Ultrasonic Radio

Nathan Cinocca

CONCEPT OF OPERATIONS

REVISION – Draft
25 January 2018

Concept of Operations
for
Ultrasonic Radio

Team 84

Approved by:

Project Leader	Date
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T/A	Date

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1. 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 vehicles navigating 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 also have multiple channels that will allow for two-way communications between correspondents. Ultimately, this radio will allow for better communication between military operators even around areas that are sensitive to electromagnetic waves.

2. 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.

2.1. 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 my research I 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. I also plan to add multiple channels to allow for two-way communication.

2.2. 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.

2.3. 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

3. Operating Concept

3.1. 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.

3.2. 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 will also allow you to both speak and listen to noise at the same time. This will be accomplished through two frequency channels.

There are several constraints that come with this project. One of them is the cost constraint. As a capstone student, I am afforded $100 to spend on our project. Since I will need to purchase transducers at an absolute minimum which can be relatively expensive. Because of this I 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.

3.3. 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 <10 V and current to <15mA.

The filters will primarily be used to get rid of noise. I will use an IC operational amplifier for this application instead of designing the amplifier from scratch. For the filters used for both the input and output signal I will need them to operate at two different frequencies to accommodate the different channel frequencies. These frequencies will be in the 50k Hz to 100k Hz range.

Next, I will need to design a frequency modulator and demodulator. To do this I will need an oscillator and some IC op amps. This will also include many resistors and capacitors to operate properly.

I will also design a power amplifier with transistors. This amplifier will need to have a very large gain of around 100 dBs. This will be important to allow the signal to be transmitted a large distance.

Finally, I will need to purchase transducers that will function with the rest of the circuit. They will also need to function within the channel frequencies of 50k Hz – 100kHz.

3.4. Modes of Operations

Many radios are only half-duplex and only allow for one party to speak at a time. With this set up, a button is typically needed to activate the transmission from one radio to the other. However, since this ultrasonic radio will be full-duplex and allow for both parties to speak at the same time, there will be no need for this mode.

Instead, ultrasonic will simply have two modes. The first being the on mode, or the mode that will allow signal transmission. The other mode will be the off mode where no power will be consumed, and no signal will transmit.

3.5. 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.

3.6. Support

The ultrasonic radio will be intuitive to use and as such should be usable without many instructions. However, a short manual would be provided with some instructions should it be needed.

4. Scenario(s)

4.1. 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.

4.2. 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.

5. Analysis

5.1. Summary of Proposed Improvements

- Allows for safer communication around equipment sensitive to electromagnetic waves
- Improves upon old design to allow both parties to speak and listen simultaneously
- Communication system is easy to use

5.2. 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

5.3. 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

5.4. 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

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

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6. Introduction

6.1. 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.

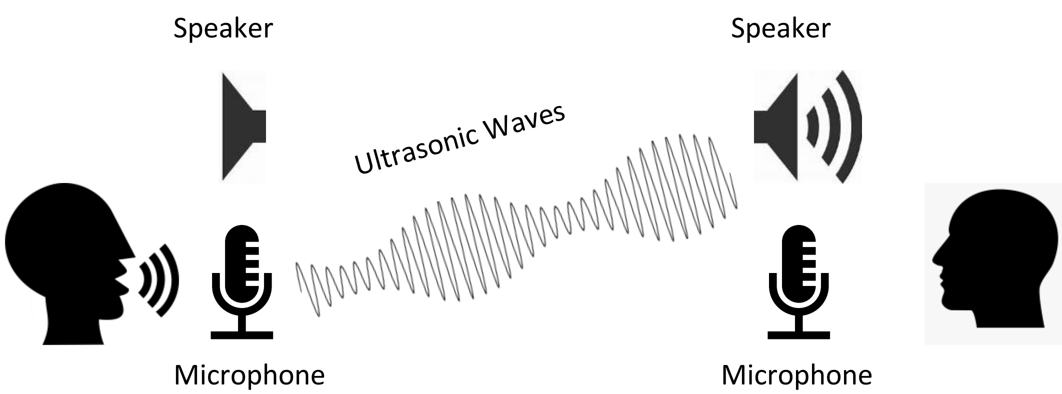

Figure 1. Ultrasonic Radio Conceptual Image

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.

6.2. Responsibility and Change Authority

The sole team member, Nathan Cinocca, will be responsible for verifying the requirements of the project are achieved. Any changes to the project may only be enacted through an agreement between Nathan Cinocca and the sponsor Dr. Oscar Moreira. Subsystem ownership for this project is listed below.

- Nathan Cinocca: Signal Amplifier, Filters, Modulator/Demodulator, and Power Amplifier

7. Applicable and Reference Documents

7.1. 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

7.2. 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

7.3. 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.

8. 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.

8.1. 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.

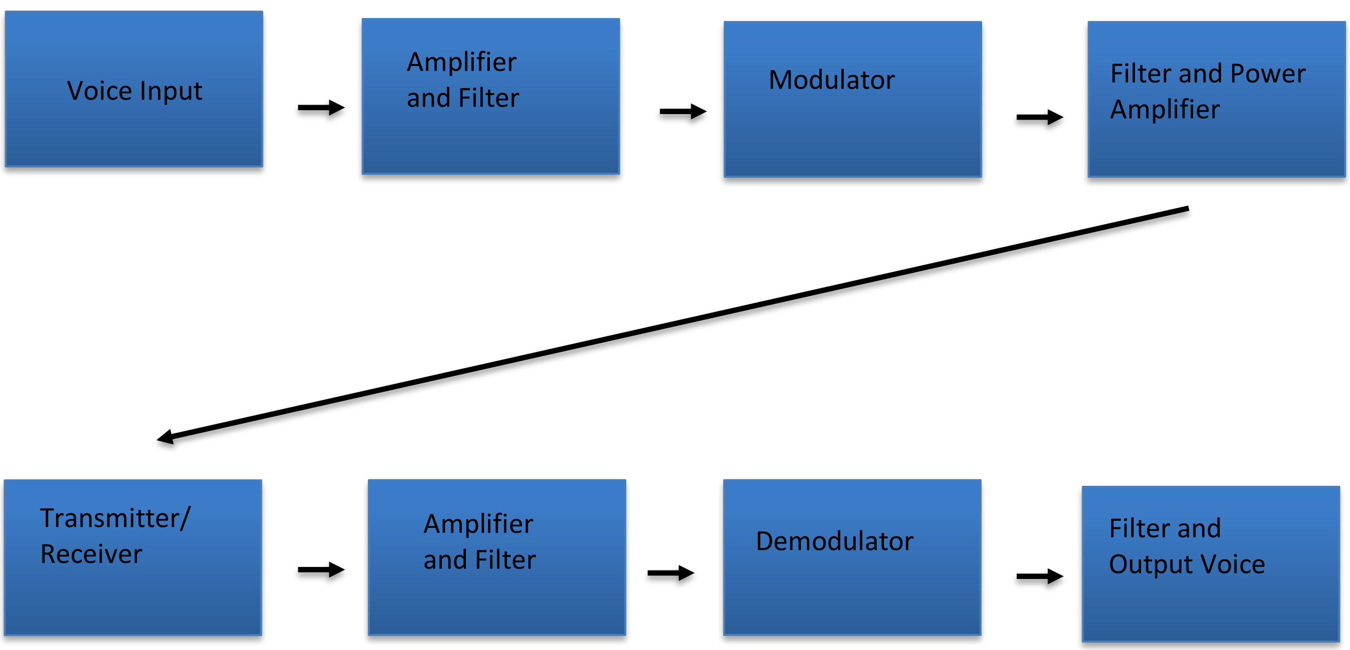

Figure 2. Block Diagram of System

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 and filtered through the signal amplifier and low frequency filter. This will make the signal stronger and filter out unneeded noise being picked up by the microphone. 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 signal may be filtered if additional noise is picked up at the higher ultrasonic frequency. Then 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 may be filtered again if necessary and then it will be output through a speaker operating within the range of human hearing.

8.2. Characteristics

8.2.1. Functional / Performance Requirements

8.2.1.1. Signal to Noise Ratio

The transferred signal from the ultrasonic radio shall have at least a 60 dB signal to noise ratio.

Rationale: Typical audio equipment that functions well has a signal to noise ratio of at least 60 dB. Very good audio equipment has even higher decibels. Since the ultrasonic radio should have a clear signal so communications can happen cleanly 60 dB is required.

8.2.1.2. Transmission Distance

The ultrasonic radio shall meet a communication distance of 15 meters or more.

Rationale: Although a long transmission distance for the ultrasonic radio is better, there are limitations from testing and the ultrasonic nature of the waves. Knowing this, a transmission distance of 15 meters or more will allow for a usable and testable ultrasonic radio.

8.2.1.3. Total Harmonic Distortion

The ultrasonic radio shall have a total harmonic distortion of less than or equal to 5%.

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 5% is acceptable and is the goal for this ultrasonic radio.

8.2.2. Physical Characteristics

8.2.2.1. 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.

8.2.3. Electrical Characteristics

8.2.3.1. 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.

8.2.3.1.1 Power Consumption

The maximum peak power of the system shall not exceed 4.5 watts.

> *Rationale: This requirement is due to the power of the system being provided by a USB wall adapter. The maximum power provided by USB 3.0 is 4.5 watts, so that is the maximum power limit.*

8.2.3.1.2 Input Voltage Level

The input voltage level for the ultrasonic radio shall be +5 VDC.

> *Rationale: USB wall adapter has a voltage level of 5 VDC which will be used to power the ultrasonic radio.*

8.2.3.1.3 Input Current Level

The input current for the ultrasonic radio shall not exceed 900 mA.

> *Rationale: 900 mA is the maximum current that can be supplied by the USB 3.0 wall adapter and is thus the maximum current that can be supplied to the ultrasonic radio.*

8.2.3.1.4 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.*

8.2.3.2. Outputs

8.2.3.2.1 Voice Output

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

> *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.*

8.2.4. 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

8.2.4.1. Pressure (Altitude)

The ultrasonic radio may be able to operate up to 2.5 atm of pressure.

Rationale: The internal pressure of a typical military submarine is roughly equivalent to 2.5 atm. Thus, to perform its function, the ultrasonic radio should be able to function up to this amount of pressure.

8.2.4.2. 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.

8.2.4.3. Humidity

The ultrasonic radio should be able to function in 0-95% relative humidity.

Rationale: The internal relative humidity of a military submarine without power can range from 0-95% relative humidity in extreme scenarios. So, the ultrasonic radio should be able to function in these emergencies.

8.2.5. Failure Propagation

3.2.5.1 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.

9. Support Requirements

4.1.1 Ultrasonic Radio Manual

To help users understand how to use the ultrasonic radio, a manual that details some of the parts of the radio and generally how to use it will be provided to customers.

Rationale: This feature will help users better understand the ultrasonic radio which will allow for improved usage of the device.

4.1.2 Power Adapter

Users of the ultrasonic radio will be provided with a USB power adapter to power the radio. However, clients must have access to a wall outlet to use the USB adapter and power the radio.

Rationale: Providing the power adapter will ensure that the correct power source is used for the ultrasonic radio. It will also allow the users to spend less time before the radio is operational.

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
MHz	Megahertz (1,000,000 Hz)
SNR	Signal to Noise Ratio
USB	Universal Serial Bus
VDC	Direct Current Voltage

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

Ultrasonic Radio
Nathan Cinocca

INTERFACE CONTROL DOCUMENT

REVISION – Draft
28 September 2023

Interface Control Document
for
Ultrasonic Radio

Prepared by:

Team 84

Approved by:

Nathan Cinocca	Date
John Lusher II, P.E.	Date
T/A	Date

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10. 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.

11. References and Definitions

11.1. References

Refer to section 2.2 in the Functional System Requirements document.

11.2. 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

12. Physical Interface

12.1. Weight

The overall weight of the system is difficult to determine at the current time as many of the subsystems have not been designed yet. The design of the systems will determine how many transistors, resistors, capacitors, and operational amplifiers will be used. All these components are light and should not add excessive weight. The heaviest subsystem in the ultrasonic radio will be the speakers and microphones. Although the speakers and microphones will be heavier compared to the transistors and other circuit elements, they are still quite small and light. Thus, it should not be difficult to keep the entire radio under 10 kilograms.

12.2. Dimensions

The dimensions of the entire ultrasonic radio should be kept under 1 cubic foot in size.

Similar to the weight section, since many subsystems are still being designed it is difficult to give accurate dimensions for each of the subsystems. However, most of the components are quite small. For example, the 2N3904 transistor which will be used is 36 mm x 18 mm x 1.5 mm. So, even using 100 transistors will still allow lots of space for the microphones, operational amplifiers, and other circuit elements. Op amp 743, which will be used in filters, and modulation/demodulation circuits has dimensions of 356 mm x 356 mm x 35 mm, which again is small even if many are used. Currently, the microphones and speakers that are being considered are also small at about 10 mm x 10mm x 3.5 mm. Since all the parts are small the ultrasonic radio should be able to meet the dimension requirement of 1 cubic foot.

13. 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.

14. Electrical Interface

14.1. Primary Input Power

The ultrasonic radio has a maximum power of 4.5 watts. More specifically this is 5 V and 900 mA of current supplied by a USB 3.0 adapter. Although the power supplied to each subsystem is TBD at this point, since most are being designed, some maximum power requirements can be determined. This will be discussed in section 5.2.

14.2. Voltage and Current levels

- Signal amplifiers shall have no more than 50 mA and 5 V for 250 mW of power
- Filters shall have no more than 15 mA and 5 V for 75 mW of power
- Modulator/demodulators shall have no more than 100 mA and 5 V for 500 mW of power
- Power amplifiers shall have no more than 300 mA and 5 V for 1.5 W of power
- Speaker and microphones shall have no more than 350 mA and 5 V for 1.75 W of power

15. Communications / Device Interface Protocols

15.1. 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.