3-2019

Sound Propagation, Reflection, and Its Relevance to Ultrasound Imaging

Thomas Allen  
*Portland State University*

Alex Chally  
*Portland State University*

Bradley Moser  
*University of New England*

Ralf Widenhorn  
*Portland State University,* ralfw@pdx.edu

Follow this and additional works at: https://pdxscholar.library.pdx.edu/phy_fac

Part of the Physics Commons

Let us know how access to this document benefits you.

Citation Details

Allen, T., Chally, A., Moser, B., & Widenhorn, R. (2019). Sound Propagation, Reflection, and Its Relevance to Ultrasound Imaging. The Physics Teacher, 57(3), 134-137.

This Article is brought to you for free and open access. It has been accepted for inclusion in Physics Faculty Publications and Presentations by an authorized administrator of PDXScholar. Please contact us if we can make this document more accessible: pdxscholar@pdx.edu.
The labs presented here build on a simple speed of sound activity and models medical ultrasound imaging by demonstrating how multiple reflections propagate in a closed system. A short sound pulse is emitted into a pipe that is closed at one end and contains one or more partially reflecting surfaces within the pipe. The variety of reflections and transmissions that occur can be measured with a microphone at the pipe entrance.

We used white PVC pipes (4 m, schedule 40, 2-in diameter) and cut them into five pieces with lengths 0.4 m, 0.6 m, 0.8 m, 1 m, and 1.2 m (Fig. 1), cut to a precision of ± 1.6 mm. We connected the pipes with couplings and modified some couplings to cause partial reflections, by covering ¼, ½, or ¾ of the coupling opening. For easiest adoption, use repair coupling rather than a standard coupling. If standard couplings are used we recommend boring them out so that the pipes can be easily be connected and disconnected.

This activity requires a source to create a sound pulse as well as a receiver and logging/visualization software. A finger snap is the traditional source of sound, but some students struggle to produce consistently strong, short pulses. Sound editors with speakers, or even headphones, can provide this consistency. For instance, we implemented this activity in a teaching lab with multiple lab groups and had good results using Audacity to generate a tone in the 1000- to 4000-Hz range, a compact digital stereo amplifier (Lvpin 2020A+), and custom-made small speakers. For the results in this paper we used Audacity to generate a 1-ms tone at 2000 Hz, and headphones as a speaker. This pulse is short enough in duration to minimize the overlap of echoes in short pipes or pipes with multiple reflectors. Students can investigate how changing the pulse duration impacts the reflection data. Additionally, a sound editor that can produce a series of pulses will allow students to investigate the importance of selecting an appropriate pulse repetition rate. We used the commercially available Vernier microphone and Logger Pro data logging/visualization software to analyze the data obtained in the following experiments. The acquisition software was triggered to start recording when the sound pressure of the initial pulse exceeded a preset pressure level, which may vary depending on the sound source. We also set the sampling rate at 10,000 samples per second and the duration of recording at 0.1 s.

The pipes and couplings can be assembled a number of ways (Fig. 2). Each pipe and coupling setup increases the complexity of the travel paths of the sound waves to mimic the reflection of ultrasound from internal body structures by allowing for reflections from multiple interfaces at different distances.

**Use in the classroom**

After completing the lab exercises, students will be able to:

- Measure the speed of sound in air.
- Identify the paths that sound waves travel based on multiple reflections.
- Establish a connection between the time-of-flight signal received from multiple interfaces in the apparatus and the reflections from multiple body surfaces measured in ultrasound imaging.

This lab activity can be divided into a series of four experiments. The lab can appear early in the curriculum on sound waves in undergraduate introductory physics or a more specialized physics in medicine course.² We use the lab in conjunction with curriculum that is relevant for pre-health students and videos by biomedical experts.³-⁵

The lab requires no advanced terminology or concepts of the physics of sound. Mathematically, it only uses the constant velocity model, \( x = vt \). Conceptually, the activity can be used to introduce the ideas of reflection and transmission off of multiple surfaces. Experimentally, the activity can be used to
establish the speed of sound and determine the location of the partial reflections.

Experiment 1

The first experiment is a basic measurement of a sound wave's echo, which appears readily in the literature.\(^5\)\(^-\)\(^9\) The sound wave propagates down a pipe, reflects from either a closed or open end, and is measured with a microphone at the pipe entrance. This experiment demonstrates reflection of sound and establishes the speed of sound in air. The various pipe lengths and couplings allow for easily changing the travel distance.

First, students explore the reflections of sound waves for different length pipes. Figure 3 shows these reflections. These data will be used as a reference for when reflective couplings are included later. However, the initial sound pulse and its first reflection are not the only signal measured. Sound amplitude peaks return at equal intervals of time. These represent subsequent reflections; the first echo reflects from the open end of the pipe, travels to the closed end, and reflects a second time. This repeats with decreasing amplitude for subsequent reflections. Students can calculate the speed of sound or use the theoretical speed of sound to calculate the distance of the reflection to the sound source. The distance measurement would be the information used in ultrasound imaging.

From the data in Fig. 3, for example:

First reflection 3-m pipe:
Reflection distance = \((340 \text{ m/s} \times 17.5 \text{ ms})/2 = 2.98 \text{ m}\)

Third reflection 1.8-m pipe:
Reflection distance = \((340 \text{ m/s} \times 31.9 \text{ ms})/(2 \times 3) = 1.81 \text{ m}\)

Experiment 2

The second experiment builds on the first one by introducing a partially reflecting surface within the pipe. These reflectors partially reflect and partially transmit the initial sound wave. We have tried multiple ways of producing partial reflections. The best results are from plastic semi-circles glued to the couplings (Fig. 1). However, this limits reflectors to being placed at the junction of two pipes. A surprising richness emerges in the time-of-flight data as the sound waves can take many different round-trip paths (Fig. 4). Each path can be identified with a little sleuthing.

Figure 4 shows three data sets from this experiment. The first data plotted are reflections from a 0.8-m long pipe with an end cap. Four reflections are distinctly visible. The next data plotted are reflections from a 2-m long pipe with an end cap, assembled by connecting a 0.8-m and 1.2-m long pipe. Again, four reflections, spaced further apart, are visible. These two data sets serve as reference for the final data, which show the reflections that occur when a \(\frac{1}{2}\) partial reflector is placed at the junction of the pipes. This allows partial transmission into the second pipe (replicating the 2-m pipe) and partial reflection (replicating the 0.8-m pipe). Therefore, the amplitude peaks should match both of the previous data sets, as is seen. The first and second reflections from the 0.8-m length pipe (5.0 ms and 10.0 ms) and 2-m length pipe (12 ms and 24 ms) are visible, although the amplitude is noticeably reduced for the first reflection and nearly extinguished after the second. This is because the amplitude is split by reflection/transmission each time the partial reflector is encountered.

The first significant feature is that the two reflecting surfaces can be distinguished—a reflection from the partial
Piezoelectric transmitters and receivers register multiple reflected signals to reconstruct a grayscale image. For this experiment, we use four different pipes and three partial reflectors (two ½ reflectors and one ¾ reflector). Figure 5 shows four sets of data using four different lengths of pipe. The 0.8-m pipe with an end cap, the 2-m pipe (0.8 m and 1.2 m) with an end cap, and the 3-m pipe (0.8 m and 1.2 m and 1 m) with an end cap, respectively. The fifth data set is the combined data showing the 3.6 m (0.8 m and 1.2 m and 1 m and 0.6 m) pipe with partial reflectors included. It is evident from Fig. 5 that a signal from each reflector can be recovered. Similar to experiment 2, the secondary reflections from the 0.8-m and 2-m tube can be observed; however, higher order reflections are too attenuated to be observed.

One artifact that reduces the image quality in ultrasound is reverberation. This artifact appears when the ultrasound beam encounters two closely spaced strong reflecting surfaces. Reverberation can be experimentally explored by placing two reflectors close together within the pipe.

Experiment 4

For the fourth experiment, the plastic reflectors are replaced with foam reflectors (inset of Fig. 6). The foam piece is inserted into a coupling. This experiment simulates reflection off of materials with absorbing properties, such as human tissue or air in medical ultrasound imaging. We use the same pipes as experiment 2 with the foam reflector placed at their connection. Although the peak amplitudes of the reflections occur at the same time, the magnitude of the amplitude of the reflection from the foam reflector is reduced compared with the plastic reflector (Fig. 6).
Conclusion

We present experiments expanding upon a typical speed of sound laboratory to model medical ultrasound imaging by including reflectors at different locations along a closed pipe and by allowing the material properties of these reflectors to be changed. Each experiment in this series builds upon the previous experiments to allow students to explore a simple model of ultrasound imaging. The length of the pipes, the location, and the number of reflectors can all be changed to add variety to the measurements made in these experiments.

References
1. Audacity is free open-source cross-platform audio software for multi-track recording and editing. http://www.audacityteam.org/.
2. G. R. Van Ness and Ralf Widenhorn, “Engaging the community through an undergraduate biomedical physics course,” Am. J. Phys. 80, 1094–1098 (Dec. 2012).
3. Elliot Mylott, Ellynne Kutschera, Justin C. Dunlap, Warren Christensen, and Ralf Widenhorn, “Using biomedically relevant multimedia content in an introductory physics course for life science and pre-health students,” I. Sci. Educ. Technol. 25 (2), 222–231 (April 2016).
4. Warren Christensen, James K. Johnson, Grace R. Van Ness, Elliot Mylott, Justin C. Dunlap, Elizabeth A. Anderson, and Ralf Widenhorn, “Developing and assessing curriculum on the physics of medical instruments,” CBE Life Sci. Educ. 12 (2), 250-61 (June 2013).
5. Physics in Biomedicine, YouTube, https://www.youtube.com/user/PhysicsinBiomedicine/.
6. M. G. Raymer and S. Micklavzina, “Demonstrating sound impulses in pipes,” Phys. Teach. 33, 183–185 (1995).
7. L. Kasper, P. Vogt, and C. Strohmeyer, “Stationary waves in tubes and the speed of sound,” Phys. Teach. 53, 52–53 (Jan. 2015).
8. R. D. Knight, B. Jones, and S. Field, College Physics: A Strategic Approach, 3rd ed. (Pearson, Boston, 2015), Chap. 15.
9. “Speed of Sound in a Snap,” Vernier, https://www.vernier.com/innovate/speed-of-sound-in-a-snap/, or “Measuring the Speed of Sound with an Xplorer GLX,” PASCO scientific, https://www.pasco.com/support/technical-support/technote/techID-lookup.cfm?TechNoteID=564. A web search will provide further possible lab experiment write-ups from faculty at various universities.

Portland State University, Portland, OR 97207-0751; thallen@pdx.edu

And the Survey Says ...

How much do physics faculty members earn?

We surveyed faculty members in two- and four-year colleges and universities in the United States to find out. We contacted faculty members teaching physics in two-year colleges and in departments that grant degrees in physics. We heard back from about 1600 faculty members. Among the data we gathered were salaries. We now have an interactive online tool that provides faculty salaries based on a number of factors including:

- Type of institution
- Highest physics degree offered in the department
- 9/10 months, 11/12 months, or by course
- Degree earned
- Gender
- Full- or part-time
- Location of institution (state or national average)
- Academic rank (including adjunct)
- Postdoc completion
- Includes HBCUs

Please go to www.aip.org/statistics/salary-calculator to use the tool to find out what physics faculty members earn.

If you have any questions, please contact us. Susan White works in the Statistical Research Center at the American Institute of Physics. She can be reached at swhite@aip.org.

Susan C. White, Column Editor
American Institute of Physics
Statistical Research Center
College Park, MD 20740; swhite@aip.org

DOI: 10.1119/1.5092467