6.101 Proposal

Battery-Powered Speaker with Tactile Input

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1 Introduction

For our final project, we aim to design and build a battery-powered speaker that implements a touch interface to control the speaker's volume. The speaker will be powered via a single 1.5V battery rather than a wall wart. The speaker will also include a meter of LEDs that indicate the amplitude of the music. We plan to machine a case in which to mount our speaker, the LED display, and subsequent circuitry. We are excited about this project because it will be visually, tactilely, and auditorily stimulating.

2 Speaker in a Box

We plan to divide the project into three main functional blocks, which we can complete in parallel. One component of the project will involve designing the 1.5V to 5V converter to power the speaker. If time permits, we will focus on efficiency to maximize the lifespan of the 1.5V battery. The touch pad for volume control will contain two pads that sense touch - one to increase and the other to decrease volume at a continuous rate when in contact with the user's finger. When neither pad detects touch, the speaker will maintain the current volume. The audio amplifier and LED display will compose the final portion of the project. We will design an ADC to convert audio signal amplitude into discrete LED display levels. The audio amplifier will be designed to handle a wide variety of music volumes.

2.1 Power Converter

This module will create a bipolar rail voltage of $\pm$5V from a single 1.5V battery. This bipolar rail voltage will be used to power the rest of the system. The input into this module is simply the 1.5V battery, and the output is the $\pm$5V supply to the rest of the circuit. Natalie will be designing this module of the project.

This module contains three main functional blocks – a colpitts crystal oscillator, a boost converter, and an inverting converter. The colpitts crystal oscillator creates an output signal at a particular frequency which is determined by the value of the crystal in the network. This oscillating signal will serve as the AC signal to drive the boost and inverting converters. The boost converter will step up 1.5V to 5V by charging and discharging an inductor. This 5V output will serve as the positive voltage supply rail for the rest of the circuit. The inverting converter will similarly use an inductor being driven by an AC signal, but will create a voltage of -5V at the output. This negative voltage will be used at the negative supply rail for the rest of the circuit. Achieving the $\pm$5V rail will be an expected goal of the project.

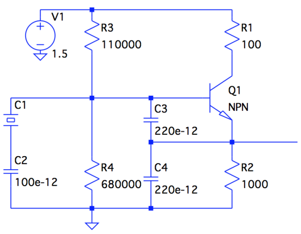

Figure 1: Colpitts Crystal Oscillator

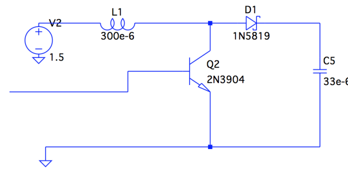

Figure 2: Boost Converter

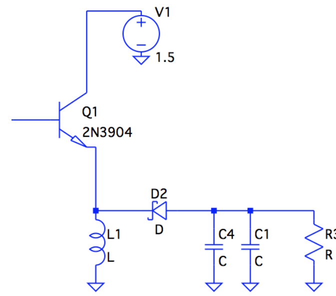

Figure 3: Inverting Converter

The main challenges in this module arise from limitations with the 1.5V battery. With such a low initial voltage, we cannot use some parts such as MOSFETs in the power converters, since we will likely not be able to meet the V_{GS} voltages to turn on these devices. We also cannot power any IC's off such a low voltage. Lastly, since we are powering the circuit from a single 1.5V battery, we must be very conscious of current draw and try to make the converters and rest of the circuit as efficient as possible to maximize battery life. The main baseline goal for this module will therefore include the use of a D cell battery, which has a much larger power rating than a AA battery. Reach goals could include finding creative ways to maximize efficiency and battery life, such as disconnecting the battery from the circuit if music is not being played. By making the power module more efficient, we can hopefully run the circuit off of a AA battery eventually.

2.2 Tactile Input and Volume Memory

This module allows the user to control the volume of the speaker through two touchpads. When the user is touching a single pad, the volume will increase/decrease at a continuous rate; when the user's finger is in contact with both pads or neither of the pads, the volume will remain stable. The only components that must be purchased for the tactile volume control are ceramic capacitors and a resistive trackpad to meet stretch goals discussed below. Madeleine will be designing this stage of the project.

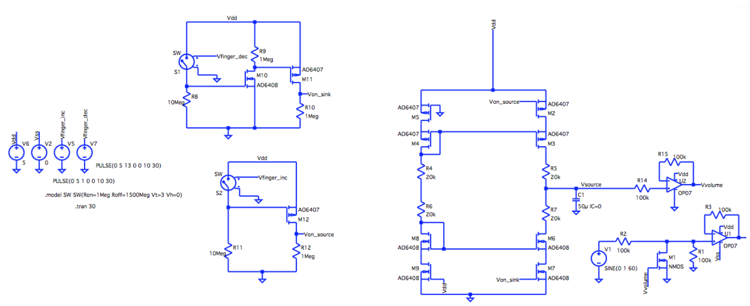

Figure 4: Touch Sensitive Volume Control

This module will take as input the ± 5 V rails from the power converter stage and will output a DC voltage between 0 V and 3V, which feeds into a FET operating in the triode region and acting as a variable resistor controlling the audio volume into the amplifier stage. The module itself will consist of 4 primary stages: user input to detect a desired increase/decrease in volume, memory stage that maintains and updates the current volume control voltage, voltage controlled regulation of audio volume, and an LED volume display for user feedback.

The touch sensing stage will include two touchpads - simple wires running parallel to each other, connected when the user touches their finger to them. These feed into a series of NMOS and PMOS transistors that output constant voltages when the user's finger connects the increase/ decrease volume circuitry, as seen in the circuit schematic. The voltage output from these two pads control current source and current sink circuitry used to charge and discharge a capacitor, whose voltage is used to control the volume of the speaker. Note that care must be taken to choose a capacitor with low leakage current, such that the volume control can remain constant over the course of a song with decaying to zero. The volume control voltage feeds into the gate of a FET, as shown. The FET acts as a variable resistor in the triode region, increasing and decreasing the audio voltage as its resistance changes with the gate voltage. The final component will be an LED bank whose purpose is to provide the user with visual feedback of the speaker's volume level. This component consists of a series of diodes, resistors and LED's in parallel to provide a discrete display in which the number of lit LED's is proportional to the volume control voltage of the speaker.

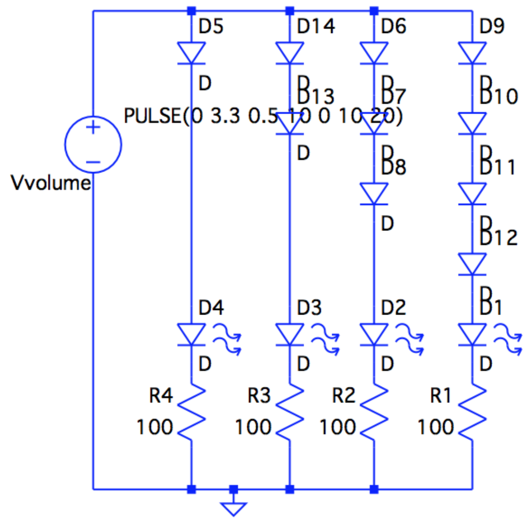

Figure 5: LED Volume Display

The trickiest part of the tactile volume control module is designing the volume control voltage to be stable over time, and using it to linearly control the audio volume. Electrolytics and many ceramic capacitors tested in lab leaked their voltage in under a minute, so a capacitor whose dielectric is air will be used as it was found to be the most stable over time.

To add complexity if all other goals are met, a resistive trackpad will be implemented to enable the user to directly select the volume, in addition to simply increasing/decreasing the volume monotonically. The user will slide their finger across the trackpad to select the volume, and the volume chosen will be remembered when the user takes their finger off of the trackpad. This trackpad, if incorporated, will be capable of overriding the increase/decrease volume pads when in contact with the user's finger, such that it can instantaneously reset the current volume to wherever the user places their finger on the trackpad. Lastly, provided enough time, the efficiency of this circuit will be optimized to maximize battery life.

2.3 Audio, Filter, and Lights

This section of the project will include the majority of the outputs. They will be in the form of audio, through a speaker, and lights, through LEDs. The audio and lights section of the project can be further divided in smaller subsections. Audio consists of the combination of an amplifier, a filter, and volume control circuity, while lights will include simply an A/D converter to measure the current volume output and a subsequent LED display that will respond to this measurement.

Coming from Madeleine's sections, a volume modified signal will be received as the input. After this stage, the signal will move into a filtering stage. The world of filters, especially in the context of music, is vast. There are many complex and sophisticated types of filters. A considerable amount of time will be spent in this section of the project, though only after there is baseline functionality throughout. To start with, this section will be a simple passband filter to remove but low and high frequency noise, but given time, a stretch goal will be to put a more complex type of filter in its place. Another possibility is to create filters which add effects to the song. Figure 7 shows a schematic of a passband filter made with a BJT. If a better filter is needed, one will be built that has more than a one pole roll off. Also, if a pre-amplify is needed before the filter because the filter reduces the signal, then that will be inserted before the filtering.

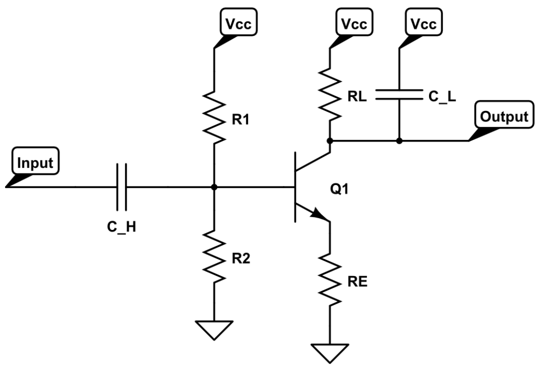

Figure 6: Passband Filter

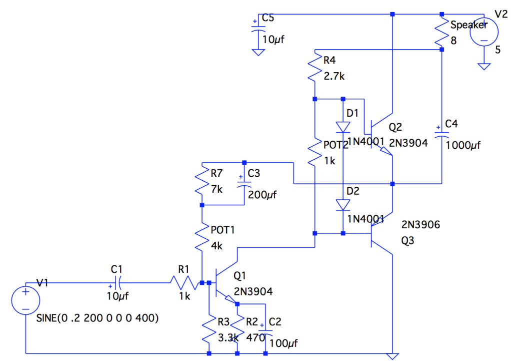

Figure 7: BJT Amplifier

The audio signal then will be put through an amplifier. Drawing on inspiration from amplifiers described in lab, this amplifier will aim to reduce distortion as much as possible, while being power efficient. A class AB amplifier will be driven by a class A amplifier. With the addition of a bootstrapping (positive feedback) configuration and a negative feedback path, the circuit will have minimal crossover distortion and more efficiency than a class AB without the feedback paths.

Much of this module's work will fall into an echo filter, the goal of this amplifier will be functionality and sound quality over complexity. A designed configuration without an op amp is displayed in Figure 7.

Similar to Madeleine's LED design, this module will also have an LED display. This LED display will have a very similar design as shown in figure 5, however, these LEDs will show the current output volume.

3 Block Diagram

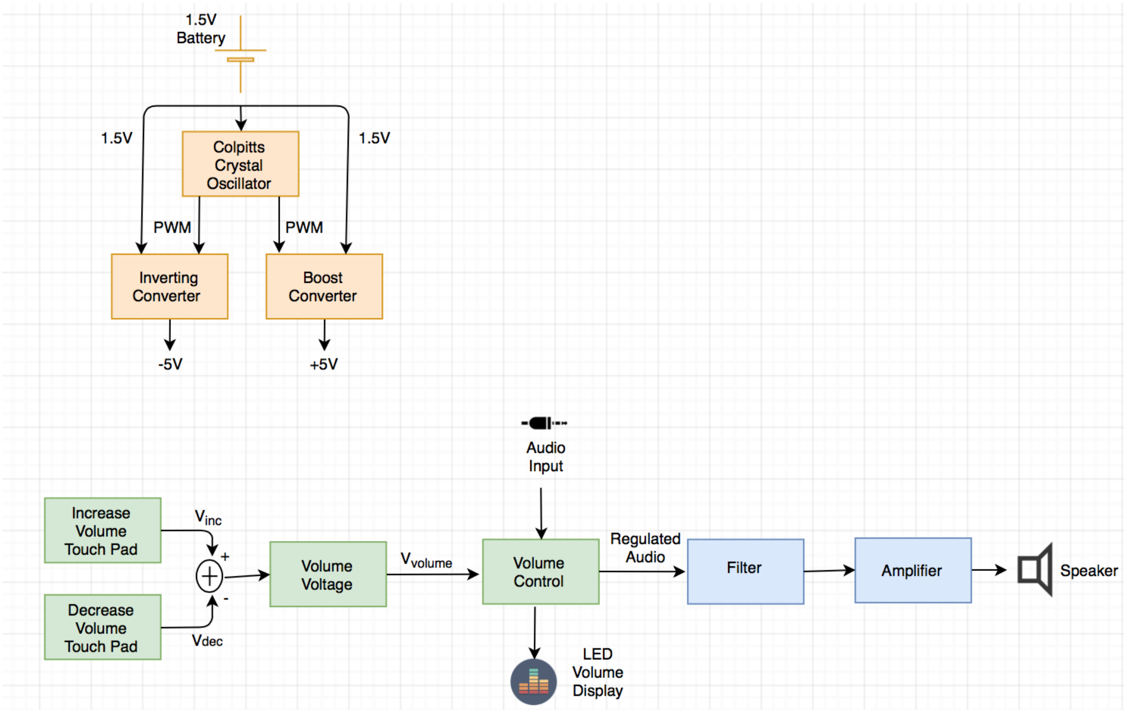

Figure 8: Overall Block Diagram

4 Testing

4.1 Power Converter

To test the module, we will begin by testing each of the three functional blocks in LT Spice or Circuit Lab. This stage of the testing process should help us determine tricky component values and explore any unforeseen issues. Once the simulation is creating ± 5V, we will begin to build the circuit physically. The physical module will be tested in sections, beginning with the colpitts crystal oscillator. We will check that the frequency of the output matches the frequency of the crystal, and that the oscillator can handle some load resistance on the output. Next, we will test the boost converter. We will begin by feeding in a PWM input from the function generator rather than the colpitts crystal oscillator so that we can test the functionality of the boost converter alone. By observing the output of the converter on an oscilloscope, we can check the accuracy of the 5V output, and check that the ripple voltage is not too large. We will then provide the colpitts crystal oscillator as the PWM signal, and check that the functionality of the boost converter is not compromised. Lastly, we will construct and test the inverting converter in the same way we test the boost converter.

4.2 Tactile Input and Volume Memory

This section will be tested first with functionality in mind. If pressing the touch pad does change the voltage, then the rest of the module can be tested from this behavior. After achieving some level of change, fine tuning it will be the next step so that it is more user friendly and intuitive.

4.3 Audio, Filter, and Lights

Testing this module will be very functionality based and can be tackled in a very systematic way. First after creating a working version in spice, it can be assembled. Assuming my modeling was correct, the circuit should work very similarly to its simulation.

The filters will also be tested the same way. The desired input-output relationship is known, therefore by applying an input to the filter and measuring the output, its functionality can be assessed. For example, the echo filter, will, ideally, be audible. Its effect will be noticeable both on an oscilloscope and through the speaker after being added to the original signal.

5 External Components and Purchases

Time permitting we will machine a box to contain the speaker and mount the remaining circuitry. Another stretch goal comes in the form of PCB. If we have the time, we will manufacture a our circuit on a PCB.

5.1 Power Converter

For this module, the only external components we expect to purchase are the inductors, crystals, and schottky diodes. If necessary, we plan to wind our own inductors for the boost and inverting converters. To wind our own inductors, we would need to purchase some copper wire and possibly some epoxy for mechanical support. These inductors would likely be air filled, so we wouldn't need to purchase a magnetic core. To test the inductors, we can hook them into the inductance meter in the lab and read the inductance from the screen. These inductors will likely be through hole, which we will keep in mind if we make a PCB.

5.2 Tactile Input and Volume Memory

We we will need to purchase two force sensing resistive pads to enable the user to input an increase/decrease in desired volume. We will also need to purchase a resistive trackpad to add complexity to the volume control circuit by allowing the user to directly select the volume they desire. All other components can be acquired from the general circuit supplies available to us.

5.3 Audio, Filter, and Lights

Several 8ohm speakers were ordered off the Internet. We purchase both 1.5W and a 1W speaker for more variety and different brands also in an effort to diversify.