

# **Self-Adjusting Speakers**

**ECE 445 Design Document**

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# 1. Introduction

## 1.1 Objective

Noise in a room is constantly changing. This typically means that the volume of music being played needs to be modified to fit the environmental noise. If many people are talking in a room then music being played may no longer be audible. On the other hand, if there is a lot of silence in a room then it is not necessary to have music blasting at the maximum volume. Currently, the only solution to this problem when using portable speakers is someone manually adjusting the volume either with push buttons or a voice command.

Our goal is to create a speaker that will analyze the amount of ambient noise in a room and then automatically adjust the volume of the music accordingly. These speakers will have the same basic functionality as many bluetooth speakers with the addition of two modes that no longer require the user to manually adjust the volume. Mode 1 will allow the speaker to behave in a normal operating mode with the user controlling the volume. Mode 2 will decrease the volume when the ambient noise increases which is useful in a situation where people want to focus on conversation rather than music. Mode 3 will increase the music volume when the ambient noise increases which would be applicable if someone is throwing a party.

## 1.2 Background

Speed-sensitive volume control exists in many vehicles today. The purpose is to automatically adjust the speaker volume based on the speedometer. The volume will increase as the vehicle speeds up so that the increased external noise does not make the music inaudible from inside the vehicle. When the speed of the vehicle decreases, the volume will also decrease so that it is not too loud over minimal external noise [15]. This differs from our application since we are changing the volume based off of an audio sensor reading rather than a speedometer and our device is used in a different setting. Companies such as Bose, Beats, and Sony have created noise cancelling headphones [17-19]. These types of headphones use a microphone on the outside of the headphone to analyze ambient sounds. They then re-create the ambient noise signal with an opposite phase in order to eliminate the ambient noise by using destructive interference [9][16].

Devices such as the Amazon Echo and Google Home have capabilities for volume to be adjusted through a voice command [20]. This eliminates the need for users to be near the device to manually adjust via the push buttons. However, this still requires that the user constantly be aware of the music volume with relation to ambient noise and then command the volume to be turned up or down accordingly. Additionally, the Amazon Echo has received negative reviews for issues in incrementing the volume when voice control is used. Some users have said if the volume is at level one and they ask for the volume to be increased then the level two volume becomes too loud for the setting [21]. Our device, which takes into account the ambient noise,

will mitigate the bothersome task of finding a suitable volume level of music that fits the environmental noise.

### 1.3 High-Level Requirements

1. The system will be able to communicate with a cell phone through Bluetooth so that the music can be sent through the phone to the speaker.
2. The speakers will operate in 3 different modes. Mode 1 will allow the speakers to operate as typical speakers with volume control buttons. Mode 2 will have the volume decrease when ambient noise increases and volume increase when ambient noise decreases. Mode 3 will have the volume increase when ambient noise increases and the volume decrease when the ambient noise decreases.
3. The self adjusting volume will take the average noise level over a 10 second period, cross matching the music being played and the noise the sensor receives in order to increase or decrease the volume on the speaker.

### 1.4 Visual Aid

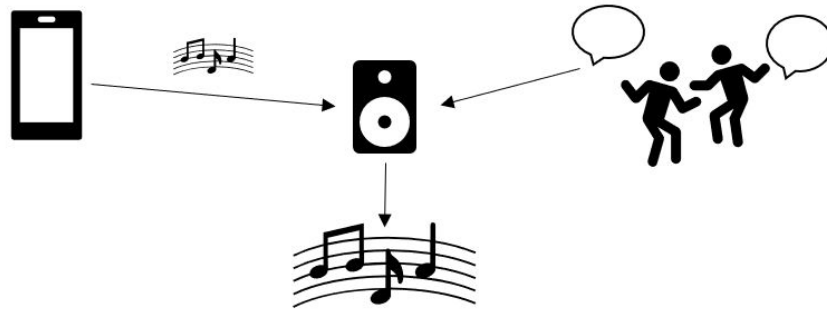


Figure 1: Visual Representation of Self-Adjusting Speakers

## 2. Design

### 2.1 Block Diagram

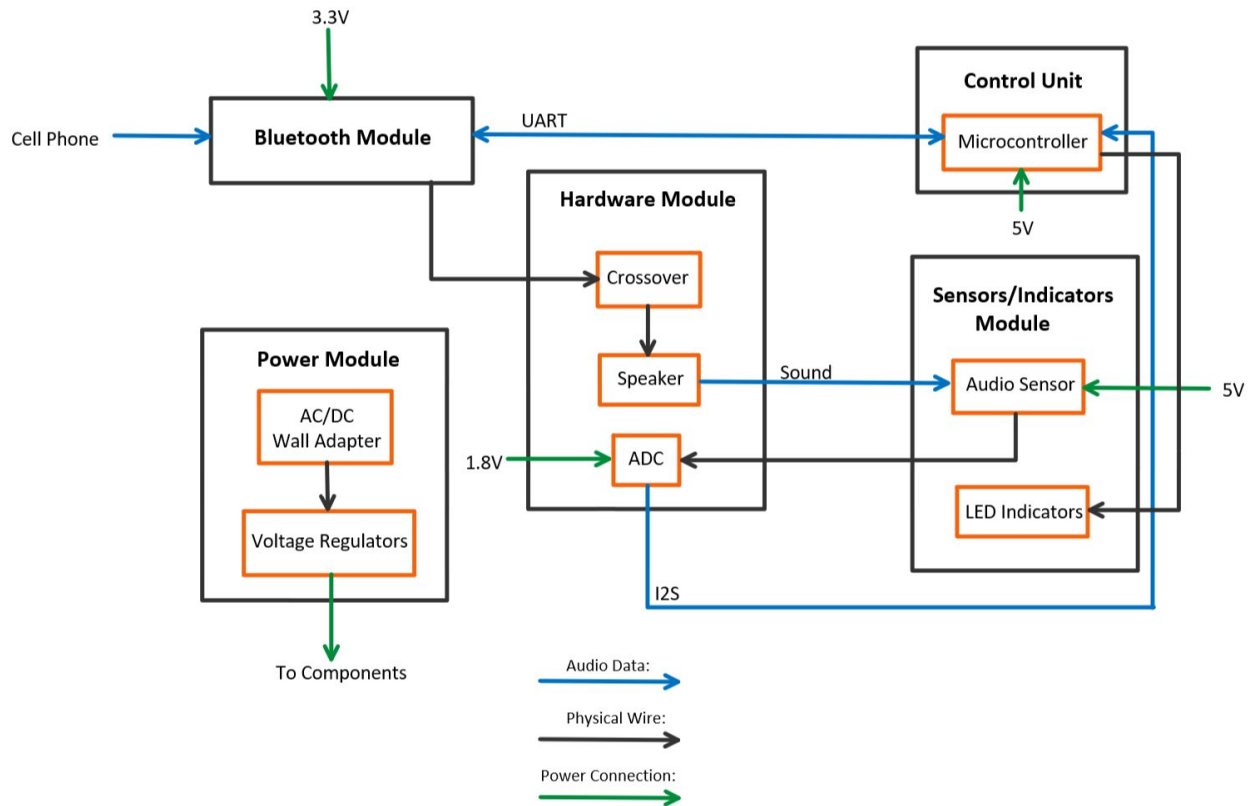


Figure 2: Block diagram outlining modules for speaker system showing data paths and power connections

### 2.2 Physical Design

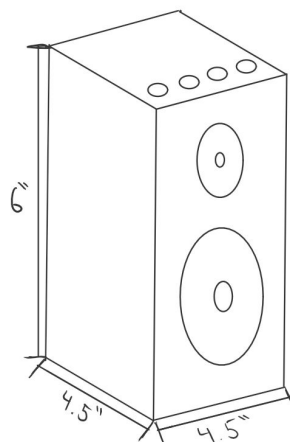


Figure 3: Physical design

The speakers will be a size that is easily portable by an individual. Figure 3 shows a rough sketch of the appearance of the speakers with estimates of the dimensions. The tweeter and woofer speakers will be seen on the front and the top of the speakers will have four push buttons with various functionality. The sensor will either be placed on the back or side of the speaker.

## 2.3 Subsystems

### 2.3.1 Hardware Module

The hardware module consists of the passover crossover circuit and the tweeter and woofer speakers. Once the bluetooth module outputs the signal, it will go through the passive crossover which splits the signal at the desired frequency. The lower frequencies are output to the woofer and the higher frequencies are output to the tweeter. The enclosure will have multiple buttons on the outside for volume control, mode select, and bluetooth

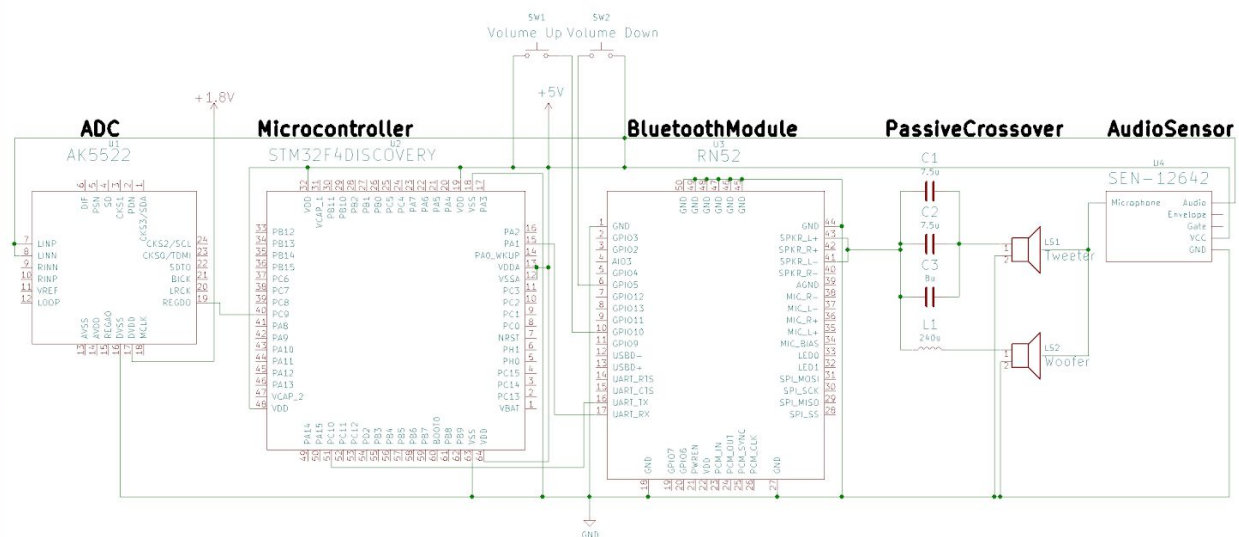


Figure 4: Schematic of the speaker modules made on KiCad

## Speakers

For the audio output, the circuit has two different speakers in order to cover the entire frequency range of human hearing and ensure the sound has minimal distortion. The device contains one woofer (GBS-85N25PR03-04) which covers frequencies from 40 Hz to 3 kHz and one tweeter (OC25SC65-04) covering a range from 1.3 kHz to 20 kHz [28-29].

## Crossover

The crossover receives the single amplified analog audio signal from the bluetooth audio module and then separates into two signals based on frequency [2] [27]. The range of frequencies

that overlap between the selected woofer and the tweeter are 1.3 kHz to 3 kHz. To ensure no frequencies are lost, the crossover was designed such that the crossover frequency is in the middle of the overlap, approximately at 2.15 kHz. The passive crossover was implemented by creating a 1st order Butterworth filter with an equivalent capacitance of 23.133 $\mu$ F and a 236.1415  $\mu$ H inductor. Simulation results are displayed in Figure 5.

Capacitors have an equivalent series resistance (ESR) which can be minimized by placing multiple capacitors in parallel. For filtering applications, a lower ESR means a faster attenuation. Therefore, to achieve the 23  $\mu$ F capacitance, two 7.5  $\mu$ F and one 8  $\mu$ F capacitors are placed in parallel.



Figure 5: LTSpice Simulation Results of Crossover Schematic with crossover at 2.15kHz

### Push Buttons

Four push buttons will be on the device as the user interface. One will cycle through the three different modes, two of them are used for volume control when manual mode is active, and the last controls the bluetooth pairing. The push button signal will be sent to the microcontroller.

### 2.3.2 Power Module

The power module is meant to provide power to the various components in the circuit. It is imperative that components such as the audio sensor, voltage regulator, digital to analog converter, and the microcontroller, are properly powered in order for the speaker unit to properly function as a whole.

All of the components in the speaker unit require a DC voltage so the two options for powering the unit were using a rechargeable battery or supplying power from a wall outlet. Since the speakers are being made for usage indoors in spaces such as apartments or homes the wall

outlet was a more fitting choice. When using the speakers indoors, the location will typically not be changed frequently so using an outlet is not a major inconvenience. Additionally, using a wall outlet will ensure that there will be a reliable power source.

The AC voltage from a wall outlet will be converted to a DC voltage through the use of an AC/DC wall adapter. Voltage regulators will then be used to step down the DC voltage to various smaller DC voltages to power components. Table 1 below outlines the different supply voltages required for each circuit component.

Table 1: Circuit Components and Required Supply Voltages

Component	Supply Voltage Required
STM32F4DISCOVERY Microcontroller Development Board	5V
SparkFun Audio Sensor	3.5-5.5V, 5V is ideal
AK5522VN Analog to Digital Converter	1.7-1.98
RN52 Audio Bluetooth Module	3.0-3.6V, ideally 3.3V

### AC/DC Adapter

An AC/DC wall adapter that converts 120-240VAC to 5V is necessary to allow the device to be plugged into a wall outlet. The PSA10F-050(P)-R allows an input of 90-264VAC with a frequency range of 47-63Hz. This input specification is within the range necessary for outlets in North America. It then provides a 5VDC output with a +/-5% tolerance and it utilizes a barrel plug as the output connector. The 5V will be used to supply the audio sensor and microcontroller development board.

### Voltage Regulator

The three DC voltage levels that the voltage regulator will need to step down to is between 1.7-1.8V and 3.3V. Since these output voltages will not need to be adjusted, a fixed voltage regulator can be used. The TPS75233QPWPREP regulator allows the voltage to be stepped down to a voltage between 3.05-3.3V which is within the range required for the bluetooth module. The TPS75318QPWPRQ1 regulator steps down to 1.8V with a +/-2% tolerance which is also within the range of the analog to digital converter selected.



### **2.3.3 Sensors/Indicators Module**

#### **Audio Sensor**

The SparkFun Sound Detector will be used to sense the amplitude of the total sound in the room. This sound detector has the capability to provide a binary indication of sound, the audio output, and an analog representation of the audio amplitude. The analog output provides the amplitude of the sound by outputting the analog voltage which will be sent back to the microcontroller. The sound detector needs to be powered by 5V. It also has a built-in LED that blinks as a response to noise being detected by the sensor [11].

#### **LED Indicators**

LEDs will be included to improve the user interface aspect of the speaker unit and also because they will prove to be beneficial during the testing phase. One LED will be used to indicate when the speaker is powered on. Two LEDs will be used to indicate what mode the speakers are operating in. Mode 1 will have neither of the LEDs on, Mode 2 cause one LED to be powered on, and Mode 3 will have both LEDs powered on. Another LED will light up to confirm that the speakers have connected to the cellphone via bluetooth. Finally, two LEDs will be used to indicate changes in volume. One color will indicate an increase in volume and the second color will indicate a decrease in volume.

### **2.3.4 Control Unit**

The control unit will consist of a microcontroller. This module will receive inputs from the bluetooth module and sensor/indicator module and it will send its outputs back to the bluetooth module and to the LED indicators. The control unit will perform the processing of the audio data received from the cellphone via bluetooth and the processing of the audio data received from the audio sensor. The flowchart in Figure 6 below outlines the method that will be used for processing the signals and modifying the volume accordingly.

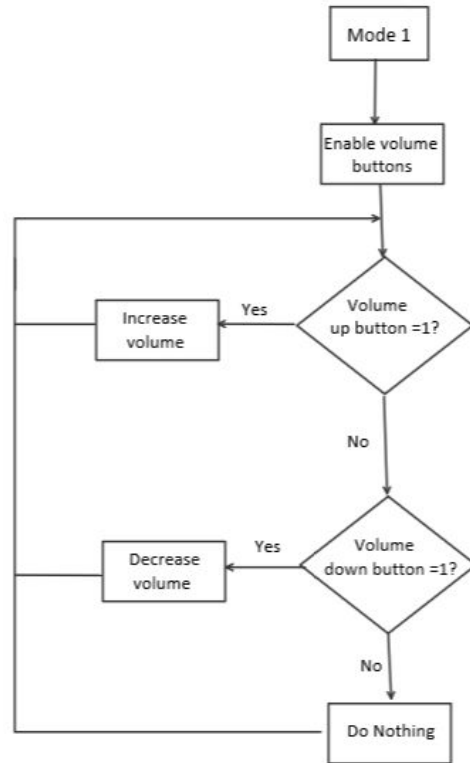


Figure 6a: Software flowchart for mode 1

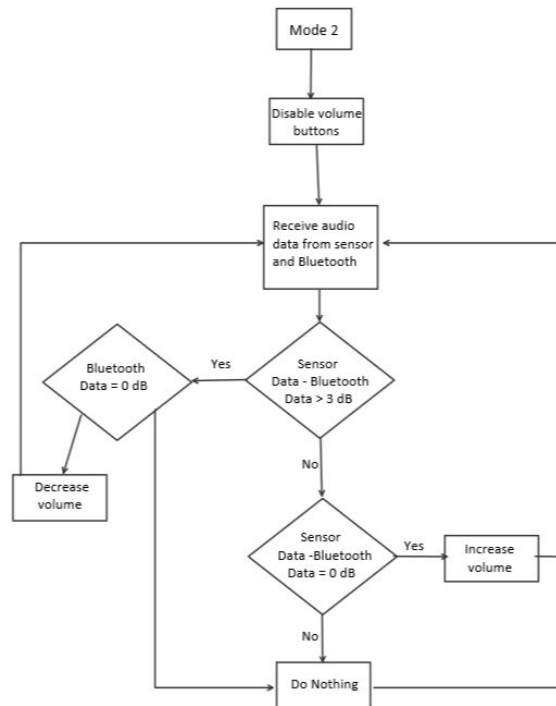


Figure 6b: Software flowchart for mode 2

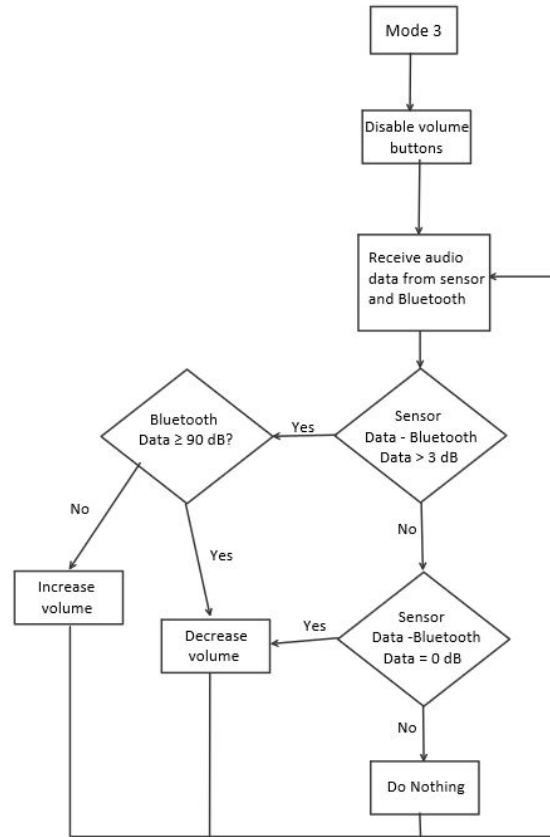


Figure 6c: Signal Processing flowchart for mode 3

### Microcontroller

The STM32F4DISCOVERY microcontroller is a development board that allows users to develop with the STM32F407VG microcontroller [30]. The microcontroller will receive 5V from the AC/DC wall adapter. The microcontroller will also receive the output of the audio sensor and the audio signal from the bluetooth module. It will also receive input from the push buttons when the speaker unit is operating in Mode 1. The first thing that will be determined is what mode the speakers are operating in. If the speaker unit is operating in Mode 1 then the volume buttons will be enabled through a signal sent from the microcontroller. On the other hand, if the speaker unit is in Mode 2 or 3 the volume buttons will be disabled. When operating in Mode 1, based on the input from the volume buttons the microcontroller will send a signal to increase, decrease, or keep the volume the same. When in Mode 2 or 3, the music data signal and audio sensor signal will be processed and compared as outlined in the flowchart above. Then the volume will be adjusted appropriately.

### Analog to Digital Converter

As discussed in Section 2.3.3, the audio sensor provides an analog output voltage. Since the microcontroller works in the digital domain it is necessary to use an analog to digital converter. The envelope output from the audio sensor will be fed to the input of the ADC. The

output of the ADC will then be sent to the microcontroller. The AK552VN ADC was selected because this specific device is very suitable for wireless speaker applications [12].

### 2.3.5 Bluetooth Module

The audio data could theoretically be sent from the cellphone to the microcontroller using either bluetooth or Wifi. For this project the mode of communication selected is bluetooth. Using bluetooth allows for the flexibility of the speakers to be used in various locations that do not necessarily have to be within a WiFi range. Since the speakers will be used indoors in relatively small spaces (a room in an apartment or house) then establishing a bluetooth connection is a feasible option. The cellphone should be able to connect to the speakers at a max of 9.5 meters with a +/-5% tolerance.

One reason that the RN52 Bluetooth Audio Module was selected is that it has a range up to 10 meters which satisfies the desired range for this project [13]. Additionally, this bluetooth module has an integrated amplifier that has the capability to run up to a 16 $\Omega$  speaker load. The tweeter and woofer have a frequency of 3.2 $\Omega$  and 3.19 $\Omega$  respectively which is well within the range of the bluetooth amplifier capacity. Analog to digital conversion and digital to analog conversion is also available with the bluetooth module. The bluetooth module will send the amplified analog audio signal to the passive crossover so the audio can be played through the tweeter and woofer. Additionally, the bluetooth module will communicate with the microcontroller via UART. It will send the digital audio signal to the microcontroller and will also receive a signal from the microcontroller instructing an adjustment to the volume in the self-adjusting modes.

## 2.4 Requirements and Verification Tables

Table 2: Requirements for project components and respective verification tests

Requirements	Verification
Passive Crossover 1. Crossover frequency at 2.15kHz with $\pm 20\%$ tolerance.	a. Connect an oscilloscope after the capacitors in parallel from Figure 4. b. Measure the period and take the reciprocal to ensure only frequencies within the acceptable ranges are output to the tweeter. c. Repeat a and b but after the inductor for the range of frequencies output to the woofer.
Speakers 1. Must be audible from 10 meters away	a. Stand 10 meters away and listen for the audio output.
Linear Regulator - 3.3V	a. Provide a 5V input to the linear

<p>1. The linear regulator must be able to supply a voltage between 3.03-3.3V.</p>	<p>regulator</p> <p>b. Connect the output of the linear regulator to a voltmeter.</p> <p>c. Confirm that the output voltage of the regulator read from the voltmeter is between 3.03-3.3V.</p>
<p>Linear Regulator - 1.8V</p> <p>1. The linear regulator must be able to supply 1.8V with a +/-2% tolerance.</p>	<p>a. Provide a 5V input to the linear regulator</p> <p>b. Connect the output of the linear regulator to a voltmeter.</p> <p>c. Confirm that the output voltage of the regulator read from the voltmeter is between 1.764-1.836V.</p>
<p>Microcontroller</p> <p>1. The microcontroller can adequately receive input from the push buttons</p>	<p>a. Power up the buttons with 5V input</p> <p>b. Connect the push buttons to the inputs of the microcontroller</p> <p>c. Using the IDE debugger, check to see if the inputs are being read by the microcontroller</p>
<p>Microcontroller</p> <p>1. The microcontroller can adequately receive input from the audio sensor</p>	<p>a. Power up the sensor with 5V input</p> <p>b. Connect the sensor to the microcontroller input</p> <p>c. Speak when standing near the sensor</p> <p>d. Using the IDE debugger, check to see if the inputs are being read by the microcontroller</p>
<p>Microcontroller</p> <p>1. The microcontroller can communicate with the bluetooth module and receive the music data.</p>	<p>a. Connect a phone to the bluetooth module</p> <p>b. Pass an audio signal into the system</p> <p>c. Using the IDE debugger, check to see if the audio signal is being received by the microcontroller</p>
<p>Audio Sensor</p> <p>1. The audio sensor will be able to receive input from ambient noise.</p>	<p>a. Power up the sensor with 5V input</p> <p>b. Speak when standing near the sensor</p> <p>c. Check the on-board LED to check that it begins to blink</p>
<p>Bluetooth</p> <p>1. The cellphone will be able to communicate with the speaker unit</p>	<p>a. Place speakers in a given location</p> <p>b. Measure 10 meters away from the speakers and bring the cellphone to</p>

from up to 9.5 meters +/-5%.	that location c. Ensure that a bluetooth connection still exists between the two devices at this distance.
ADC 1. The ADC will take the analog signal sent from the audio sensor and convert it into a digital signal	a. Run analog voltage signal to input of ADC. b. Probe the input signal with analog oscilloscope. c. Probe the output signal and clock inputs to ensure the signal's frequency and amplitude is converted correctly.

## 2.5 Tolerance Analysis

An important part of the hardware module is the ability to send the high frequency signals to the tweeter and low frequency signals to the woofer. This is done with a passive crossover circuit. Our selected crossover frequency is 2.15kHz which is achieved by two 7.5 $\mu$ F capacitors with a +/-20% tolerance, one 8 $\mu$ F capacitor with a -10%/+100% tolerance, and one 240 $\mu$ H inductor with a +/-5% tolerance. The overlapping frequency range for the woofer and tweeter determine that the crossover frequency must always remain between 1.3kHz and 3kHz to ensure that all necessary signals will be played by either the tweeter or woofer. By simulating the crossover circuit in LTSpice we are able to determine the frequency at which the crossover occurs. Table 3 below displays the crossover frequency data obtained for the various minimum and maximum component values that may occur based on the component tolerances given from the datasheet. As seen from the data below, all of the crossover frequencies at the extreme component operating points are still within the required range of frequencies.

Table 3: Crossover Frequency Data from LTSpice Simulation

$C_1$	$C_2$	$C_3$	$L_1$	Crossover Frequency
6 $\mu$ F	6 $\mu$ F	7.2 $\mu$ F	224.2 $\mu$ H	2.419kHz
9 $\mu$ F	9 $\mu$ F	16 $\mu$ F	247.8 $\mu$ H	1.722kHz
9 $\mu$ F	9 $\mu$ F	16 $\mu$ F	224.2 $\mu$ H	1.821kHz
6 $\mu$ F	6 $\mu$ F	7.2 $\mu$ F	247.8 $\mu$ H	2.301kHz

Another aspect of the project that is crucial for success is the data received from the audio sensor. Without precise measurements from the audio sensor, the volume will not be accurately

adjusted to fit the ambient noise. One factor that would impact the quality of the sensor output would be a noisy power supply since the sensor is created with an analog circuit. The sensor is created by using an electronic microphone capsule which feeds into an envelope follower which then goes into a schmitt trigger [10-11]. The microphone capsule includes a voltage divider across the power rails.

$$V_{R2} = V_{in} * (R_2/R_1 + R_2)$$

A variation in the supply voltage will lead to a variation in the output voltage. This output voltage is then fed into a high gain amplifier which means that the noise seen on the input signal will be amplified. Testing done in other literature has proven that a voltage variation of 30mV or higher can cause extreme sensitivity or instability in the sensor readings. The AC/DC wall adapter selected provides a 5V DC output with a +/-5% variation which provides a ripple of less than 30mV. Therefore the device should operate relatively smoothly. However, in the event that the DC voltage is not clean enough, a voltage regulator will be incorporated to provide a steady DC supply voltage to the sensor.

### 3. Cost and Schedule

#### 3.1 Labor

Table 4: Labor Costs

Name	Hourly Rate	Hours	Total	Total x 2.5
Samira Tungare	\$40	160	\$6,400	\$16,000
Sarah Kolak	\$40	160	\$6,400	\$16,000
Edward Harper	\$40	160	\$6,400	\$16,000
<b>Total</b>				\$48,000

#### 3.2 Parts

Table 5: Components Cost

Description	Quantity	Manufacturer	Vendor	Cost/unit	Total Cost
Woofer Speaker	1	Peerless by Tymphany	Digikey	\$24.85	\$24.85
Tweeter	1	Peerless by	Amazon	\$15.04	\$15.04

Speaker		Tymphany			
AK552VN Analog to Digital Converter	2	AKM Semiconductor Industry	Digikey	\$0.93	\$1.80
Embedded Evaluation Board	1	STMicroelectronics	Digikey	\$19.90	\$19.90
7.5 $\mu$ F Capacitor 493-6692-1-N D	4	Nichicon	Digikey	\$0.86	\$3.44
8 $\mu$ F Capacitor WBR8-250A- ND	2	CDE	Digikey	\$5.62	\$11.24
Inductor	1	API Delevan Inc.	Digikey	\$1.84	\$1.84
Linear Regulator TPS75233QP WPREP	2	Texas Instruments	Digikey	\$5.51	\$11.02
Linear Regulator TPS75318QP WPRQ1	2	Rochester Electronics, LLC	Digikey	\$1.27	\$2.54
AC/DC Wall Adapter PSA10F-050( P)-R	1	Phihong USA	Digikey	\$12.56	\$12.56
Push Button 1301.9314	4	Schurter	Digikey	\$0.24	\$0.96
RN52 Bluetooth Audio Module	1	Roving Networks	Amazon	\$24.95	\$24.95



Total	22			\$113.57	\$169.94
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### 3.3 Schedule

Table 6: Design Schedule

Week	Task	Assigned To:
2/25/2020	Design Document Check	All
2/27/2020	Design Document Due	All
3/1/2020	PCB Design	All
3/1/2020	Order Components	Samira
3/3/2020	Design Review	All
3/8/2020	Soldering Assignment	All
3/8/2020	Programming Microcontroller	Eddie
3/8/2020	Sensor Testing	Sarah
3/8/2020	Configure Bluetooth Module	Samira
3/22/2020	Solder PCB	Eddie
3/29/2020	Individual Progress Report	All
3/29/2020	Testing and Debugging	All
4/12/2020	Assemble Speakers into Enclosure	Eddie/Machine Shop
4/19/2020	Mock Demo	All
4/26/2020	Demonstration	All
5/3/2020	Final Presentation	All

## **4. Safety and Ethics**

### **4.1 Safety**

Our speaker will be a relatively safe product, with only a couple potential issues. We first need to ensure our components do not overheat, so as long as we keep our temperature inside the specified range then all of our parts will operate correctly. Although most of our processing will be done with digital signals so we do not foresee overheating being a major issue. Since our project deals with audio we have to keep the volume at a level that doesn't harm anyone's hearing. There will be bounds on the upper limit of the volume in order to prevent damage to human ears. The Occupational Safety and Health Administration (OSHA) sets limits in the workplace on noise exposure. The noise is measured in decibels, a unit of sound pressure level, which is measured on a logarithmic scale which means a small increase in the number of decibels could be a large change in volume [22]. Volume from music listening devices may cause hearing loss. Noise above 70dB can begin to damage your hearing when exposed over a prolonged period of time while noise above 120dB can damage ears immediately [23]. Our speaker will be limited to 90dB so that it can provide music to the listeners at a comfortable volume while taking precautionary measures against hearing damage.

### **4.2 Ethics**

An ethical issue that comes from many devices such as the Amazon Echo or Google Home is the fact that these devices could be monitoring someone's private conversation [24-25]. This could be a potential issue with a device like ours since we will be using an audio sensor to measure the noise. However, this is not something that our specific project will run into because we will not be analyzing the specific conversations rather just the overall noise intensity.

Another ethical issue comes from the use of Bluetooth in the speaker. Cellular devices using Bluetooth are subject to hackers gaining access to its data. Hackers can use a number of various methods known as Bluejacking, Bluesnarfing, Bluebugging, and more [24]. If this product were to become marketable, actions should be taken to secure the Bluetooth connection.

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