Tangible Electricity: Audio Amplifier and Speaker

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Full Paper: Tangible Electricity - Audio Amplifier and Speaker

Abstract

Projects help students connect concepts to physical reality and allow students to experience the process of design, construction, and testing. Finding suitable projects can be difficult. They should be challenging yet enjoyable, demonstrate the concepts in an understandable way, tangible (hands-on), not cost too much, and not require too much time of either students or instructors. This paper describes one such project: soldering an audio amplifier and building a speaker. The primary goal of this project was to make electrical engineering tangible, as early students (or those in other disciplines) often complain that they cannot "feel" or "see" electricity. This project allowed them to feel, see, and hear the movement caused by an electrical signal and to interact with it through a volume knob. Concepts addressed included circuit theory, operational amplifiers, and electromagnetic fields but could be extended to other topics as well, such as spherical wave propagation or system modeling. This project was implemented with 190 first-year students during the 2017 fall semester. Students were given all of the necessary parts, including a printed circuit board (PCB), electrical components, magnets, and wire. Each student soldered the components onto the PCB and constructed his or her own speaker from household materials, like plain paper, cups, plastic bottles, paper plates, etc. Amplifiers were tested for operation. Speakers were tested for frequency response and loudness. The initial, one-time equipment cost is $5-20 per student, depending on equipment already available, and the recurring materials cost is $10-15 per student. The students were enthusiastic about their designs both before and after they completed their projects. This paper includes more detail about the project, examples of student designs, speaker testing results, student feedback, and future plans.

Introduction

Most engineering educators recognize the effectiveness of hands-on learning and seek to implement labs and projects into their courses, especially in the first year [1–6], as encouraged by Recommendation 4 in the National Academy of Engineering's 2005 report [7]. Many first-year electrical engineering projects involve programmable microcontrollers, but for courses that do not teach programming or require it as a prerequisite, this is not an option. This paper provides an example of a first-year project aimed at helping students understand electricity, signals, and electrical engineering without the need for programming.

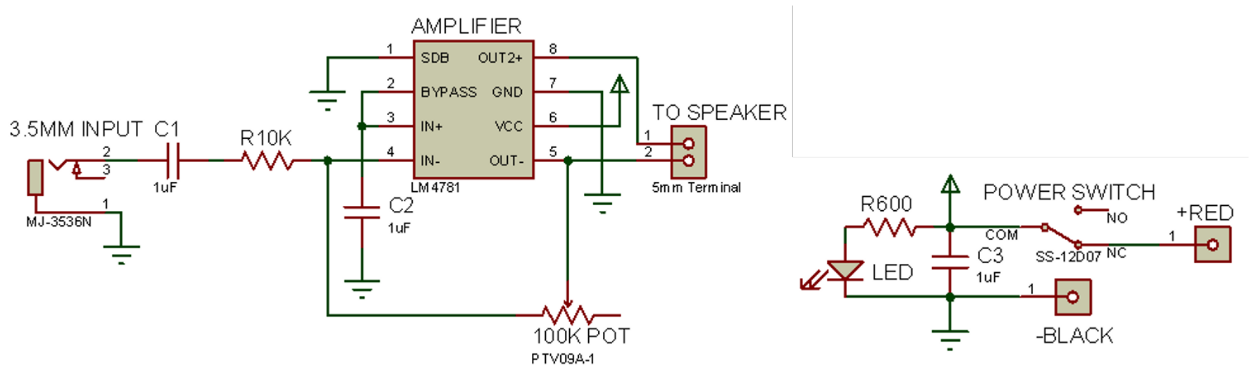

Figure 1: Amplifier circuit schematic

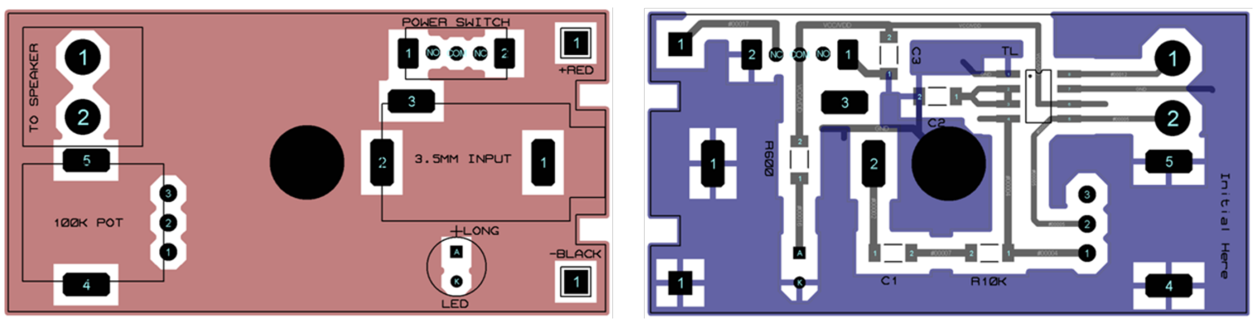

Figure 2: Amplifier PCB layout (left=top, right=bottom)

Project Setup

The project has two parts: soldering an amplifier board and building a speaker. More detail about each of these is given below. The project was conducted in three lab sessions, one-per-week, 75 minutes each.

- Week 1: Amplifier soldering
- Week 2: Finish soldering and amplifier testing
- Week 3: Speaker testing

Students were then asked to write a brief (<1 page) report and comment on their experience.

Amplifier

Since this was the first time soldering for many students, they were required to watch two video tutorials [8, 9] and answer a few questions before coming to lab. In lab, students were given a printed circuit board (PCB) and a set of the components to construct the amplifier. The design was done by instructors (see Figures 1 and 2), and the students were only responsible for soldering the components on the PCB.

Amplifier Testing

Students who did not finish soldering in Week 1 could come during evening “lab hours” staffed by undergraduate teaching assistants or finish during lab on Week 2. Testing of the amplifier was binary: working or not working. The amplifier input was connected to the headphone output of a mobile device or laptop, and the amplifier output was connected to a commercial speaker. If music played correctly, the amplifier worked. Problems were usually found by visual inspection. Occasionally, a multimeter was used to check resistance/continuity.

Speaker

Students were given the basic principles of speaker operation, such as current flowing through a coil of wire produces a magnetic field. They were also provided with a list of possible trade-offs in design parameters, such as a larger diameter cone moves more air mass and produces low frequencies better but, given the limited power input, may not be as loud as a smaller diameter cone.

They were shown videos of other “homemade” speakers to provide ideas for their own [10–15]. Most of these can be built with basic household materials: paper, cardboard, tin cans, disposable plates, cloth, etc. Students were given small neodymium magnets and magnet wire and were expected to source the remaining materials for themselves. This led to good variety in student designs, as can be seen in the examples below. Hot glue guns were provided in lab to speed the building process.

Speaker Testing

Figure 3 shows the speaker testing setup. Students used their amplifier-speaker system, since all of the amplifiers should have a similar response. These were connected to the headphone output of a computer, and microphones were connected through an audio mixer to the microphone input of the computer. The audio mixer was necessary to power the microphones and be a pre-amplifier for the signals. The microphone was placed approximately six inches above the speaker, pointed directly at it. MATLAB was used to generate test signals, gather responses, and analyze them.

It is worth noting that these tests need to be repeatable/consistent but not necessarily accurate or comparable with commercial measures. The goal is simply to compare students’ speakers (and perhaps compare them to a commercial speaker), so all that is needed is a measure that yields better results for better speakers.

Two tests were performed:

- Tone Test – The purpose of this test was to determine total harmonic distortion (THD), which is a measure of how non-ideal the tone is, and sensitivity, which is a measure of loudness vs. power input, like efficiency. A 1 kHz sine wave was played through the amplifier-speaker combination. Amplitude was measured at 1 kHz, and THD was measured using MATLAB’s THD function. (It was actually THD+N.) The voltage and current from the power supply were recorded manually while the tone was playing. This was used to

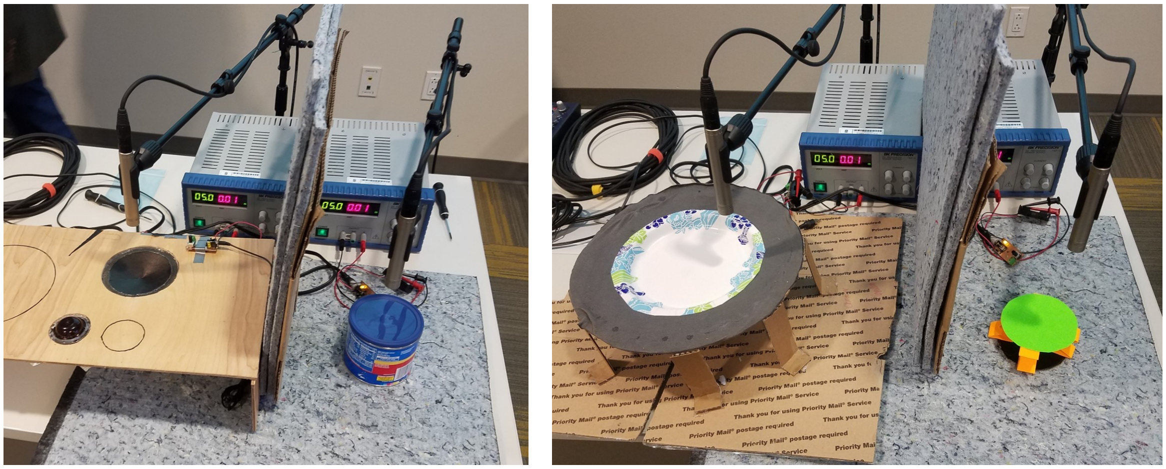

Figure 3: Student examples and test setup.

calculate power, which was used to calculate sensitivity as microphone signal voltage per watt (V/W).

- Sweep Test – The purpose of this test was to determine loudness in low, mid, high, and full frequency ranges. The frequency was swept from 20 Hz to 20 kHz. The maximum amplitude of the FFT of the microphone signal was recorded for each frequency. This data was then divided into three regions: low (20-200), mid (200-2k), and high (2k-20k). The amplitude values were averaged within each region, giving a single value to indicate the performance of the speaker for bass (low), midrange (mid), and treble (high). The entire frequency range was also averaged to provide a single value for the overall performance of the speaker.

Student Examples

Figure 3 shows four examples of student designs. As described above, these vary widely in terms of size, materials, and complexity. There was a correlation between build quality and performance, particularly with how well students wound the voice coil and the position of the coil relative to the magnets. Other factors were less clear. In particular, size had very little to do with performance. There were good examples using both 2-inch foam cups and 8-inch paper plates. Some students did not fully understand and/or consider the basic principles when building. They did not wind the voice coil correctly, or they attached the magnets to the speaker cone making it too heavy. Their speakers performed poorly, if at all.

Student Feedback and Learning

Both from their comments and based on how they engaged with the project, students seemed to very much enjoy it. Here are a few comments from student reports:

- “Overall, I loved this project as I was able to design and create a speaker from scratch. Being able to complete this task from the start to finish was great for my understanding of the processes that go into it.”

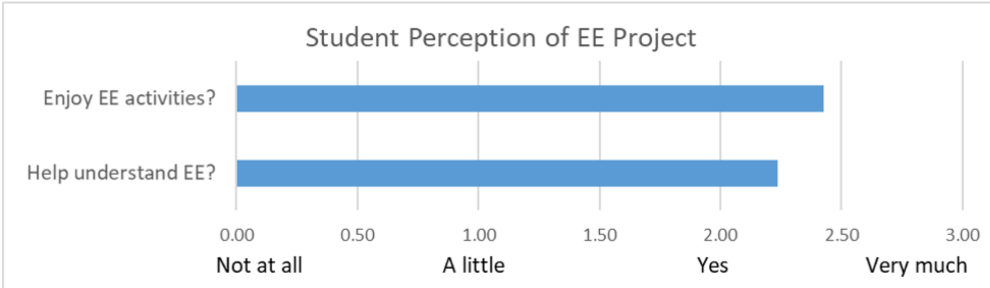

Figure 4: Student survey

- "One of my favorite experiences regarding the EE lab was the use of the soldering iron to construct the speaker amp. It was very interesting to watch the tutorial videos and to actually learn soldering techniques. I learned that safety is a priority and that organization and safe practices are key to technical undertakings."
- "This lab was really fun and allowed me to have hands on experience in Electrical Engineering. Building a speaker, allowed me to explore different techniques and problems a real Electrical Engineer can run into while dealing with. Like increasing the volume, or creating less bass from the sound. I thought this Lab was a great experience in my problem solving."

Some of the other positive comments from students were about learning soldering skills, surprise at the simplicity of a speaker, overcoming failure or improving performance by iterating their design, seeing a wide variety of solutions to the same problem, and experiencing the technical evaluation of a prototype. Students also appreciated the accessibility of simple construction materials.

An end-of-semester survey was conducted that included two questions regarding this project: "Did you enjoy the electrical engineering (EE) activities?" and "Did those activities help you understand electrical engineering better?" Figure 4 gives the results for 84 students (a response rate of 44%). Of those, 74 (88%) responded "Yes" or "Very much" to enjoying the EE activities and 75 (89%) responded the same way to understanding EE better because of the activities.

Conclusion and Future Plans

This project is a great learning experience for students, but it does takes significant effort to order and organize all of the equipment and components, to help students with their soldering, to troubleshoot amplifiers that are not working, to give guidance to students as they design their speakers, to setup for testing, and then tear it all down. That is the nature of projects!

However, there were a few issues that we intend to rectify the next time:

- Spools of wire – We created a machine for re-spooling wire from the large roll we purchased to smaller rolls for the students. The smaller rolls were wound around rolled-up paper. The paper would collapse, and the wire would tangle so badly that it could not be used.

- Lab time – Seventy-five minutes is not long enough to solder the amplifier board or test all of the speakers. A two-hour period would be much better.
- Speaker testing – Testing became a little repetitive; however, most students did want to test their speaker individually to see how it compared with everyone else. We need to find a way to keep the whole group engaged while testing individual speakers. One possibility is to have multiple stations. Another is to write or display results in real time and make it a competition.

Readers are encouraged to contact the authors if they would like further details about the project, including assignments, PCB files, and bill of materials.

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