ASEE AMERICAN SOCIETY FOR ENGINEERING EDUCATION

Paper ID #35160

A Bluetooth Speaker Project for High School Outreach

Prof. Gene L. Harding P.E., Purdue University (PPI)

GENE L. HARDING is an associate professor of Electrical and Computer Engineering Technology at Purdue University, where he has taught since 2003. He has three years of industrial experience with Agilent Technologies, 28 years of combined active and reserve service in the United States Air Force, holds an MSEE from Rose-Hulman Institute of Technology, and is a licensed professional engineer.

Mr. Taylor Andrew Hansen, Purdue Alumni

Taylor Hansen is a DIY loudspeaker speaker designer. His many designs have competed in the Parts Express Mid-West Audio Fest Speaker Building Competition, and have been globally recognized in popular media outlets such as Audioholics. He has 4 years of industrial experience working with companies such as Belden, Aptiv, and BAE Systems. Additionally, he holds a BS in ECET, emphasizing in analog signal processing and audio technologies.

A Bluetooth Speaker Project for High School Outreach

Gene L. Harding*
glhardin@purdue.edu
Victor Perez
perez139@purdue.edu
Taylor Hansen
taylor_a_hansen@outlook.com
Davin Huston
davin@purdue.edu
Purdue University

Abstract

This paper describes a student-designed Bluetooth speaker project intended for use in a summer recruiting event aimed at high school students. Although recruiting is not a problem for the main campus of Purdue University, it is a challenge for most of the satellite campuses. This project was chosen because Bluetooth speakers are very popular among teenagers, and it provides a nice vehicle for studying a number of engineering topics. As such, it simultaneously markets the local campus and exposes students to multiple engineering/technology disciplines, thus helping them choose a major that fits their interests.

This paper describes the design of the speaker and its enclosure, integration of the components, and parts sources to assist others who may want to replicate it. For context, it also describes how it would be constructed during the camp, along with the camp goals and structure, tentative schedule, and accompanying educational activities.

Introduction

The Purdue Polytechnic Institute of Purdue University has nine satellite locations, called Statewide Technology, dispersed around the state of Indiana. Each location offers a subset of the degree programs offered at the main campus, based on needs of local industry in each area. These locations are largely responsible to do their own recruiting, which includes visiting high schools, hosting groups of high school students for tours, and running summer camps for students of various ages.

For a few years the South Bend location offered an electric go-kart summer camp for high school students, but the go-karts are currently being refurbished and are not expected to be available in the coming year. The local director requested the faculty come up with an alternative summer camp for local high school students. The purpose of the camp is to serve as a recruiting tool and to keep Purdue Polytechnic South Bend engaged in the local community while exposing potential college students to the engineering technology programs offered locally.

One of the authors, observing the popularity of Bluetooth speakers among teenagers, got the idea of offering a summer camp during which students would build their own Bluetooth speakers. He regularly speaks to high school students about engineering careers. Each time he did so he asked what they thought about such a camp. Interest was high among students, and the director liked the idea, so it was set. The plan was to design a Bluetooth speaker, then develop hands-on educational activities to combine with the speaker construction. The educational activities would introduce students to some technical disciplines in engineering technology while teaching them about how that technology is used to design a loudspeaker. The primary focus of this paper is the speaker itself. A follow-on paper is planned to describe the camp itself in more detail.

The professor recruited an interested student to do a directed project to develop the Bluetooth speaker and propose a set of camp activities. The rest of this paper describes the process the student went through to design the speaker, lessons he and the professor learned along the way, the final design, and projected camp activities.

Speaker Design

The initial plan was to design the speaker from scratch using discrete components to keep costs down and give the student a chance to do a ground-up design. This section describes that process, and how it ultimately led to the selection of a pre-designed do-it-yourself kit.

The student began searching the web for speakers, amplifiers, and Bluetooth modules. His search turned up numerous possibilities on Amazon (www.amazon.com), but those products generally did not have technical datasheets posted, making informed design decisions virtually impossible. One of the authors, a colleague with much more audio design experience, recommended using Parts Express (www.parts-express.com). Their listings include datasheets, and sometimes other technical information.

Key design decisions for the electronics were mono vs. stereo, one vs. two speakers per channel, integrated vs. separate amplifier and Bluetooth receiver modules, battery pack/charge-control module, and plug-in power supply.

A single-channel amplifier used with a single speaker or set of speakers (e.g., woofer and tweeter) would require some sort of mixer to superimpose the left and right channels prior to amplifying the newly generated mono signal. This type of amplifier was not found on the Parts Express web site. Thus, either a pair of one-channel amps or a stereo amp was required. We decided to use a stereo amplifier with an integrated Bluetooth receiver, both for simplicity and cost. Our initial selection, recommended by one of the authors who had used it very successfully, was a 2 x 30-W stereo amplifier with volume control built into the board, and integrated Bluetooth 4.2. Unfortunately, this part went obsolete before being ordered, leading to selection of a 2 x 15-W stereo amp with integrated Bluetooth 2.1, part #325-100 [1]. It also came with a wiring harness.

The initial speaker selection was the Dayton Audio ND65-8 [2], a full-range, 8-Ω driver with frequency response from about 90 Hz – 12 kHz [3]. This choice would have allowed for a single driver for each channel, with a band-pass filter (BPF) to limit frequency input, but no additional crossover network required.

The only option for a battery/charge controller was the highly rated (4+ stars) Dayton Audio KAB-BE, which manages power to and from three 3.7-V 18650-series Li-ion batteries [4]. Two AC power adapters were tried, one 19-V [5], the other 12-V [6].

Initial integration of one speaker with the amp/Bluetooth module went well. The module paired quickly with a cell phone, and and produced good quality audio including bass frequencies.

The next step was to design a BPF to limit frequencies into each speaker to the range of 90 Hz – 12 kHz. Both second- and third-order filters were considered, using online calculators to generate inductor and capacitor values [7], [8]; followed by simulation using Multisim v14.1 [9] to verify functionality.

The second-order filter was initially designed for a low-frequency cut-off of 88 Hz and high-frequency cut-off of 12 kHz. Calculated capacitor and inductor values were rounded to standard values, as shown in Figure 1. This resulted in a low-frequency cut-off, f_L, of about 96 Hz, and high-frequency cut-off, f_H, just below 12 kHz, as shown in the simulated frequency response of Figure 2.

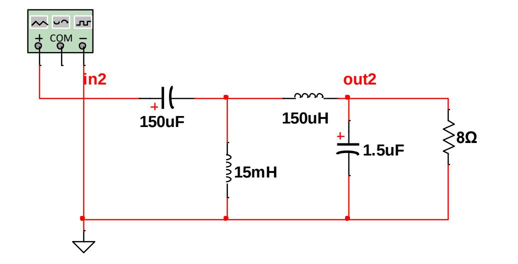


Figure 1: Second-order BPF circuit

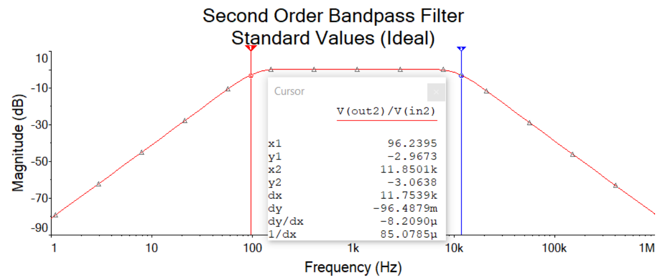


Figure 2: Second-order BPF frequency response

The third-order filter, also using standard capacitor and inductor values, is shown in Figure 3**,** and its frequency response in Figure 4. Although it has the expected 60-dB/decade roll-off of a third-order filter, it also exhibits 3-4 dB of peaking not seen in the 2nd-order filter. Its half power frequencies are 77.5 Hz and 12.9 kHz.

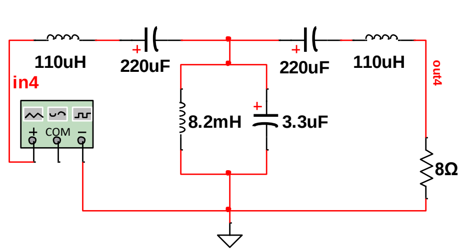


Figure 3: Third-order BPF circuit

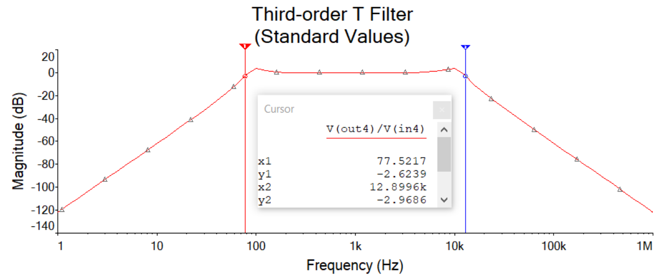


Figure 4: Third-order BPF frequency response

All seemed good until we tried to implement the circuits in the lab, using standard parts from our lab stock. This turned out to be a mistake. The frequency responses were not only distorted from those shown above, the pass bands were also around -5 dB. The loss in signal power was audibly very noticeable. After consulting with a colleague who is more experienced in audio system design, we discovered what was, in retrospect, very obvious: The low impedance of audio loudspeakers mandates “special” inductors and capacitors with very low resistance values. This is especially true of the inductors, which can often have 20-60 Ω of resistance.

At this point the end of the semester was near. In order to complete the directed project and get a working prototype before the semester ended, we went with the recommendation of a colleague experienced in speaker design (one of the co-authors), and selected a predesigned kit: the Dayton Audio MKBoom Portable Bluetooth Speaker Kit [10]. The MKBoom is a complete kit including woofers, tweeters, and bass reflex port tubes; amp/Bluetooth module; battery pack/charger and AC adapter; crossover networks; control panel with power switch, volume knob, power and aux input jacks, and LED indicators; and a knock-down cabinet (i.e., precut enclosure pieces) ready for assembly. The assembled speaker is shown in Figure 5, along with a 6” ruler for reference. The final version will be painted black and have a gold Purdue “P” added to the middle of the front panel.

Figure 5: Assembled MKBoom speaker

The student author, with some help from our technician, assembled the kit in 5-6 hours. Although assembly was generally straightforward, the directions lacked a few details, and there were a few screws missing, which were easily sourced from a local hardware store. The sound, however, was amazing, with great bass response. Even at max volume there was no noticeable distortion in the sound. The kit seems rather pricey at $129, but its sound is impressive. Moreover, informal testing confirmed that the claimed battery life of 8-10 hours (at moderate volume) appears to be accurate.

Camp Layout

The camp was set to run in mid July 2020, Tuesday – Thursday from 9am – 4pm each day, with ½ hour or so for lunch. This allows for a full day Monday to set up and prep, and a full day Friday to tear down and wrap up. The flyer used for advertising is shown in the appendix.

Unfortunately, the fallout from the Coronavirus pandemic shut down the camp shortly after registrations began. Virtually all activity related to running the camp was put on hold in the middle of the spring 2020 semester, and remains in limbo as of the writing of this paper. At this point it is still not clear when we will be able to run the camp, but the high-level plan for it is described below.

The philosophy of the camp is to combine technical instruction with hands-on time building and using lab equipment. It is meant for students who are interested in engineering and technology, not for those who just want to build a cool speaker. Details of the activities have not been finalized, but the first run of the camp will be limited to eight students to allow for a high worker-to-student ratio while faculty and staff learn lessons and deal with contingencies. The general schedule for each day is laid out in the following paragraphs.

First, the plan is to assemble and paint all but one of the speaker cabinets ahead of time. The final cabinet build will be a demo. This will allow us to control the quality so that there are no "failed" cabinet builds, while still providing an opportunity to discuss manufacturability and quality control issues. It will also save valuable time, which is important because a lot of activity is being packed into the three-day period of the camp.

The day one schedule is expected to be:

- 0900 – 0930: Introductions and a short icebreaker
- 0930 – 1030: Discuss manufacturability issues and quality control; industrial engineering technology activity
- 1030 – 1045: Snack/bathroom break
- 1045 – 1145: Intro to electricity, resistors, DC power supply, digital multimeter; proto-board activity
- 1145 – 1230: Lunch
- 1230 – 1330: Materials/mechanics discussion/activity
- 1330 – 1445: Multisim intro; circuit building/simulation activity
- 1445 – 1545: Acoustics discussion and activity
- 1545 – 1600: Wrap-up and high school students depart
- 1600 – 1700: Address any issues left over from the day

The plan for day two is:

- 0900 – 1000: Intro to AC; Multisim AC analysis activity
- 1000 – 1015: Snack/bathroom break
- 1015 – 1200: Assemble control panel, amplifier/Bluetooth module, battery module
- 1200 – 1230: Lunch
- 1230 – 1330: Mount logo to front speaker panel; additive manufacturing discussion/activity
- 1330 – 1430: Low- and high-pass filter exercise with oscilloscope, function generator, small speaker, and music source; discuss crossover networks
- 1430 – 1545: Install crossover networks (includes soldering a pair of wires to each crossover) and speakers, glue top of enclosure; plug in to charge overnight
- 1545 – 1600: Wrap-up and high school students depart
- 1600 – 1700: Finish any work not done by students; test each speaker to verify operation

Day three is organized as follows:

- 0900 – 1000: Amplifier discussion, battery DC to speaker AC energy conversion
- 1000 – 1015: Snack/bathroom break
- 1015 – 1115: Sound comparison activity with various cabinet/enclosure types/materials
- 1115 – 1200: Testing discussion/activity

- 1200 – 1245: Lunch
- 1245 – 1345: Radio discussion/activity
- 1345 – 1445: Test and play each speaker
- 1445 – 1545: Tour facilities
- 1545 – 1600: Wrap-up and high school students depart

The schedule for the final day is intentionally set up to be “soft” to accommodate any issues that may need to be worked out before students leave.

Future Work

A substantial amount of work is yet to be done before the camp is run. The sessions covering Electricity Basics, Multisim Introduction, Multisim AC Analysis, and Low-pass and High-pass Filters have been planned, but none of them have gone through a dry run to be refined and tested for time.

The Amplifier session has been planned at a high level, but a detailed plan still needs to be done. The pre-camp and post-camp assessment surveys have been drafted (see Appendix B), but are not yet finalized.

The Industrial Engineering Technology activity, Materials/Mechanics investigation, Acoustics discussion, and Radio session have yet to be laid out.

Conclusion

This paper described the development/acquisition of a Bluetooth speaker intended to be assembled during an interactive summer camp for high school students. The speaker was the end product of a directed project at Purdue Polytechnic Institute’s South Bend location. Links to the components used are included in the references for anyone who is interested in the project.

Informal surveys of high school students indicated a high degree of interest in a summer camp involving construction of a Bluetooth speaker and exploration of its technology. Although this paper focused on the speaker development, the ultimate goal of developing the speaker is to use it in a summer camp to expose potential college students to engineering technology programs offered in the community, and provide them with a take-home souvenir to spur conversations about, and interest in, the local campus. The camp itself will combine hands-on activities building the speakers and using test equipment in the lab, while mixing in technical instruction to illuminate local engineering technology degree programs.

References

[1] "Dayton Audio KAB-215 2x15W Class D Audio Amplifier Board with Bluetooth 2.1." Accessed January 14, 2021. Available: https://www.parts-express.com/dayton-audio-kab-215-2x15w-class-d-audio-amplifier-board-with-bluetooth-21--325-100

[2] "Dayton Audio ND65-8 2-1/2" Aluminum Cone Full-Range Neo Driver 8 Ohm." Accessed January 14, 2021. https://www.parts-express.com/dayton-audio-nd65-8-2-1-2-aluminum-cone-full-range-neo-driver-8-ohm--290-206

[3] "ND65-8 datasheet. Accessed January 14, 2021." https://www.parts-express.com/pedocs/specs/290-206-dayton-audio-nd65-8-specifications.pdf

[4] "Dayton Audio KAB-BE 18650 Battery Extension Board for Bluetooth Amplifier Boards." Accessed January 14, 2021. https://www.parts-express.com/dayton-audio-kab-be-18650-battery-extension-board-for-bluetooth-amplifier-boards--325-113

[5] "19V 4.8A DC Switching Power Supply AC Adapter." Accessed December 26, 2019. https://www.parts-express.com/19v-48a-dc-switching-power-supply-ac-adapter-with-25-x-55mm-center-positive-(-)-plug--120-058

[6] "12V 3A DC Power Supply AC Adapter." Accessed December 26, 2019. https://www.parts-express.com/12v-3a-dc-power-supply-ac-adapter-with-21-x-55mm-center-(-)-plug-and-6-ft-input-output-cord--129-057

[7] "Claredot Second-order Band-pass Filter calculator." Accessed January 14, 2021. www.claredot.net/en/sec-Sound/band-pass-cross-over-12dB.php

[8] "Electronics Notes Constant-K LC Band Pass Filter Circuit Design & Calculations." Accessed January 14, 2021. https://www.electronics-notes.com/articles/radio/rf-filters/constant-k-simple-bandpass-lc-rf-filter-design-calculations.php

[9] "Multisim SPICE simulation and circuit design software." Accessed January 14, 2021. https://www.ni.com/en-us/support/downloads/software-products/download.multisim.html#306441

[10] "Dayton Audio MKBoom Portable Bluetooth Speaker Kit." Accessed January 14, 2021. https://www.parts-express.com/dayton-audio-mkboom-portable-bluetooth-speaker-kit--300-7166#lblProductDetails

Appendix A: Bluetooth Speaker Camp Flyer

PURDUE UNIVERSITY | Polytechnic Institute South Bend

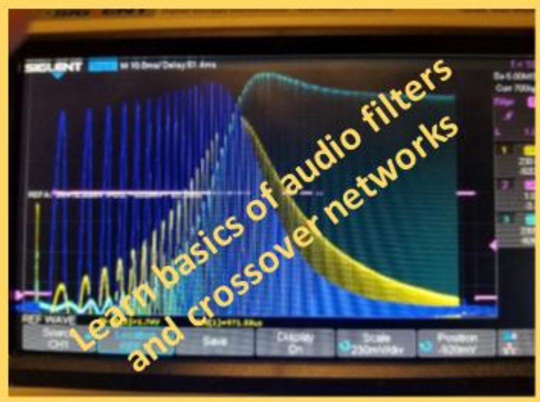
Bluetooth Speaker Camp

Are you interested in engineering and technology? Do you like audio?
Register today for Purdue's Bluetooth Speaker Camp!
https://conf.purdue.edu/bluetooth2020

Build your own

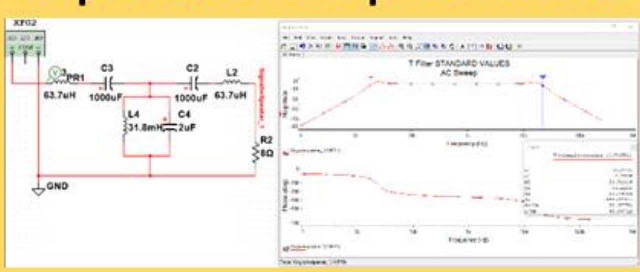
Bluetooth stereo speaker!

Use Purdue lab instruments to measure and test the components



Spend 3 days exploring electronics, acoustics, mechanics, and manufacturability!

Perform computer simulations to predict circuit performance



July 14-16, 2020
9am – 4pm each day
Lunch provided
Cost: $150
Grades: 10-12
Questions? Call 520-4180 for more info

Appendix B: Pre-camp and Post-camp Surveys

Pre-camp Survey

1. What interested you in the Bluetooth Speaker Camp?
2. What do you hope learn from the camp?
3. What does Ohm's Law say about the relationship between voltage and current?
4. What is the difference between AC and DC electricity?
5. What is the purpose of a crossover network in a speaker?
6. What does an amplifier do?
7. How does a Bluetooth device communicate with another device to know what to play?
8. What is additive manufacturing?

Post-camp Survey

1. What did you learn from the camp?
2. What does Ohm's Law say about the relationship between voltage and current?
3. What is the difference between AC and DC electricity?
4. What is the purpose of a crossover network in a speaker?
5. What does an amplifier do?
6. How does a Bluetooth device communicate with another device to know what to play?
7. What is additive manufacturing?