

# HETERODYNE BAT DETECTOR

By

Kyle Jedryszek

Evan McGowan

Bill Waltz

Design Document for ECE 445, Senior Design, Spring 2026

TA: Gayatri Chandran

27 February 2026

Project No. 3

# Contents

<b>1. Introduction.....</b>	<b>3</b>
1.1 Solution.....	3
1.2 Requirements for Success.....	4
<b>2. Design.....</b>	<b>5</b>
2.1 Onboard Bat Call Audio Demo Module.....	5
2.4.1 Playback Button.....	7
2.4.2 ATTiny85.....	7
2.4.3 On-board Flash Memory.....	7
2.2 Bat Detector Frequency Module.....	7
2.3.1 Pre-Amplifier & Filter.....	8
2.3.2 Oscillator.....	9
2.3.3 Mixer.....	9
2.3.4 High-Frequency Microphone.....	10
2.3 Audio Output.....	10
2.2.1 3.5mm Auxiliary Jack.....	12
2.2.2 Speaker.....	12
2.2.3 Audio Amplifier.....	12
2.4 Power Supply.....	13
2.1.1 AA battery holder.....	14
2.1.2 Voltage Regulator and Switch/Power Button.....	14
2.5 Software Design.....	14
2.6 Tolerance Analysis.....	17
<b>3. Cost and Schedule:.....</b>	<b>17</b>
3.1. Cost:.....	17
3.2. Schedule:.....	20
<b>4. Discussion of Societal Impact, Engineering Standards, Ethics, and Safety Considerations:.....</b>	<b>21</b>
4.1 Contributions.....	21
4.2 Standards.....	21
4.3 Ethics.....	21
4.4 Safety.....	22
<b>5. References.....</b>	<b>22</b>

## **1. Introduction**

Bat detecting is popular overseas in the United Kingdom and Australia, but lacks the same market share in the United States. As such, many bat detectors used in the United States are imported, incurring additional taxes and higher shipping costs. Domestic options are either too expensive and/or have low audio quality, specifically those that plug into phones and tablets. Our client, Dr. Joy O'Keefe, requires a high-quality, mass-produceable, and domestically made device for the purpose of providing several groups of people with a bat detecting device for Bat Walks at the Central Illinois Bat Festival at a reasonable price.

### **1.1 Solution**

We propose a battery-powered handheld device equipped with a microphone, capable of detecting frequencies between 15kHz and 100kHz to be converted down to a human-audible range. The frequency to be mixed with is controlled by a large dial (with illuminated frequency labels) on the front of the device. The sound will then be amplified and output via quality speakers. This model will also have stored, prerecorded sound bytes that can be played so that first-time users can know what to listen for, a feature our client desires that has not been seen yet. An accessible, inexpensive, and reliable option does not yet exist in the domestic market, and our product fills this niche.

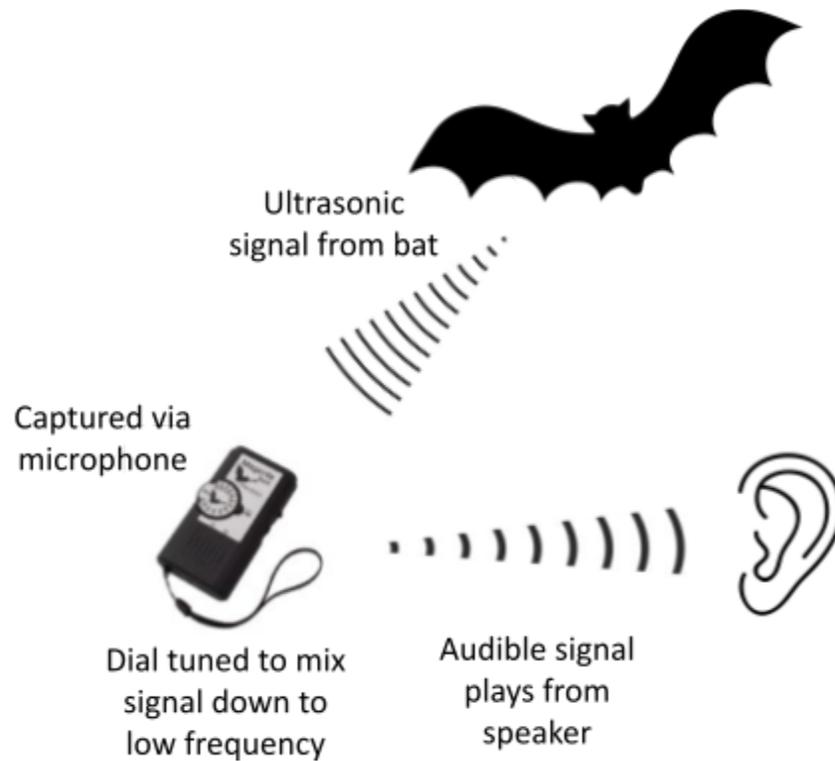


Figure 1: Bat detector use visual aid

## 1.2 Requirements for Success

- The device must be tunable between 15kHz and 100kHz frequencies using the onboard tuner, testable using Dr. O’Keefe’s Ultrasound Calibrator.
  - The Ultrasound Calibrator is a small device which outputs ultrasonic sound at a known frequency. We can tune our device to the calibrator’s output frequency and if we can hear the output, we know it works.
- When an ultrasonic source radiates sound, the device must downconvert it to audible frequencies, playing it through the onboard speaker and filtering out background noise with an SNR of at least 25 dB.
- Battery life (rechargeable or otherwise) lasts the length of at least one bat walk (1-2 hours)

## 2. Design

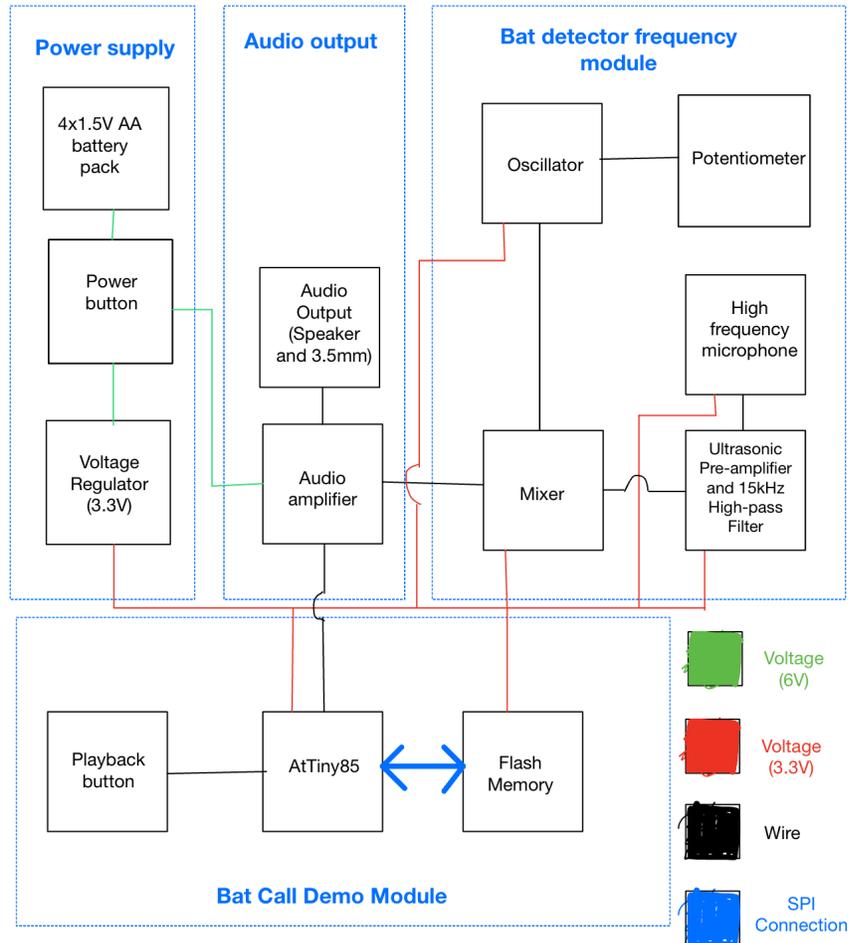


Figure 2: Circuit Design Block Diagram

### 2.1 Onboard Bat Call Audio Demo Module

- The on-board bat call audio demo will allow the user to listen to pre-recorded (and down-converted) bat sounds in order to be able to identify bats detected by the device when used in detector mode.

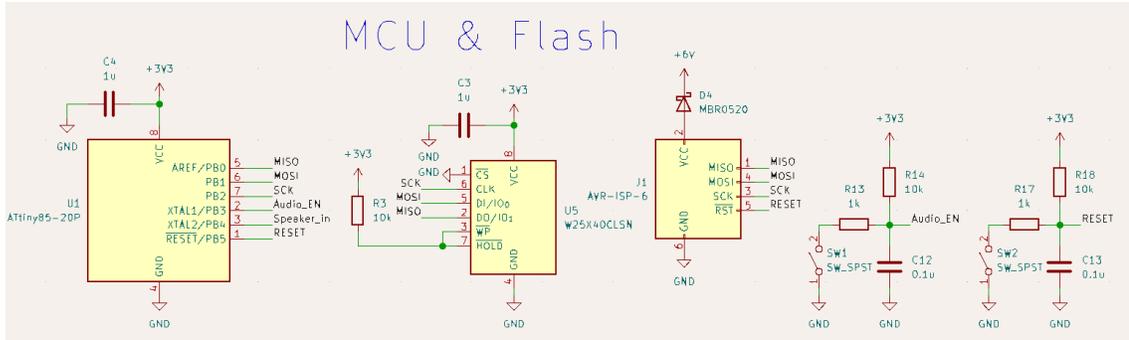


Figure 3: Bat Call Audio Demo Module Circuit Schematic

Requirements	Verification
Briefly halt mixer output to the speaker while the pre-recorded audio plays	<ul style="list-style-type: none"> <li>● Prompt playback of pre-recorded audio through use of button</li> <li>● Listen to audio output, successful if the speaker only plays audio loaded into flash without any additional sound via the microphone.</li> </ul>
Allow for on-demand user input to hear pre-recorded audio through the microcontroller	<ul style="list-style-type: none"> <li>● Listen to audio output during standard amplification use</li> <li>● Prompt pre-recorded audio playback through button</li> <li>● Listen to audio output after prompting playback</li> <li>● Pre-recorded audio should play if and only if the button is pushed, and only for the duration of the sound bytes</li> </ul>
Store pre-recorded sound data to be provided to microcontroller via SPI protocol	<ul style="list-style-type: none"> <li>● Load a predetermined audio sample onto the flash</li> <li>● Read flash data and compare to initial data loaded</li> </ul>
Allow the user to cycle between multiple pre-recorded bat calls to listen to	<ul style="list-style-type: none"> <li>● Press button to listen to chosen bat call audio</li> <li>● Press button to listen to next bat call</li> <li>● Repeat step one: each audio sample should not be played more than once until all other audio samples cycled</li> </ul>

Table 1: Bat Call Audio Demo Module Requirements and Verification

### 2.4.1 Playback Button

- The playback button can be pressed by the user to play the pre-recorded audio. When the button is pressed, it will tell the microcontroller to play the audio to the speaker.

### 2.4.2 ATTiny85

- The ATTiny85 is our microcontroller of choice [3]. When prompted through the button, it will read audio data from the flash memory and output it to the speaker.

### 2.4.3 On-board Flash Memory

- The on-board flash memory will store pre-recorded bat sounds that will be read by the microcontroller for output to the speaker.

## 2.2 Bat Detector Frequency Module

- The bat detector frequency module is the main component of the device. It will receive ultrasonic frequencies from the microphone, mix them down based on the value of the potentiometer dial, and send the output to the audio output subsystem.

Requirements	Verification
Filter out frequencies below 15kHz	<ul style="list-style-type: none"><li>• Play a sounds below 15kHz (within human hearing) while the device is powered on</li><li>• External sounds that can be heard should not be heard through the device's speaker</li></ul>
Produce an oscillating signal that can be controlled within the ranges of 15kHz to 100kHz	<ul style="list-style-type: none"><li>• Power the board on, place voltmeter prongs on ground and the oscillator testpoint terminal, and verify the frequency ranges from below 15kHz to above 100kHz by turning the potentiometer</li></ul>

<p>Mix down ultrasonic frequencies provided by the microphone to frequencies audible by the human ear</p>	<ul style="list-style-type: none"> <li>● Play chosen ultrasonic frequency using ultrasound calibrator</li> <li>● Set device frequency dial to same frequency as ultrasound calibrator</li> <li>● Use an oscilloscope to analyze the frequency to ensure it is within standard audible range</li> </ul>
<p>Microphone is able to detect audio frequencies between 15kHz and 100kHz</p>	<ul style="list-style-type: none"> <li>● Play 100kHz ultrasonic frequency using ultrasound calibrator</li> <li>● Use an oscilloscope to analyze frequency received by the microphone to ensure it is in the expected range</li> <li>● Repeat process with 15kHz sound</li> </ul>

Table 2: Bat Detector Frequency Module Requirements and Verification

### 2.3.1 Pre-Amplifier & Filter

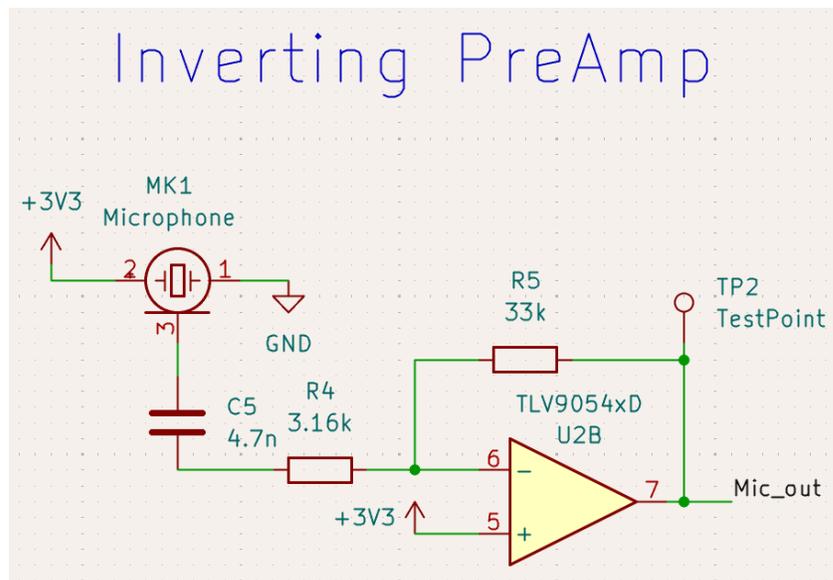


Figure 4: Bat Detector Frequency Module Inverting Pre-Amplifier Circuit Schematic

- The inverting preamp [8]-[9] amplifies the input received from the microphone. It is placed before the passive high-pass filter (having a 3dB bandwidth of 15kHz) to ensure that all low-frequency noise is removed.

### 2.3.2 Oscillator

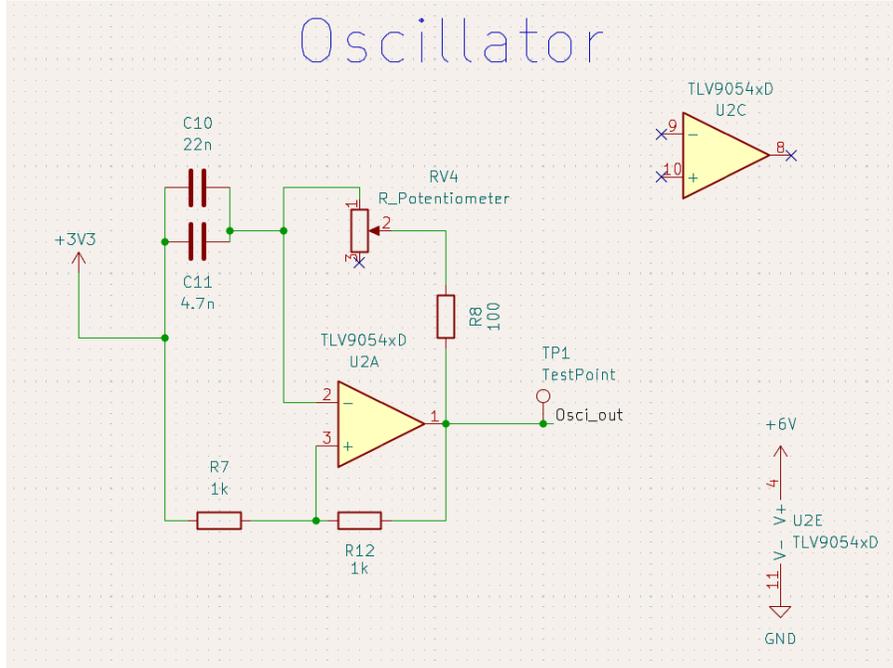


Figure 5: Bat Detector Frequency Module Oscillator Circuit Schematic

- The oscillator will produce a frequency that mixes with the ultrasonic signal, with its frequency being controlled by an onboard potentiometer.

### 2.3.3 Mixer

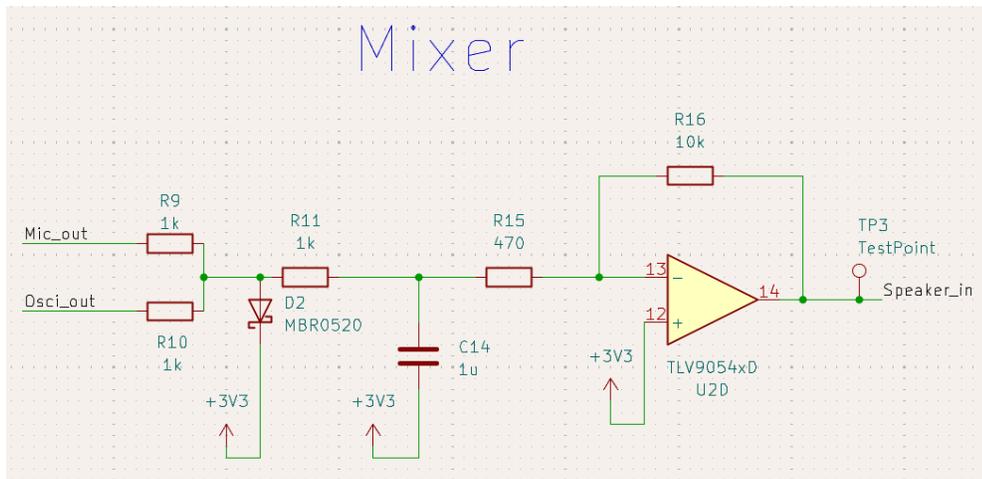


Figure 6: Bat Detector Frequency Module Mixer Circuit Schematic

- The mixer will receive amplified ultrasonic waves and the local oscillator signal, and mix them together to bring them down to a frequency that can be heard by the human ear, which is then output to the audio subsystem. The same frequency deviation is present, but now at an audible frequency.

### 2.3.4 High-Frequency Microphone

- The high-frequency microphone is the device's input. It will receive ultrasonic audio input from bats to be mixed down by the mixer [5].

## 2.3 Audio Output

- The audio output contains both a 3.5mm auxiliary jack and a built-in speaker to allow for audible audio output from either of the sources. It will receive the audio output from either the mixer or the microcontroller through the playback feature.

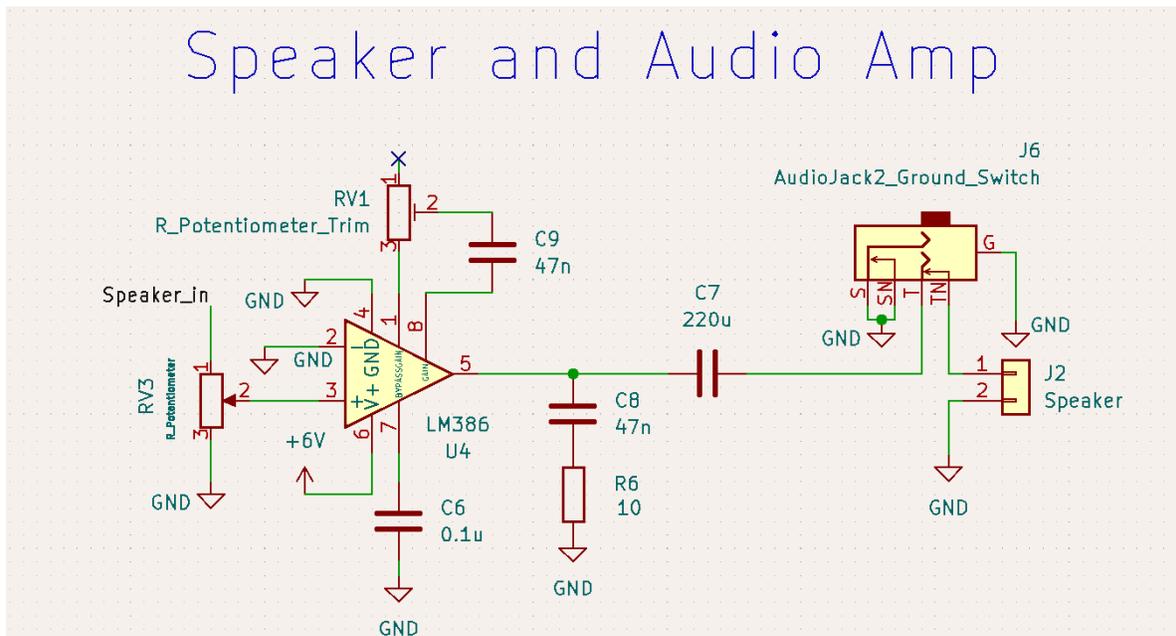


Figure 7: Bat Detector Frequency Module Speaker and Audio Amplifier Circuit Schematic

Requirements	Verification
Allow for the user to plug in and use external headphones and speakers to listen to bat calls	<ul style="list-style-type: none"> <li>● Play audio through the device's built-in speaker</li> <li>● Plug in an external audio output device via the auxiliary jack</li> <li>● Audio should be heard through plugged in audio output device</li> </ul>
Disable use of the speaker while an external output device is plugged into the audio jack	<ul style="list-style-type: none"> <li>● Play audio through the device's built-in speaker</li> <li>● Plug device into the auxiliary jack</li> <li>● Audio should no longer be heard through the built-in speaker</li> </ul>
Output audible mixed-down ultrasonic signal	<ul style="list-style-type: none"> <li>● Play chosen ultrasonic frequency using ultrasound calibrator</li> <li>● Set device frequency dial to same frequency as ultrasound calibrator</li> <li>● Audio output should be audible through the built-in speaker</li> </ul>
Amplify audio received from the mixer and microcontroller	<ul style="list-style-type: none"> <li>● Play chosen ultrasonic frequency using ultrasound calibrator or play pre-recorded audio from the microcontroller</li> <li>● If using the heterodyne audio, set the frequency dial to chosen frequency</li> <li>● Use an oscilloscope to analyze the amplitude of the incoming and outgoing audio signal</li> <li>● Amplitude of the outgoing signal should be greater than the incoming signal, with the same general waveform</li> </ul>

Table 3: Audio Output Requirements and Verification

### **2.2.1 3.5mm Auxiliary Jack**

- The 3.5mm jack will allow the user to use their own headphones to listen to the device's audio output instead of the built-in speaker.

### **2.2.2 Speaker**

- The speaker will be built into the detector, allowing the user to hear bat calls through the device through the mixed-down frequency received from the mixer chip.

### **2.2.3 Audio Amplifier**

- The audio amplifier amplifies audio signals received from the mixer and microcontroller into audible frequencies, while filtering out the higher spurious frequencies. It will then send the amplified sound to the speaker.

## 2.4 Power Supply

- The power supply provides power to the necessary components in the other subsystems. It is powered by AA batteries with a 3.3V voltage regulator. It is also equipped with a power switch to allow the user to turn the detector on or off.

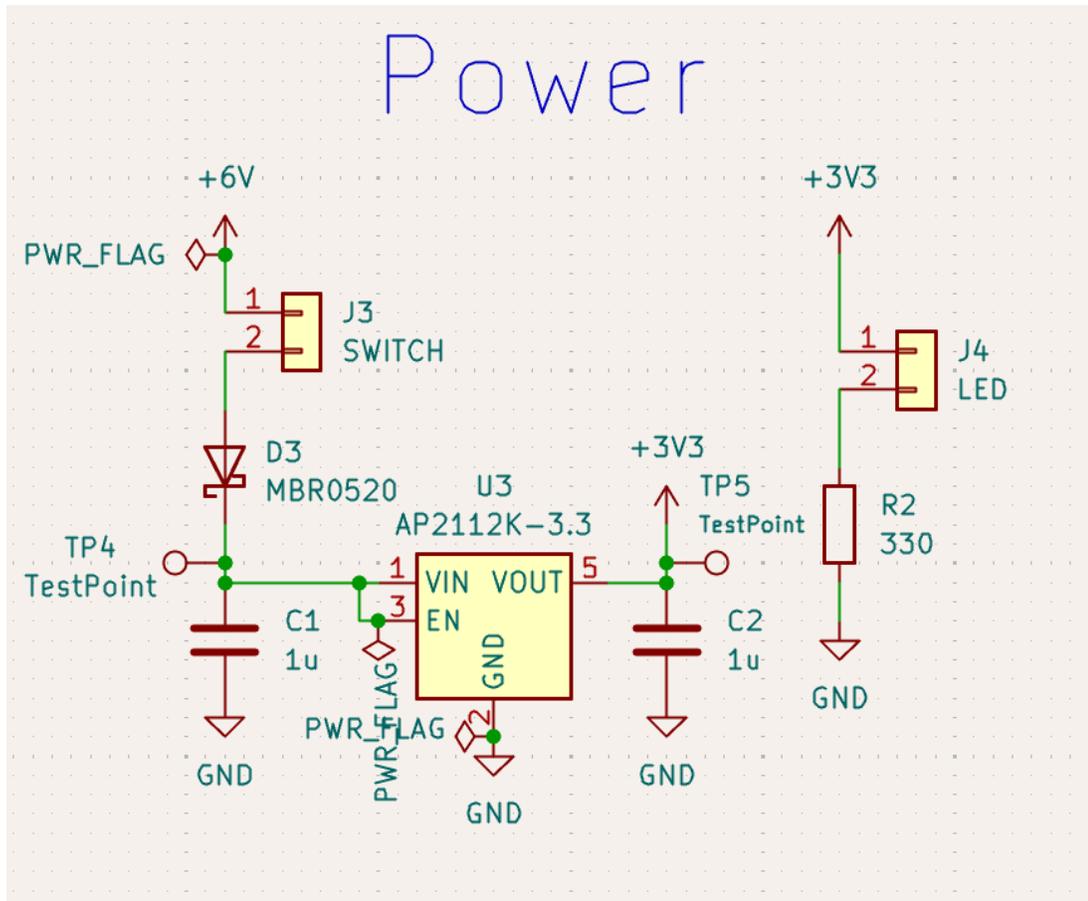


Figure 7: Bat Detector Frequency Module Power Supply Circuit Schematic

Requirements	Verification
Provide sufficient power for at least 1-2 hours	<ul style="list-style-type: none"> <li>Place a set of of fresh batteries into the battery holder</li> <li>Turn device on and set it to maximum volume</li> <li>Persistently play audio within the 15kHz-100kHz range using the</li> </ul>

	<ul style="list-style-type: none"> <li>ultrasound calibrator <ul style="list-style-type: none"> <li>Set a timer and ensure the device is still functioning properly by the 1 hour mark</li> </ul> </li> </ul>
Allow the user to control when the device is powered on or off	<ul style="list-style-type: none"> <li>Turn the power switch on</li> <li>Use the ultrasound calibrator to play a frequency within the 15kHz-100kHz range</li> <li>Turn power switch off, the device should only output when the power switch is on</li> </ul>
Provide 3.3V to the microcontroller, flash memory, and microphone	<ul style="list-style-type: none"> <li>Turn the device's power on</li> <li>Use a multimeter to ensure that each of the microcontroller, flash memory, and microphone are receiving 3.3V to their respective power pins</li> </ul>

Table 4: Power Supply Requirements and Verification

### 2.1.1 AA battery holder

- The battery holder contains AA batteries to provide voltage to the regulator, amplifiers, and input/output.

### 2.1.2 Voltage Regulator and Switch/Power Button

- The voltage regulator will maintain and distribute a constant voltage to the required components of the circuit. The switch will control when the device is on or off.

## 2.5 Software Design

The software component of our project is crucial as it is the component that makes our solution unique. In our design, the microcontroller handles audio playback of various pre-recorded bat calls so that the user knows which sounds to listen for while using the device to detect bats. Upon startup, the device will set the index of the current bat call to the first call stored (index 0). If the button on the device is

pressed, the internal bat call index will increment to the next bat call. If the current bat call index is on the last bat call and the button is pressed once again, the internal index will reset back to zero. If the button is held down instead of pressed, the current bat call selected will be played through the speaker. This will be done through interaction between the microcontroller and the flash through the SPI data protocol. When playing audio from the flash, the microcontroller will receive the data on a byte-by-byte basis. This is due to the microcontroller's limited on-board memory. Once all bytes have been received and output, the device will return to wait for input. Since we will be flashing the audio ourselves, we will know the number of bat calls and the length of each call ahead of time, so these values can be hardcoded.

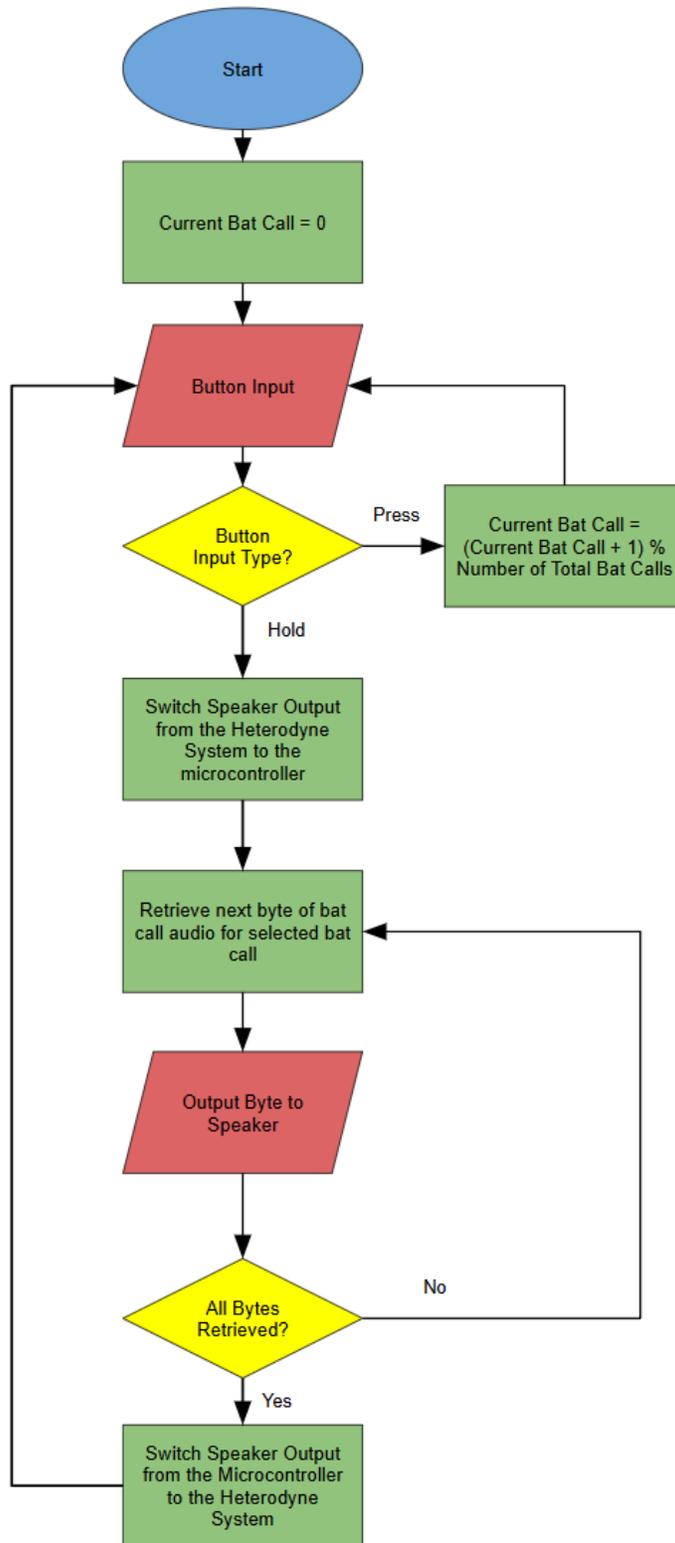


Figure 8: Software Flowchart

## 2.6 Tolerance Analysis

Our design contains many components that remain active for the majority of the device's operation. This includes amplifiers, regulators, and the microcontroller. One concern lies with the device's battery life, and whether the goal of 1-2 hours of battery life can be achieved.

Our limiting component in the design is the LM386N-1 [1] audio amplifier, which has an operating range of 4V-12V. Our four AA batteries must thus maintain power draw for two hours such that their individual voltages do not drop below 1.0V. Using the Duracell MN1500 as a benchmark [2], we can draw more than 500mA during the device's 2-hour operation to stay above this limit.

The ATtiny85 is specified to draw 2mA of current while powered, with up to 40mA per I/O pin, a value which we will not come close to reaching. A maximum of 15mA can be drawn from the flash storage at any given time [4], as well. Microphone current is negligible, with a supply current of up to 0.2mA.

The AP2210 voltage regulator has a maximum current output of 300mA [6], which we also will not come close to reaching in standard operation, so our other components will receive adequate power throughout operation. The four op-amps each have a maximum of 50mA for output current[7]. This puts us at an absolute maximum power draw of 500mA, which is adequate for two hours of battery life.

## 3. Cost and Schedule:

### 3.1. Cost:

Delineated below is our extensive bill of materials, including all material and labour needs for this project as well as their cost. We estimate our project will cost \$110.19 before tax and after labor. If we consider

the materials we will be able to retrieve for free from the E-Shop Self Service, our estimated project cost is \$100.54 before tax and after labor.

Part/Item	Quantity	Description	Commercial Cost	In Self Service?
GRM2165C1H472JA01D	2	4.7nF (±5%) SMD Cap	\$ 0.28	No
C0805C223G4HACTU	1	22nF (±1%) SMD Precision Cap	\$ 0.30	No
885012207096	2	47nF (±10%) SMD Cap	\$ 0.20	No
CC0805KRX7R9BB104	3	0.1uF (±10%) SMD Cap	\$ 0.24	Yes
C0805C105K3RACTU	5	1uF (±10%) SMD Cap	\$ 0.60	Yes
UWT1C221MCL1GS	1	220uF (±20%) Electrolytic SMD Cap	\$ 0.40	No
RC0805FR-0710RL	1	10Ω (±1%) SMD Resistor	\$ 0.10	No
CRCW0805100RFKEA	1	100Ω (±1%) SMD Resistor	\$ 0.10	No
RMCF0805JT330R	1	330Ω (±5%) SMD Resistor	\$ 0.10	Yes
RMCF0805FT470R	1	470Ω (±1%) SMD Resistor	\$ 0.10	Yes
CRCW08051K00FKEA	7	1kΩ (±1%) SMD Resistor	\$ 0.70	Yes
RC0805FR-073K3L	1	3.3kΩ (±1%) SMD Resistor	\$ 0.10	Yes
CRCW080510K0FKEA	4	10kΩ (±1%) SMD Resistor	\$ 0.40	Yes
RMCF0805FT33K0	1	33kΩ (±1%) SMD Resistor	\$ 0.10	Yes
MBR0520LT1G	3	20V 0.5A Schottky Diode	\$ 0.69	No
BHR-06-VUA	1	2x3 IDC Connector	\$ 0.22	Yes
0022232021	3	1x2 Molex Male Connectors	\$ 0.48	Yes
0022012021	3	1x2 Molex Female Connectors	\$ 0.45	Yes
0039000038	12	Molex crimps	\$ 0.48	Yes
SPVA1A0LR5H-1	1	Ultrasonic Microphone	\$ 1.18	No
SPKM.23.8.A	1	Speaker	\$ 1.16	No

SJ1-3555NG	1	3.5mm Auxiliary Audio Barrel Jack	\$ 0.98	Yes
PJ-002A	1	Power Barrel Jack	\$ 0.47	Yes
PTV09A-4030F-A102	1	1k Rotary Potentiometer	\$ 0.89	No
TC33X-2-103E	1	10k Trim Potentiometer	\$ 0.25	No
PTV09A-4020U-B103	1	10k Rotary Potentiometer	\$ 0.89	No
1825910-6	2	Push buttons	\$ 0.26	Yes
ATTiny85-20PU	1	Microcontroller	\$ 1.66	Yes
TLV9054	1	Op-amp	\$ 1.04	No
AP2112K-3.3	1	Voltage regulator (3.3V)	\$ 0.22	Yes
LM386N-1	1	Audio amplifier	\$ 1.05	Yes
W25X40CLSNIG	1	Flash storage for sounds	\$ 0.56	No
BAT-HOLDER-4XAA	1	Battery holder with terminals	\$ 0.59	Yes
C503B-GCN-CY0C0792	1	Green LED	\$ 0.35	Yes
N/A	6	Stranded copper wires	\$ 0.10	Yes
N/A	1	PCB	\$ 0.50	No
N/A	~100g	PLA Filament	\$ 2.00	No
Machine Shop Labor			\$ 0.00	N/A
Labor: Evan		24 minutes of soldering	\$ 30.00	N/A
Labor: Kyle		18 minutes of soldering and 6 minutes of connecting auxiliary components and fastening in case	\$ 30.00	N/A
Labor: Bill		18 minutes of soldering and 6 minutes of programming MCU and flash memory and testing	\$ 30.00	N/A
<b>Total Cost</b>			\$ 110.19	\$ 100.54

Table 5: Itemized List of Components, Labor, and Cost

### 3.2. Schedule:

Below is a tentative weekly schedule for our team. We aim to split up the design work for the electrical, software, and mechanical design and construction evenly, and we plan to be finished with a demo-able product by mid-April.

<b>Week</b>	<b>Kyle</b>	<b>Evan</b>	<b>Bill</b>	<b>Everyone</b>
2/21 - 2/28	Complete Design Document	Complete Design Document	Complete Design Document	Practice Design Presentation
2/28 - 3/7	Start CAD for Chassis	Fix PCB for second order	Begin Breadboarding, coding firmware for MCU and Flash	Peer Reviews + Design Presentation
3/7 - 3/14	Finish Breadboarding + Functionality Testing	Begin Soldering PCB	Flash MCU and Memory (on Breadboard) and Redesign PCB if needed	Teamwork Evaluation + Breadboard Demo
3/14 - 3/21	Enjoy Spring Break	Enjoy Spring Break	Enjoy Spring Break	Work on PCB Redesign if Needed
3/21 - 3/28	Work on Individual Progress Report	Work on Individual Progress Report	Work on Individual Progress Report	Work on Individual Progress Report
3/28 - 4/4	Finish Chassis Design in CAD	Finish Soldering PCB	Flash MCU and Memory (on PCB) and design dials in CAD	Finish Individual Progress Report
4/4 - 4/11	Print Chassis Panels	PCB Integration	Functionality Testing	Progress Demos + Team Contract Assessment
4/11 - 4/18	Redesign Dials if needed	Redesign Chassis if Needed	Continued Functionality Testing	Begin Final Paper
4/18 - 4/25	Prep for Mock Demo + Presentation	Prep for Mock Demo + Presentation	Prep for Mock Demo + Presentation	Mock Demo + Presentation
4/25 - 5/2	Prep for Demo + Presentation	Prep for Demo + Presentation	Prep for Demo + Presentation	Final Demo + Presentation

5/2 - 5/9	Finish Final Paper	Finish Final Paper	Finish Final Paper	Final Paper + Lab Notebook
-----------	--------------------	--------------------	--------------------	----------------------------

Table 6: Project Progression Schedule

## 4. Discussion of Societal Impact, Engineering Standards, Ethics, and Safety Considerations:

### 4.1 Contributions

We hope that our project will help to raise awareness of local bat populations in Central Illinois, leading to some people being more courteous toward the environment. It is also our hope that the device will foster more socialization during Central Illinois Bat Festival Bat Walks, result in a better experience for Bat Walkers, and, hopefully, result in a more educational Bat Festival.

### 4.2 Standards

Our PCB will satisfy UL94 standards, as we are ordering it from a UL94 certified vendor. Also, each of the parts we have ordered are compliant with UL and IEEE standards (or are UL and IEEE recognized). Finally, since we have designed our own variable oscillator for this project, the IEEE 1193 Standard will apply to our oscillator and its interaction with our designed mixer.

### 4.3 Ethics

Our team believes that our product lacks ethical concerns. The only interaction that our product has with the outside world is in amplifying the high-frequency sounds of bats out in the wild through the use of a microphone. Nothing is sent back out to the bat to communicate with it or otherwise interrupt nature. No recording is enabled by the device, eliminating the possibility of recording without the permission of others. This device only amplifies inaudible sound waves, so it cannot be used to listen in on private

conversations. Component choices may be obtained via reverse engineering of existing products, such as the Magenta Bat4, but no circuit or intellectual property is to be copied without permission.

## 4.4 Safety

The device is not believed to harbor any safety concerns. The only moving parts on the device are plastic dials, and the device is not heavy enough to cause unintentional damage from dropping or otherwise. No metal parts of the device are exposed through the chassis, eliminating most chances for an electric shock.

## 5. References

[1] *LM386 Low Voltage Audio Power Amplifier Data Sheet*, Texas Instruments, 2023.

[2] *Global Product Technical Data Sheets - Duracell Batteries*, Duracell.com, 2016.

[3] *ATTiny25/45/85 Data Sheet*, Atmel, 2013.

[4] *W25X40CL Data Sheet*, Winbond Electronics, 2014.

[5] *SPVA1A0LR5H-1 Data Sheet*, Syntiant, 2024.

[6] *AP2210 Data Sheet*, Diodes Inc., 2021.

[7] *TLV9054 Op Amp Data Sheet*, Texas Instruments, 2024.

[8] *Op Amps for MEMS Microphone Preamp Circuits*, InvenSense, 2013.

[9] "Choosing Between Inverting and Noninverting Op Amp Circuits," ODG, Aug. 25, 2025.

<https://www.origin-ic.com/blog/op-amp-inverting-and-noninverting-amplifier-circuits-guide/47942>  
(accessed Feb. 17, 2026).