Proceedings of Meetings on Acoustics

Volume 9, 2010 http://asa.aip.org

159th Meeting
Acoustical Society of America/NOISE-CON 2010
Baltimore, Maryland
19 - 23 April 2010
Session 3eED: Education in Acoustics

3eED4. The Singing Shoebox: A $5 Loudspeaker Project

Scott Porter*, Daniel J. Domme and Jeffrey S. Whalen

***Corresponding author's address: The Graduate Program in Acoustics, The Pennsylvania State University, Applied Science Building, State College, Pennsylvania 16802, spp143@psu.edu**

Moving-coil loudspeakers typify the interdisciplinary nature of acoustics. In order to reproduce sound, these devices employ principles of electricity, magnetism, mechanics, and acoustics. The widespread use of loudspeakers has made them familiar to students and thus a valuable opportunity to introduce students to acoustics. In this paper, the authors demonstrate a loudspeaker-enclosure system that is easily built from scratch. The system is mostly constructed from common household supplies, making it low-cost and accessible to a wide audience. In addition, this project is well-suited for use by the K-12 educator as the content can be scaled to fit a variety of different academic levels. To this end, the speaker's design and construction will be presented and its relevance as an educational demonstration discussed. Finally, the loudspeaker will be auditioned and its performance demonstrated.

Published by the Acoustical Society of America through the American Institute of Physics

Received 17 May 2010; published 22 Jul 2010

1 Introduction

Sound reproduction is a fantastic feat of science. We are so thoroughly surrounded and bombarded with this modern miracle that we often take it for granted. It is incredible, however, that a bit of wire, some magnets, and a few other parts may be fashioned into a device which can mimic the sound of a piano or a guitar or a voice or even a whole orchestra at once![1] A scientific demonstration that captures this excitement will provide an excellent opportunity to introduce students to acoustics. In this spirit, the authors have sought to demonstrate a low-cost, easy-to-build moving coil loudspeaker to serve as an educational aid.

There are many merits to this demonstration. First, because of its ubiquitous nature, the loudspeaker is familiar to nearly all students. Second, it is a technically rich and well understood problem, providing an abundance of learning opportunities for a wide range of academic levels. Third, the loudspeaker allows students to directly experience acoustics – by *listening* to the demonstration. Most importantly, this demonstration fits within the scope of *Project Listen Up* because of its low cost and simple design.

2 Supplies

Low cost is achieved by using common household items as materials for the project. For example, the loudspeaker enclosure is constructed from a shoebox, the voicecoil former is made from a toilet paper roll, and the radiating piston is a compact disc (CD). However, not all components are readily available.

The mechanical suspension, magnetic circuit, and voicecoil required special materials to be purchased specifically for the project. For these, the authors used a latex sheet, Alnico horseshoe magnets, and magnet wire, respectively. These supplies were purchased from online vendors (McMaster-Carr and Amazon) and a local electronics store (Radio Shack); it is only these three components that would need to be included in a *Project Listen Up* kit. Not only are these items compact, but there is a possibility that they may be interchangeable with parts in other *Project Listen Up* demos. Table 2 shows the estimated component cost for the authors' prototype speaker totaling $7.10. It is anticipated, however, that bulk purchase of the components could decrease the cost to less than $5.

3 Construction

Because of its simple design, the shoebox speaker can be made by almost anyone. Additionally, the assembly is accomplished with regular craft supplies and does not require specialized tools. The construction procedure is outlined below.

[1] Paraphrasing from Hans Fantel, "Your speaker's voice," *Opera News*, 1 March 2002

Item	Cost
Horseshoe magnets	\$4.50
Latex sheet	\$1.50
Magnet wire	\$1.10
Total	**\$7.10**

Table 1: Estimated cost for the authors' shoebox speaker prototype.

- First, using the CD as a guide, a circular hole is cut in the bottom of the shoebox with approximately 1 cm of extra radius (a 14 cm diameter) as shown in Figure 1. Cutting this hole is most easily done with a hobby knife or scissors.

Figure 1: Shoebox with speaker hole cut out.

- The toilet paper roll is trimmed so that when one end is flush with the bottom of the box (where the CD will be), the other end has proper clearance from two horseshoe magnets situated on the lid as shown in Figure 2. The goal is to mount the tube so that the middle of the voicecoil is level with the ends of the horseshoe magnets.
- The most delicate step is winding a coil of magnet wire with an axial length of approximately 2 cm on one end of the toilet paper roll. Although patience is required, this can be accomplished with hand winding. The coil works best when adjusted to

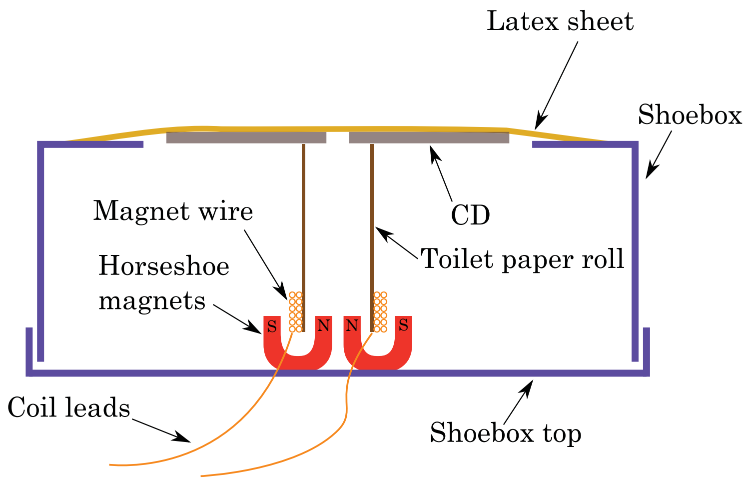

Figure 2: Schematic of the speaker construction.

be as close to the end of the roll as possible while still keeping the center of the coil level with the ends of the magnet. In this configuration, the coil may be depressed several millimeters before bottoming out against the magnets. After situating the coil, it is secured using a few strips of tape (excessive tape will inhibit heat transfer away from the coil).

Electrically, the coil should have adequate resistance to avoid either damaging the amplifier or putting the amplifier into protection mode. Coils with a DC resistance of less than $1\,\Omega$ should be avoided. On the other hand, too many windings will make the coil too thick to fit in the magnet gaps. A power-rated resistor in series with the voicecoil may be used to raise the speaker impedance to a standard $4\,\Omega$ or $8\,\Omega$ load. Vendors of speaker components (such as Parts Express) offer these resistors in a wide range of values. For the authors' prototype, the best coils typically consisted of 70+ turns of 26 AWG magnet wire, which yielded approximately $2\,\Omega$ of DC resistance. Therefore, including a $2\,\Omega$ resistor in series with the voicecoil presented the amplifier with a load of approximately $4\,\Omega$.

- Hot glue is used to bond the non-coil end of the toilet paper roll to the center of the compact disc. A strong bond is required, but excess glue should be minimized. Next, the CD-roll assembly is taped to the center of the latex sheet (roughly 20 cm $\times$ 20 cm). This is shown in Figure 3.
- Using the CD-roll assembly as a guide, the inside of the box top should be marked for placement of the horseshoe magnets; tracing around the coil is a useful guide. The magnets must be oriented so that the closest ends have the same polarity; this is easily

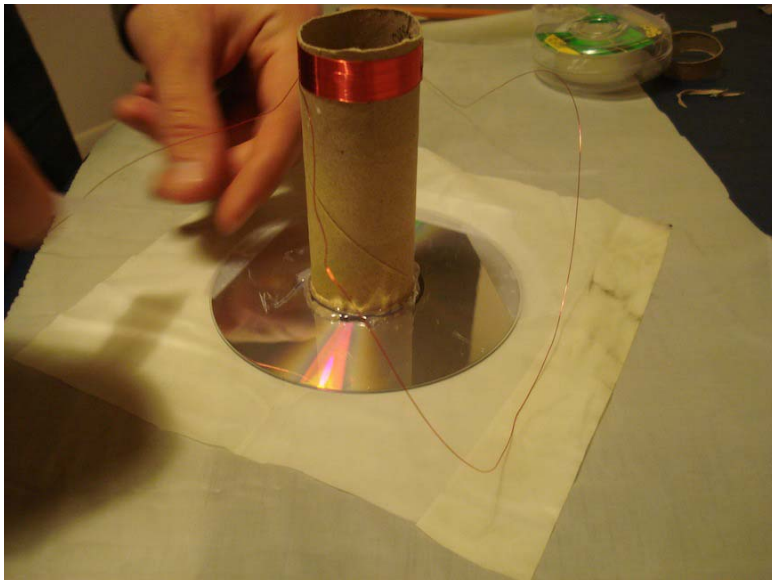

Figure 3: Moving mass assembly (piston, former, and coil) with compliance.

determined by making sure these ends repel before gluing them into place. Liberal application of hot glue is used to secure the magnets to the inside of the box top as shown in Figure 4. Next, the lead wires from the coil are routed through a small hole (also shown in Figure 4) punched in the lid with a pencil. The insulating enamel is removed from the magnet wire by burning the ends with a match and removing any residue with sandpaper. Students using matches should always be supervised.

- Finally, the roughly 20 cm × 20 cm sheet of 6 mil (0.15 mm) latex is attached to the shoebox with tape. The sheet should be gently tensioned to provide an adequate restoring force, but excess tension will degrade the latex. Care should also be taken in the tensioning process to align the coil so that it slips between the legs of the horseshoe magnets without interference. In its final position, the coil assembly should not rub against the magnets, but move up and down freely.

4 Performance

Once built, the speaker is powered by an audio amplifier. A well-built shoebox speaker can reproduce sound surprisingly well considering the crudeness of its construction. Because of the inefficiencies of the simplified design, low-power amplifiers produce unsatisfactory volumes. It was convenient for the authors to use a secondhand stereo receiver rated at 90 watts per channel. This provided adequate volume for demonstration. As always, when

Figure 4: Magnet placement and hole for routing lead wires.

working with electricity, students should be supervised.

Figure 5 shows the electrical input impedance for the prototype speaker built by the authors, measured with a Wayne Kerr 6500B Impedance Analyzer. Key features of the impedance magnitude are the low resonance frequency which defines the lower limit of the loudspeaker's frequency response, the motional impedance peak which describes the mechanical behavior at resonance, and the inductive rise of the impedance magnitude with frequency that characterizes the electrical domain.

An advantage of the shoebox enclosure is that it allows the device to be immediately separated into two assemblies for visual inspection of components. This gives observers an opportunity to notice that the powered device does not function when the coil is removed from the magnet gaps.

5 Educational opportunities

There are many educational topics of varying complexity which are within the scope of this project. Because of this, the demonstration may be tailored to fit groups of students at a variety different academic levels.

Students below the high school level can be introduced to some of the more advanced concepts of physics, such as the interrelationship between electricity and magnetism, with little theoretical complexity. Real evidence of these relationships is both visible and familiar in the form of the shoebox loudspeaker. High school physics teachers can introduce more

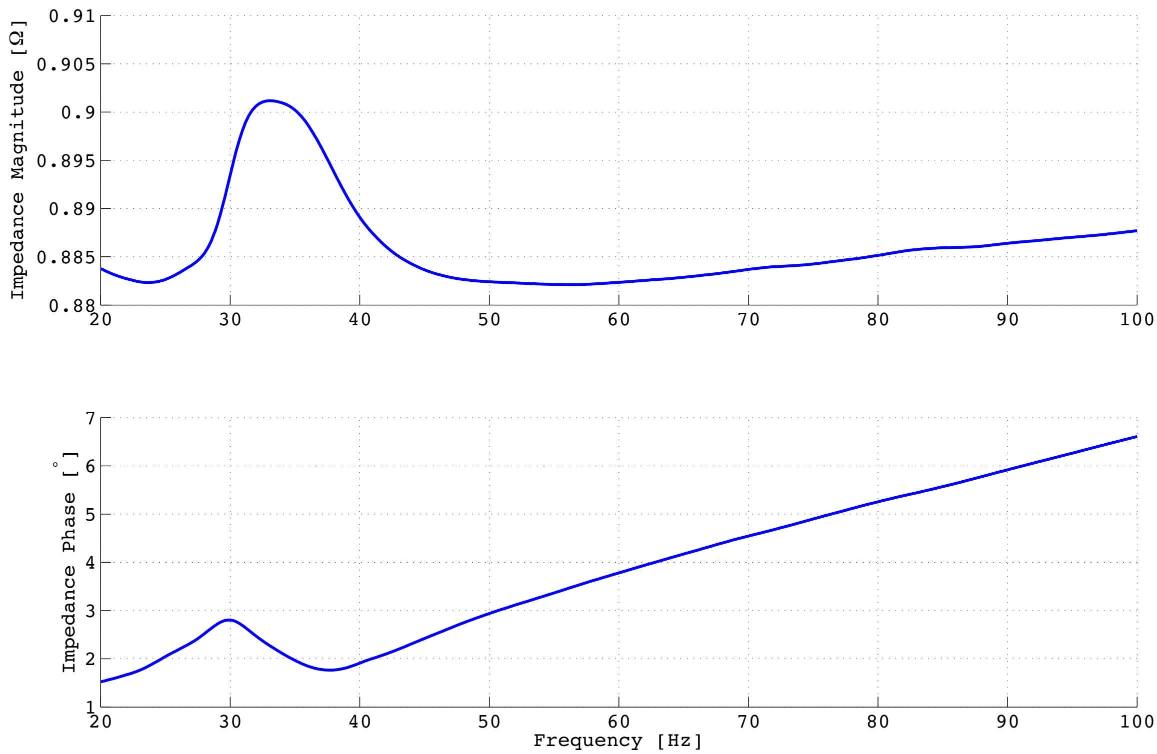

Figure 5: Smoothed impedance curves for the prototype speaker

complex concepts, such as the Lorentz force principle, the restoring force, the simple harmonic oscillator, and Joule heating. College students in science or engineering disciplines can dissect the problem even further, exploring the concepts of electroacoustic transduction, magnetic circuits, and radiation resistance/frequency response. In every case, the shoebox loudspeaker provides a tangible realization of these principles, eroding the barrier between theoretical concepts and practical applications.

6 Conclusions

A working loudspeaker for educational purposes is constructed using many everyday items and craft materials. This gives students first-hand experience with sound reproduction from an electroacoustic transducer they have built from scratch. Furthermore, this demonstration provides access to learning opportunities for students at a wide range of academic levels. The authors hope the process of building and experiencing a craft-project loudspeaker will fill students with a sense of wonder that inspires them to investigate the science of sound.

7 Acknowledgements

The authors wish to acknowledge several insightful conversations with Professor Steven Garrett. Also, the authors are grateful to Joonho Daniel Park for suggesting the "singing shoebox" name used in the title.