

HETERODYNE BAT CALL TRANSLATOR

ECE 445 DESIGN DOCUMENT – FALL 2026

Team # 16

Michael McNally, Theo Xiong, Liwei Koh

Professor: Dr. Arne Fliflet TA: Tim Jiang Sponsor: Dr. Joy O'Keefe

Contents

Contents.....	2
1 Introduction.....	3
1.1 Problem.....	3
1.2 Solution.....	3
1.3 Visual Aid.....	4
1.4 High Level Requirements.....	6
2 Design.....	8
2.1 Physical Design.....	8
2.2 Block Diagram.....	10
2.3 Subsystem Design, Requirements & Verification.....	10
2.5 Software Design.....	18
2.6 Tolerance analysis.....	20
2.7 Cost.....	20
2.8 Schedule.....	22
2.9 Risk analysis.....	27
3 Discussion, Ethics and Safety.....	27
4 References.....	29

1 Introduction

1.1 Problem

Reliable heterodyne bat-call detectors are difficult to obtain for under \$150 in the United States. Affordable options such as the Magenta Electronics Bat4, which costs approximately £80 [1], generally require international purchasing and shipping, making them less accessible to the U.S.-based customers. Comparable devices available in the United States, such as the Elekon Batscanner, which costs approximately \$395 [2], are significantly more expensive. The Magenta Bat4 can also be less intuitive for new users because recommended tuning frequencies are not automatically provided, requiring users to manually sweep through possible frequency ranges that may be present in the area. The combination of these issues limits researchers, students, and bat enthusiasts who are looking for an affordable and accessible way to detect and listen to ultrasonic bat calls.

1.2 Solution

To address the cost and accessibility issue of obtaining a quality batscanner as a US consumer, we propose building a portable heterodyne bat detector with a 3D-printed housing that is able to detect ultrasonic bat calls and convert them into frequencies that can be heard by the user. The device will aim to provide similar core functionality to the Magenta Bat4, minus the flashlight, while also using signal processing to recommend a frequency range for the user to tune to. A MEMS ultrasonic microphone feeds two paths in parallel:

1. An analog heterodyne chain (bandpass filter, amplifier, mixer, and audio amplifier) that converts bat calls (20kHz-100kHz) to audible frequency.

2. An ESP-WROOM-32E that samples the signal (ADC), runs a FFT, and displays the dominant frequency on an LCD to inform the user of the optimal range to tune the device to.

1.3 Visual Aid



Figure 1: Magenta Bat4 Available commercially overseas but not the US

The commercially available Magenta Bat4 uses a switched potentiometer for both volume control and system power, along with a separate potentiometer for frequency tuning. The tuning range extends up to approximately 130 kHz, which allows the device to detect higher-frequency calls produced by some bat species found in Europe. The device is powered by four AAA batteries, which supply power to the linear heterodyne oscillator, LED torch, and audio output

subsystems. The Magenta Bat4 operates by detecting an incoming ultrasonic signal, amplifying it, and mixing it with a locally generated oscillator signal. The mixer produces the difference between these two frequencies, converting the ultrasonic bat call into a frequency within the audible range. This allows the user to listen to bat activity in real time [3]. The Magenta Bat4 also uses a highly directional ultrasonic microphone that is more sensitive to signals arriving directly in front of the device than to signals arriving from the sides. By scanning the surrounding area and observing where the strongest ultrasonic signal is detected, the user can determine the approximate direction of the bat or source of ultrasonic activity [3].

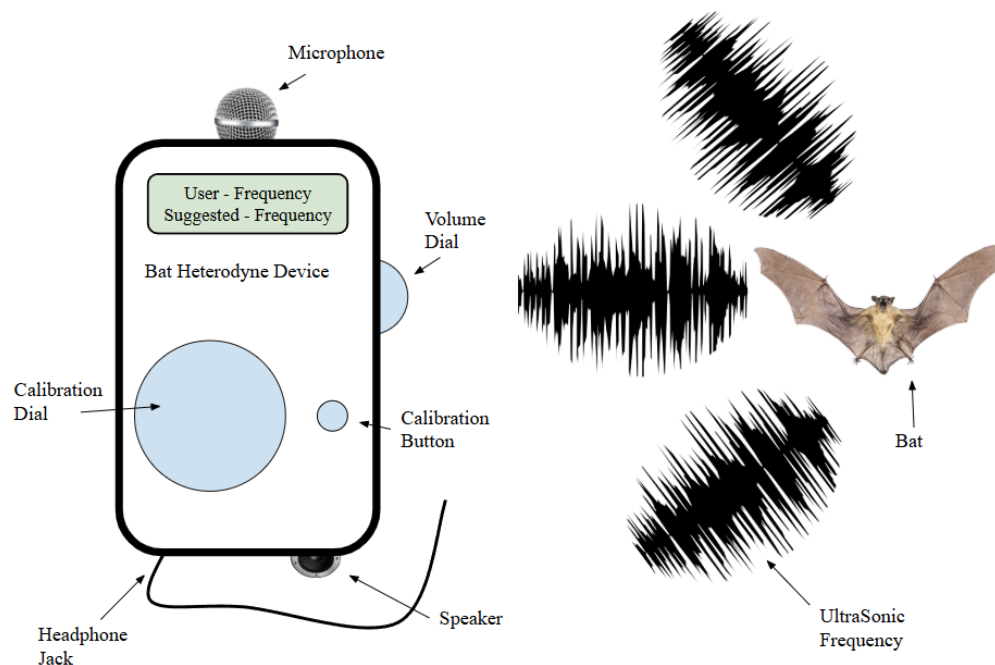


Figure 2. Bat UltraSonic Detector with bat visual

At a high level, our bat detector will utilize a 2x16 character LCD display that shows the user's currently selected frequency from the tuning dial, as well as a suggested frequency range that is

determined after the calibration button is pressed. When comparing our design to the original Magenta Bat 4 device, we decided to remove the flashlight because it was not useful for our sponsor's intended application. We chose to retain the wired headphone capability because it allows users to listen to detected bat calls without disturbing wildlife in the surrounding area. This feature is also beneficial when multiple researchers are working in the same area and may be using similar devices at the same time. The overall physical placement of the controls will remain similar to that of the original Magenta Bat 4 because we did not identify any significant issues with its existing user interface. Keeping a similar layout also avoids unnecessarily complicating the design. One major improvement we are implementing is the recommended frequency range display. This feature will provide a more user-friendly experience by clearly showing the frequency range in which bat activity is detected. This reduces some of the guesswork normally required when tuning the device in the field and allows the user to more easily select an appropriate listening frequency.

1.4 High Level Requirements

We formulated three quantitative objectives to determine the success of our proposed solution.

1. Battery Charge Condition:

- Under reasonable estimates: $Device\ Usable\ Hours = \frac{Battery\ Capacity}{Average\ Current\ Draw}$
 - Estimate that the completed device will average around 500 mAh $\rightarrow$ 600 mAh of draw
 - Typical Energizer Max battery will hold around 1600 mAh given a 500 mA discharge. This gives:

$$\text{Best Case Scenario} = \frac{\sim 1600\text{mAh}}{500\text{mA}} = 3.2 \text{ Hrs}$$

$$\text{Worst Case} = \frac{\sim 1350\text{mAh (Assuming semi linear falloff)}}{600\text{mA}} = 2.25 \text{ Hrs}$$

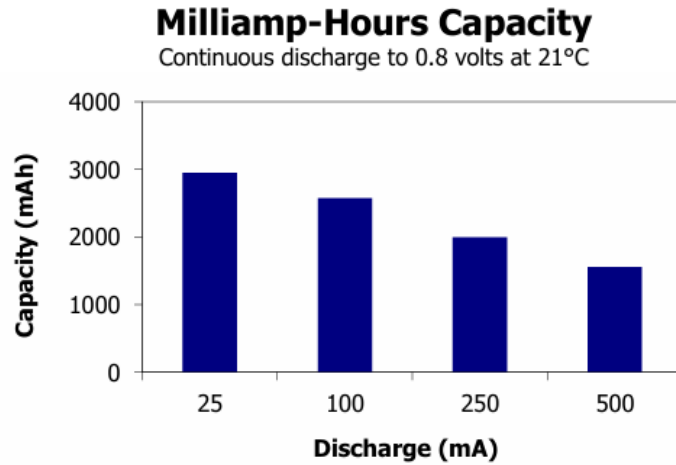


Figure 3: Milliamp-Hours Capacity graph of Energizer E91 [4]

2. Frequency Range Detection Accuracy:

- For a continuous ultrasonic test tone (20–80 kHz) presented 1m away from the device, it must display the dominant frequency to within ± 1 kHz of the true frequency.

3. Heterodyne Output Quality Under Different Operating Conditions:

- With the local oscillator tuned to within 5 kHz of a 20–80 kHz test tone, the speaker output must contain a tone at the intermediate frequency.

4. Cost (Sponsor Requirement):

- The cost of all components ordered should be no more than \$75.

2 Design

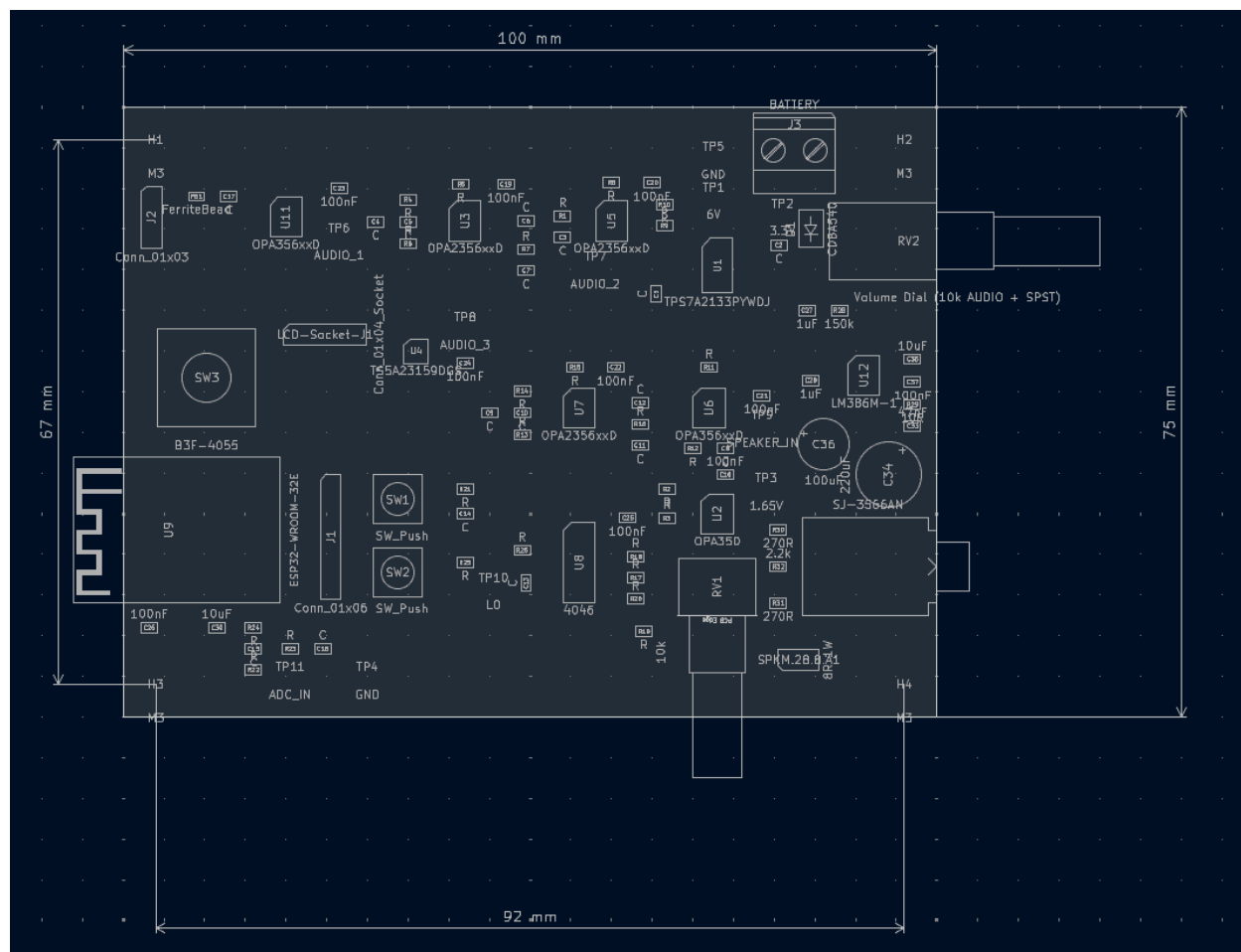
2.1 Physical Design



Figure 4. Original Magenta Design



Figure 5. Possible Design For Housing



2.2 Block Diagram

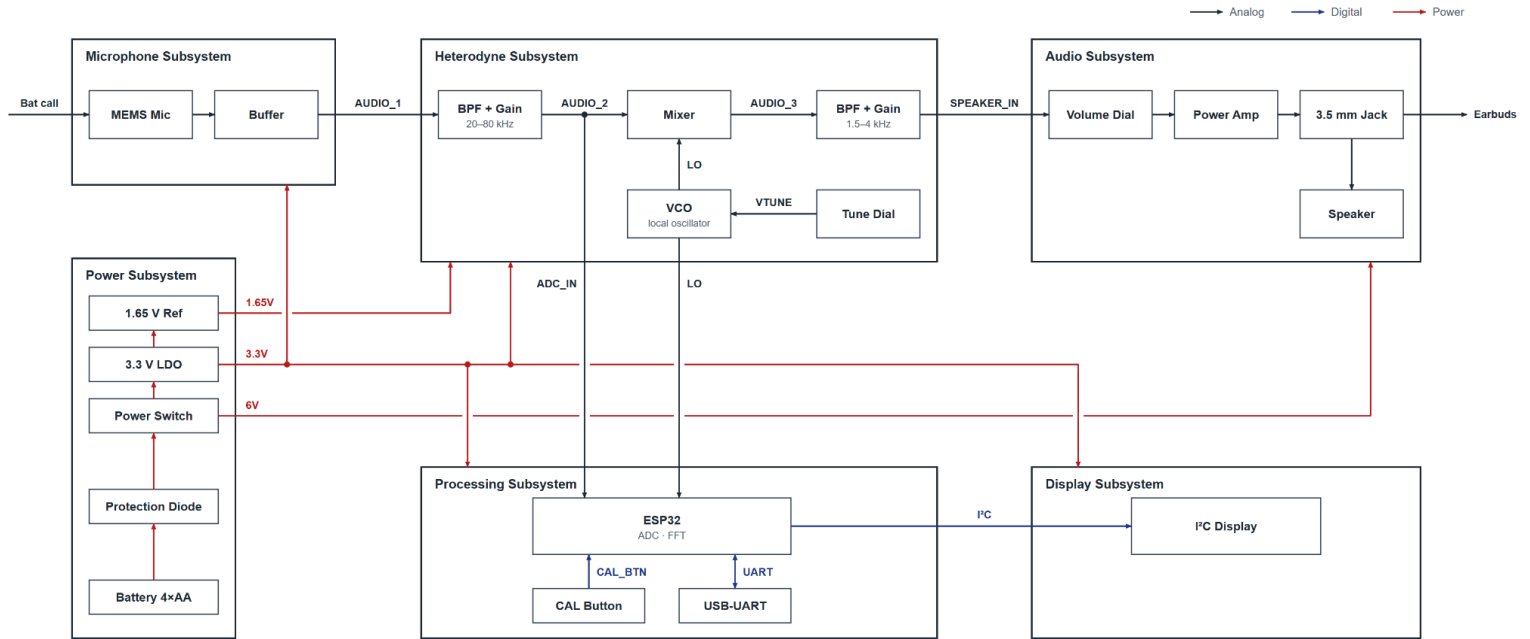


Figure 7. High-Level Block Diagram

2.3 Subsystem Design, Requirements & Verification

2.3.1 Power Subsystem

The detector is powered by a 4×AA battery pack, which provides a nominal 6 V supply. A LD1117S33TR low-dropout (LDO) regulator steps this down to a stable 3.3 V rail that feeds the microphone, processing, heterodyne, display, and audio subsystems. The four-cell configuration gives the regulator ample headroom above its 3.3 V output as the batteries discharge, which extends usable battery life. Basic filtering on the supply and an on/off switch keep the power clean and give the user direct control over the device.

The power subsystem supplies every active component in the detector, including the amplifiers, filters, oscillators, microcontroller, and display. Using one regulated rail for all of them keeps the

supply voltage consistent across the system, so the analog stages and digital components see the same clean 3.3 V regardless of how far the batteries have discharged.

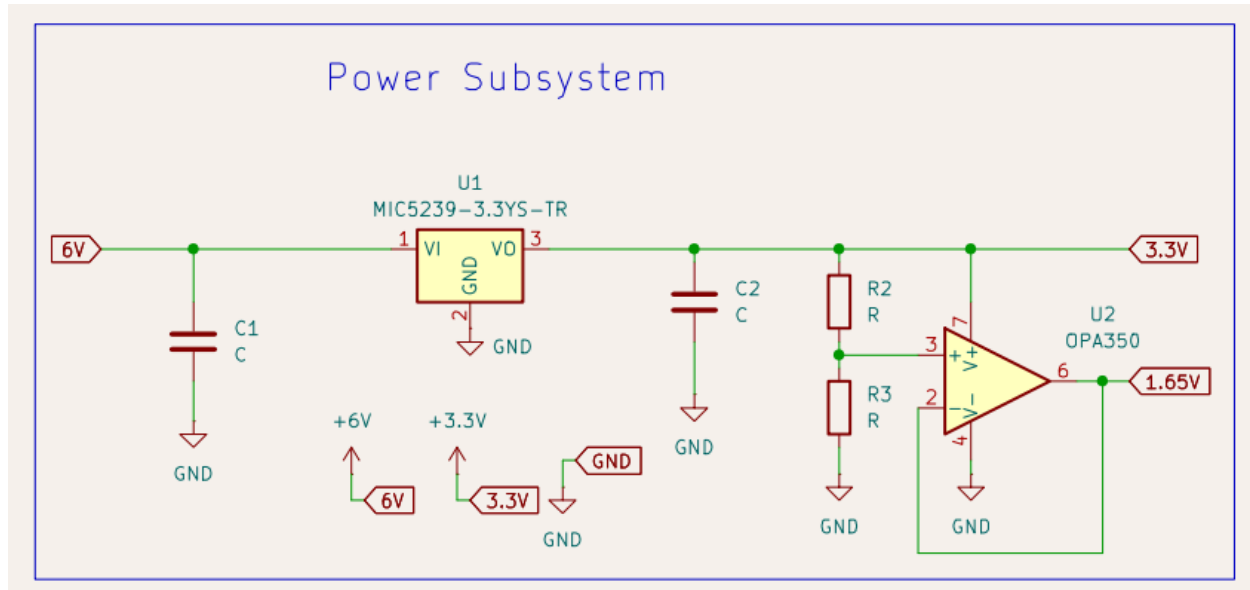


Figure 8. Power Subsystem Schematic

Table 1. Power Subsystem R&V

Requirements	Verification
The rail stays at $3.3\text{V} \pm 5\%$ (3.135-3.465V) for battery input from 4.5-6.5V and load current from 0 to 400 mA.	Sweep bench supply across battery input range, load rail with resistor or electronic load, record rail voltage with multimeter at corners.

Rail ripple and noise are less than 20 mVpp at maximum speaker output (likely significant current consumer)	Scope rail at supply pin while playing 2kHz tone at full volume
The rail settles within 200ms of power-on and VCO begins oscillating without issue	Scope rail and VCO output together during power-up

2.3.2 Microphone Subsystem [Michael]

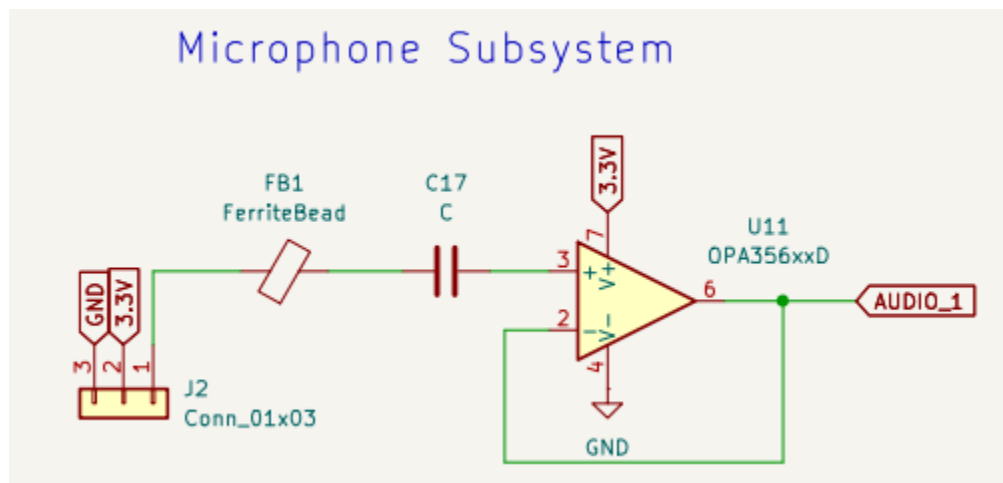


Figure 9. Microphone Subsystem Schematic

The Microphone Subsystem picks up the bat call and passes it to the Heterodyne Subsystem. We chose to use a Syntiant SPVA1A0LR5H-1 MEMS microphone because it covers well into the ultrasonic range, and it is mounted on a small breakout board that connects to the main board through J2.

The audio signal passed through FB1 which filters our EMI noise from the other components, and a capacitor (C17) that removes the microphone's DC output level. An OPA356

op-amp (U11) wired as a unity-gain buffer then re-centers the signal on 1.65 V and drives AUDIO_1. The buffer is needed because the first filter in the Heterodyne Subsystem only behaves as designed when it is driven by a low-impedance source.

Table 2. Microphone Subsystem R&V

Requirements	Verification
The microphone must consistently pick up ultrasonic frequencies within the 20-80kHz range.	• In a quiet room, place the microphone 1m away from an ultrasonic test source. • Record AUDIO_1 (TP6) with the source both on and off. • Record a table of the difference in dB. Pass if every difference is ≥ 10 dB.

2.3.3 Heterodyne Subsystem

The heterodyne subsystem converts the ultrasonic signal from the microphone into a tone the user can hear. The microphone signal first passes through a bandpass filter (20-80 kHz) that limits it to the ultrasonic band of interest. An amplifier then raises its level before it reaches the mixer. The filters and amplifiers are built from low-power, rail-to-rail MCP6271-E/SN op amps (single and dual versions), which run from the 3.3 V rail.

The mixer is a TS5A23159DGS analog switch. It is driven by a square wave from a CD74HC4046AM voltage-controlled oscillator, which the user tunes across 20 kHz to 80 kHz with the dial. Switching the signal path at the oscillator frequency multiplies the microphone signal by the square wave, producing sum and difference frequencies. The difference frequency, the gap between the bat's call and the oscillator, lies in the audible range. A second bandpass filter (1.5 kHz to 4 kHz) selects that beat note and rejects the oscillator, the sum frequencies, and other harmonics outside the passband. A final amplifier brings the beat note up to a level suitable for the audio subsystem.

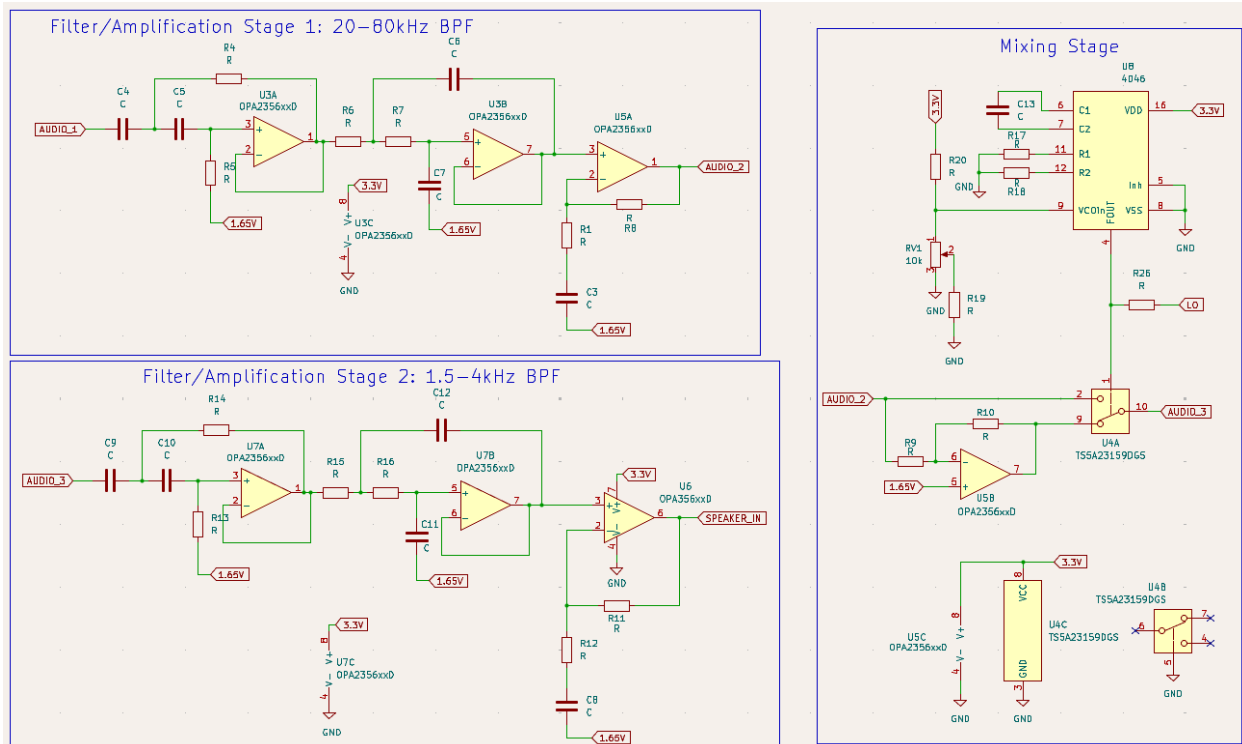


Figure 10. Heterodyne Subsystem Schematic

Table 3. Heterodyne Subsystem R&V

Requirements	Verification
The VCO tunes from ≤ 20 kHz to ≥ 80 kHz at worst-case component tolerances.	Set dial to each end, measure VCOOUT with oscilloscope to manually measure frequency
VCOOUT is a square wave with duty cycle $50\% \pm [10]\%$ and high level $\geq [3.0]$ V.	Scope VCOOUT at 20, 50, and 80 kHz.
A 40 kHz test tone with the LO at 38 kHz produces a 2 kHz tone. Frequency error is $\leq \pm 200$ Hz and amplitude is within 3 dB of the calculated value.	Feed 38kHz tone into mixer using function generator, measure outputted audio frequency to check accuracy
The op-amp amplifiers output swing without clipping, with THD $\leq 1\%$ at 2 kHz. Op-amps sit at mid-supply ($1.65\text{V} \pm 5\%$) with no signal.	Measure DC with multimeter/oscilloscope, drive 2kHz wave and increase amplitude until clipping appears, record THD with FFT on oscilloscope.
The band-pass filters have -3dB points at border frequencies (20 and 80kHz, 1.5 and 4kHz), passband flatness within 3dB, attenuation greater than 30dB outside range (3kHz for filter 1, 20kHz for filter 2)	Sweep a function generator through relevant frequency values. Plot gain versus frequency and check the corners.

2.3.4 Processing Subsystem

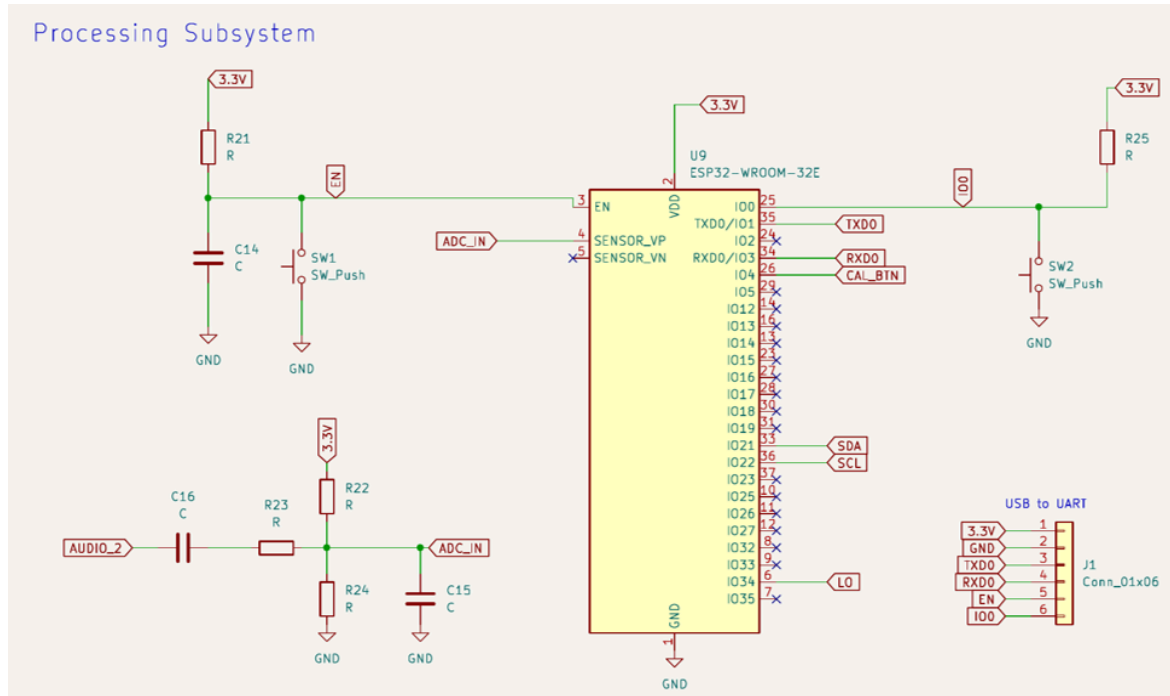


Figure 11. Processing Subsystem Schematic

The Processing Subsystem is the frequency-detection half of the detector. An ESP32-WROOM-32E MCU (U9) samples ADC_IN (scaled and re-biased copy of AUDIO_2), at 240 kSa/s with the ADC's DMA-driven continuous mode. It computes a 1024-point FFT of every 4.27 ms frame, and reports the strongest frequency between 20 and 80 kHz. It also counts the LO square wave with its pulse-counter (PCNT) peripheral to measure the frequency the user has tuned to, reads the calibrate button (SW3 on CAL_BTN), and writes both frequencies to the display over I²C. A six-pin header (J1) with reset (SW1) and boot (SW2) buttons lets a USB-UART adapter program the module and read a CSV debug log used throughout verification.

Table 4. Processing Subsystem R&V

Requirements	Verification
The ADC must sample ADC_IN at 240 kSa/s and report the dominant frequency within ± 500 Hz for input signals from 20 to 80 kHz.	• Disconnect microphone then drive J2 pin 1 with 20-80kHz sine in 5kHz steps. Send SDA & SCL through UART and print using a python script. • The dominant frequency reported by the processing subsystem must be within 500Hz of the generated frequency for each test signal.
The tuned frequency (LO) shown on the display must be within ± 0.5 kHz of the actual LO frequency, from 20 to 80 kHz.	• Probe Test Point 10. • Record measured and displayed frequencies.
With no ultrasonic source present, at least 19 of 20 calibrate presses must show “No Signal” instead of a frequency range.	• In a quiet room with the microphone installed and no source, press calibrate 20 times and record each result. • Repeat while two people talk normally 1 m away.

2.3.5 Display Subsystem

Display Subsystem

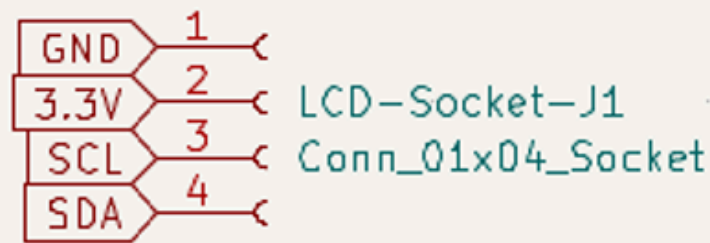


Figure 12. Display Subsystem

The Display Subsystem is a 16×2 character LCD with an I²C adapter board that plugs into the four-pin socket on the main board (GND, 3.3 V, SCL, SDA). It connects to the ESP32’s I²C pins (GPIO21 and GPIO22), so only two signal wires are needed. Line 1 shows the frequency the tuning knob is currently set to. Line 2 shows “Press Cal” at startup, the recommended frequency range after the calibrate button is pressed (for example, “040-045 kHz”, or “No Signal” if no bat call was found).

Table 5. Display Subsystem R&V

Requirements	Verification
--------------	--------------

The SDA and SCL lines must never rise above 3.47 V (3.3 V + 5 %).

- With the bus idle, measure SDA and SCL to GND.
- While the display is updating, measure the high level of both lines on the oscilloscope. Record the maximum value.

2.3.6 Audio Subsystem

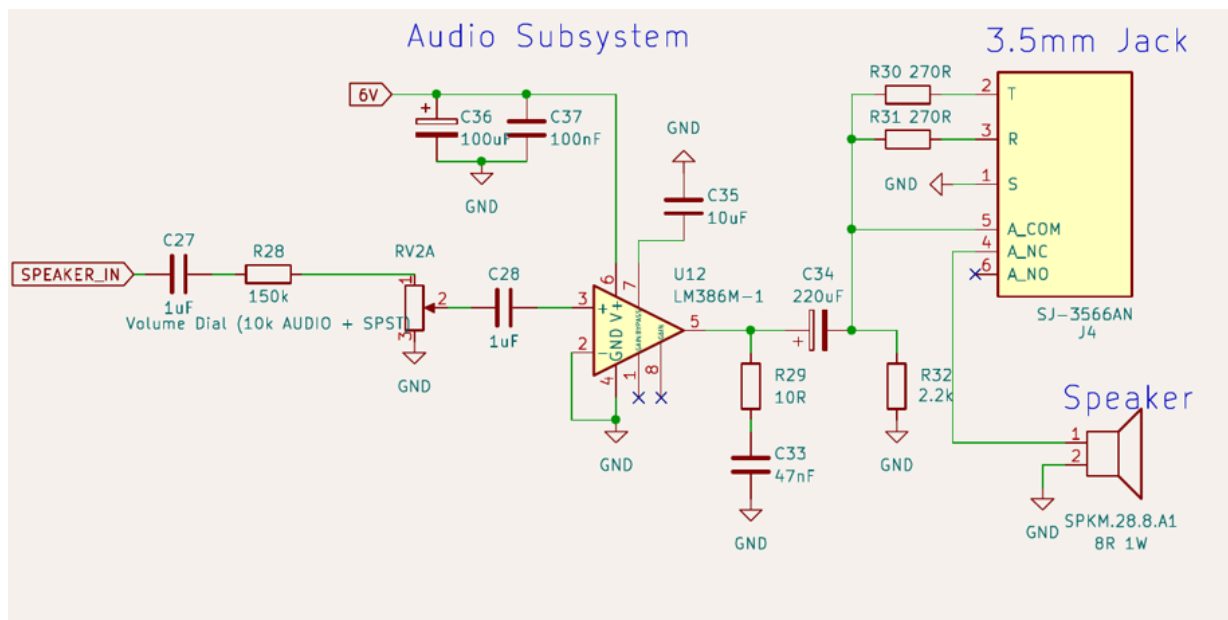


Figure 13. Audio Subsystem Schematic

The Audio Subsystem turns SPEAKER_IN into sound playback through either a speaker or earbuds connected through a 3.5mm audio jack. SPEAKER_IN is AC-coupled (C27), attenuated by R28 and the volume dial (RV2A, 10 kΩ audio taper), and amplified by an LM386 (U12) with a fixed gain of 20, powered directly from the 6 V battery rail.

The amplifier drives an $8\ \Omega$, 1 W speaker through a $220\ \mu\text{F}$ coupling capacitor, or a pair of earbuds through the 3.5 mm jack (J4); inserting a plug opens the jack's switch contact and disconnects the speaker. The second section of the same knob (RV2B) is the power switch.

R28 and the volume knob reduce SPEAKER_IN before the LM386 so that even at full volume the largest signal the heterodyne chain can produce comes out at about the same size after the amplifier's gain of 20. That works out to about 170 mW into the speaker, well under the speaker's 1 W rating and below the level where the LM386 starts to distort. The $270\ \Omega$ resistors in series with the headphone jack limit earbud power to about 0.5 mW per side, which protects the user's hearing and protects the amplifier if the plug shorts during insertion. We chose the LM386 because it runs directly from the 4–12 V battery voltage and has no switching noise that could interfere with the ultrasonic filters.

Table 6. Audio Subsystem R&V

Requirements	Verification
With SPEAKER_IN at 3.0 V _{pp} /3 kHz and the volume turned to max, the speaker must receive at least 2.9 V _{pp} ($\approx 125\ \text{mW}$ into $8\ \Omega$) with no visible clipping.	- Power from a bench supply at 6.0 V. Drive J2 pin 1 at 45 kHz with the LO at 42 kHz, adjusting the amplitude until TP9 reads 3.0 V_{pp}. - Measure across the speaker terminals with the oscilloscope and check that

	the waveform peaks are not flattened. Record the voltage and save a screenshot.
Speaker voltage must increase/decrease with volume-dial rotations.	- Drive J2 pin 1 at 40kHz the same way. - Measure the speaker voltage at 0 %, 25 %, 50 %, 75 %, and 100 % rotation and record the values.
When the 3.5mm jack (J4) is plugged in, the speaker must be disconnected.	- Insert earbuds into J4. - While inserted, measure voltage across the speaker, the value should be negligible.

2.3.7 Test Points

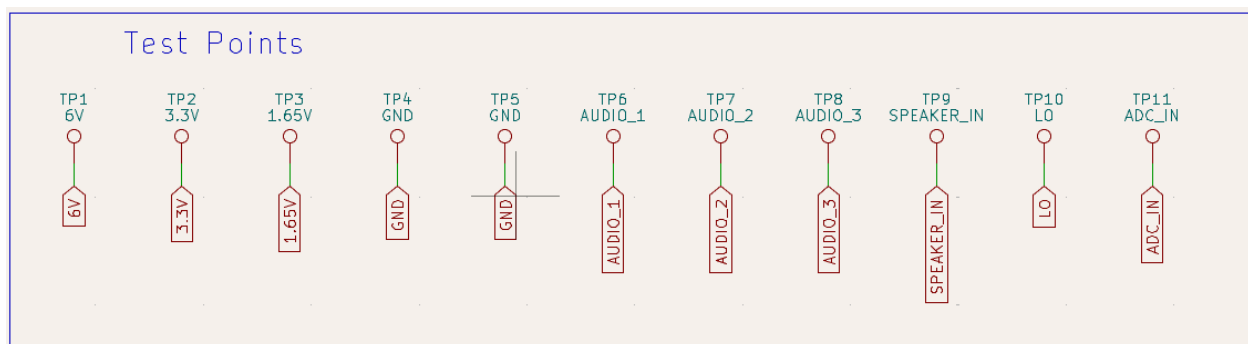


Figure 14. Test Points

2.5 Software Design

The ESP32 firmware is written in C on ESP-IDF v5 and FreeRTOS. It does four things: acquire and analyze the ultrasonic signal, measure the LO frequency, run the user

interface on the display and calibrate button, and log results over UART for verification. Wi-Fi and Bluetooth are never initialized.

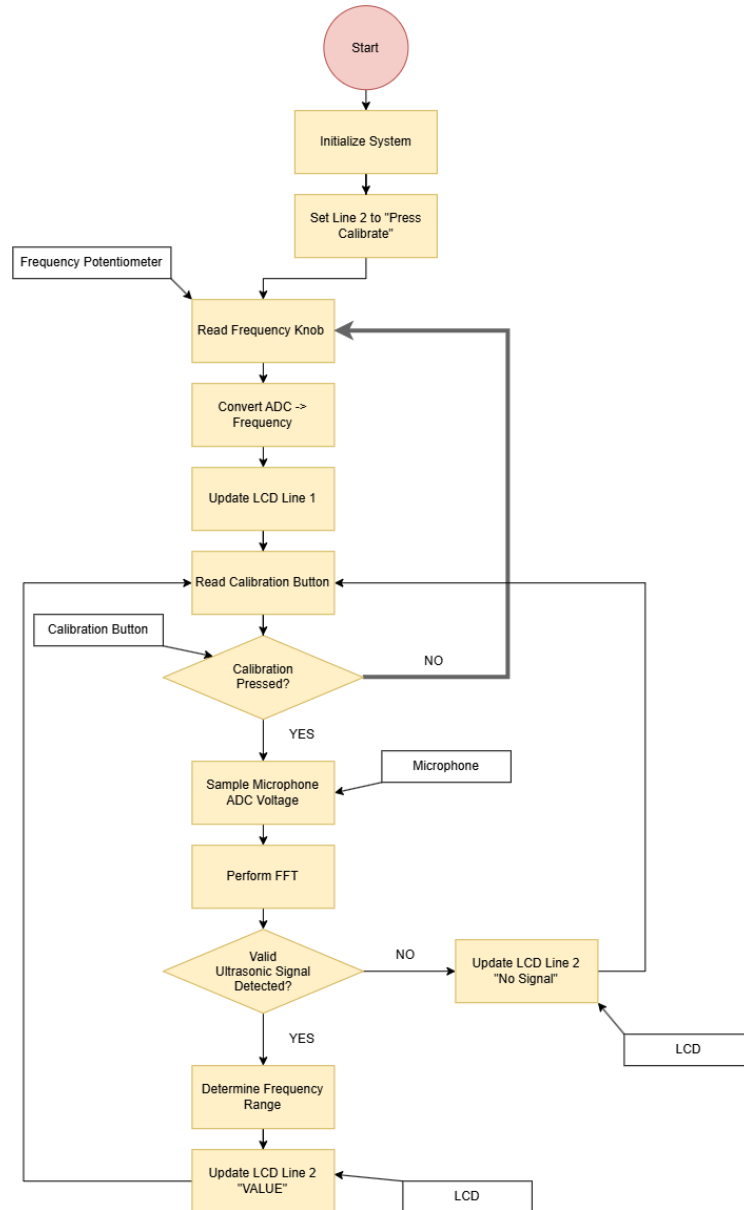


Figure 15. LCD Display update flowchart

At startup, it sets up the ADC, the I²C connection to the LCD, and the calibrate button, then shows "Press Calibrate" on line 2. In its main loop, it reads the frequency knob with the 12-bit ADC and converts the reading to the oscillator frequency using a calibration table measured at

13 points from 20 to 80 kHz. It then shows that tuned frequency on line 1, averaging several readings so the display doesn't flicker. Next, it checks the calibrate button, which must stay pressed for 20 ms to count. If the button isn't pressed, it goes back to reading the knob, so line 1 updates several times per second. When the button is pressed, it records 1024 microphone samples at 240 kSa/s, which covers everything up to 120 kHz, and runs an FFT with Espressif's ESP-DSP library. The FFT splits the signal into frequency bins

$\Delta f = \frac{f_s}{N} = \frac{240 \text{ kHz}}{1024 \text{ samples}} = 234 \text{ Hz}$ wide. This repeats for about half a second so short bat calls aren't missed. The strongest peak between 20 and 80 kHz counts as a bat call only if it is at least 10 dB above the typical level across that band. If it is, the frequency is rounded down to the nearest 5 kHz and shown on line 2 as a range (for example, "040-045 kHz" for a 43.2 kHz call). Otherwise, line 2 shows "No Signal." Wi-Fi and Bluetooth stay off to save power and reduce noise, and every measurement is also printed over UART so it can be logged during testing.

2.6 Tolerance analysis

In the heterodyne bat-call detector, the VCO section of the CD74HC4046AM will generate the 20kHz to 80kHz local-oscillator square wave that the TS5A23159DGS switching mixer will use to shift the microphone ultrasonic signal into the audible range. The VCO runs from the 3.3V rail (supply range 3V to 6V) and its output will have a 50% duty cycle. The audible output will equal the difference between the bat call's frequency and the oscillator frequency, so any error in the oscillator moves the output frequency by the same amount. The second bandpass filter is 2.5 kHz wide (1.5 to 4kHz), so oscillation accuracy and stability are critical tolerance risks in this subsystem. Unlike the previously-planned Wien Bridge oscillator, the tolerances of the

surrounding passive components will not prevent oscillation from occurring. However, variations in these values can and will affect the frequency of oscillation.

The frequency at which the VCO will oscillate is directly determined by the external timing resistances and capacitances, along with the input voltage at VCOIN (pin 9). At a fixed control voltage, frequency is proportional to $1/(R \times C)$, so the fractional errors from R and C will compound. The chip requires the surrounding resistors R1 and R2 to be within 3k to 300k Ω , and C1 above 40pF so stray capacitance stays negligible. Assuming 1% resistor tolerance and 5% capacitor tolerance, the frequency error is 6.3% at the high corner and -5.7% at the low corner—resulting in a root-sum-square estimate for $\pm 5.1\%$ for a typical unit.

The VCO's temperature drift is the next most significant source of variation. The datasheet gives a typical frequency change of 0.11%/°C (for R1 = 100 k Ω), and Figures 22 through 26 show how it varies with R1 and supply voltage. Over 0 °C to 40 °C, measured against calibration at 25 °C, the worst-case shift is about $25\text{ °C} \times 0.11\%/^{\circ}\text{C} \approx \pm 2.75\%$. That is $\pm 2.2\text{ kHz}$ at 80 kHz and $\pm 0.55\text{ kHz}$ at 20 kHz. In use, a 10 °C change shifts the beat note by about 0.9 kHz at 80 kHz, which stays inside the passband but is audible as pitch drift.

The control voltage adds three smaller sources of variation. First, if VCOIN is divided from the regulated 3.3V rail, an assumed rail tolerance of $\pm 2\%$ shifts the frequency by roughly the same fraction. Secondly, the VCOIN input leakage is specified on the datasheet at $\pm 0.1\text{ }\mu\text{A}$ at 25 °C and up to $\pm 1\text{ }\mu\text{A}$ over temperature. Across an assumed source resistance of 10 k Ω , this produces up to 10mV of error, about 1% of VCO at the bottom of the predetermined 1.1-1.9V input range. Third, the datasheet's typical VCO frequency linearity of 0.4% contributes a small dial-mapping error.

Table 7: VCO error sources summary

Source of Error	Error Contribution
R1 and C1 tolerance (1% R, 5% C)	+ 6.3%/-5.7%
VCO temperature drift (0-40 °C)	$\pm 2.75\%$
Supply and control voltage (assumed $\pm 2\%$)	$\pm 2\%$
VCOIN leakage (10 k Ω source)	$\pm 1\%$
VCO linearity	$\pm 0.4\%$
Worst-case total	+12.5%/-11.9%
Root-sum-square total	$\pm 6.2\%$

To account for a theoretical maximum of 12.5% frequency error from the VCO, we must increase the frequency range of our tuner. Using these values, the frequency dial should tune to a minimum frequency of 17.8kHz and a maximum frequency of 90.8kHz.

2.7 Cost

Table 8: Itemized list of Components and Costs

Description	Part	Qty	Unit	Ext.	Link	Source
MCU	Espressif ESP32-WROOM-32E-N4	1	\$4.99	\$4.99	Link	Digikey
3.3 V LDO	TI TPS7A2133PYWDJ	1	\$0.76	\$0.76	Link	Digikey
1.65 V reference op-amp	TI OPA350UA	1	\$5.15	\$5.15	Link	Digikey
Dual filter op-amp	TI OPA2356AIDR	3	\$3.52	\$10.56	Link	Digikey
Single op-amp	TI OPA356AIDR	2	\$2.57	\$5.14	Link	Digikey
VCO / PLL (local oscillator)	TI CD74HC4046AM96	1	\$1.04	\$1.04	Link	Digikey
Analog switch (mixer)	TI TS5A23159DGSR	1	\$0.80	\$0.80	Link	Digikey
Audio amplifier	TI LM386M-1/NOPB	1	\$1.45	\$1.45	Link	Digikey
Reverse-polarity Schottky diode	Comchip CDBA540-HF	1	\$0.77	\$0.77	Link	Digikey
Ultrasonic MEMS microphone	Syntiant SPVA1A0LR5H-1	1	\$1.58	\$1.58	Link	Digikey
3.5 mm switched stereo jack	Same Sky SJ-3566AN	1	\$1.99	\$1.99	Link	Digikey

Speaker, 8 Ω 1 W	Taoglas SPKM.28.8.A	1	\$2.43	\$2.43	Link	Digikey
Calibrate button, 12 mm	Omron B3F-4055	1	\$0.52	\$0.52	Link	Digikey
Ferrite bead (mic line)	Murata BLM21PG221SN1D	1	\$0.11	\$0.11	Link	Digikey
Tuning knob, 10 k Ω linear	Bourns PTV09A-4225F-B103	1	\$1.24	\$1.24	Link	Digikey
Volume knob, 10 k Ω with SPST switch	Adafruit 3481	1	1.5	1.5	Link	Digikey
4×AA battery holder, 6 in. leads	Keystone 2478	1	\$2.08	\$2.08	Link	Digikey
16×2 I ² C LCD module	DFRobot DFR0063	1	\$11.90	\$11.90	Link	Digikey
Filter capacitor, 220 pF C0G 0603	Murata GRM1885C1H221JA01D	4	\$0.12	\$0.48	Link	Digikey
Filter capacitor, 3.3 nF C0G 0603	KEMET C0603C332J5GACTU	4	\$0.45	\$1.80	Link	Digikey
Filter resistor, 11.5 k Ω 1 % 0603	YAGEO RC0603FR-0711K5L	3	\$0.10	\$0.30	Link	Digikey
Filter resistor, 26.1 k Ω 1 % 0603	YAGEO RC0603FR-0726K1L	3	\$0.10	\$0.30	Link	Digikey
Filter resistor, 46.4 k Ω 1 % 0603	YAGEO RC0603FR-0746K4L	3	\$0.10	\$0.30	Link	Digikey
10 Ω 1 % resistor, 1210	Vishay Dale CRCW121010R0FKEA	4	\$0.21	\$0.84	Link	Digikey
Generic 0603 resistors and capacitors		1	\$0.00	\$0.00		E-Shop
Electrolytic capacitors (10 μ F, 100 μ F, 220 μ F)		1	\$0.00	\$0.00		E-Shop
Reset/boot tactile switches (SW1, SW2)		2	\$0.00	\$0.00		E-Shop
Headers J1, J2, LCD socket; terminal J3		1	\$0.00	\$0.00		Self-Service
PCB, 100 × 75 mm two-layer		1	\$0.00	\$0.00		PCBWay
3D-printed housing		1	\$0.00	\$0.00		Liwei
Parts total			\$58.92			

Labor Cost: The average starting salaries for Illinois electrical and computer engineering graduates in 2024–25 were \$87,429 and \$119,064 [5]. Averaging the two and dividing by 2,080 working hours per year gives about \$50 per hour. We estimate each team member will spend about 10 hours per week for 12 weeks, or 120 hours:

$$\text{Labor per person} = \$50/h * 2.5 * 120hr = \$15,000$$

For three members, the total labor is \$45,000.

$$Total\ Cost = \$45,000.00 + \$58.92 = \$45,058.92$$

2.8 Schedule

Table 9: Proposed Schedule

Week	Task	Person
Sept.28 - Oct 5	Order parts for prototyping	Everyone
	Work with Michael to help with verifying availability of certain components and do a final check on footprints	Liwei
	Finalize PCB Design and component footprints	Theo
	Research improvements to lessen the cost of certain components as well as ease of hand soldering.	Michael
Oct.5 - Oct. 12	Prepare for breadboard DEMO	Everyone
	Assemble and solder the first PCB	Liwei
	Develop LCD communication and basic display	Theo
	Check the heterodyne signal chain and verify mixer/filter	Michael
Oct. 12 – Oct. 19	Do a re-order of parts if necessary	Everyone

	Continue to solder and assemble first PC and debug if necessary	Liwei
	Implement the FFT/frequency detection algorithm on the ESP32	Theo
	Optimize filters, heterodyne frequency response, and gain stages	Michael
Oct. 26 – Nov. 2	Prepare for the progress demo	Everyone
	Assemble the revised PCB if required	Liwei
	Complete ESP32 Software integration / user interface and frequency recommendation behaviors	Theo
	Tune analog filters, audio amplifications and validate the full 0-80kHz tuning range	Michael
Nov. 9 – Nov. 16	Start working on finishing touches for enclosure layout and mounting design. Help other two if needed	Liwei
	Finalize LCD interface, tuning software, and calibration logic	Theo

	Characterize heterodyne performance at multiple input frequencies. Verify system performance requirements are met	Michael
Nov. 16 – Nov. 23	Prepare for the mock demo and presentation / test device against high level requirements	Everyone
	Finalize enclosure and cosmetic assembly	Liwei
	Get a stable working code on the ESP 32 that can be used as a fallback	Theo
	Finalize measured heterodyne performance results	Michael
Nov. 23 – Nov. 30	Fall break / temporary pause on development	Everyone
	Help with the code documentation and PCB inspection / cleanup	Liwei
	More code verification and documentation	Theo
	Start to document the analog / heterodyne performance and component decisions	Michael
Nov. 30 – Dec. 7	Final demo and presentation preparation	Everyone

	Perform final hardware cleanup, PCB inspection and help out with the software if needed	Liwei
	Document analog/heterodyne performance and component decisions	Michael
	Final software verification and code documentation	Theo

Figure x: Schedule for Project Progression

2.9 Risk analysis

One risk associated with the bat heterodyne system is potential hearing damage or environmental disturbance if the audio output from the speaker or headphone jack becomes excessively loud. To reduce this risk, we selected a volume potentiometer with an integrated power switch. This design requires the user to rotate the volume control to its minimum setting before the device can be powered off, ensuring that the system starts at its lowest volume setting the next time it is turned on. In addition, the maximum amplifier gain will be limited so that the audio output remains within a reasonable range under worst-case input conditions. During testing, the maximum output voltage and perceived volume will be measured to verify that the system does not produce unexpectedly high audio levels. These measures reduce the likelihood of sudden loud outputs that could cause user discomfort, hearing damage, or unnecessary disturbance to nearby wildlife.

3 Discussion, Ethics and Safety

Our project follows the IEEE Code of Ethics Section 1.1, which emphasizes protecting the welfare, safety and health of the public and potential environmental impacts [6]. The biggest concern to the violation of this section comes with the excessive headphone or speaker volume that could cause user discomfort or hearing damage in the worst case with unnecessary audible outputs that could disturb wildlife during field use.

Our project aims to align with IEEE Code of Ethics Section I.2, which encourages engineers to improve the understanding of technology by individuals and society [6]. The main goal of our project is to make bat detection technology more accessible to users in the United States, including hobbyists, students, and field researchers who may not have extensive experience with ultrasonic monitoring equipment. To reduce the amount of prior technical knowledge required to operate the detector, our design includes a calibration button and a 2x16 LCD display that help remove much of the guesswork associated with tuning and calibrating the device. These features provide users with clearer feedback and make the system easier to operate in the field. In addition, our lower-cost design helps reduce the financial barrier associated with specialized commercial bat detectors, many of which are relatively expensive or must be shipped from overseas. By improving both usability and affordability, our project aims to make bat detection technology more approachable to a wider range of users.

IEEE Code of Ethics Section I.5 emphasizes honesty when making technical claims, particularly when estimates and results are based on gathered data [6]. This is especially important for our project because the bat detector provides users with a recommended frequency range based on detected ultrasonic signals. Our device is designed to operate over a frequency range of 0 kHz to

80 kHz, and we recognize that this limitation may prevent the detection of certain bat species outside of North America, as some species can produce calls at frequencies approaching 120 kHz in extreme cases. We will clearly document this limitation so that users understand the operating range of the device. In addition, we will include a disclaimer stating that the detector should not be used to make definitive claims about bat species identification. The recommended frequency range is intended to serve as a preliminary field reference rather than a conclusive classification tool. More precise long-term recording and analysis equipment exists for species-level identification and should be used when accurate identification is required.

Our overall goal for this project is to make bat detectors more accessible within the United States and help increase general interest in bats. Our device will provide experienced field researchers with a tool that can be used to form preliminary hypotheses about the types of bats present in an area before setting up more precise recording equipment. At the same time, the device will provide consumers with a user-friendly interface that allows them to more easily explore and engage with the world of bats.

4 References

[1] Magenta Electronics, “Bat4 Bat Detector,” *Magenta Electronics*. [Online]. Available:

<https://magenta2000.co.uk/product/bat4-bat-detector/>.

[2] Bat Conservation and Management, Inc., “Elekon BATSCANNER,” *Bat Conservation and Management, Inc.* [Online]. Available: <https://batmanagement.com/products/elekon-batscanner>

[3] Magenta Electronics Ltd., Bat4 Product Sheet, Magenta Electronics, 2016. [Online].

Available: <https://magenta2000.co.uk/wp-content/uploads/2022/12/Bat4ProductSheet.pdf>

[4] Energizer Holdings, Inc., E91 MAX AA Alkaline Battery – Product Datasheet, Energizer, 2025. [Online]. Available: https://energizer.com/wp-content/uploads/2025/01/e91_max_na.pdf

[5] University of Illinois Urbana-Champaign, “Salary Averages,” Department of Electrical and Computer Engineering. [Online]. Available: <https://ece.illinois.edu/admissions/why-ece/salary-averages>

[6] IEEE Code of Ethics, IEEE, 2026. [Online]. Available: <https://www.ieee.org/about/corporate/governance/p7-8.htm>