Ultrasonic Radio

Nathan Cinocca
Jacob Ralls

FINAL PROJECT REPORT

FINAL PROJECT REPORT

FOR

Ultrasonic Radio

TEAM 84

PREPARED BY:

Jacob Ralls Date

Nathan Cinocca Date

APPROVED BY:

Jacob Ralls Date

Prof. Kalafatis Date

Omar Manhood Date

1. Change Record

Rev.	Date	Originator	Approvals	Description
1.0	9/14/2023	Nathan Cinocca	Nathan	Draft Release
2.0	12/6/2023	Nathan, Jacob	Jacob	End of 403 Semester
3.0	4/29/2024	Nathan, Jacob	Jacob	End of 404 Semester

2. Table of Contents

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5. Execution and Validation Plan

5.1 Execution plan

	October 2nd	October 9th	October 16th	October 23th	October 30th	November 6th	November 13th	November 20th
Design and simulate signal amplifier								
Power Amplifier Research								
Modulation/demodulation Research								
Order Parts								
Filter Design								
Signal Amplifier Test								
Design and simulate modulation/demodulation								
Power Amplifier Design								
Filter Test (For Modulation)								
Test modulation/demodulation								
Power Amplifier simulation and test								
Completed Altium PCB								
All PCBs soldered								
Final Testing (Filters)								
Final Testing (Modulator)								
Final Testing (Demodulator)								
Final Testing (Power Amplifier)								

	January 29th	February 5th	February 12th	February 19th	February 26th	March 4th	March 18th	March 25th	April 1st	April 8th	April 15th
Finish Validating and Testing all Subsystems (ALL)											
Order New PCB if Needed (ALL)											
Order Ultrasonic Microphones and Speakers (ALL)											
(Transmitter End) Connect/Validate Signal Amplifier and Filter (NC)											
(Transmitter End) Connect/Validate Power Amplifier With Other Transmission Subsystems (NC)											
(Transmitter End) Connect/Validate Frequency Modulator With Other Transmission Subsystems (NC)											
(Receiver End) Connect/Validate Signal Amplifier and Filter (JR)											
Connect/Validate Both Transmitter and Receiver Parts of Radio (ALL)											
Final Validation and Testing of Radio (ALL)											

5.2 Validation plan

Paragraph #	Test Name	Success Criteria	Methodology	Status	Responsible Engineer(s)
13.2.1.1	Total Harmonic Distortion	The output signal should have a total harmonic distortion less than or equal to 10%	Test the output total harmonic distortion at the output node of the radio with an oscilloscope	TESTED	Jacob Ralls
13.2.1.2	Frequency Match	The transmitted signal frequency and tuned demodulator frequency should be matched within 3 kHz	Measure the modulator frequency and demodulator frequency with an oscilloscope	TESTED	Full Team
13.2.2.1	Mass	Have the entire ultrasonic radio be less than or equal to 10 kilograms	Weigh all PCBs that make up the radio on a scale	TESTED	Full Team
13.2.3.1.1	Power Consumption	The maximum peak power of the system shall not exceed 4.5 watts	Use multimeter to check power consumption of ultrasonic radio	TESTED	Full Team
13.2.3.1.2	Input Voltage Level	The input voltage level for the ultrasonic radio shall be +5 VDC for the transmitter and +9 VDC for receiver	Use multimeter to check voltage levels of ultrasonic radio	TESTED	Full Team
13.2.3.1.3	Input Current Level	The input current for the ultrasonic radio shall not exceed 900 mA	Use multimeter to check current levels of ultrasonic radio	TESTED	Full Team
13.2.3.1.4	Voice Input	The ultrasonic radio shall take user voice input that operates from 100 Hz to 3 kHz	Test input microphone with different voice frequency recording within the 100 – 3kHz range	TESTED	Nathan Cinocca
13.2.3.2.1	Voice Output Frequency	The ultrasonic radio shall output the voice input at frequencies 100 Hz to 3 kHz	Test output speaker with different voice frequency recording within the 100 – 3kHz range	TESTED	Jacob Ralls
13.2.3.2.2	Voice Output Volume	The ultrasonic radio shall be heard from up to 15 meters away	Measure output volume in decibels to determine audible distance of output noise	TESTED	Jacob Ralls
13.2.4.1	Pressure	The ultrasonic radio may be able to operate at 1 atm of pressure	Use ultrasonic radio in a standard room with 1 atm of pressure	TESTED	Full Team
13.2.4.2	Thermal	The ultrasonic radio may be able to operate at thermal temperatures ranging from 55 degrees Fahrenheit to 95 degrees Fahrenheit	Use ultrasonic radio outside at different temperatures	TESTED	Full Team
13.2.5.1	Recovery	The Ultrasonic radio should provide a way to reset the entire system	Reset the system by unplugging power supply from both transmitter and receiver for 10 seconds to reset system	TESTED	Full Team

Ultrasonic Radio

Nathan Cinocca
Jacob Ralls

CONCEPT OF OPERATIONS

CONCEPT OF OPERATIONS
FOR
Ultrasonic Radio

TEAM 84

APPROVED BY:

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Project Leader Date

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Prof. Kalafatis Date

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T/A Date

Change Record

Rev.	Date	Originator	Approvals	Description
1.0	9/14/2023	Nathan Cinocca		Draft Release
2.0	4/30/2024	Nathan, Jacob		End of 404 Semester

6. Executive Summary

Communicating information is an important aspect of almost any military operation. However, depending on the situation, it can be difficult to transmit information safely. For example, in planes and submarines it is difficult to communicate with regular equipment as the electromagnetic waves will interfere with the vehicle's navigation equipment. To solve this issue, an ultrasonic radio will be developed that will operate at a low frequency using acoustic waves outside of the range of human hearing. The radio will be half-duplex to allow for one way communication. Ultimately, this radio will allow for better communication between military operators even around areas that are sensitive to electromagnetic waves.

7. Introduction

This report is an introduction to the development of an ultrasonic radio. This ultrasonic radio will be designed to operate using low frequency acoustic waves outside of the range of human hearing to transmit data without affecting other electromagnetic waves at higher frequencies. This ultrasonic radio will primarily be used for military operations that involve planes, submarines, and other forms of transportation with sensitive equipment. However, this radio could also be used by civilians in similar situations.

7.1 Background

Radios have been around for a very long time and operate at a large range of frequencies from 3 Hz to 300 GHz. However, most of these radios use electromagnetic waves to transmit information. Radios that use electromagnetic waves are effective methods of communication as they can send and receive information very quickly. Despite this electromagnetic wave-based communication can have problems where multiple devices create wave interference. This can be a very dangerous issue when sensitive, vital equipment such as airplane equipment is interfered with. The danger of electromagnetic wave interference is multiplied in dangerous military situations.

A way to get around the limitations posed by electromagnetic waves and their applications is to create an ultrasonic radio that uses acoustic waves. Using acoustic waves at lower frequencies will allow for minimal electromagnetic interference but will limit range of transmission. This trade off is acceptable as it will allow for safe communication during military operations in both planes and submarines.

In our research we have only found one ultrasonic acoustic radio that has been developed. This radio was developed by Qin Zhou, Jinglin Zhenga, Seita Onishia, M. F. Crommie, and Alex K. Zettl. Their ultrasonic radio is designed to operate at a band centered around 300 kHz with only a single channel. Their design is effective, but I plan to improve upon it by lowering the operational frequency to have less interference.

7.2 Overview

There are many different parts involved in creating this ultrasonic radio and a large focus for this project will be designing individual parts. An overview of the components involved in this radio is as follows. Firstly, the incoming signal will be amplified using a transistor-based amplifier. Then the signal will be filtered using a bandpass circuit and moved to a higher frequency, if necessary, with a mixer. Next, the signal will be modulated using frequency modulation. Then the signal will be filtered once more for noise and amplified with a power amplifier of very large gain (~100 dB). After this the signal will pass through the input transducer and the output transducer. After the signal passes through the output transducer the signal will be amplified again using a transistor-based amplifier, and then filtered. Finally, the signal may be filtered again to reduce noise before the final signal is output.

7.3 Referenced Documents and Standards

- Graphene electrostatic microphone and ultrasonic radio (pnas.org)
- *C95.1*, Standard for Safety Levels with Respect to Human Exposure to Radio-Frequency Electromagnetic Fields, 3 kHz to 300 GHz

8. Operating Concept

8.1 Scope

The ultrasonic radio is primarily intended to be used for military operations in areas where electromagnetic communications are difficult. This primarily includes during plane and submarine transportation. The ultrasonic radio could also be used at a lower capacity by regular consumers during flights.

8.2 Operational Description and Constraints

The ultrasonic radio should be simple to operate and will be operable without any in-depth knowledge or training. Essentially you should be able to speak on one side of the radio and hear the output of your voice on the other side in relative clarity. The radio at this time will only allow one-way communication but eventually can be improved to allow two-way communication with more time and resources.

There are several constraints that come with this project. One of them is the cost constraint. As a capstone student, we are afforded $100 to spend on our project per person. For a two person group we are afforded $200 to spend. Since we needed to purchase transducers and multiple PCBs this project is relatively expensive. Because of this we will most likely be using discrete components to design the amplifiers and filters. This will lead to more noise and less precision in the designs. Another constraint on this ultrasonic radio is that since the system will be using acoustic waves, the transmission of information will be slower than most electromagnetic wave transmissions. Finally, because we are a small two person group, have no sponsor, and a $200 dollar time constraint we were not able to implement a full-duplex communication system. However, with more budget, time, and manpower a two-way communication system is feasible.

8.3 System Description

The ultrasonic radio can be divided into roughly five different parts. These include signal amplifiers, filters, signal modulator/demodulator, power amplifier, and the input/output transducers.

The signal amplifier will be used to amplify the noise input and output from the radio. The signal amplifier will be designed from discrete transistors. I will attempt to keep the power consumption relatively low by limiting the voltage to +5 VDC and current to <20mA.

The filter on the receiver is primarily used to get rid of noise. The receiver filter is a 2nd order Bessel bandpass filter. This filter has an operational frequency around the 50 kHz range and helps to mitigate unwanted noise at frequencies outside of this range.

To modulate and demodulate the incoming signal we will need to design a frequency modulator and demodulator. To do this we used a transistor with an RC tank circuit that creates an oscillation at 50 kHz to modulate an incoming signal. For the demodulator we used a Phase Locked Loop (PLL) which is a feedback system that acts to adjust or lock the phase difference between the output of a voltage-controlled oscillator (VCO) and an input reference signal.

We also design a power amplifier with multiple transistors in common emitter gain stages. This amplifier has a very large gain of around 70 dBs at the operational frequency of 50 kHz. This power amplifier is very important to allow the signal to be transmitted a further distance.

Finally, transducers were purchased that were able to operate at around 40 kHz. Unfortunately, we could not find any other acoustic transducers that operated closer to 50 kHz that were in our price range. All other transducers we found were either more than $100 or required a special order with long delivery times (while also being expensive).

8.4 Modes of Operations

The ultrasonic radio will simply have two modes. The first being the on mode, or the mode that will allow signal transmission. In this mode the ultrasonic radio is connected to power and allows the user to speak into the microphone. The other mode will be the off mode where the power is disconnected and no signal will transmit.

8.5 Users

The ultrasonic radio is primarily intended to be used by military personnel usually during plane and submarine transportation. The ultrasonic radio could also be used at a lower capacity by regular consumers during flights. The radio should be able to be used with very little experience and a short manual. Overall, the radio should be usable by both the military and civilians with relative ease.

8.6 Support

The ultrasonic radio will be intuitive to use and as such should be usable without any instructions.

9. Scenario(s)

9.1 Plane Communications

The first scenario in which the ultrasonic radio could be used is in the case of plane transportations. To avoid the impact of electromagnetic waves the ultrasonic radio could be used by both military personnel and civilians traveling in planes. This would allow communication between individuals on and off the plane.

9.2 Submarine Communications

Similar to the first scenario the ultrasonic radio could be used to avoid electromagnetic wave interference with submarine instruments. This scenario is less applicable to the public as few civilians use submarines for transportation. The radio would allow contact between submarines or contact between submarines and individuals on land depending on the distance.

10. Analysis

10.1 Summary of Proposed Improvements

- Allows for safer communication around equipment sensitive to electromagnetic waves
- Communication system is easy to use
- Cheaper production

10.2 Disadvantages and Limitations

- The ultrasonic radio with acoustic waves will have less range than an electromagnetic radio
- Increased noise due to cheaper components from budget limitations
- Slower transfer of information due the low operational frequency

10.3 Alternatives

- Improved electromagnetic shielding
    - Shield sensitive plane/submarine components from all other EM waves so that regular electromagnetic communications can be used
    - Could be more effective but would be much more expensive and technically difficult

10.4 Impact

- The ultrasonic radio must abide by radio frequency standards
- The radio may be used to gain a tactical advantage in military operations

Ultrasonic Radio
Nathan Cinocca
Jacob Ralls

Functional System Requirements

REVISION – Draft
28 September 2023

Functional System Requirements
for
Ultrasonic Radio

Prepared by:

Team 84

Approved by:

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Nathan Cinocca Date

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John Lusher, P.E. Date

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T/A Date

Change Record

Rev .	Date	Originator	Approvals	Description
1.0	9/28/2023	Nathan Cinocca		Draft Release
2.0	4/30/2024	Nathan, Jacob		End of 404 Semester

11. Introduction

11.1 Purpose and Scope

This document covers the functional system requirements for the project. The purpose of the project is to provide an alternative way to send communications that does not use electromagnetic waves. By limiting the creation of electromagnetic radiation, this ultrasonic radio will allow for communications in locations that are susceptible to electromagnetic interference. To do this, the radio will operate at lower ultrasonic frequencies as opposed to higher electromagnetic wave frequencies. Additionally, acoustic waves will be used instead of electromagnetic waves.

This specification defines the technical requirements for the development items and support subsystems delivered to the client for the project. Figure 1 shows a representative integration of the project in the proposed CONOPS. The verification requirements for the project are contained in a separate Verification and Validation Plan.

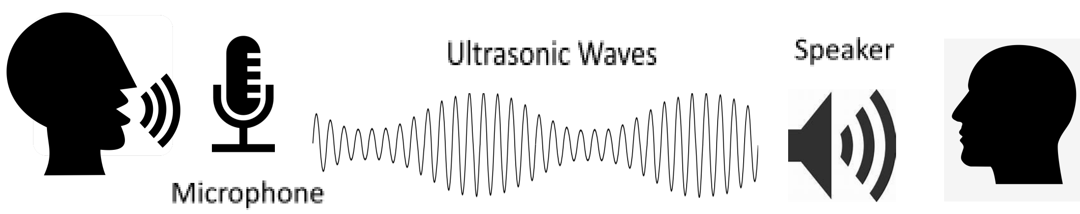

Figure 1. Ultrasonic Radio Conceptual Image

The following definitions differentiate between requirements and other statements.

Shall:	This is the only verb used for the binding requirements.
Should/May:	These verbs are used for stating non-mandatory goals.
Will:	This verb is used for stating facts or declaration of purpose.

11.2 Responsibility and Change Authority

Nathan Cinocca and Jacob Ralls will be the only individuals working on this project. It is the responsibility of these two members for the project to successfully be designed, tested, and validated. There is no sponsor for this project as there was a dilemma on a proper sponsor. Subsystem ownership for this project is listed below.

- Nathan Cinocca: Signal Amplifier, Modulator and Power Amplifier
- Jacob Ralls: Filter and Signal Amplifier, Demodulator

12. Applicable and Reference Documents

12.1 Applicable Documents

The following documents, of the exact issue and revision shown, form a part of this specification to the extent specified herein:

Document Number	Revision/Release Date	Document Title
IPC A-610E	Revision E – 4/1/2010	Acceptability of Electronic Assemblies
MIL-STD-461	Revision E – 8/20/1999	Requirements for the Control of Electromagnetic Interface Characteristics of Subsystems and Equipment
IEEE Standard C95.1	4/16/1999	Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz

Table 1. Applicable Documents

12.2 Reference Documents

The following documents are reference documents utilized in the development of this specification. These documents do not form a part of this specification and are not controlled by their reference herein.

Document Number	Revision/Release Date	Document Title
1	2015	Graphene electrostatic microphone and ultrasonic radio
2	2010	Analog and Digital Communications
3	2011	RF and Microwave Transmitter design
4	2014	FM Modulation/de-modulation circuit
5	2009	Engineering Acoustics: An Introduction to Noise Control
5	2020	Thermal Stress Inside a Disabled Submarine

Table 2. Reference Documents

12.3 Order of Precedence

In the event of a conflict between the text of this specification and an applicable document cited herein, the text of this specification takes precedence without any exceptions.

All specifications, standards, exhibits, drawings or other documents that are invoked as “applicable” in this specification are incorporated as cited. All documents that are referred to within an applicable report are considered to be for guidance and information only, except ICDs that have their relevant documents considered to be incorporated as cited.

13. Requirements

This section defines the minimum requirements that the development item(s) must meet. The requirements and constraints that apply to performance, design, interoperability, reliability, etc., of the system, are covered.

13.1 System Definition

Provide a brief overview of the project, and then describe some of the main sub-systems of your proposed solution.

The ultrasonic radio is a method of communication that limits the creation of electromagnetic waves so electromagnetic interference is minimized. By minimizing the emission of electromagnetic waves, this communication device will allow for information transfer around devices sensitive to other electromagnetic waves. This ultrasonic radio will limit electromagnetic wave emission by using acoustic waves and low ultrasonic frequencies to transmit information. The ultrasonic radio is largely made up of five different subsystems. These subsystems include: the signal amplifier, filters, power amplifier, modulator/ demodulator, and the speakers/microphones.

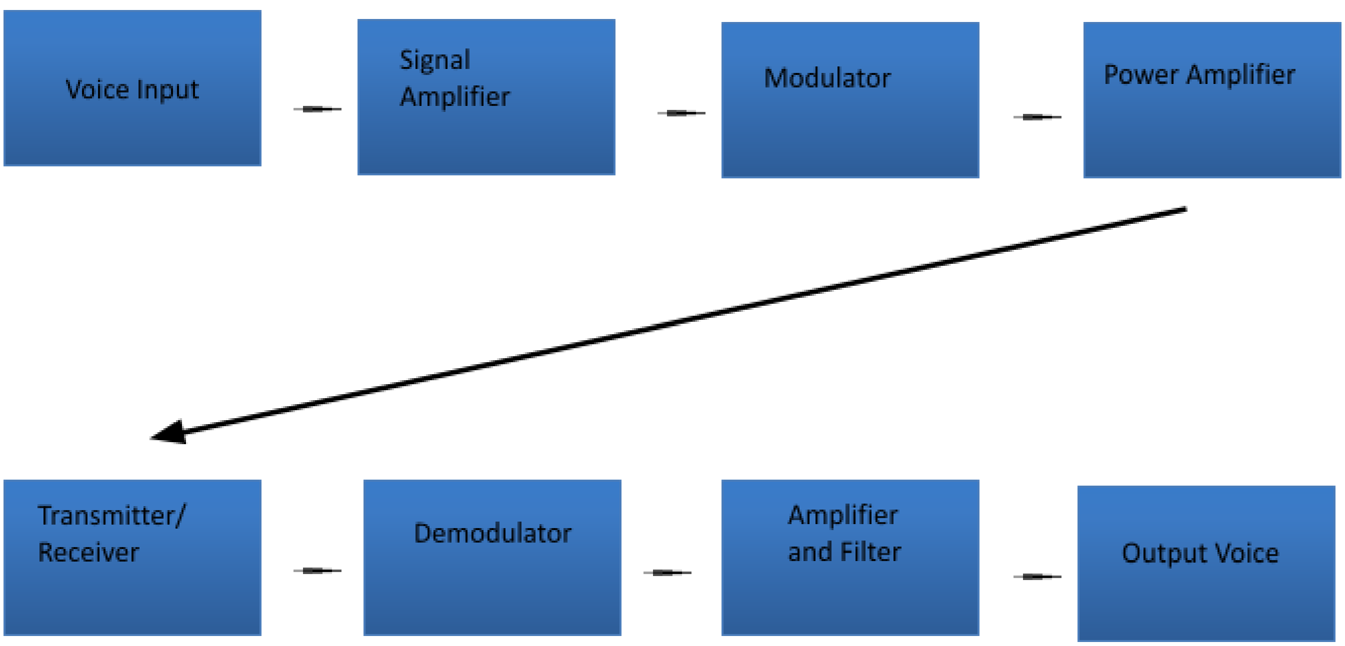

Figure 2. Block Diagram of System

The first part of the ultrasonic radio is the input microphone which will operate to encompass human voice frequencies. This range of operational frequencies will be around 100 Hz to 3 kHz. This microphone will translate the voice into an electrical signal that will then be amplified through the signal amplifier. This will make the signal stronger and easier to transmit through the rest of the system. Following this, the signal will go through a modulating circuit which moves the input signal to ultrasonic frequencies to prepare for transmission. After modulation, the modulated signal will go through the power amplifier which will give the signal the desired gain to transmit through the ultrasonic speaker to the ultrasonic microphone some distance away. Once the signal is picked up by the microphone it will be filtered and amplified again to prepare for demodulation. Then the signal will be demodulated down to frequencies within the range of human hearing. Finally, the signal will be output through a speaker operating within the range of human hearing.

13.2 Characteristics

13.2.1.1 Total Harmonic Distortion

The ultrasonic radio shall have a total harmonic distortion of less than or equal to 10%.

Rationale: It is important to keep total harmonic distortion low to keep good audio quality. Typically, a total harmonic distortion level less than or equal to 10% is acceptable and is the goal for this ultrasonic radio.

13.2.1.2 Frequency Match

The transmitted signal frequency and the tuned demodulator should be within 3 kHz.

Rationale: It is important to have the frequency modulator and demodulator at roughly the same frequency or they will not be compatible.

13.2.2 Physical Characteristics

13.2.2.1 Mass

The mass of the ultrasonic radio shall be less than or equal to 10 kilograms.

Rationale: While there isn't a specific weight requirement for the ultrasonic radio, it should be relatively easy to move around for maximum use. A weight of up to 10 kilograms should be easy for any military man/woman to move.

13.2.3 Electrical Characteristics

13.2.3.1 Inputs

The electrical inputs should not be changed by users of the ultrasonic radio. All tests will be performed under these conditions and system performance under separate conditions is not guaranteed.

13.2.3.1.1 Power Consumption

The maximum peak power of the system shall not exceed 9 watts.

Rationale: This requirement is due to the power of the system being provided by a 9 V battery on the receiver end. High power consumption will drain the battery quickly resulting in poor performance of the ultrasonic radio. Additionally the maximum current of a 9 V battery is 1 A giving a maximum power consumption of 9 watts

13.2.3.1.2 Input Voltage Level

The input voltage level for the ultrasonic radio shall not exceed +9 VDC.

Rationale: 5 V and 9 V batteries are readily available, so using them to power the ultrasonic radio is a reasonable limit on voltage level.

13.2.3.1.3 Input Current Level

The input current for the ultrasonic radio shall not exceed 1 A.

Rationale: 1 A is the maximum current that can be supplied by a 9V battery and is thus the maximum current that can be supplied to the ultrasonic radio.

13.2.3.1.4 Voice Input

The ultrasonic radio shall take user voice input that operates from 100 Hz to 3 kHz.

Rationale: The ultrasonic radio needs to be able to handle any range of human voice frequencies and transmit them which ranges from 100 Hz to 3 kHz.

13.2.3.2 Outputs

13.2.3.2.1 Voice Output

The ultrasonic radio shall output the voice frequencies at 100 Hz to 3 kHz and shall be heard up to 15 meters away.

Rationale: The ultrasonic radio will allow communications to pass into the microphone and out through the output speaker a distance up to 15 meters away to satisfy the conditions of a radio.

13.2.4 Environmental Requirements

The ultrasonic radio shall be designed to withstand and operate in the environments and laboratory tests specified in the following section.

Rationale: This is a requirement specified by the intended usage of the ultrasonic radio

13.2.4.1 Pressure

The ultrasonic radio may be able to operate up to 1 atm of pressure.

Rationale: The internal pressure of a typical military submarine is roughly equivalent to 1 atm around sea level. Thus, to perform its function, the ultrasonic radio should be able to function at this amount of pressure.

13.2.4.2 Thermal

The ultrasonic radio may be able to operate at thermal temperatures ranging from 55 degrees Fahrenheit to 95 degrees Fahrenheit.

Rationale: The internal thermal temperatures of a military submarine without power can range from 55 degrees Fahrenheit to 95 degrees Fahrenheit in extreme scenarios. So, the ultrasonic radio should be able to function in these emergencies.

13.2.5 Failure Propagation

13.2.5.1 Recovery

The Ultrasonic radio should provide a way to reset the entire system.

Rationale: This is a feature of the radio that should help fix errors that occur with the ultrasonic radio.

14. Support Requirements

14.1 5V and 9V Batteries

In order to properly power the transmitter circuit and receiver circuit a 5V battery and a 9V battery will need to be used respectively. These batteries will be provided initially but overtime they will get depleted.

Rationale: We understand that batteries will drain and will need to be replaced which is why we are recommending users to have some available

Ultrasonic Radio

Nathan Cinocca
Jacob Ralls

INTERFACE CONTROL DOCUMENT

REVISION – Draft
28 September 2023

Interface Control Document
for
Ultrasonic Radio

Prepared by:

Team 84

Approved by:

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Nathan Cinocca Date

____
John Lusher II, P.E. Date

____
T/A Date

Change Record

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1.0	9/28/2023	Nathan Cinocca		Draft Release
2.0	4/30/2024	Nathan, Jacob		End of 404 Semester

15. Overview

This Interface Control Document (ICD) will provide detail on how the various subsystems of the ultrasonic radio will function together. This document will also detail physical descriptions of various subsystems of the ultrasonic radio. The Interface Control Document will also explain how the subsystems will interface together to meet the requirements explained in the Functional System Requirements document and ConOps document.

16. References and Definitions

16.1 References

Refer to section 2.2 in the Functional System Requirements document.

16.2 Definitions

ATM	Atmosphere
CONOPS	Concept of Operations Document
dB	Decibels
Hz	Hertz
ICD	Interface Control Document
Kg	kilograms
kHz	Kilohertz (1,000 Hz)
mA	Milliamp
MHz	Megahertz (1,000,000 Hz)
Mm	Millimeter
mW	Milliwatt
SNR	Signal to Noise Ratio
TBD	To be determined
USB	Universal Serial Bus
VDC	Direct Current Voltage
W	Watt

17. Physical Interface

17.1 Weight

The overall weight of the system is well under the 10 kg maximum weight at roughly 0.171 kg. The majority of the weight comes from the batteries and output speaker which are moderately heavy compared to our PCBs.

17.2 Dimensions

The dimensions of the entire ultrasonic radio should be kept under 3 cubic feet in size.

Although there have been different iterations of the ultrasonic radio throughout the development process, the largest radio consisted of 4 different PCBs which was roughly 2 feet in length. On the other hand, with our fully consolidated boards the ultrasonic radio was about 1.2 feet in length. For width all of our iterations were roughly 4 inches with a height of around 3 inches. These dimensions are significantly smaller than the 3 cubic feet limit so the only moderate size concern is in length. Regardless, the ultrasonic radio dimensions are well within the 3 cubic feet requirements as our PCB boards are relatively small.

18. Thermal Interface

Since the ultrasonic radio will be functioning at relatively low power, it will not need any heat sink to maintain low heat and high efficiency.

19. Electrical Interface

19.1 Primary Input Power

The ultrasonic radio has a maximum power of 9 watts. More specifically this is 9 V and 1A of current supplied by a 9 V battery on the receiver side. Although the transmitter side can operate with a 9 V battery it can operate just as well with only 5 V and 1 A. Operating the entire ultrasonic radio at 9 V gives a maximum input power consumption of 549 mW. This is far below the maximum of 9 W making our system efficient.

19.2 Voltage and Current levels

- The Transmitter used a total of 39 mA at 5 V for a total of 195 mW
    - At 9 V the transmitter used 39 mA for an absolute maximum power usage of 351 mW when using a 9 V battery
- The Receiver used a total of 22 mA at 9 V for a total of 198 mW.

20. Communications / Device Interface Protocols

20.1 Communications Safety

Although this radio operates at a frequency that can not be heard by the human ear. The ultrasonic radio can still cause hearing loss from excessive exposure to ultrasonic frequencies. Thus, clients that are using the ultrasonic radio for extended amounts of time should wear ear protection.

Ultrasonic Radio

Nathan Cinocca
Jacob Ralls

SUBSYSTEM REPORTS

REVISION – Draft
3 December 2023

Subsystem Reports
for
Ultrasonic Radio

Prepared by:

Jacob Ralls & Nathan Cinocca 12/3/2023

Author Date

Approved by:

Nathan Cinocca 12/3/2023

Project Leader Date

John Lusher, P.E. Date

T/A Date

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21. Introduction

The Ultrasonic Radio plays a pivotal role in revolutionizing communication technologies by introducing an innovative approach to data transmission. The primary objective of this system is to establish reliable communication channels in environments sensitive to electromagnetic interference. By utilizing ultrasonic frequencies and acoustic waves, this subsystem mitigates the challenges posed by traditional electromagnetic wave-based communication systems. The system is broken down into the signal amplifier, filter, modulator, demodulator, and power amplifier. The subsystems are the key components within the broader framework of the Ultrasonic Radio project, as outlined in the Concept of Operations (ConOps), Functional System Requirements (FSR), and Interface Control Document (ICD).

22. Transmitter Side

22.1. *Signal Amplifier*

22.1.1 Subsystem Introduction

The signal amplifier is the second stage on the transmitter side of the ultrasonic radio. The goal of the signal amplifier is to increase the strength of the incoming signal from the microphone. Typically, the input from the microphone was in the range of millivolts to microvolts. This level of voltage was on the order of circuit noise so the information signal needed to be amplified. The amplified signal will then be able to move through the frequency modulator more easily.

22.1.2 Subsystem Details

The precise value of the signal amplifiers gain is not exceedingly important. As such I decided that a gain of around 20 dB - 25 dB would be an effective amplification. The signal amplifier should operate within the 100 Hz to 3330 Hz range to amplify all possible voice inputs. Additionally, the goal was to maintain relatively low current as the maximum allowed current is 900 mA. The resulting signal amplifier design is shown in **Figure 3** and the PCB that was tested is displayed in **Figure 4**.

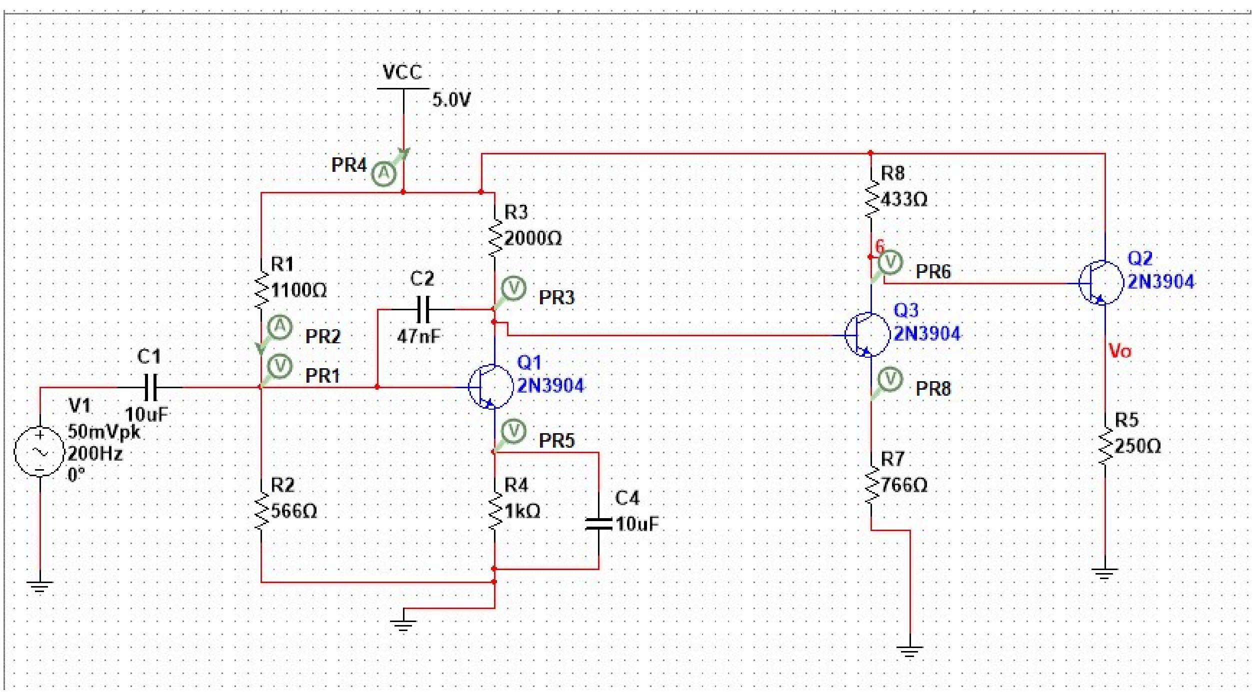

Figure 3: Signal Amplifier Schematic

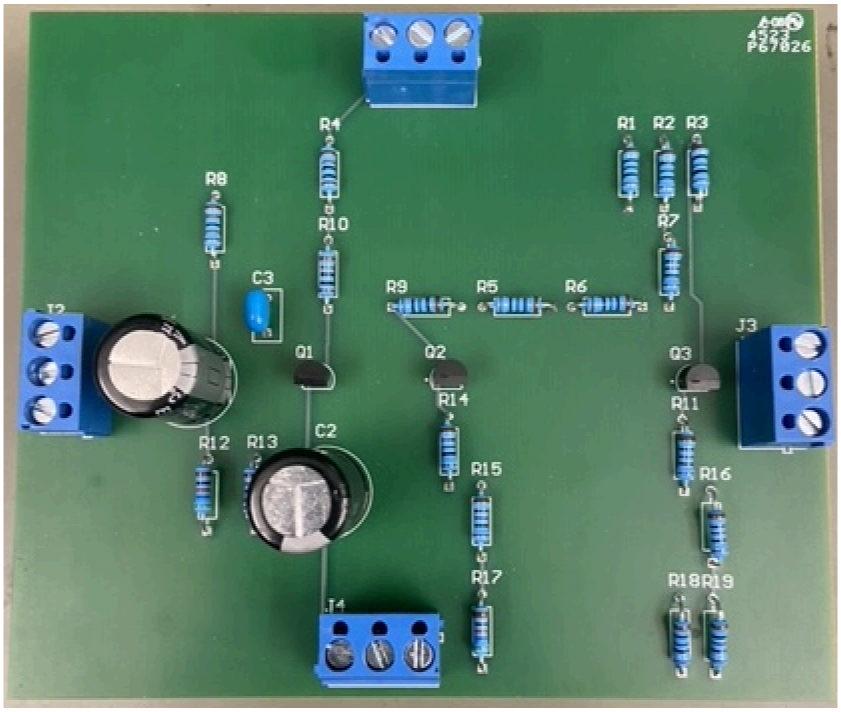

Figure 4: Signal Amplifier PCB

22.1.3 Subsystem Validation

The power consumption of the signal amplifier operated as expected according to the simulations. As shown in **Figure 5**, the signal amplifier consumed 17 mA and used 5 V. This 85 mW of power is very acceptable considering the maximum power allowed is 4.5 W.

Figure 5: Signal Amplifier PCB Power Consumption

The signal amplifier worked as expected shown in **Figure 6**. The signal amplifier had a strong gain of roughly 27 dBs centered around 1 kHz. The amplifier maintained gain at the edges of the target frequency range. More specifically, the amplifier had a gain of approximately 15 dBs at 100 Hz and 23 dBs at 3 kHz. This response is very similar to what was found in simulations which is shown in **Figure 7**. There are only two small differences between the simulations and PCB testing. Firstly, the frequency response is a little bit noisy on the PCB testing. This is likely due to surrounding signals in the testing room. However, the noise in the frequency response is hardly an issue as it primarily occurs in the 100 kHz range which is irrelevant to the transmitting signal's frequency. This frequency range is also being diminished by the signal amplifier, therefore this should have practically no effect on the signal amplifier.

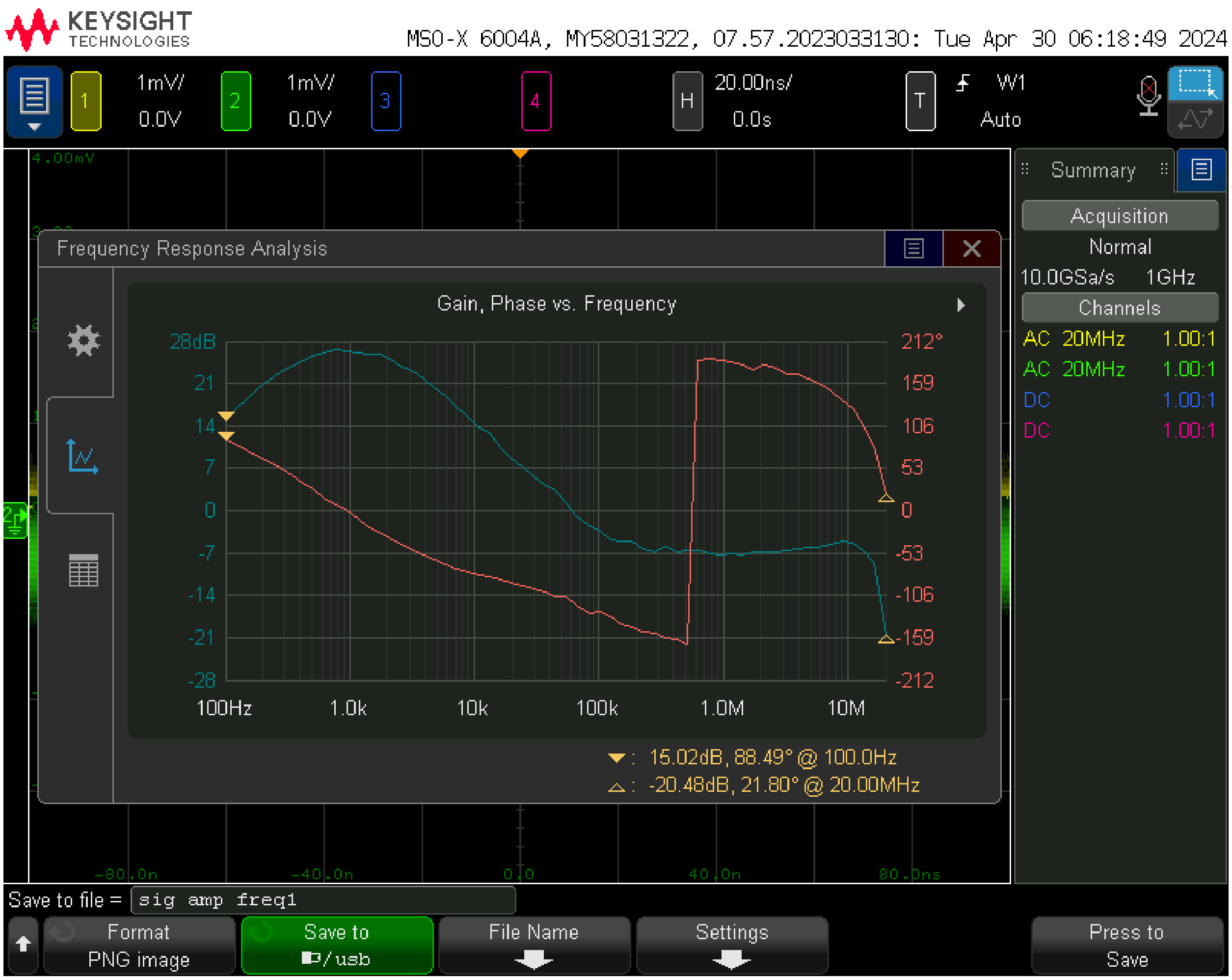

Figure 6: Signal Amplifier PCB Frequency Response

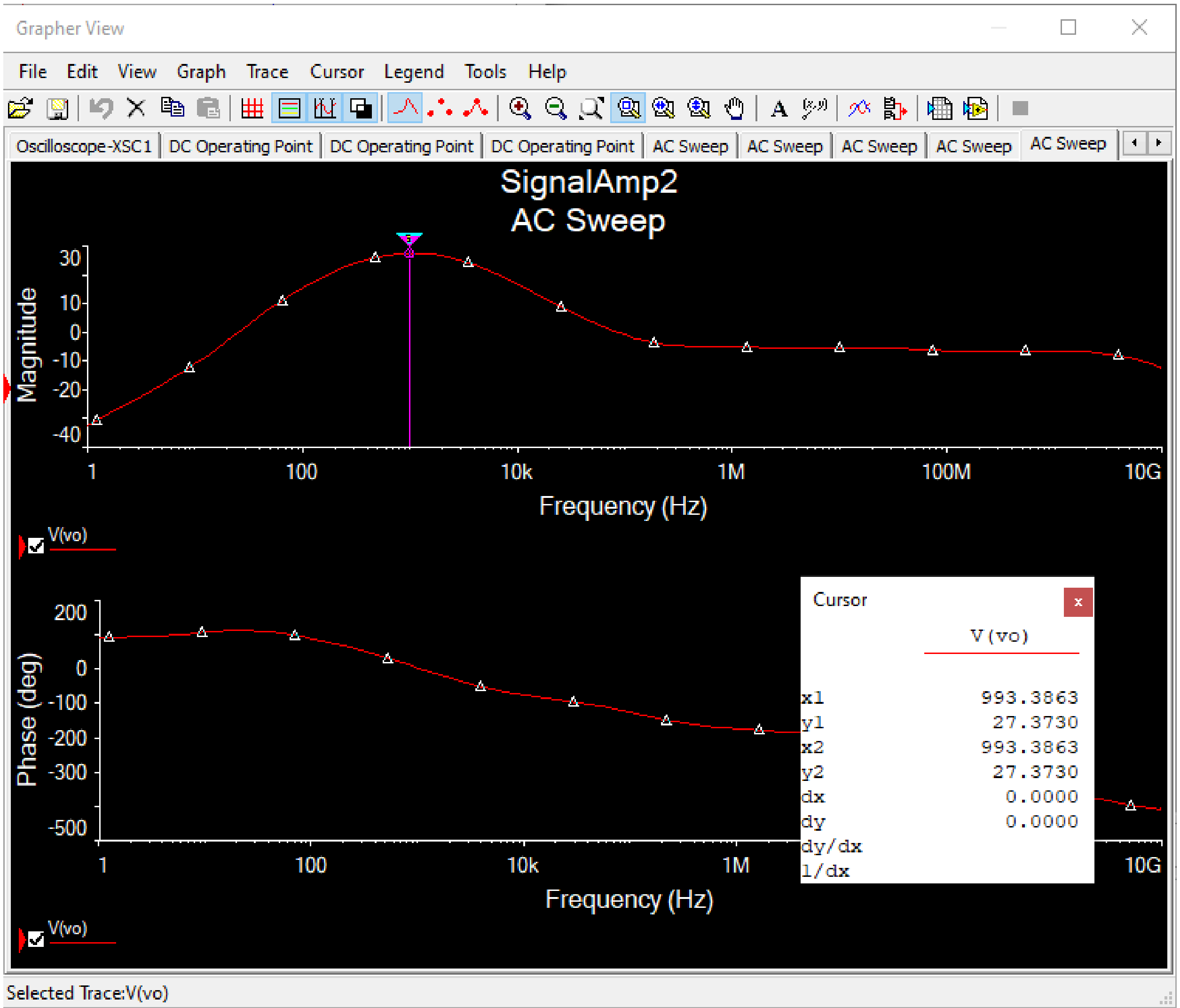

Figure 7: Signal Amplifier Simulated Frequency Response

To prove and validate that the microphone input was transmitted into the circuit various noises were sent through the microphone and measured at the output of the signal amplifier. These noises included speaking, taps on the microphone, and even music. Real noises are not pretty to work with so although the output signals look messy, **Figure 8** shows that input sounds were amplified up to a reasonable >60 mV peak to peak. This proves that the transmitter side can successfully intake and amplify a wide range of frequencies that the rest of the system can transmit.

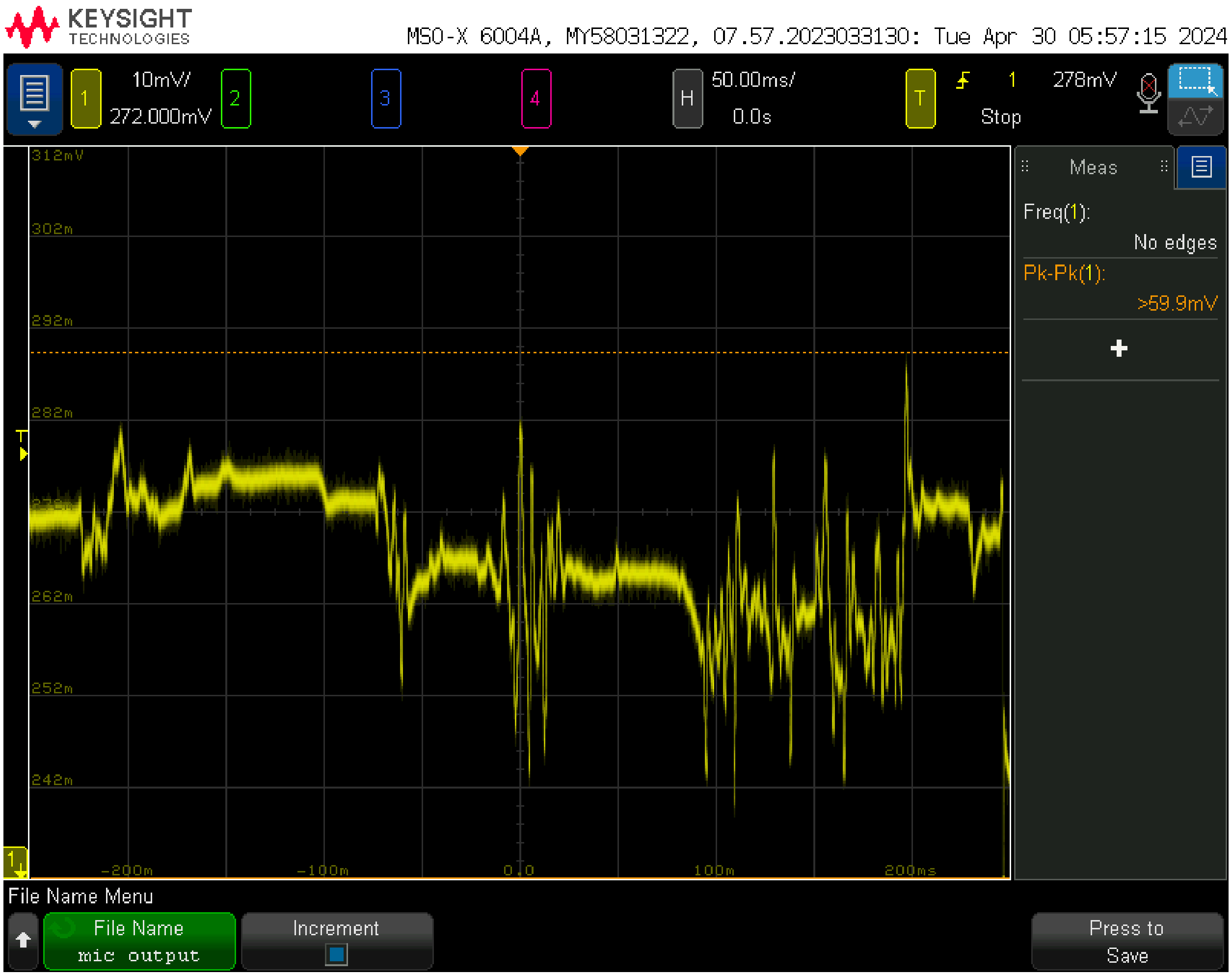

Figure 8: Signal Amplifier Output With Microphone Input

22.1.4 Subsystem Conclusion

In conclusion, the dc power (85mW) of the signal amplifier worked at the proper levels and was validated as acceptable power consumption. The gain of the signal amplifier was also able to amplify all microphone inputs up to reasonable levels for the rest of the transmitter side of the ultrasonic radio. Therefore all aspects of the signal amplifier and input signal voice requirements have been validated.

22.2 Frequency Modulator

22.2.1 Subsystem Introduction

After the audio signal is amplified in the signal amplifier, the signal travels through the frequency modulator. The frequency modulator is what creates the ultrasonic aspect of the ultrasonic radio. In other words, the frequency modulator changes the carrier frequency from a regular audio frequency (100 - 3300 Hz) to an ultrasonic frequency which is above human hearing at around 20 kHz. This will allow the information to travel faster and with more accuracy.

Frequency modulators change the frequency of the output signal based on the amplitude of the input signal. For this frequency modulator, the frequency will be modulated to around 50 kHz when the input signal has a low amplitude. The output signal will be at a lower frequency when the input signal amplitude is larger.

22.2.2 Subsystem Details

As stated before, the frequency modulator will modulate the incoming signal to around 50 kHz at its fastest frequency. Just like all the other transmitter subsystems the frequency modulator will use 5 V and work to maintain a low current usage so that the maximum current limit is not exceeded. **Figure 9** shows the frequency modulator schematic and **Figure 10** shows the frequency modulator PCB.

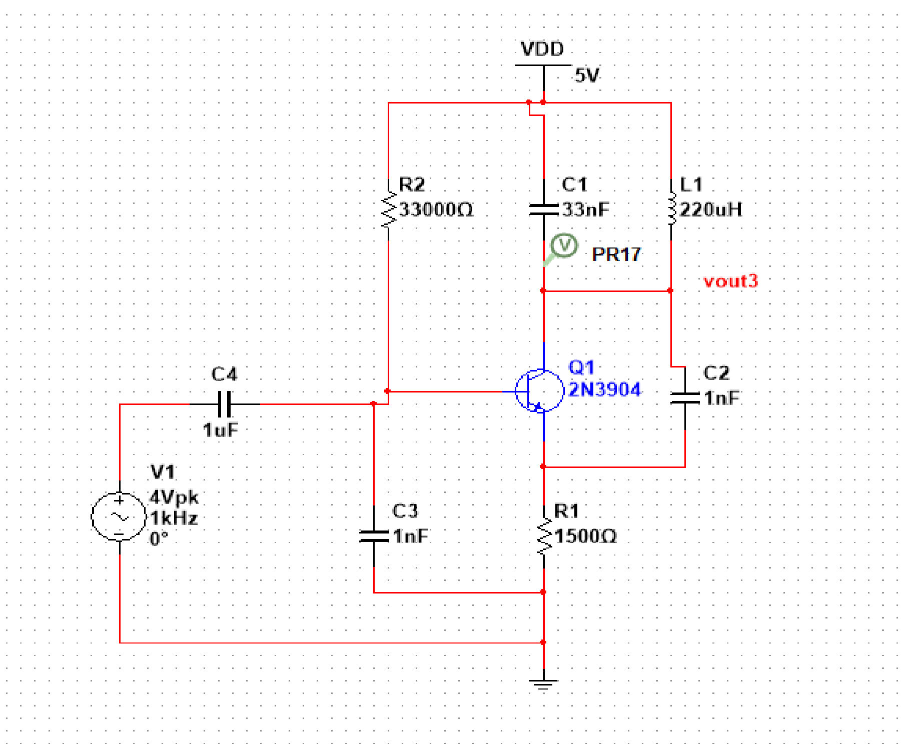

Figure 9: Frequency Modulator Schematic

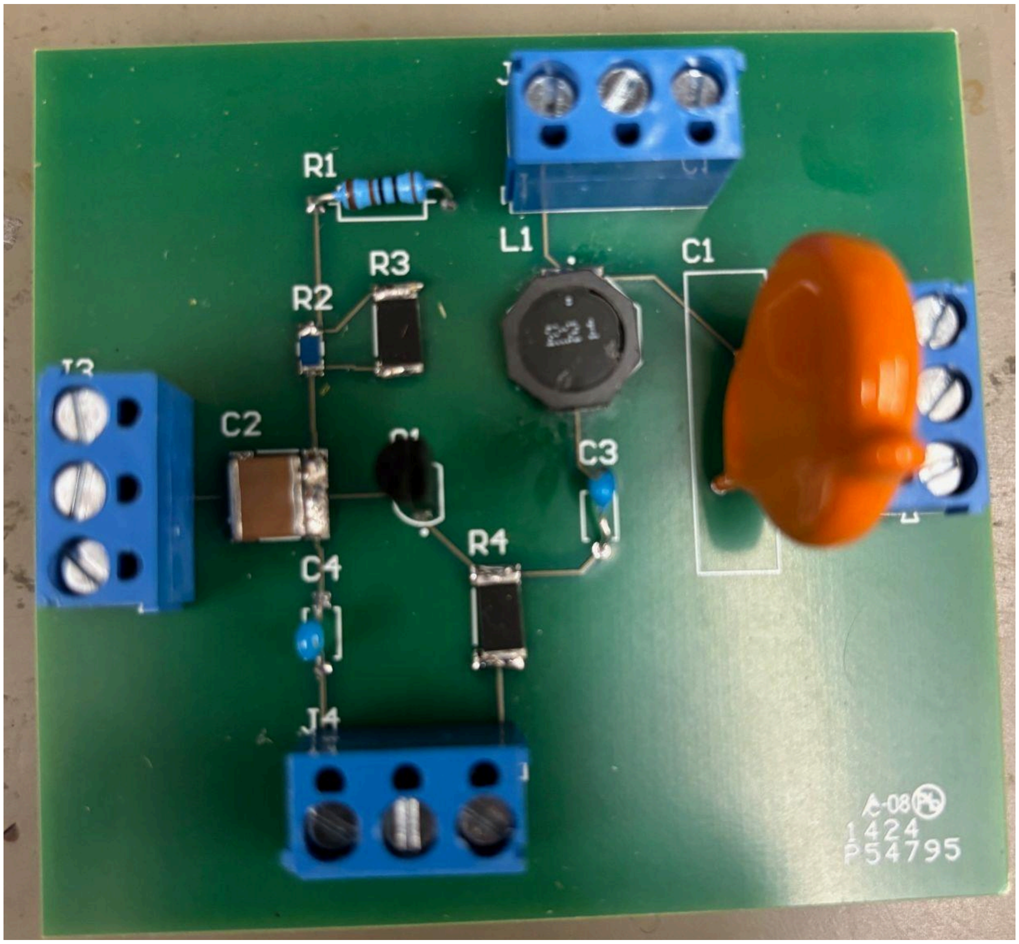

Figure 10: Frequency Modulator PCB

22.2.3 Subsystem Validation

The Frequency Modulator met the voltage and current requirements. As shown in **Figure 11**, the frequency Modulator used 5V and around 2 mA of current for a total of 14 mW of power. This makes the power consumption very low and not a burden to the total ultrasonic radio.

Figure 11: Frequency Modulator Power Consumption

The transient simulation that shows how the input signal was modulated was very similar to simulations. The frequency modulator was tested with a 1 kHz sinusoidal wave input. The resulting output is shown in **Figure 12**. **Figure 12** shows the input signal modulated up to 50 kHz with a peak to peak of 462 mV. Although it is difficult to show without a video, the frequency alternated around this 50 kHz center going as low as 45 kHz and as high as 60 kHz. This is what you can expect from a frequency modulated signal as it changes frequency slightly based on the input signal's amplitude while staying centered around the desired frequency which in this case was roughly 50 kHz.

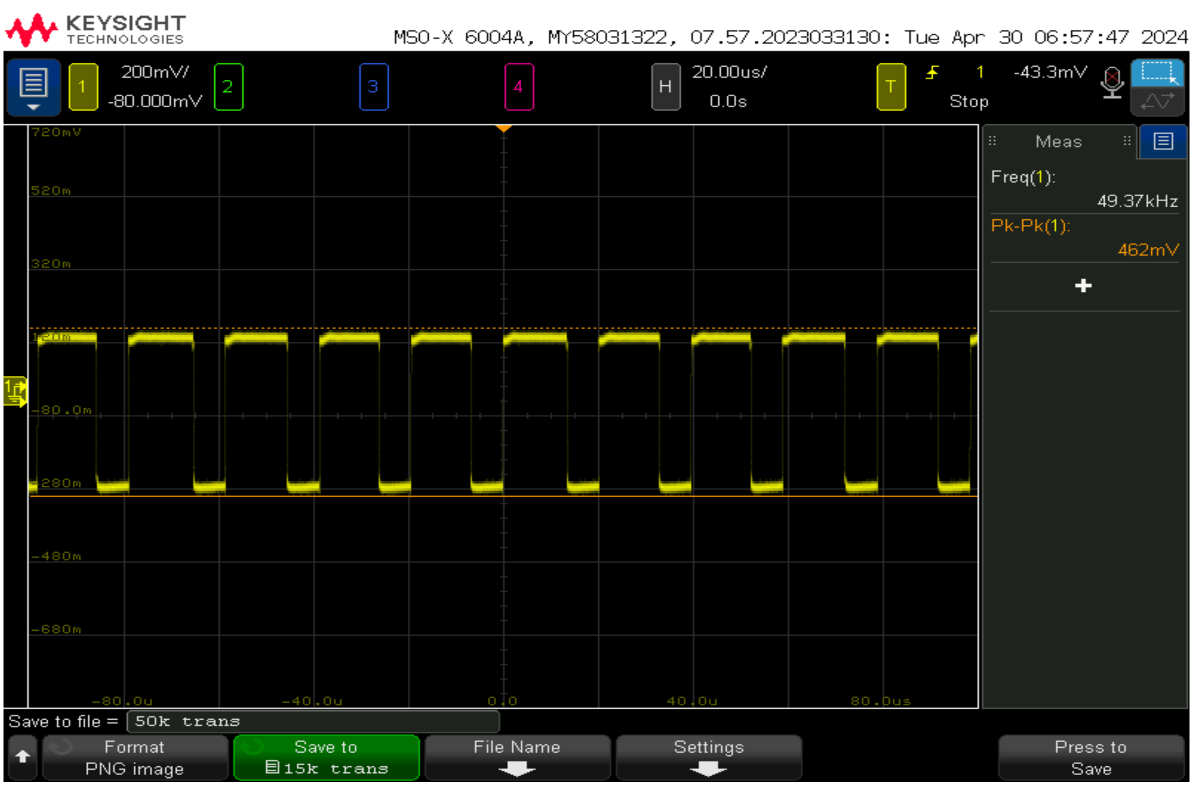

Figure 12: Frequency Modulator Transient

Figure 13 shows a transient simulation of the frequency modulator in multisim. In the image you can see the time difference between the peaks of the output sin wave is approximately 20 microseconds which corresponds to a frequency of 50 kHz. Therefore, this simulation matches up closely with actual tests shown in **Figure 12**.

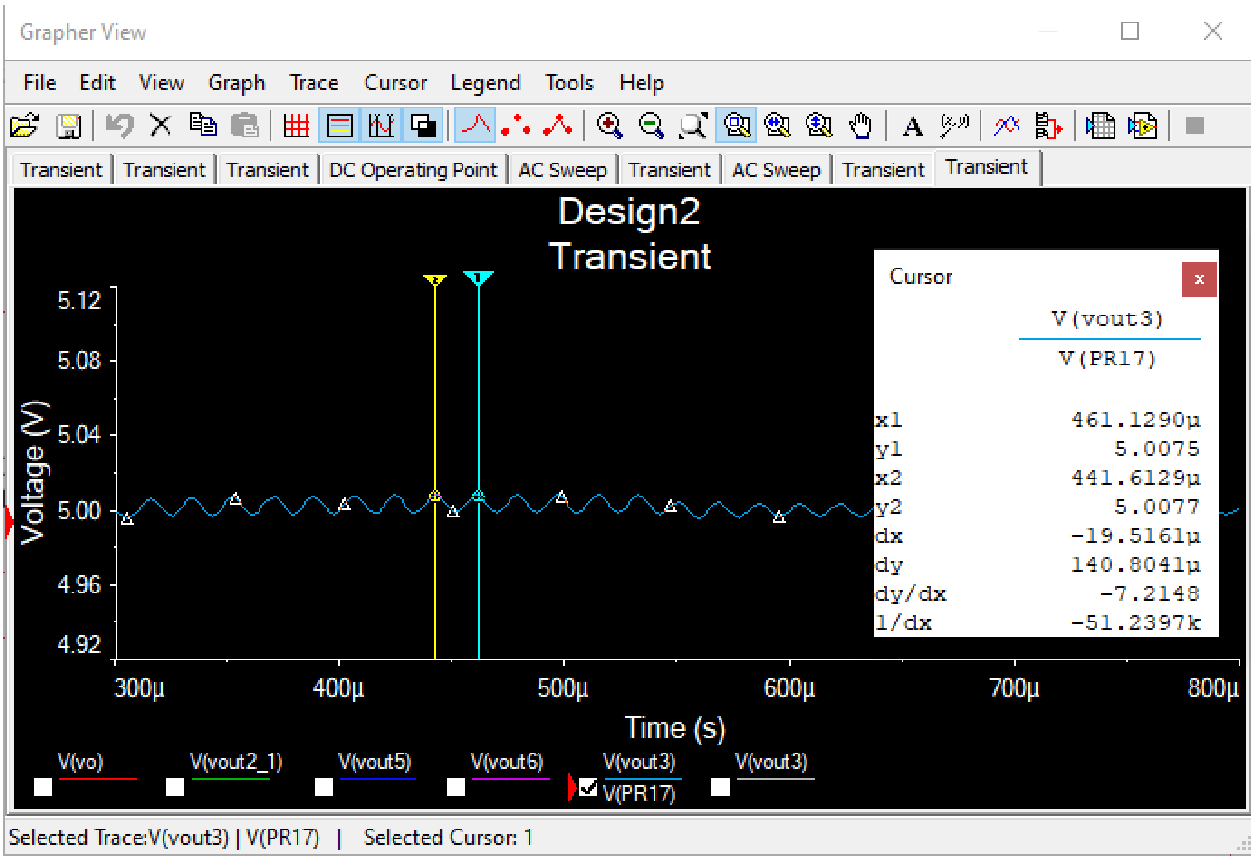

Figure 13: Frequency Modulator Simulation

22.2.4 Subsystem Conclusion

In conclusion, the frequency modulator worked as expected. The modulator operated at the correct 50 kHz frequency and used a small amount of power so as to not impact the maximum power consumption threshold. Overall there seemed to be no issues with the frequency modulators function.

22.3 Power Amplifier

22.3.1 Subsystem Introduction

The final subsystem on the transmitter side of the ultrasonic radio is the power amplifier. The power amplifier increases the strength of the signal by a very large amount. This is important because the signal will attenuate and lose strength as it is being transmitted. If the signal loses too much power, it will be very difficult to receive and the signal to noise ratio will be very low. Additionally, since the signal will be transmitted acoustically and not through electromagnetic waves, there will be much higher attenuation than in usual communication methods.

22.3.2 Subsystem Details

Similarly to the other subsystems, the power amplifier will operate using 5 V while trying to use a low amount of current. The power amplifier should operate at 50 kHz or higher in order to properly amplify the modulated signal at around 50 kHz. Additionally, the gain at this frequency should be at least 60 dB in order to transmit the signal a sufficient distance. The schematic of the power amplifier is shown in **Figure 14** and the PCB of the circuit is shown in **Figure 15**.

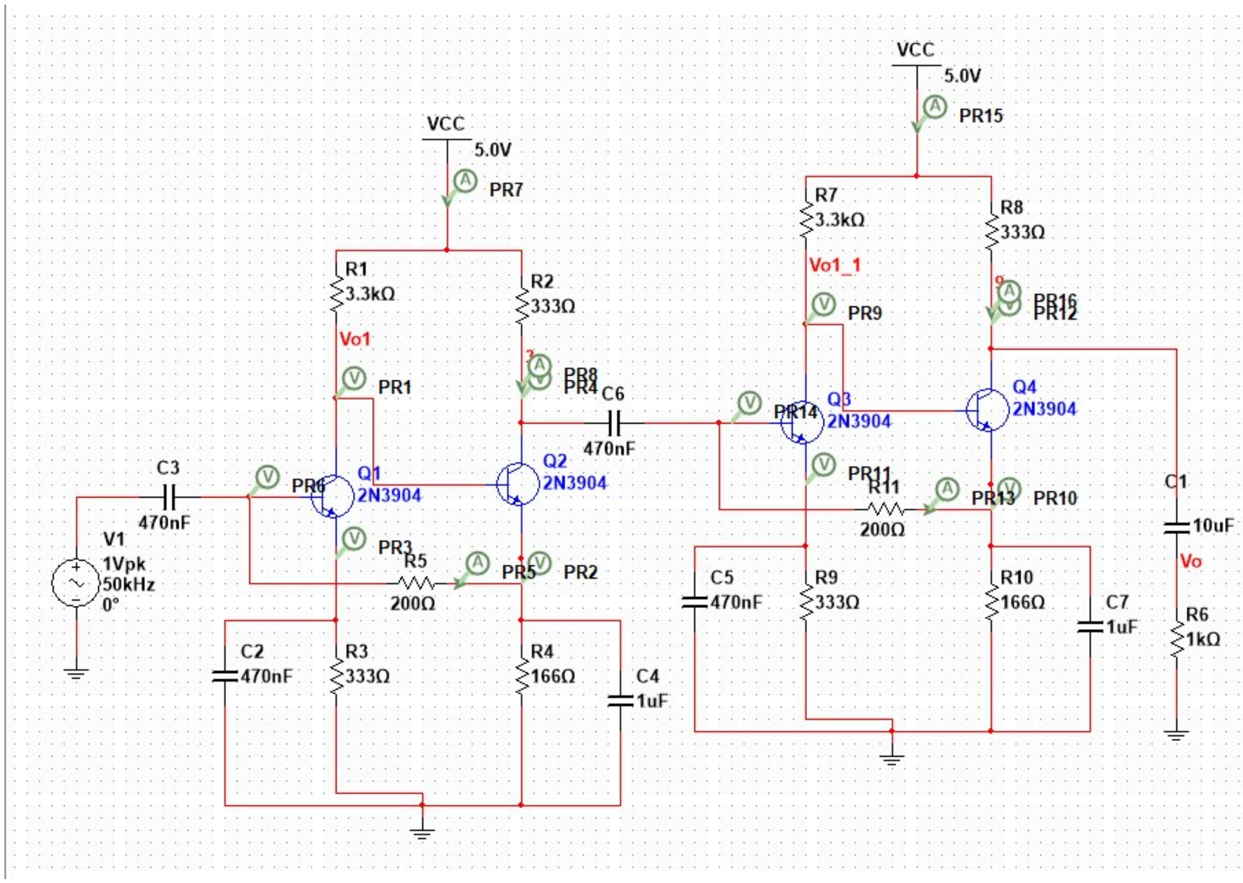

Figure 14: Power Amplifier Schematic

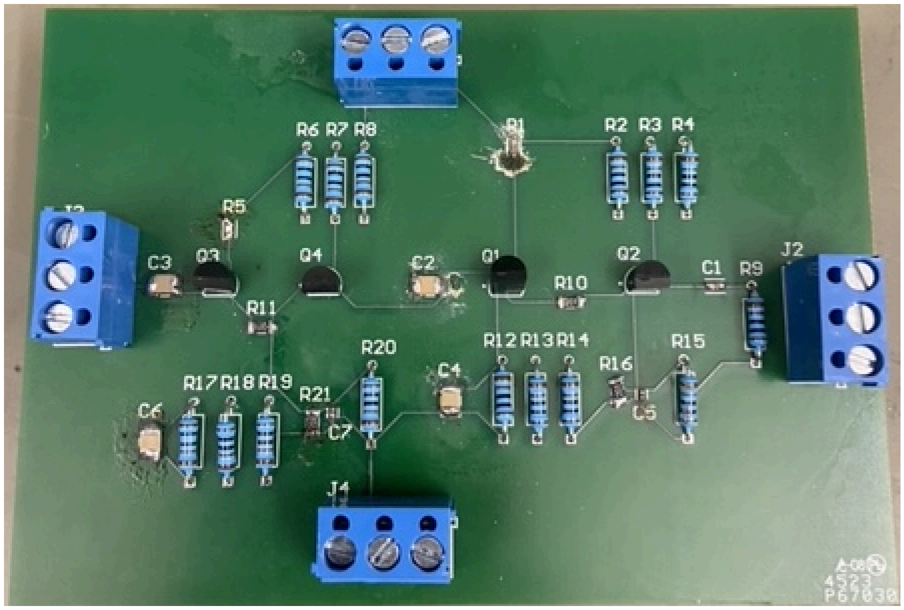

Figure 15: Power Amplifier PCB

22.3.3 Subsystem Validation

When testing the power amplifier PCB, it was able to meet the power consumption requirements. As shown in **Figure 16**, the power amplifier used the proper 5 V and used only 20 mA of current for 101 mW of power. Combined with the current consumption of the rest of the transmitter subsystems, the current consumption is well under the maximum 900 mA.

Figure 16: Power Amplifier Power Consumption

Figure 17 shows the frequency response of the power amplifier. As shown the power amplifier meets the required gain of above 60 dBs with a gain around the 50 kHz range of approximately 70 dBs. The power amplifier has decent bandwidth from 20 kHz to 100 kHz to account for the signal changing frequencies and any variation in the frequency modulator center frequency. The power amplifier does have quite high gain at frequencies that are not necessarily transmitted such at 1.1 Mhz. However, this should not be too much of an issue as only low frequency signals are transmitted. Additionally, there is a filter at the output on the receiver side which should be able to mitigate any transmitter MHz noise.

Figure 17: Power Amplifier PCB Frequency Response

Figure 18 shows the simulated frequency response for the power amplifier. The response is quite similar to the tested PCB response, but has about 30 dBs less gain. While this is significant, since the power amplifier still meets the required gain amount this should not be much of a problem. Additionally, this may also just be a measurement limitation as oscilloscopes can only measure so much gain. Therefore, the gain may be unable to be measured properly.

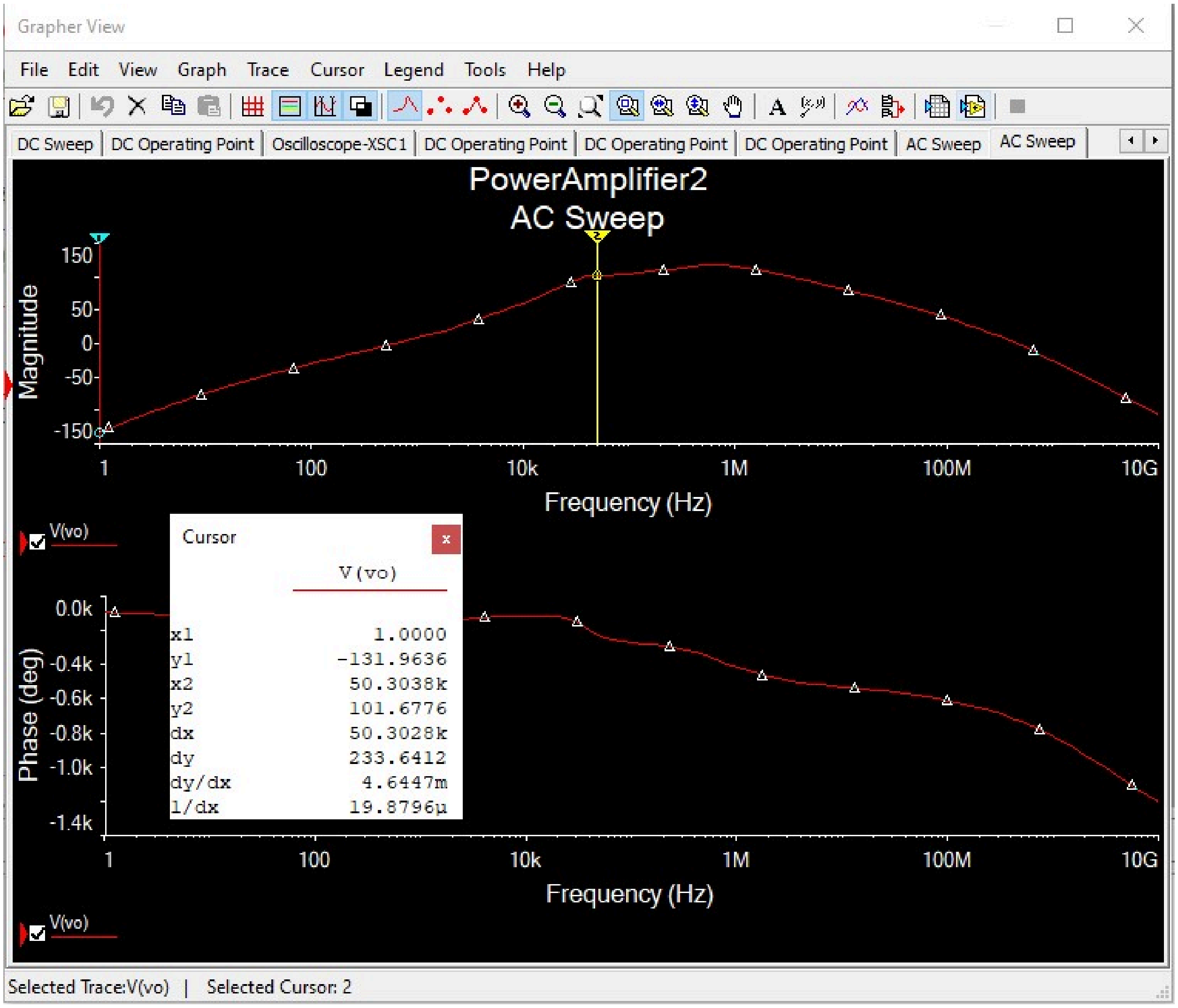

Figure 18: Power Amplifier Simulation Frequency Response

22.3.4 Subsystem Conclusion

In conclusion, the power requirements of the power amplifier were met. The power amplifier also amplified the signal to the required amount of > 60 dBs and operated in the required frequency range of around 50 kHz. Therefore, the power amplifier functions properly.

23. Receiver Side

This section will go over the receiver side of the Ultrasonic Radio project. This portion of the project is responsible for capturing, processing, and translating incoming ultrasonic signals back into audible communication. Let's break down the key subsystems involved in the receiver side.

23.1 Filter and Amplifier Subsystem

23.1.1 Subsystem Introduction

The Filter and Amplifier Subsystem on the receiver side of the Ultrasonic Radio project plays a crucial role in enhancing the quality and strength of the incoming ultrasonic signals before they undergo further processing. This subsystem is dedicated to ensuring that the received signals are clear, free from interference, and optimized for the subsequent stages of demodulation and conversion into audible communication. The filtering component of the subsystem aims to eliminate undesired noise or interference that may have been picked up during the transmission of ultrasonic signals. Along with the filtering process, the subsystem incorporates amplification mechanisms to boost the strength of the filtered signals. This is essential to ensure that the signals maintain clarity and integrity throughout the demodulation and conversion stages.

23.1.2 Subsystem Details

The circuit that was chosen was a 2nd order Chebyshev Bandpass Filter as this model allows for a specific range of frequencies to pass through while attenuating frequencies outside that range. A gain of roughly 20-40 dB was selected to ensure that weak ultrasonic signals are adequately amplified for further processing. As for the bandwidth, ultrasonic frequencies generally start above human hearing frequencies (20 kHz) and can operate at frequencies into several hundred kHz. However for this project the filter will only operate with a max of roughly 150 kHz. Below you can see the schematic for this circuit along with the corresponding bodeplot:

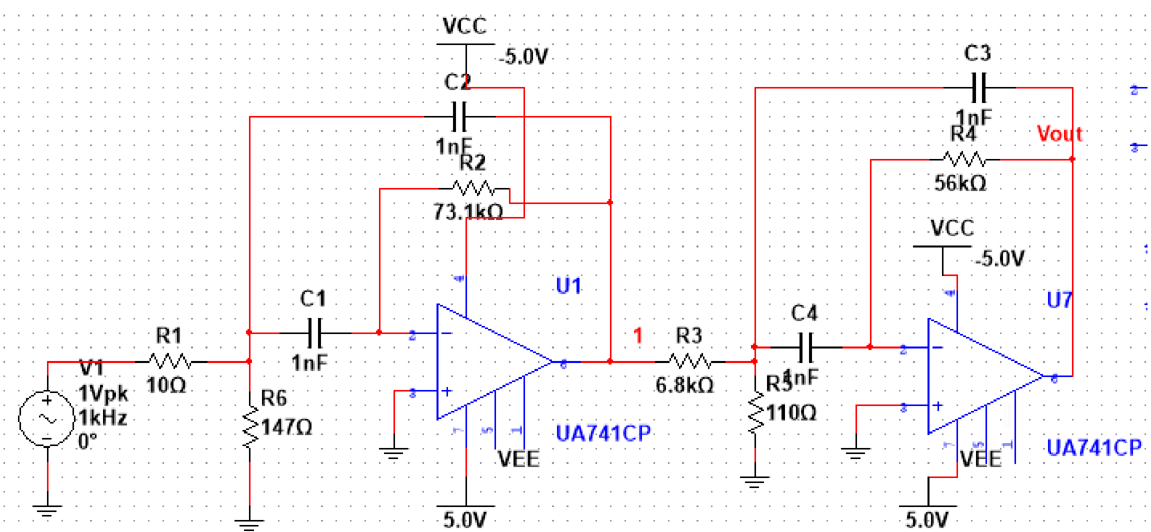

Figure 19: 2nd Order Chebyshev Bandpass Filter

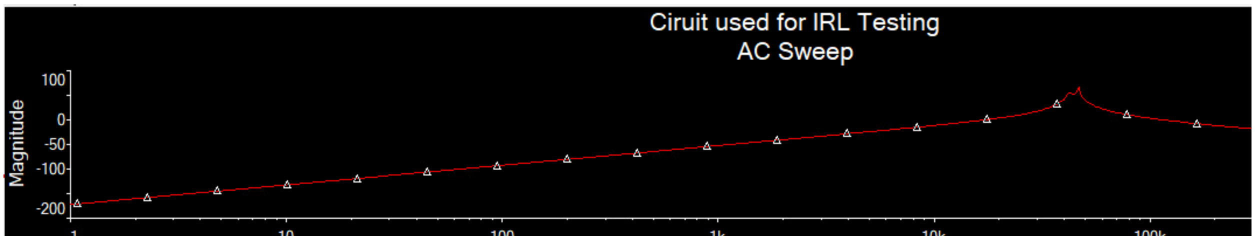

Figure 20: Simulated Bodeplot for designed BPF

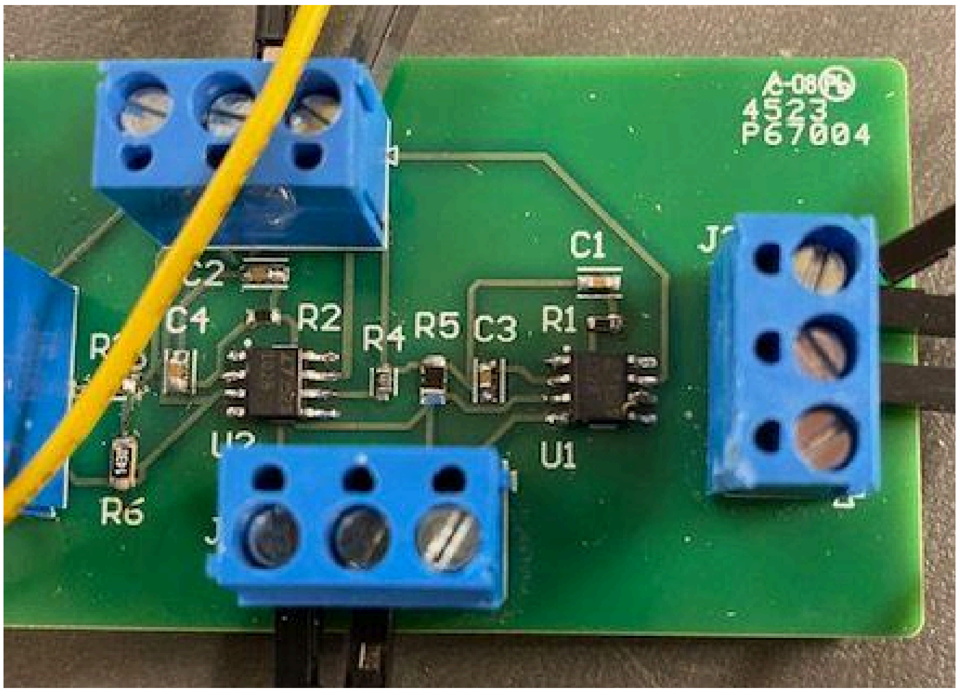

Figure 21: BPF PCB

23.1.3 Subsystem Validation

Before creating the PCB design, the circuit was tested extensively on a breadboard. In hindsight this was not the most optimal use of our time but some promising results regarding the peak gain did come out of it. Here was the bodeplot measured:

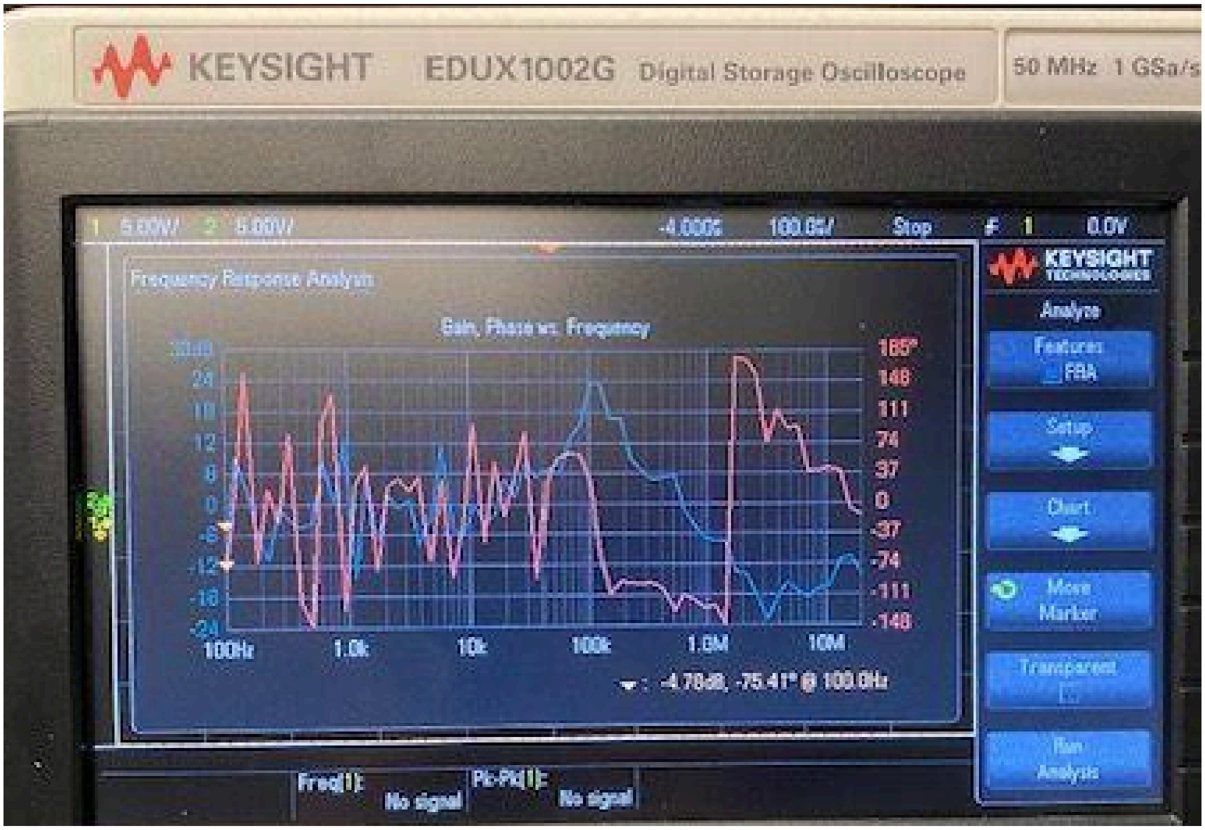

Figure 22: Bodeplot of Breadboard BPF

Table 3: BPF Table of Gain Values w.r.t. Frequency

Freq (Hz)	Gain (dB)
36.49k	5.65
44.72k	5.75
54.81k	6.41
67.18k	12.1
82.33k	17.39
100.9k	24.32
123.7k	23.04
151.6k	15.72
185.8k	11.86
227.7k	8.91
279.0k	3.26

From ***Table 1*** as well as ***Figure 22*** we can state that the design and testing of this bandpass filter worked when taking into account the amount of noise that the breadboard and LM741 op amps read as low end devices.

After the subsystem was designed on a PCB as shown in ***Figure 23***, it was then validated through the A2D Oscillator Bodeplot function. Below was the graph the plot produced:

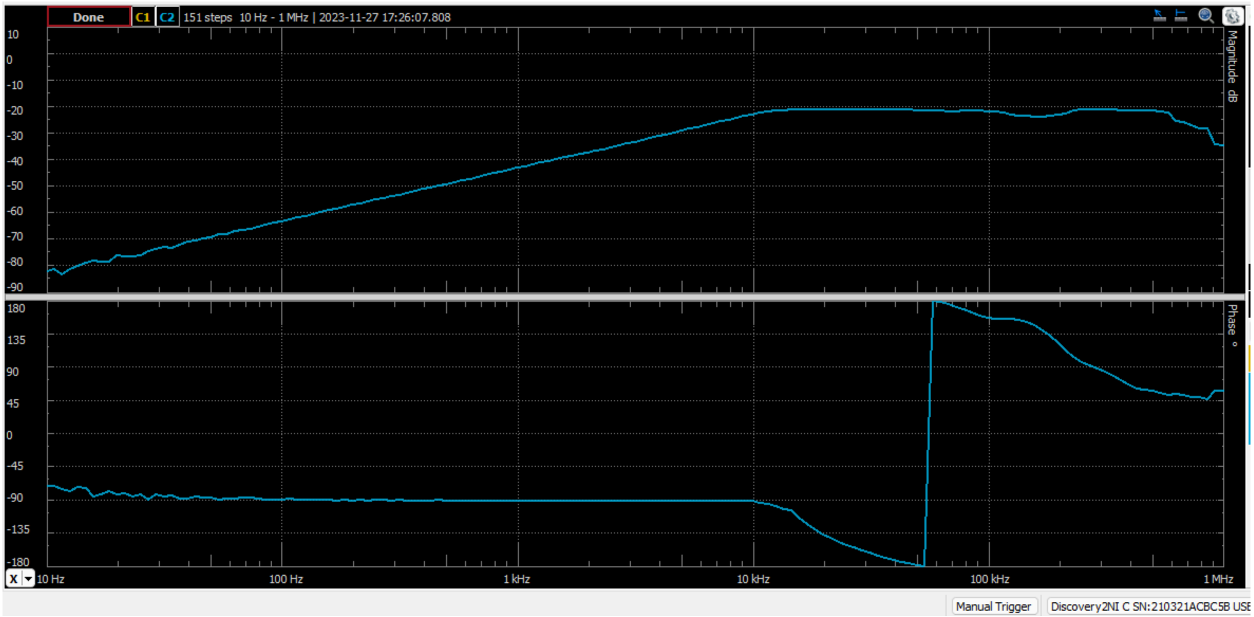

Figure 23: Bodeplot of the PCB BPF

It may be difficult to see in this image but the gain of the BPF does not adequately represent the peak gain we got in our simulations as well as our breadboard testing, maxing only at approximately -20 dB. A positive outcome from this graph is that the bandwidth matches our design in that it ranges from roughly 20 kHz to roughly 150 kHz when the graph reaches a relative min.

23.1.4 Subsystem Conclusion

We can safely state that the system is faulty when it comes to the expected gain. I did some more continuity tests and ensured that all pins of each electrical component were soldered correctly. To better verify that this circuit is designed properly, the subsystem was modeled in LTSpice instead of multisim. This is shown in the following **Figure 24**:

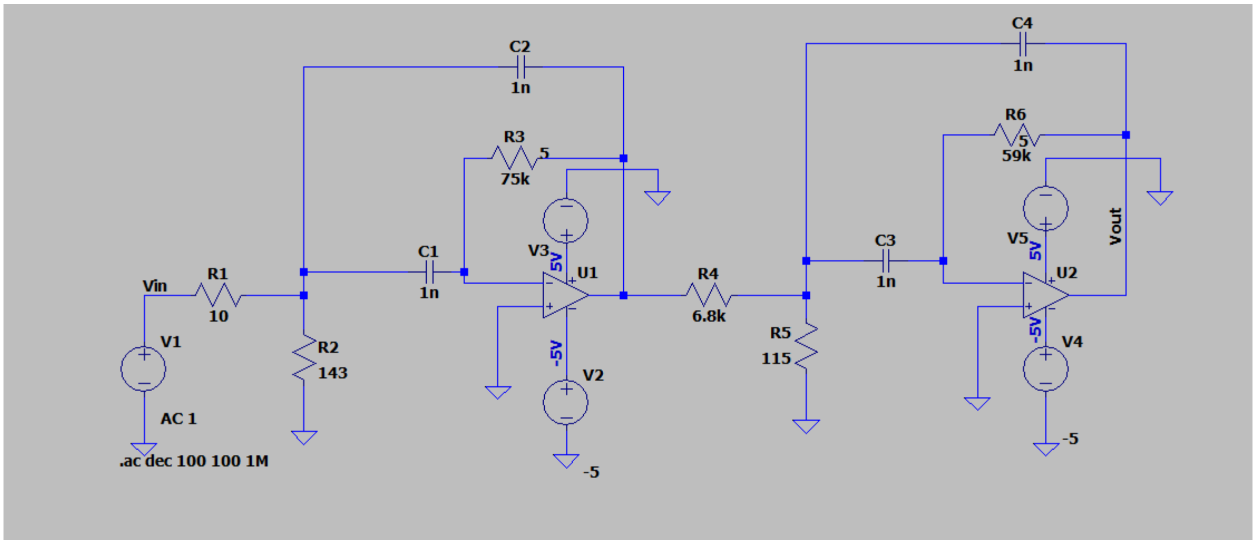

Figure 24: LTSpice Schematic of the Bandpass Filter

Running the simulation for this circuit does not give the expected results that we saw earlier. This is shown:

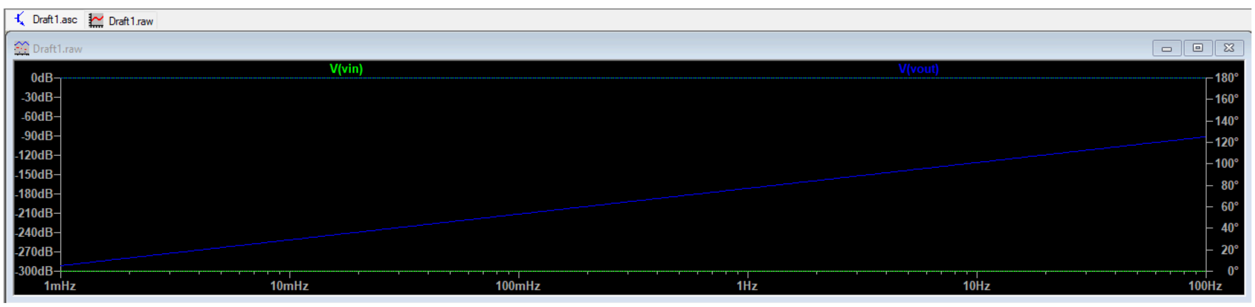

Figure 25: LTSpice Simulation of the Bandpass Filter

It is highly likely that this is due to an issue with the design in LTSpice as the designer is more familiar with the Multisim software than LTSpice. More trouble shooting will be done to get an acceptable graph.

Moving forward, if this subsystem ends up not working within LTSpice after trouble shooting has been done, it is highly likely that the resistor values need to be increased in order to reduce Johnson-Nyquist noise as well as interference from external sources which low resistance is susceptible to.

23.2. Demodulator Subsystem

23.2.1 Subsystem Introduction

The Demodulator Subsystem plays a crucial role in extracting the transmitted information from the received ultrasonic signals. This subsystem is responsible for reversing the modulation process applied at the transmitter, converting the modulated ultrasonic signals back into their original form for further processing.

23.2.2 Subsystem Details

The circuit that was chosen was a Phase Locked Loop (PLL) which is a feedback system that acts to adjust or lock the phase difference between the output of a voltage-controlled oscillator (VCO) and an input reference signal. Below is the block diagram for this system:

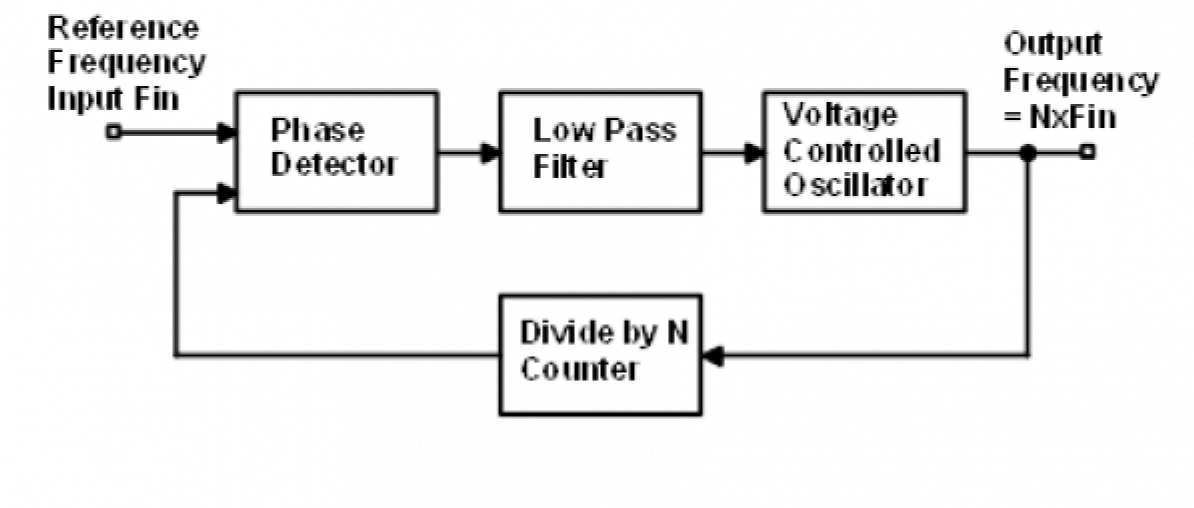

Figure 26: Block Diagram of a Phase Locked Loop

For the VCO, a AD654 was used and configured in the precise way to generate an output signal whose frequency is proportional to the input control voltage. Attached before this was a simple low pass filter that filters out high-frequency components from the output of the phase detector. Finally for the Phase Detector an XOR phase detector configuration was used as it was simple in design which equates to lower manufacturing costs. The schematic of each of these parts is shown below:

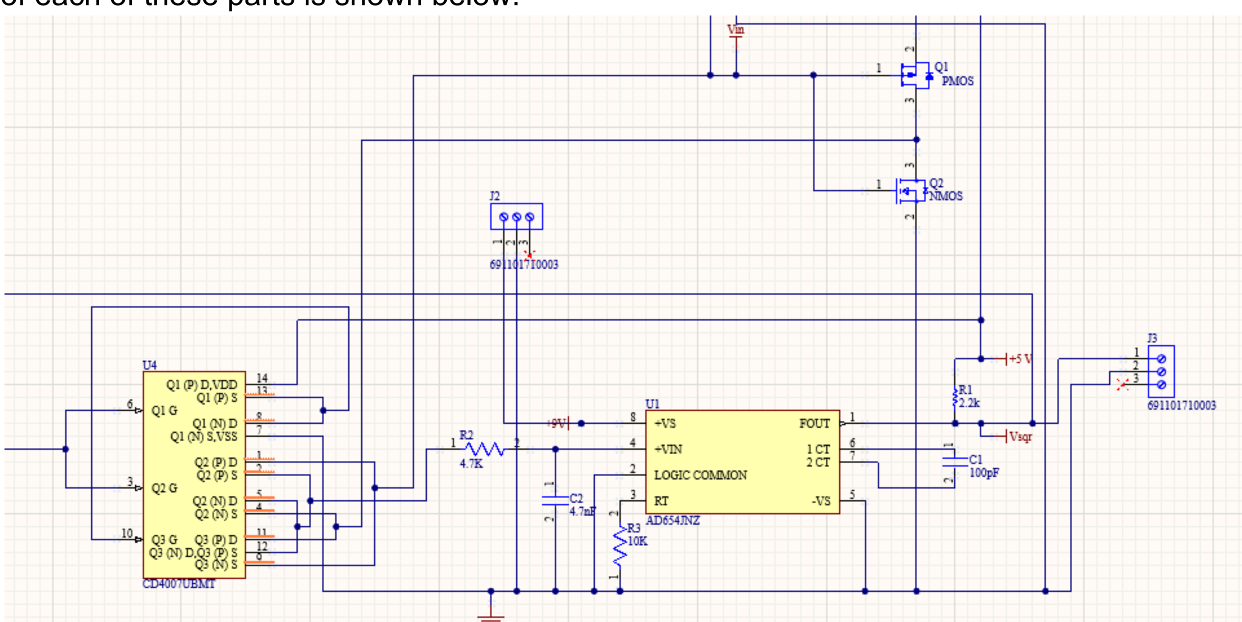

Figure 27: Schematic of Phase Locked Loop Demodulator

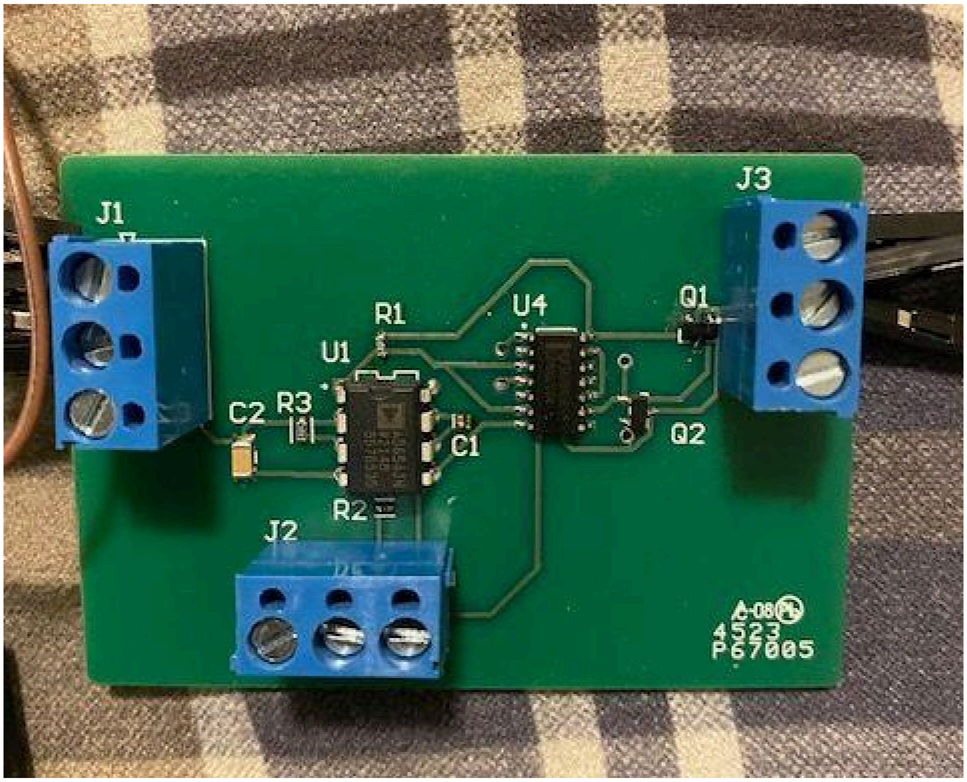

Figure 28: PCB of Phase Locked Loop Demodulator

23.2.3 Subsystem Validation

Just like with the Filter and Amplifier Subsystem, the A2D from Diligent was used as an oscilloscope. This time the Transient Analysis was used as it was necessary to verify the results of the PLL. First, the frequency was set to 250kHz as it is the frequency corresponding to a control voltage of 2.5 V on the VCO. On the transient response we should see that two square saves are stable which means they are properly locked to each other. Vsq should be shifting approximately 90 degrees with respect to the Fref. The filtered output of the XOR phase detector will be at one half of its range. This is roughly 2.5 V when the inputs are 90 degrees apart in the phase. Below is the expected output along with the tested output.

Figure 29: Expected Relation of Fref and Vsqr

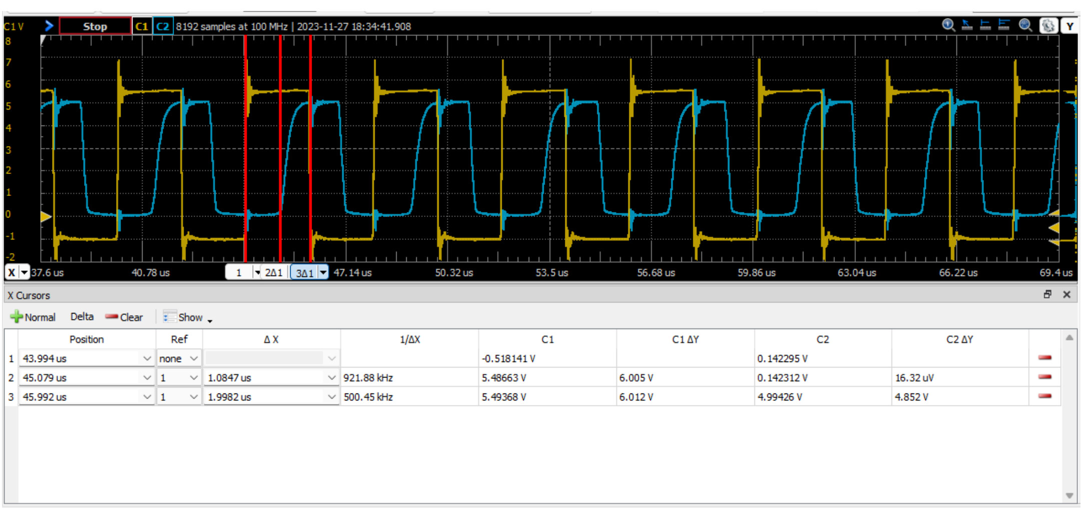

Figure 30: Actual Relation of Fref and Vsqr

When running the calculation on the phase difference between Fref and Vsqr we can see that we get a phase difference of about 94.20 which is overstepping the 90 degrees slightly but this still is a very acceptable result within our bounds.

23.2.4 Subsystem Conclusion

The PLL Demodulator was shown to work as expected. The relationship between Fref and Vsqr was satisfactorily proven to be roughly a 90 degrees phase difference. This should serve its purpose of extracting the information from a carrier wave. The VCO output will become the demodulated signal, free from the carrier frequency but carrying the encoded information from the transmitter.

Ultrasonic Radio

Nathan Cinocca

Jacob Ralls

INTEGRATED SYSTEM REPORT

24. Overview

The preliminary integration process with our extensive array of PCBs yielded suboptimal testing outcomes. The abundance of PCBs on both the transmitter and receiver sides, coupled with challenges encountered in validating certain subsystems during the 403 semester, prompted the recommendation to consolidate PCBs for each side. This strategic consolidation not only enhanced the project's aesthetic appeal but also facilitated the resolution of issues inherent within our subsystems. Subsequently, following the completion of this consolidation initiative, we undertook a refined integration phase, which yielded markedly improved results.

25. Execution

This section of the report is dedicated to illustrating the integration procedures undertaken for both the transmitter and receiver circuits of the ultrasonic radio system. It delves into the intricacies of merging these components, providing a comprehensive overview of the integration process across both sides of the project.

25.1 Transmitter

For the transmitter side's integration there were several issues encountered. The first of which was that the original frequency modulator design (shown in **Figure 31**) had an amplitude in the microvolts range which was not only unmeasurable by the oscilloscope but also could not be amplified enough by the power amplifier to be transmitted.

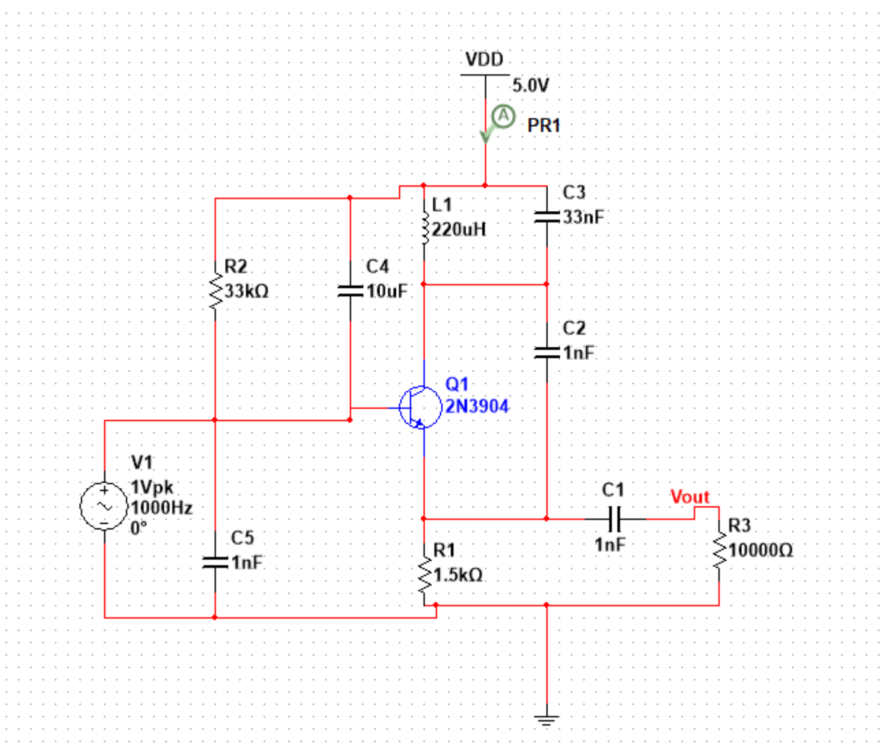

Figure 31: Old Frequency Modulator Design

After realizing this issue I created the new frequency modulator design that had a stronger modulated signal shown in **Figure 32** . Before ordering a new PCB I created this circuit on a breadboard and I achieved correct functionality. After the breadboard modulator worked correctly I created a combined PCB of the entire transmitter system (**Figure 33**) and a single PCB board of just the frequency modulator (**Figure 34**) to replace the old one.

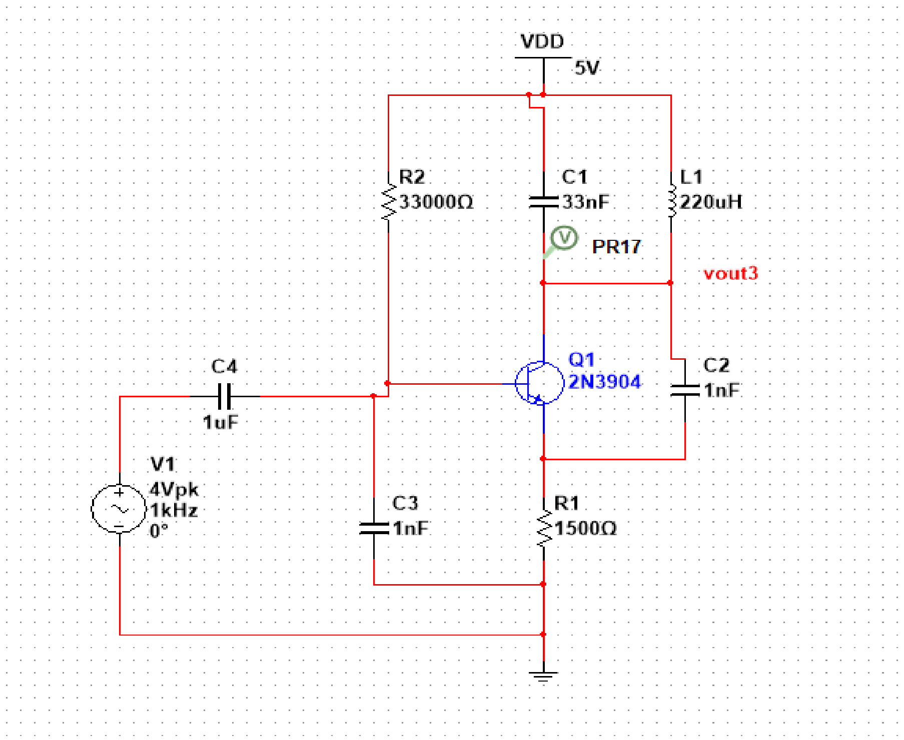

Figure 32: New Frequency Modulator Design

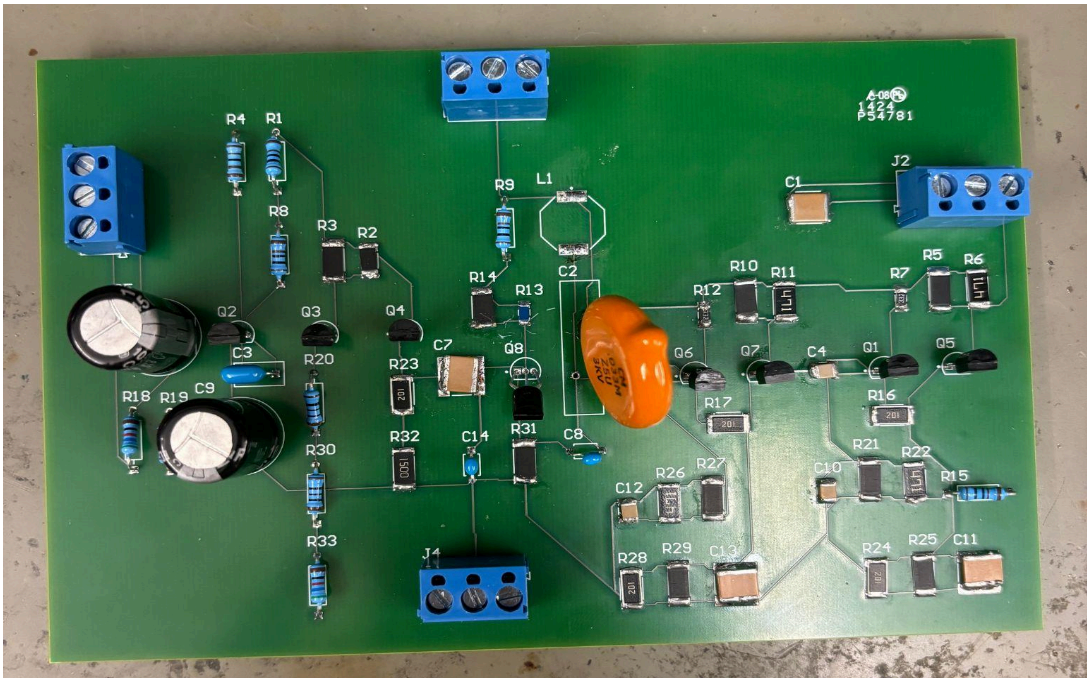

Figure 33: Combined Transmitter PCB

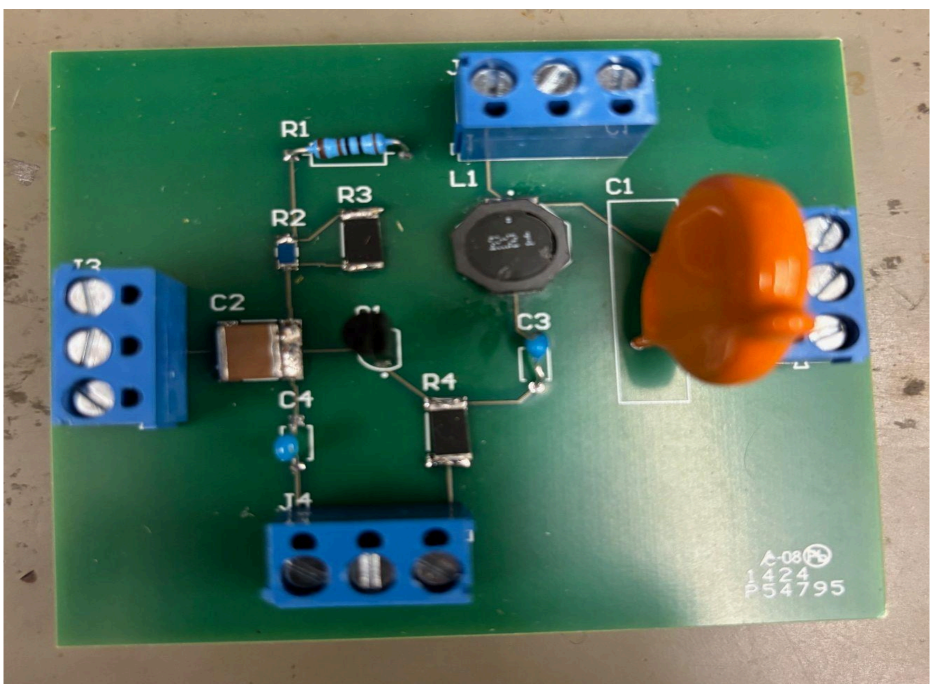

Figure 34: New Frequency Modulator PCB

However, after soldering and testing these new boards we learned that there was a problem with the transmitted frequency. At first the transmitted frequency was around 3.6 MHz. To troubleshoot this issue we changed the capacitor and inductor tank values to reduce the frequency. Doing this was only able to yield a lowered frequency of around 1.2 MHz no matter what we tried (shown in **Figure 35**). Because of these unfortunate results we determined that there must have been some design error in the PCBs. Since there was no time left in the semester we opted to use the breadboard modulator in our final setup as this gave us a better transmitted frequency.

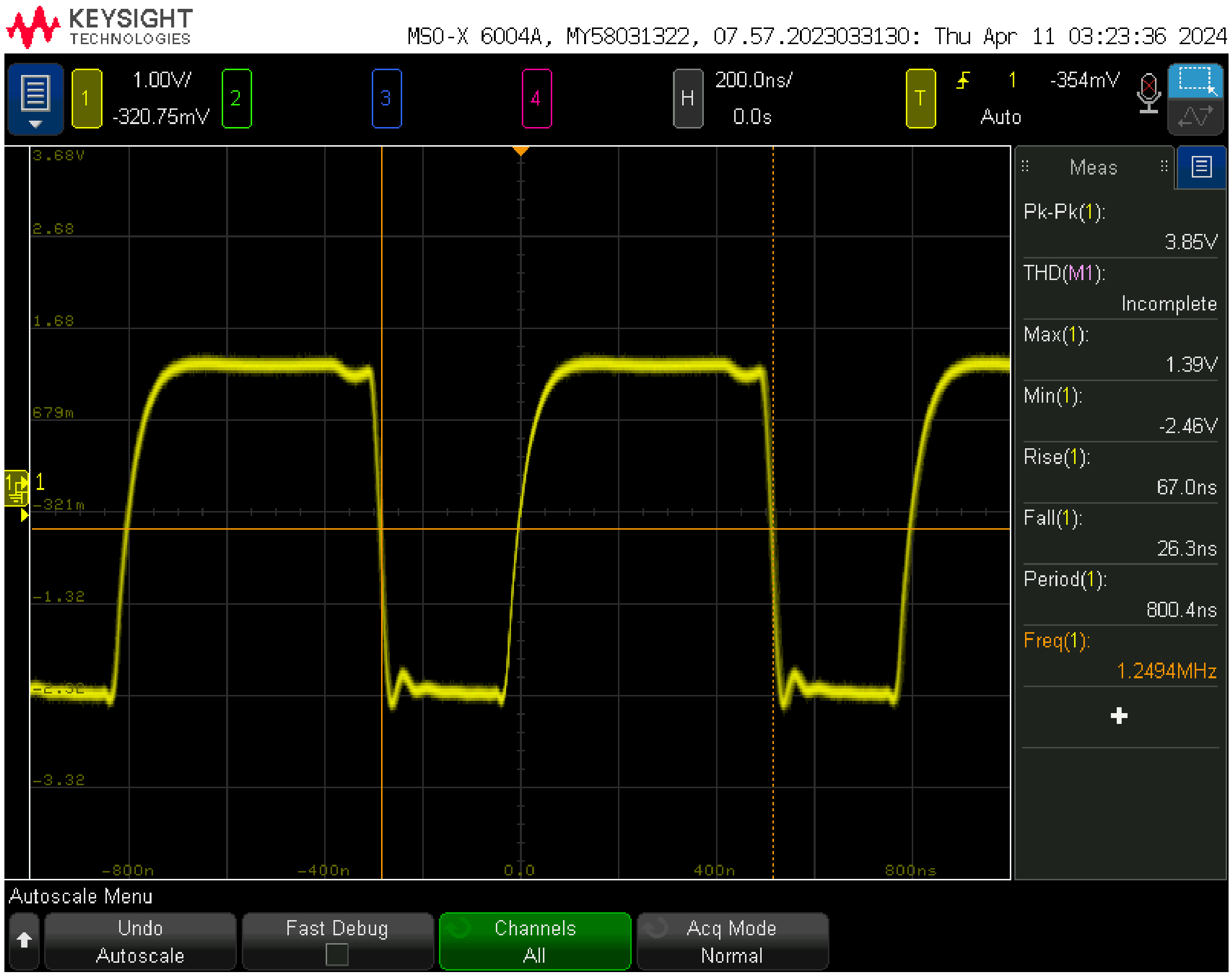

Figure 35: Combined PCB Results

Overall the entire transmitter circuit can be described as follows. The low frequency microphone is hooked up to the signal amplifier that consists of three transistors. These transistors form two common emitter gain stages followed by a common collector stage to increase output swing from the microphone. The signal then travels through a modified colpitts oscillator which functions as a voltage controlled oscillator through a capacitor/inductor tank. This modulates the signal to ultrasonic ranges to transmit. Finally, the signal goes through the power amplifier. The power amplifier consists of four transistors all in the common emitter gain stage. Additionally the power amplifier is divided into halves each with their own feedback component to increase the gain of the circuit. Using this configuration, the power amplifier is able to achieve around 70 dBs of gain at the required ultrasonic frequencies. This strong signal allows the transmitted signal to go through the ultrasonic transducer and be received by the receiver side of the ultrasonic radio.

25.2 Receiver

Due to the continued failed in person and LTSpice tests of the 4th order Chebyshev bandpass filter, it was decided to simplify the design to a 2nd order Bessel bandpass filter. I understood that this decision would create a weaker transition between the passband and stopband resulting in a lesser precise frequency control but the issues regarding my phase distortion were too prevalent. This circuit would be implemented into my integrated receiver circuit:

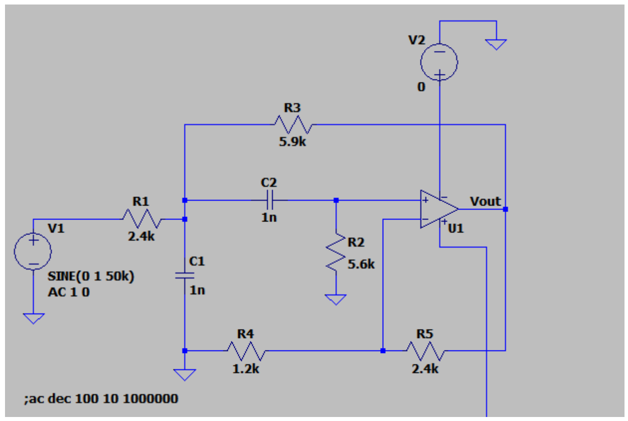

Figure 36: Modified Bessel BandPass Filter

After the first integration of the transmitter and receiver subsystems there were two prevalent issues for the receiver side subsystems. For one, due to the demodulator circuit being only able to be locked into the 50 kHz frequency, anytime a frequency range was transmitted that was +- 5kHz, it seemed like the waveform would not fit the 90 degree phase shift to be properly demodulated. This was an issue due to instances where the transmitted frequency would be upwards to 60 kHz. Secondly, the output volume for the speaker was very soft. It required an individual to press their ear to the speaker to hear anything.

The solution to both of these problems was to utilize trimmers (potentiometers) in the integrated design. One trimmer would serve as a frequency filter which would tune frequencies within a range of 6.5 kHz and 95.6 kHz and another trimmer would adjust the output volume of the speaker to be hearable with 15 m of distance. Below is the design utilizing these two separate trimmers:

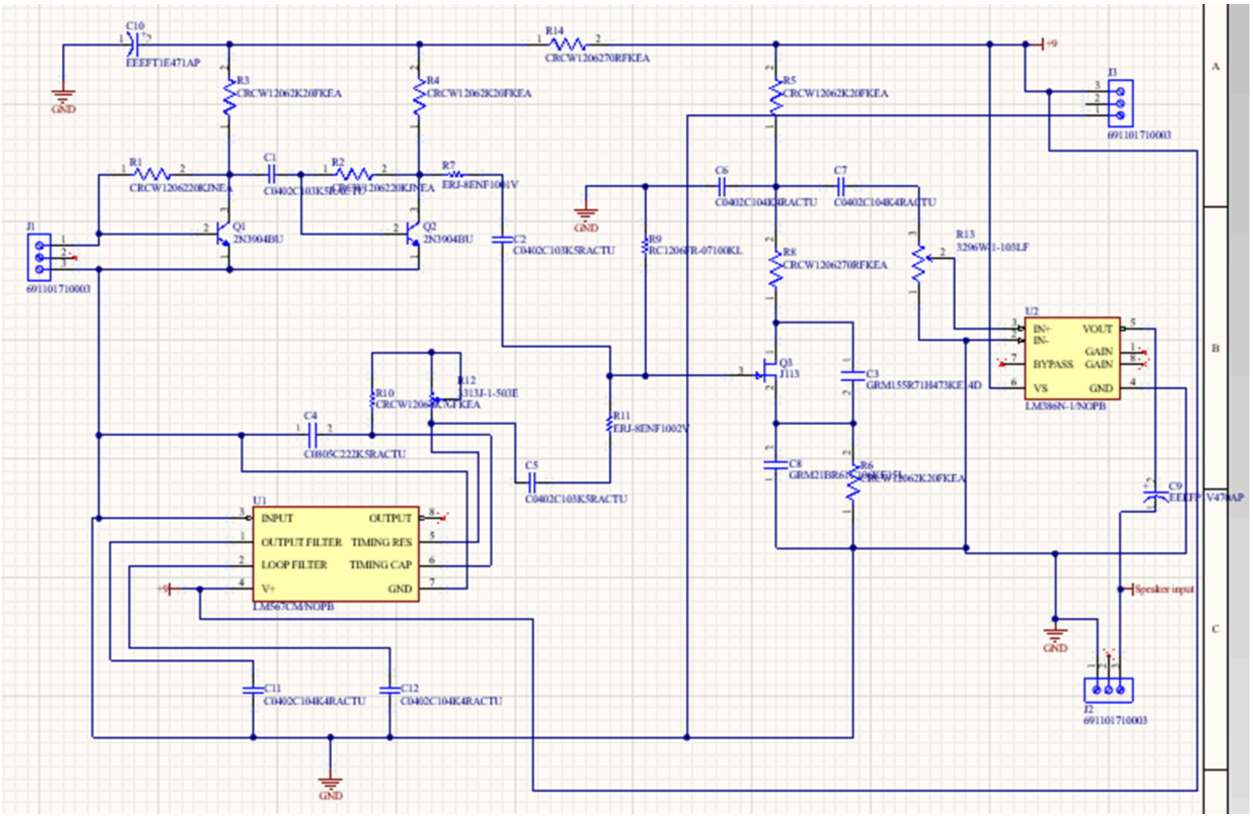

Figure 37: Integrated Receiver Circuit Schematic

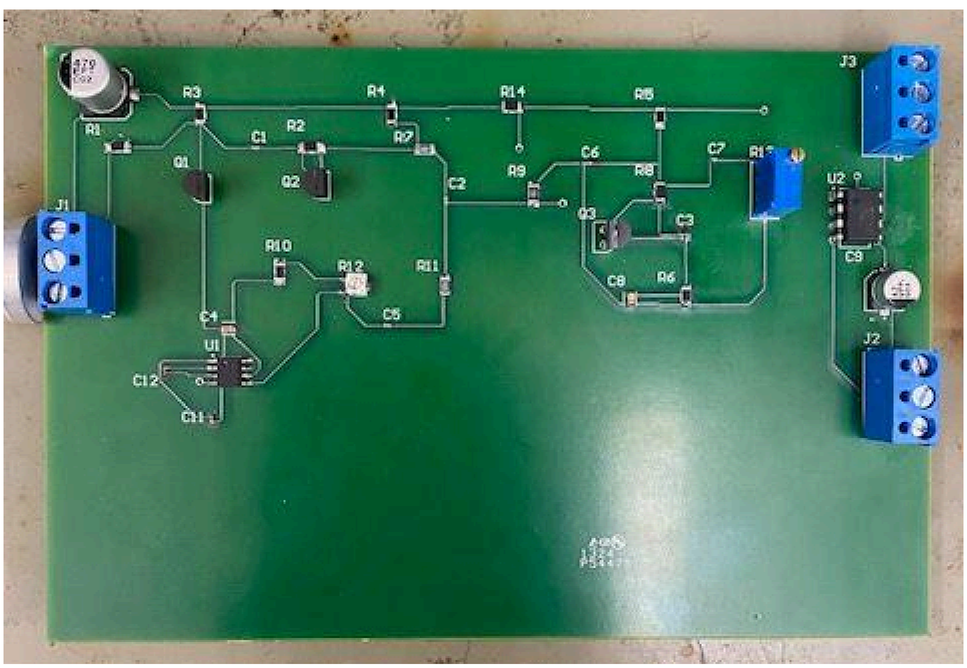

Figure 38: Integrated Receiver Circuit

The design utilizes the previous 2 receiver side subsystems. It operates with transistors Q1 and Q2 amplifying ultrasonic signals received from the transducer at J1. Subsequently, the collector output of Q2 drives the input of the JFET (Q3) in a manner resembling a product-detector circuit configuration. I was concerned about my PLL demodulator circuit being able to operate at frequencies beyond 55 kHz and below 45 kHz so I utilized a PLL integrated circuit. Similar to the demodulator circuit, the PLL (U1) stage functions like a tunable heterodyne oscillator, simultaneously feeding the input of the JFET detector circuit. The incoming ultrasonic signal combines with the heterodyne-oscillator frequency, producing both sum and difference frequencies. To eliminate the high-frequency component, a component network comprising C3, R8, and C6 filters out the undesired signal. The resultant low-frequency output is then permitted to enter the input of the LM386 audio amplifier akin to the bessel bandpass filter shown in ***Figure 36***. R12 serves as the frequency filter adjuster where clockwise rotation is lower frequency range and counter clockwise is higher frequency ranges. R13 serves as the volume adjuster where clockwise rotation provides a softer output and a counterclockwise rotation provides a louder output through the speaker connected at J2.

25.3 Unified System

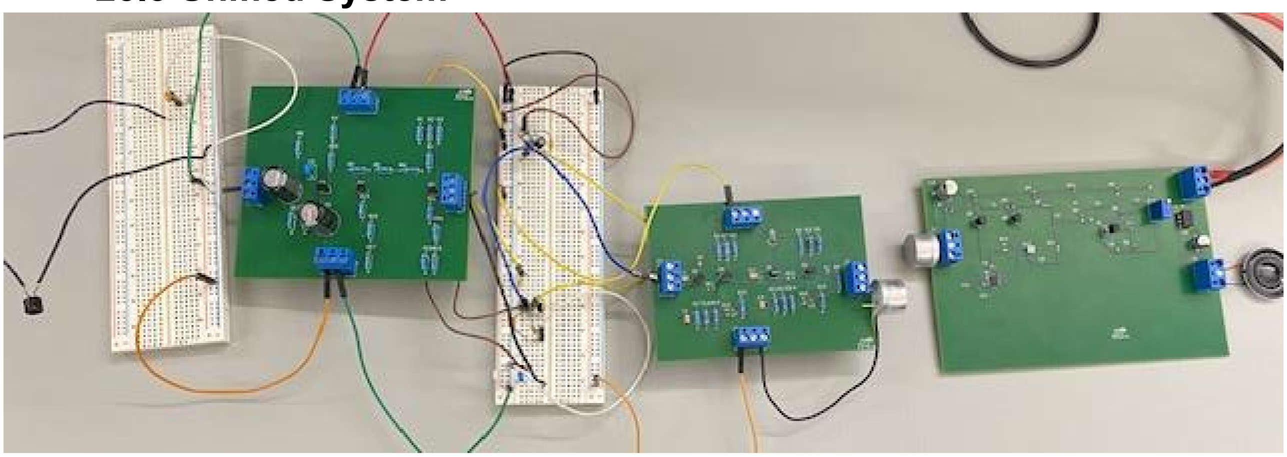

Figure 39: Integrated Ultrasonic Radio

Due to the transmitter combined PCB circuit transmitting waveforms from ranges 1.2 Mhz to 3.6 Mhz, we choose to stick with the build with the breadboards as it would transmit a frequency ranging from 15 kHz - 60 kHz. This range makes it possible for the receiver circuit to pick up.

26. Validation

26.1 Total Harmonic Distortion

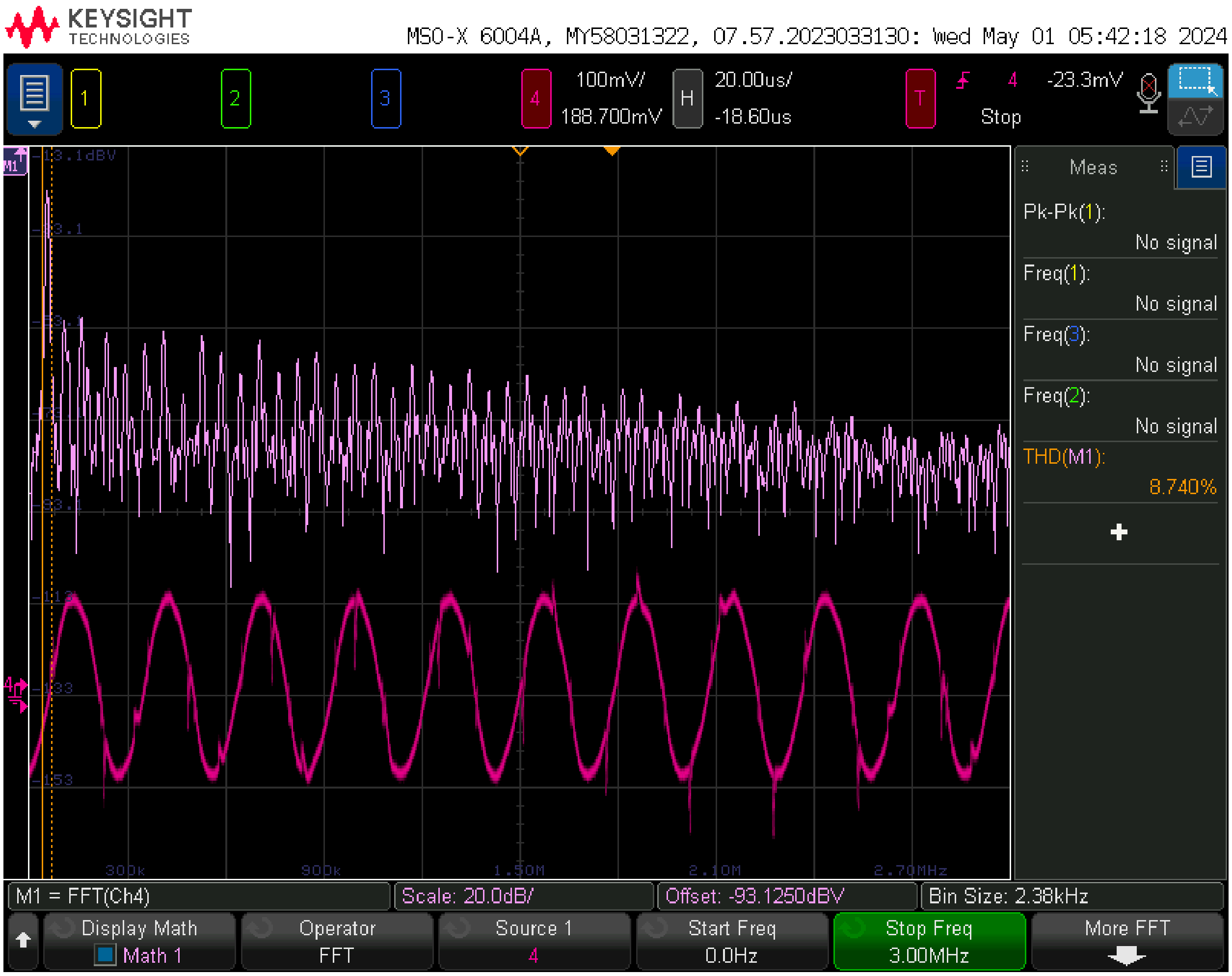

Figure 40: THD of output wave through speaker

Shown above is the THD of the output speaker waveform. As shown we got a THD of 8.74% which fits our condition of having a THD < 10%. It is important to note that the THD was susceptible to the tuning of R13 as if R13 was tuned to the most extreme ranges of volume the THD of the waveform would increase to roughly 22% along a visible amount of noise shown on the waveform itself.

26.2 Frequency Match

Shown below is the receiver successfully tuning to the same frequency as the transmitted circuit. This showcases the effectiveness of R12 as it was able to match by turning the trimmer clockwise. The yellow waveform represents the transmitted waveform and the green waveform represents the tuned frequency to eventually be sent to the output.

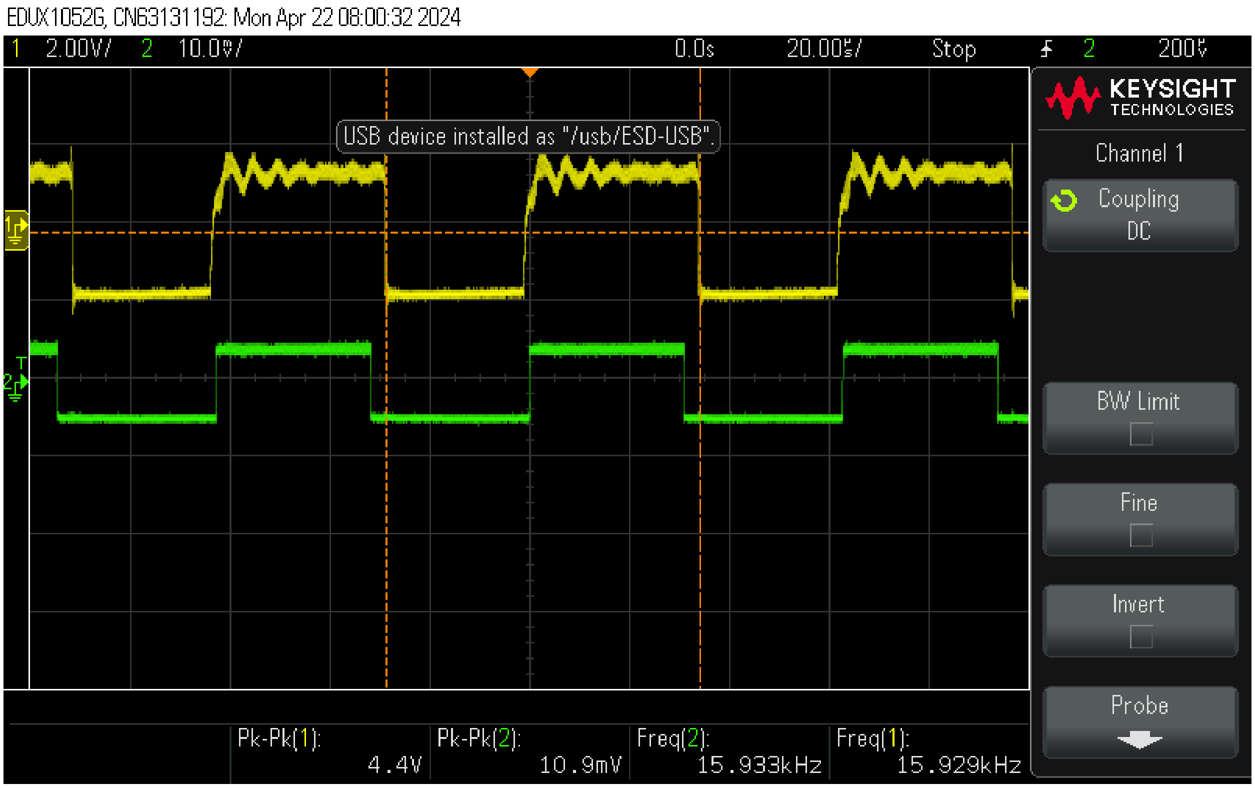

Figure 41: Transmitted signal and tuned received signal at 15.9 kHz

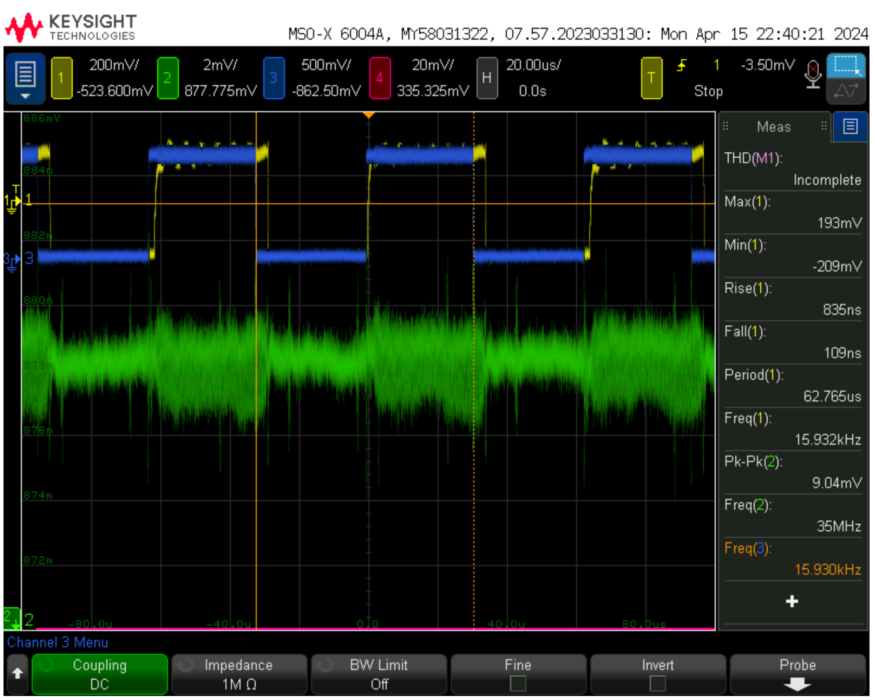

Figure 42: Transmitted signal and Tuned received signal at 15.9 kHz w/ Rec

Shown above is the same frequency being transmitted and received stacked on top of each other. This time though there is frequency coming directly from the transducer itself. This value would range between roughly 10 kHz to as high as the number you see in the figure. This wide range of frequencies is to be expected as the receiver circuit is quite sensitive. It should pick up a wide range of frequencies. That is why the R12 trimmer is an important component within the system as it is able to reduce all the noise shown in green to a single frequency range.

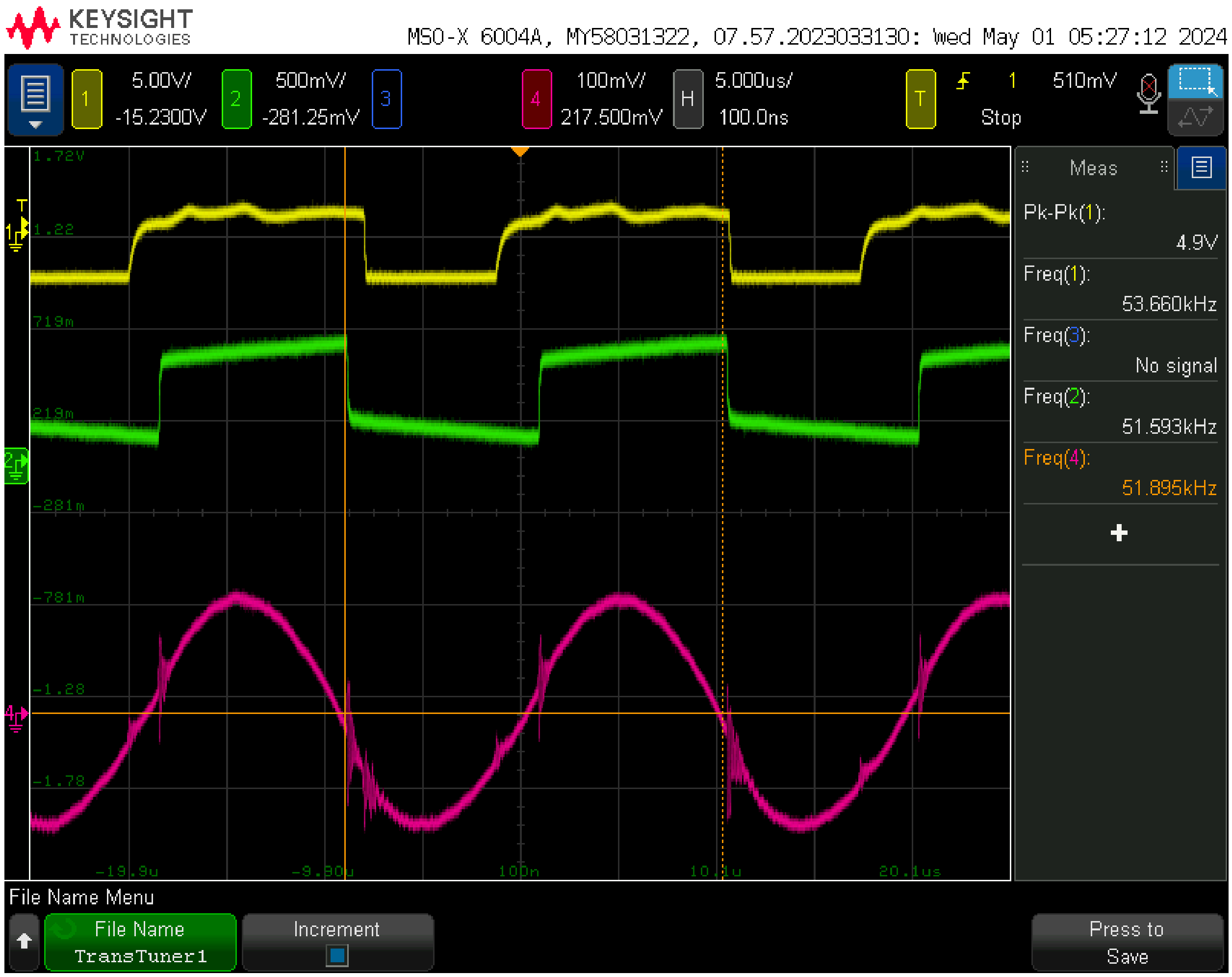

Figure 43: Transmitted signal and Tuned received signal at ≈ 52 kHz w/ Output

The figure above shows the transmitter and the tuned receiver matching at our optimal frequency of roughly 52 kHz further showcasing their matched tuning.

Figure 44: Transmitted signal and Tuned received signal at ≈ 60 kHz w/ Output

Here we have the transmitter (yellow) transmitting a 60 kHz waveform where the receiver circuit utilizes R12 to tune to the same frequency (green). Additionally we have the output of the speaker (pink) with its THD at a medium volume. Once again the THD of 7.57 % is within our range of 10 %

26.3 Mass

Figure 45: Mass of Receiver PCB

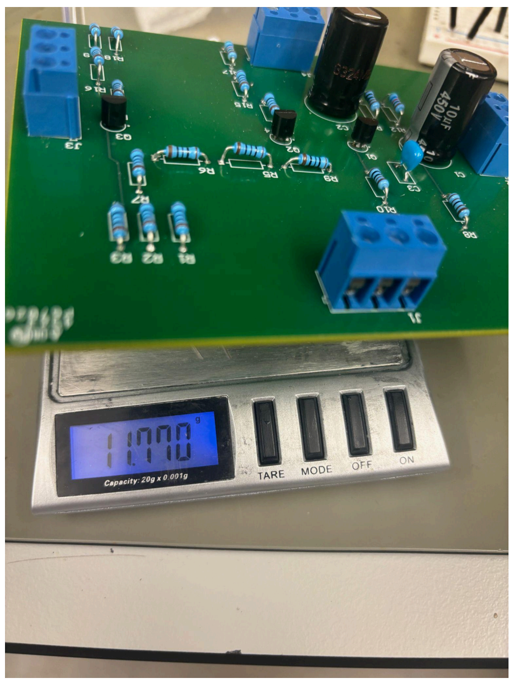

Figure 46: Mass of Signal Amplifier PCB

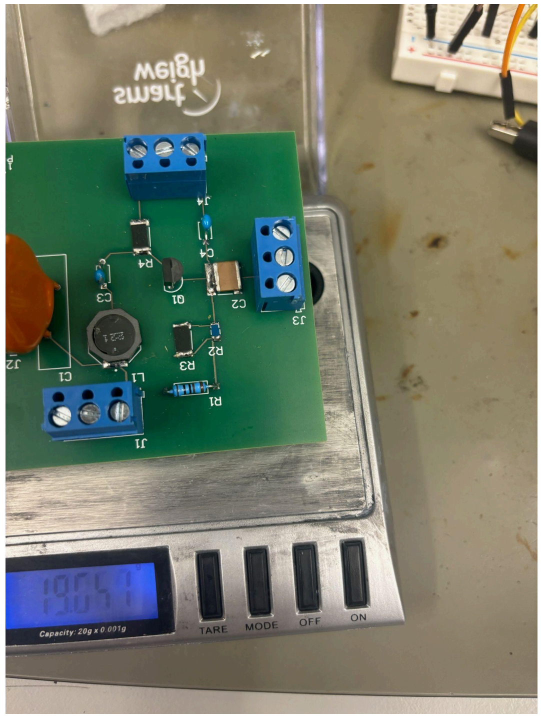

Figure 47: Mass of Frequency Modulator PCB

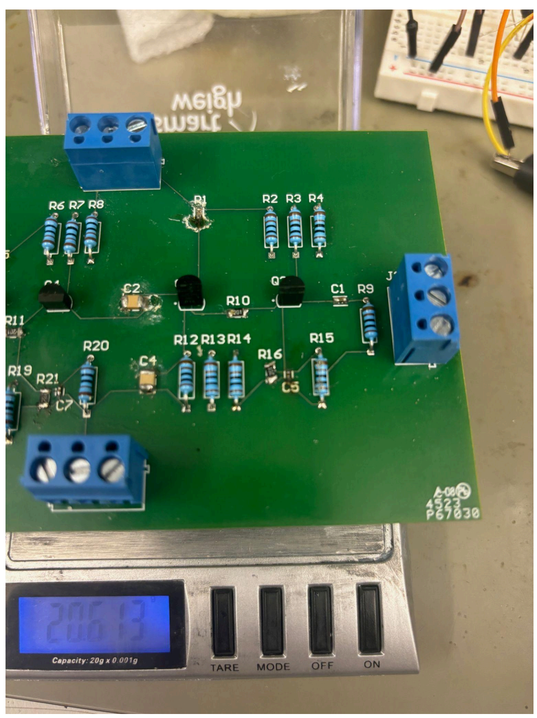

Figure 48: Mass of Signal Amplifier PCB

Our mass was able to be validated by utilizing a scale for multiple parts. The table below details the mass of all components

Table 4: Mass of Parts

Part	Mass (g)
Receiver Circuit	7.421
9 V Battery	33.92
Speaker	44.52
Signal Amplifier PCB	11.770
Power Amplifier PCB	20.613
Frequency Modulator PCB	19.051
9 V battery	33.92
Total	171.22

As shown above, our system ended up being less than 10 kgs by having a mass of 0.171 kg

26.4 Power Consumption

Figure 49: Input Voltage and Current of Receiver circuit

The values shown above give us a power consumption roughly 0.197 W for the receiver PCBs. Using a 9 V battery the transmitter PCBs used a maximum power of 0.351 W (Figures shown in the Subsystem Report). This total power passes our validation of not exceeding 9 W.

26.5 Input Voltage Level

Using ***Figure 49*** we can also note that the input voltage level of 8.998 V is below the max voltage level allowed for the receiver circuit at 9 V. Looking at the images in the subsystem report for the transmitter you can see that the input voltage is <= 5 V.

26.6 Input Current Level

Using ***Figure 49*** we can also note that the input current level of 0.022 A for the receiver is below the max current level allowed for our circuits at 1 A. Looking at the subsystem report images for the transmitter it is shown that the total current is 0.039 A which is far below the maximum.

26.7 Voice Input

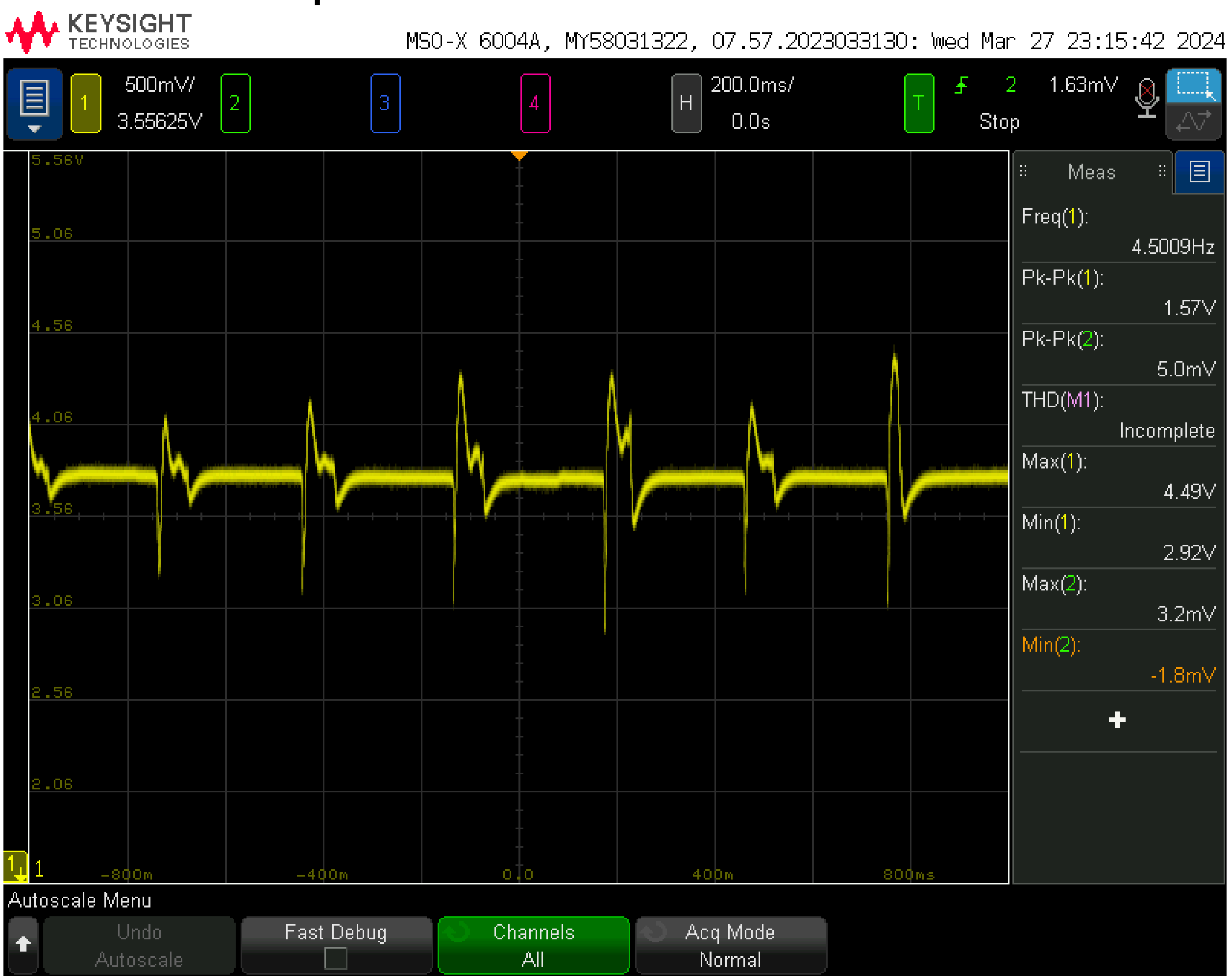

Figure 50: Steady pulse of input into the microphone

The figure above shows the circuit taking in a constant soundwave pulse into the microphone. Despite the frequency showcasing 4.5 Hz. The microphone did detect our voices validating our test.

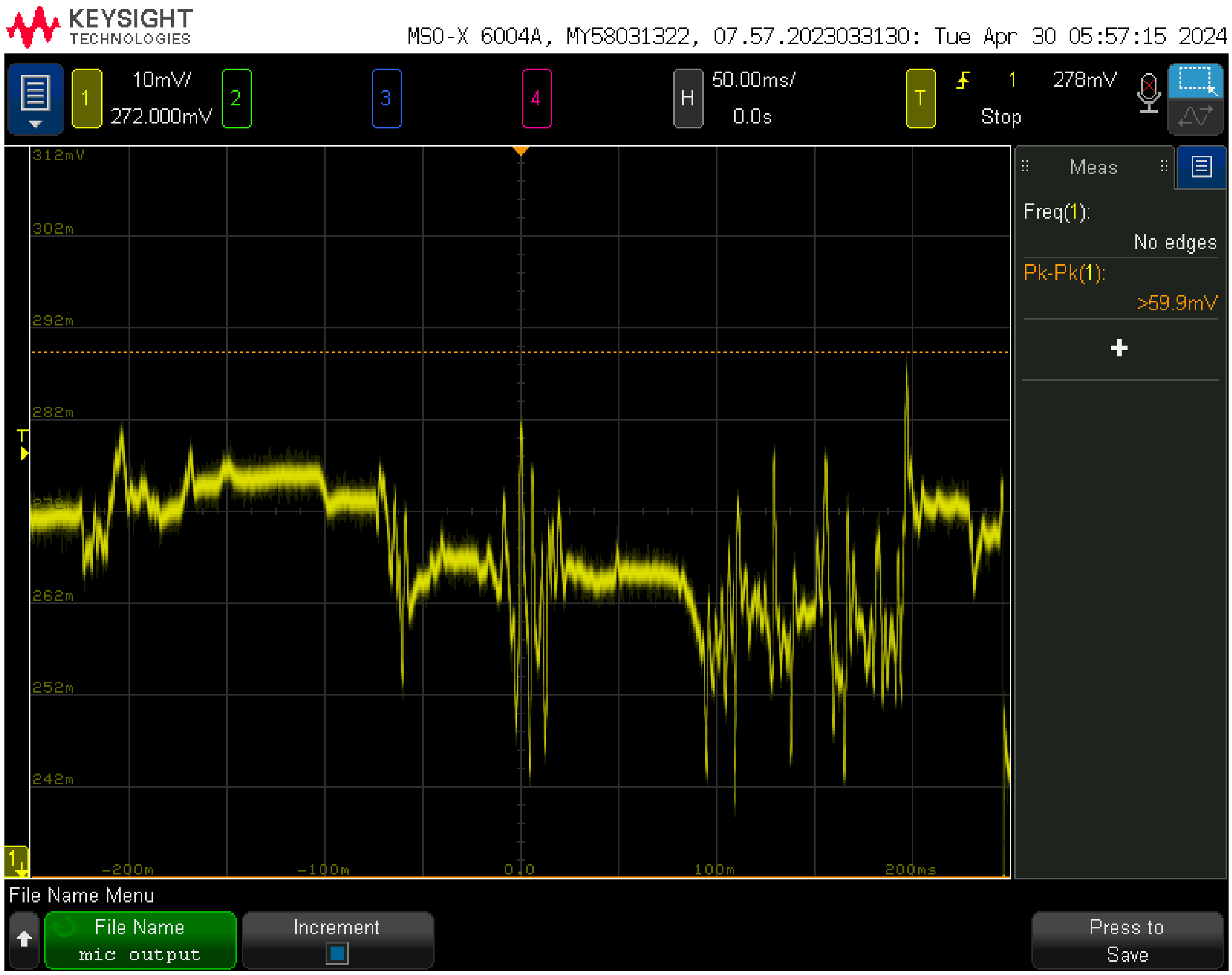

Figure 51: Output of Microphone and Signal Amplifier

The figure above also show a wide range of frequencies that can be detected by the microphone indicating again that the microphone can deal with human speaking frequencies.

26.8 Voice Output Frequency

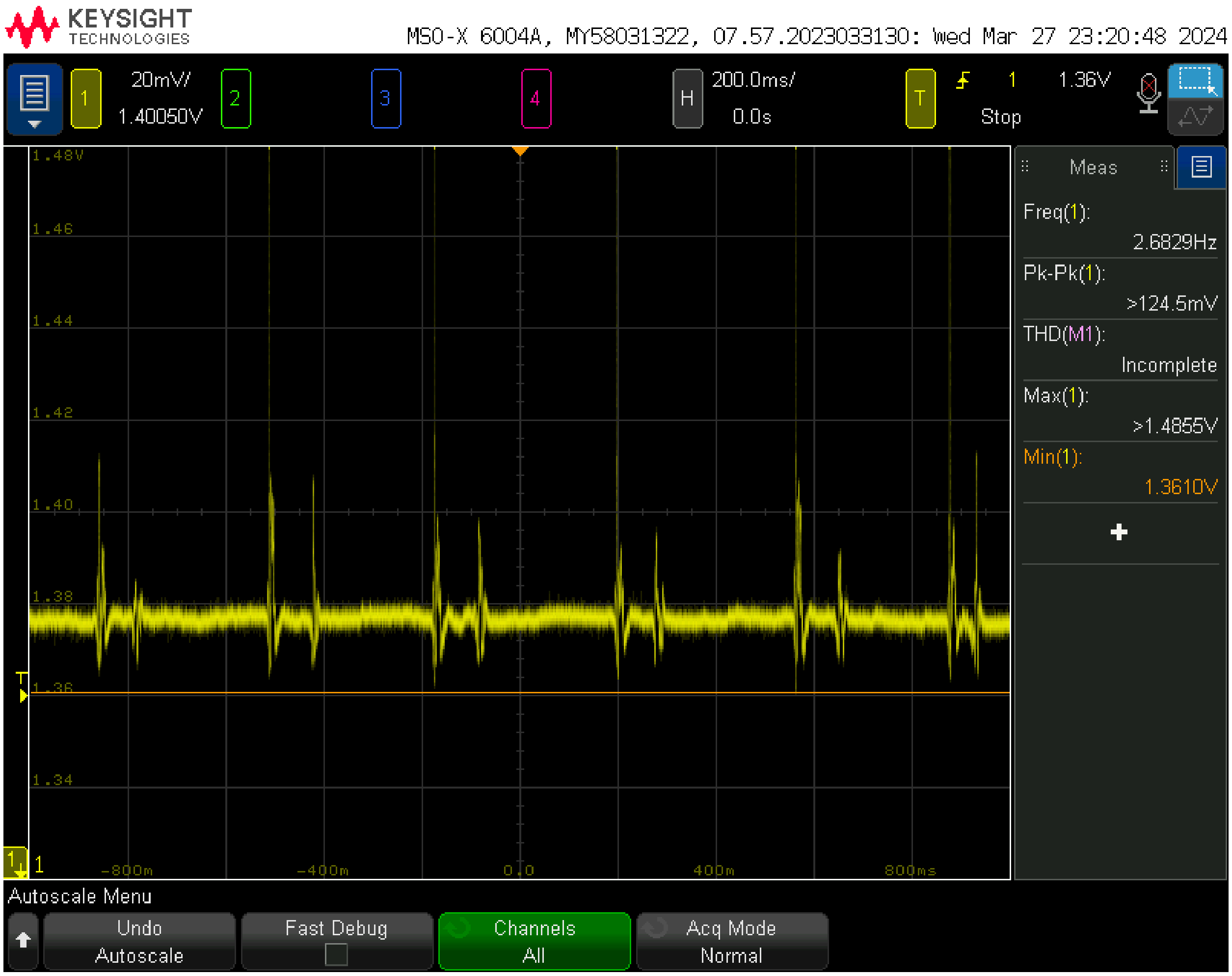

Figure 52: Output through speaker of steady pulse of input into the microphone

The figure above shows the output of the manual pulse input shown in ***Figure 50***. This was shown when our noise is almost completely cut and represents the ideal instance of our ultrasonic circuit.

26.9 Voice Output Volume

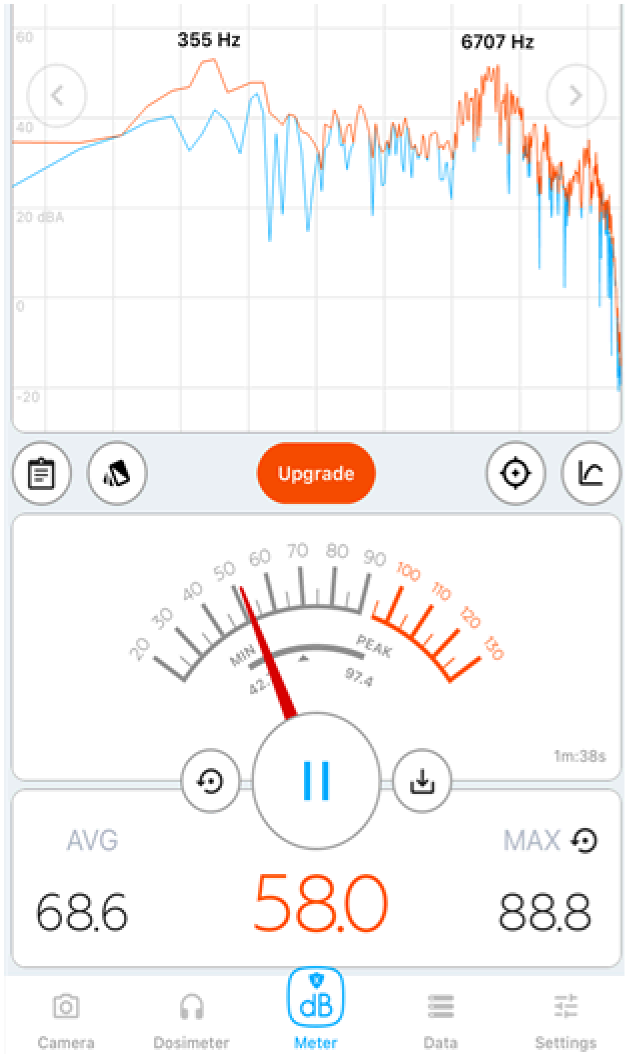

Figure 53: Volume of speaker output

As shown by the figure above when R13 was turned completely counter clockwise to its maximum volume, the reading from our sound level meter was at max of 88.8 dB when placed 2 feet away. This indicates that the output through the speaker would be able to be heard 15 meters away.

26.10 Pressure & Thermal

The ultrasonic radio was tested in a room with pressure at approximately 1 atm and worked properly validating the pressure requirement.

The ultrasonic radio was tested in a room with an approximate temperature of 70 degrees. Although we did not do specific tests to ensure functionality of the system at 95 degrees and 55 degrees, since the system was all soldered at far greater temperatures the system should function without problem at relatively standard temperatures. Additionally, most of our parts had data sheets indicating functionality far beyond our temperature testing range of 55-95 degrees. Therefore validating the thermal requirement.

26.11 Recovery

The system can be put into recovery by disconnecting battery power for 10 seconds. This gives the capacitors time to discharge and reset the entire system before reinserting the batteries and transmitting/receiving the ultrasonic waves again.

27. Overall Performance

Our validation process encompassed several critical components, from input microphone operation to signal modulation and demodulation, ensuring the transmission and reception of voice frequencies in the ultrasonic range. Additionally, specific characteristics were defined, such as total harmonic distortion, frequency matching. Also we looked into physical attributes like mass as well as electrical requirements including power consumption and voltage levels. Environmental factors such as pressure and thermal conditions were also considered to ensure the device's operability in various scenarios.

Despite successful validation of many aspects, a prominent challenge emerged concerning the clarity of the output through the speaker from the input into the microphone. This issue primarily stemmed from excessive noise within the receiver circuit and inadequate transducers as 50 kHz transducers were difficult to come across. It is important to note that noise can come from many aspects in an electrical system. This can include electromagnetic interference, thermal noise, and component imperfections due to soldering or faulty parts. Despite our system having filtering mechanisms we did simplify them in order to get functional systems. It is possible these electromagnetic signals or internal thermal fluctuations could have infiltrated the circuit, distorting the intended signal. Our suboptimal transducers for 40 kHz might have contributed to signal degradation during transmission or reception, hindering the system's overall performance.

In an effort to resolve the clarity issue during the output-to-microphone transmission, several strategies were pursued. Various techniques were explored to mitigate the excessive noise present in the receiver circuit, including the optimization of grounding strategies to minimize the impact of external electromagnetic interference and thermal fluctuations on the circuit's performance. Specifically, it was deduced that the main source of noise was being generated by the LM567 (U1) IC thus I tried grounding the base of the Q1 transistor which mitigated the buzzing but never fully eliminated it. Additionally I tried to address the possible issue of inadequate transducers by utilizing piezo transducers and 25 kHz transducers (since at the time the transmitted signal was roughly 20 kHz) with little to no success. Disconnecting the gate of the FET from the R11 junction with C2 cuts the buzzing entirely but that connection is needed for a functioning system. C11 and C12 were resoldered and replaced to no avail. All of these endeavors aimed to enhance the overall performance and reliability of the ultrasonic communication system by refining critical components and mitigating sources of signal degradation and interference. These efforts only put a bandaid on a very prevalent problem.

28. Conclusions

28.1 Limitations

The ultrasonic radio has its own limitations compared to other forms of communication. For example, the signal is slower and does not travel as far as electromagnetic signals.

While working on this project we faced other limitations not directly related to the ultrasonic radio. Firstly, we had no sponsor which made it difficult to ask questions and get advice from anyone. Also, because of our many PCB iterations and ultrasonic transducers we barely had enough budget and had to spend personal money. Finally, as a two person team we had less efficiency compared to larger teams.

28.2 Impacts

This project had an incredible impact on our learning and understanding of electronics and signals as undergraduate electrical engineering students. During this project we learned about the different methods for transmitting signals, namely frequency modulation and amplitude modulation. We also learned how to demodulate both signals although we only explicitly used frequency modulation and demodulation in this project. We also learned a great deal about designing amplifiers, filters, and circuits in general from scratch. The team dealt with and grew from the challenges of working with real, messy analog signals. During this project we also gained the knowledge on how to create PCBs from circuit schematics and the advantages of using PCBs. Finally, more broadly, we learned the strengths and weaknesses of electromagnetic signals compared to acoustic signals for communication.

Overall, this was an enriching experience that allowed us to learn a great deal about electrical engineering in a practical setting.

Appendix A: Acronyms and Abbreviations

ATM	Atmosphere
CONOPS	Concept of Operations Document
dB	Decibels
Hz	Hertz
ICD	Interface Control Document
Kg	kilograms
kHz	Kilohertz (1,000 Hz)
mA	Milliamp
mW	Milliwatt (0.001 Watt)
MHz	Megahertz (1,000,000 Hz)
SNR	Signal to Noise Ratio
USB	Universal Serial Bus
VDC	Direct Current Voltage
W	Watt

Appendix B: Definition of Terms

Electromagnetic waves	Waves produced by the movement of electric charge and the propagation of electric and magnetic fields.
Electromagnetic radiation	When electromagnetic waves interfere with each other when they should not
Receiver	Equipment that accepts transmitted waves carrying signals from another location
Transmitter	Equipment that generates and transmits waves carrying signals to another location
Ultrasonic	A range of frequencies from 20 kHz to 20 MHz