the FRF
- The overall amplitude decreases with frequency

Differences:
- The peaks and valleys occur at different frequencies for each can
- The width of peaks is different for each can
- The rate at which the amplitude decreases with frequency is different for each can

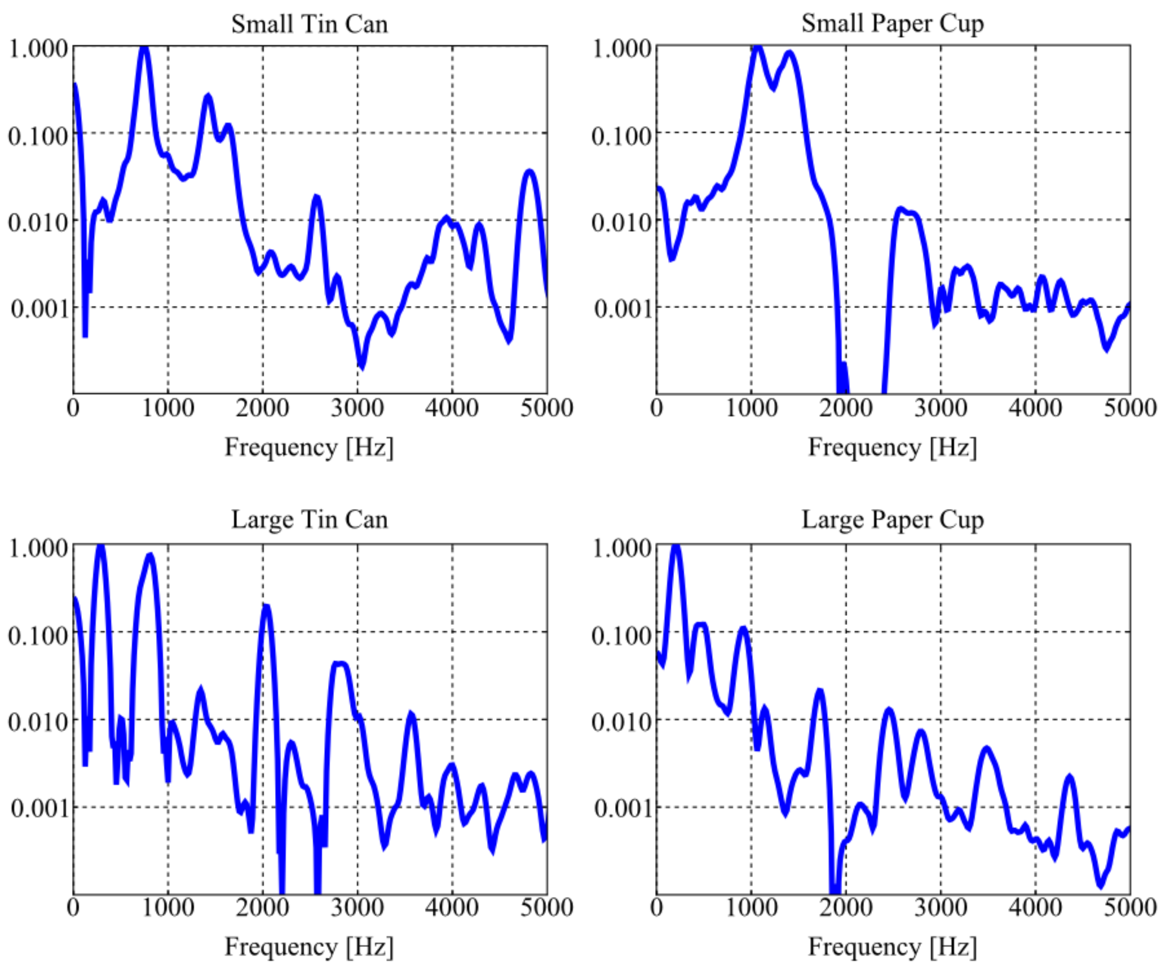

Figure 5. FRF measurement for each of the tin-can telephones.

7. Why can't I understand?

How do the FRFs shown in Figure 5 affect the listener's ability to perceive speech through the tin-can telephone? A simple listening test was performed to discover which can sizes and types transmitted speech with the greatest intelligibility. Five groups of 10 spectrally balanced sentences[1] (50 unique sentences) were recorded with high fidelity on a computer. Four of the groups of sentences were then digitally filtered by each of the four measured FRFs so that they would sound like they had been spoken through the four different tin-can telephones. One group of sentences was left unaltered to act as a control group. To determine which can size and type transmitted sound with the greatest intelligibility, the sentences were played back to listeners using loudspeakers. The listeners were asked to repeat the words of the sentence that they heard. The number of words that they repeated correctly were divided by the total number of words to form the percent of words correct. The results of this test (shown in Figure 6) were averaged over 9 different listeners and indicate that the size of the can has the greatest impact on whether the listener can understand what the speaker is saying.

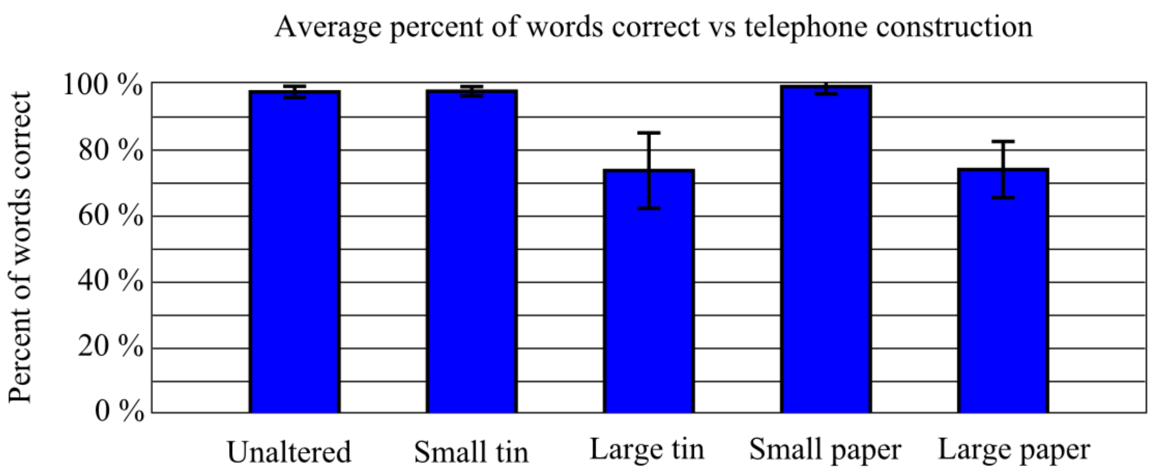

Figure 6. Results of listening test.

Why did the listeners have a difficult time understanding some of the words, particularly for the large cans? To illustrate, the word SKIPS is shown in Figure 7 for unaltered speech in red and speech through the large paper cup in blue. It is seen that the signal received through the large paper cup is significantly different than the normal speech signal, especially in regions that correspond to the 'S' sounds ('S' is a high frequency sound). The loss of information in the tin-can telephone can make it difficult for listeners to clearly understand certain sounds and words, such as the 'S' in SKIPS. Since certain sounds and letters are not well transmitted, some words become garbled and sound different than they did when spoken. In a normal conversation, when the speaker says the word SKIPS the listener will most likely hear the word SKIPS. In a tin can telephone conversation, when the speaker says the word SKIPS, the listener will most likely hear KIP.

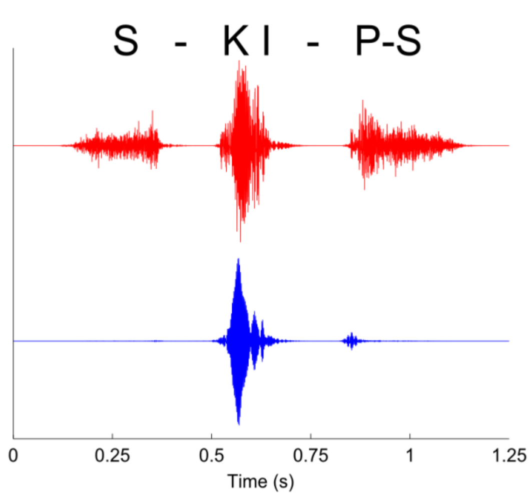

Figure 7. Time signal of the word "SKIPS", (top) unfiltered and (bottom) filtered by the large paper cup telephone.

8. Things to try

Be creative with various tin-can telephone configurations. Try using cans of different sizes and materials for the source and receiving ends. Try using different materials to connect the cans such as rope, string, wire, or rubber. Also, try adjusting the length of the string, but stay far enough away so that the listener cannot hear the speaker without using the can. See if hanging small objects, like ornaments, from the string connecting the cans changes how words sound.

Experiment with different sounds and with different words that sound similar. Do words like kits, ticks, fixed, skits, and kiss sound the same or do they sound different? Read a sentence to a friend and see how many words they hear correctly.

Gather a group of friends and play telephone. Have one person say a phrase to a listener. Then let the listener repeat the phrase they heard to a new listener. Repeat several times, and see what the final listener heard. Did they hear the original phrase correctly?

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