Wirelessly Operated PA Loudspeaker System for RMAX Search-and-Rescue UAV

A Preliminary Design

A Senior Project

presented to

the Faculty of the Electrical Engineering Department

California Polytechnic State University, San Luis Obispo

In Partial Fulfillment

of the Requirements for the Degree

Bachelor of Science, Electrical Engineering

by

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June, 2011

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Acknowledgements

We would like to acknowledge Professor Lynne Slivovsky for advising us over the course of the design and giving us the opportunity to work on such a great project. Additionally, we would like to thank Marcel Stieber for offering his expertise in the field of radio communications, which has been vital in developing our system.

Abstract

This paper discusses the approach used to implement a wireless PA loudspeaker system on a search-and-rescue RMAX UAV.

The purpose of this project is to allow the continuation of communication between search-and-rescue workers as well as potential rescuees in an environment that won't always allow it. Since rugged terrain tends to cause interference between two radio communications, there needs to be a way to bypass this problem. In addition, people in need of rescue are unlikely to be using a radio on an emergency frequency, so there needs to be a way to efficiently issue orders or evacuation notices without any equipment required for the recipient of the message. Our design will bypass these issues by operating a wireless loudspeaker system that can fly above this problematic terrain and issue audible orders without any other equipment required.

This device is intended for use by emergency services on their UAV, but anyone in need of a wireless PA system would be able to implement this system for personal use.

Introduction

Communication is a vital piece of any search and rescue mission. Whether it is orders being sent to the rescue workers or commands being issued to those in distress, it is important that some line of connections stays open. However, in the rugged environment of mountains and valleys, communication is not always available. Short range radio transmissions have trouble passing through a variety of different obstacles, so there needs to be a way to bypass this problem. Thus, our project was designed with the intent to allow the operator to talk to anyone involved in the search at any time.

This project seeks to explore practical forms of communication to implement upon an RMAX search-and-rescue UAV that can be easily employed by an untrained user.

Related Work

We were able to identify only one instance of a wireless public address system, similar to the system we implemented. The MURS Wireless PA (Public Address) system works in a very similar fashion as ours. A handheld radio is used to communicate with a receiver/amplifier station that connects to a horn. The intention of these radios is to allow the installation of a PA system where a hard-wired PA would be impossible, too expensive, or temporary. Indeed, the RMAX UAV is a perfect application for this system. The main differences between our systems are voltage input, range, power, and cost. The typical range of the MURS PA is only about 2 miles, whereas the operating range of our handheld radios is up to about 8 miles, depending on line-of-sight establishment and elevation. Also, the speaker used in the MURS is optimally configured for a 30W output, whereas our speaker can achieve up to 100W. The DC voltage input for the MURS is about 12.5VDC @ 1.2A, while our system utilizes a 12VDC @ 1A. The MURS system costs $698, before taxes and shipping. Our system cost around $200 in components, or approximately 28% of the cost of the MURS.

Product Definition

This section deals with the requirements of the project given by the customer and the objectives we set out to accomplish on our design.

Problem Summary

Environmental conditions can interrupt communication between search-and-rescue teams. In addition, there is no effective way for a rescue worker to communicate with a person in need of rescue. There needs to be a system, implementable on an RMAX UAV, which can allow for commands to be issued to both rescue workers and those in need of rescue.

Requirements

The requirements set forth by the customer for this project were fairly lenient. The ultimate goal of this project is to allow communication from an operator to anyone else working on the ground. In order to do this, a wirelessly operated PA loudspeaker should be designed to be mounted on the search-and-rescue UAV that will allow the issuance of vocal commands via long distances. In order to fully meet the physical requirements, the system should weigh less than ten pounds and have a radio range of at least five miles. In addition, the system should be versatile enough in design to comfortable mount anywhere on the UAV.

A preliminary design and prototype must be completed by June of 2011, with the final project being completed by December of the same year.

Since there is only need for one such communication system, cost is not a heavily driving factor. Rather, most of the funding is at our own discretion as we are the ones purchasing materials.

Objectives

We seek to create an early prototype that can exhibit the basic functionality requirements as set forth in the requirements section. We must allow an operator at a base station to input a vocal command, which can, in turn, be sent to the RMAX UAV and broadcast via a loudspeaker audio system.

So the overall goals of this project can be broken down into several key pieces. First, we must find a suitable PA loudspeaker horn that can achieve the desired output noise levels as set forth in the requirements. Following this, we must design an audio power amplifier that can support the required input of the horn. Our amplifier should be able to utilize power from the pre-existing on-board power supply. We must then design a device that can receive audio signals of the desired frequency range.

Since the scope of this project is too large to be entirely completed in a single quarter, the goal is to create a functioning prototype that exhibits the basic functionality called for in the requirements. In this sense, we have no expectations in terms of weight, power, range, or size in the design of this quarter. All issues that arise from this preliminary design will be handled during the following academic year. However, should the preliminary design be completed early, time will be invested into addressing the goals of the final design.

Design

Our team decided to work collectively on each piece of the project. This allowed for different perspectives and interpretations in terms of what would work for an individual piece and what wouldn't. This process also ensured that both team members knew exactly what was going on for each step – essential since one team member will be leaving the project this summer.

The design of this project comes down to three primary sections: radio communication, audio signal amplification, and physical output of the audio signal. For the preliminary design, we opted to create the final versions of the audio amplification and loudspeaker systems first and use a temporary solution to handle radio communication.

System Architecture

The architecture was broken into three different blocks to break the work up into major subdivisions. Figure 1 shows the basic block diagram of the design.

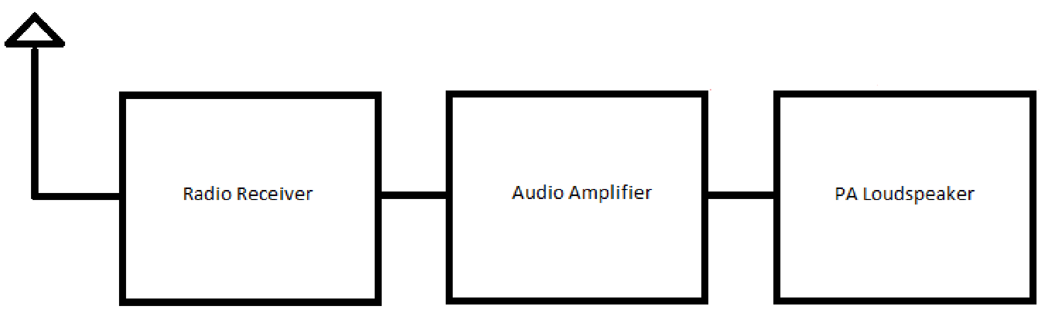

Figure 1: Basic System Block Diagram

The first stage of the system is the radio receiver. It should be noted that a radio transmitter is necessary to operate this system, but the project is designed such that any arbitrary transmitter

operating on given radio frequencies and settings will suffice. The goal of the receiver is to intercept a radio signal traveling through the air and convert it to a usable format. In the preliminary design, this task is essentially completed for us as we are currently using two hand-held radios to achieve communication. The output of the receiving radio is in the format of a 3.5mm stereo out audio jack. This cable is connected directly into the second stage via a 3.5mm to 6.35mm audio jack converter which plugs into the MIC in of our audio amplifier.

The second stage of the system is the audio amplifier. The goal of this stage is to take in a low power audio signal and amplify it into the 50-100 watt range that the speaker operates on. The amplifier takes in an audio signal that is around 2.45mV or 245mV, depending on which input is used, and outputs a maximum of 100 watts to the 8-ohm loudspeaker load. The amplifier is broken down into a transformer, bridge amplifier, level control, and the input and output stages.

The final stage of the system is the actual speaker. The speaker uses the amplified audio signal to power a pressure generating driver. This driver is what converts the electronic signal into pressure waves that can be discerned by the human ear.

Hardware Components

This section deals with the detailed description and implementation of each stage in the design.

Radio Communication

Radio communication is a very complex and intricate part of this project. The end-goal of the radio communication is to transmit an audio signal over very long ranges, upwards of 20 miles, while still retaining a high quality signal. Given the complexity of this problem, we did not plan on completing it in a single quarter. While time was spent on its construction, a different method of communication was applied to our first design.

Communication between an operator and the RMAX UAV is currently being accomplished by the incorporation of two Midland GXT760 radios, shown in figure 2.

Figure 2: Midland GXT760 Radios

These are simple two-way radios that operate on either a rechargeable battery pack or three AAA batteries. They can output at 5 watts with a nominal 36-mile range, which in reality is up to about eight miles in perfect conditions with line-of-sight. Both radios support 42 channels on the FRS/GMRS bands, with each channel offering 142 privacy codes. These privacy codes relate to one of the large

problems we must face in creating our own FM receiver. Since radio frequency bands are used in so many applications, the bands that are legal to operate on can get saturated with other users. Thus, using any given channel without some sort of privacy code means that we could easily pick up a signal from outside sources, and the last thing we want is to turn the search-and-rescue UAV into an extremely expensive stereo.

One radio is used by the system operator while the other radio is connected directly to the audio amplifier. This connection is made using a 3.5mm to 6.35mm audio jack. Figure 3 shows both of these connectors.

Figure 3: 3.5mm and 6.35mm Audio Jacks

The transmitting radio functions on a simple Push-To-Talk (PTT) button while the receiving radio is constantly in a listening state. In the future we hope to remove these radios and implement our own FM receiver unit. In the meantime, these radios offer a cheap, temporary solution to allow us to test the rest of the project.

Audio Amplifier

The amplifying stage is based around the TDA7396 class AB audio amplifier. This amplifier was chosen for a few very important characteristics relevant to our project. The first reason was for its relatively low distortion across the voice frequency range, approximately 300-3,000 Hertz. The figure below demonstrates total harmonic distortion (THD) vs. frequency for the amplifier.

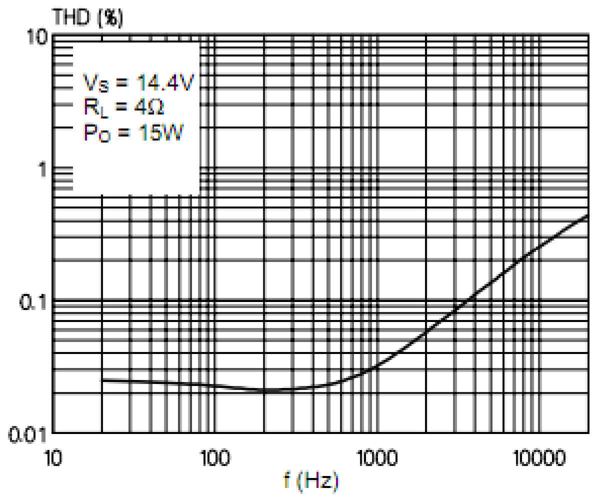

Figure 4: Total Harmonic Distortion vs. Frequency for TDA7396

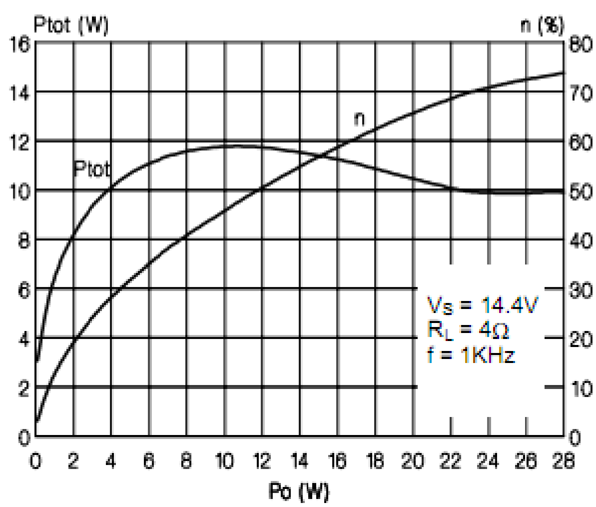

Figure 5: Total Power Dissipation & Efficiency vs. Output Power (4 ohm load)

The TDA7396 also shows very high efficiencies for high power levels. Since our speaker will require a large range for its audio projection, the system will likely be running at high power when the speaker is on. This efficiency is important for the overall power efficiency of the UAV. Figure 5 shows the efficiency and power dissipation at given power output levels for the amplifier.

Another reason the TDA7396 was chosen was due to its ease of implementation. Very few external components were required for the final design.

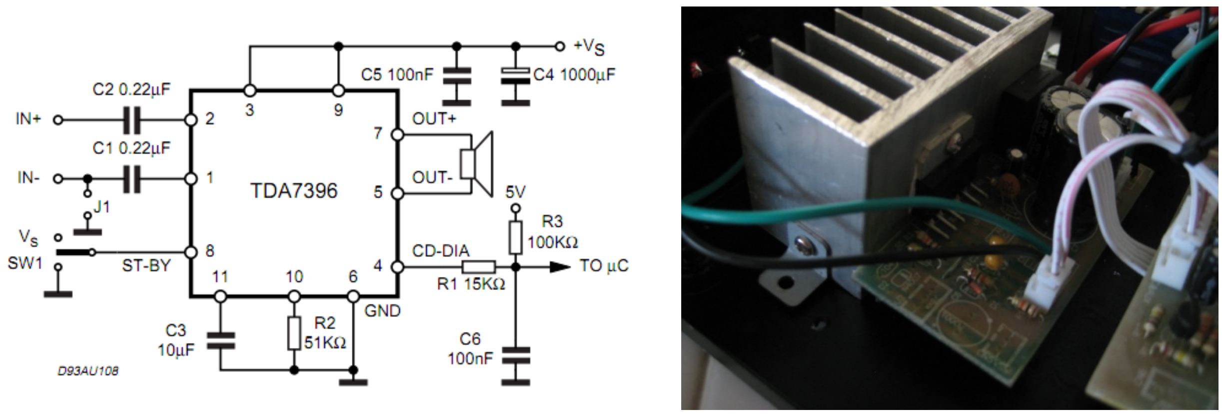

Figure 6: TDA7396 Application Block Diagram (left), TDA7396 implemented in the project (right)

This figure shows the block diagram of the implementation as well the physical implementation in our design. As shown, the amplifier is very compacted, with the heatsink being the biggest problem. However, large heatsinks are inevitable for any high power audio application, so there was no simple alternative to that which remained practical.

The TDA7396 offers around 26 dB voltage gain with around 50 W RMS output power and only 4 microvolts of input noise. Overall the chip was well suited as a solution to our amplifying stage.

Figure 7 shows the level adjustment circuit used to control the power or volume of the output. This block consisted primarily of variable resistors to dictate level control, two BA15218N dual op-amps, and accompanying RC components. Aside from volume control, this stage also served as a pre-amplifier for the TDA7396-based amplifying stage.

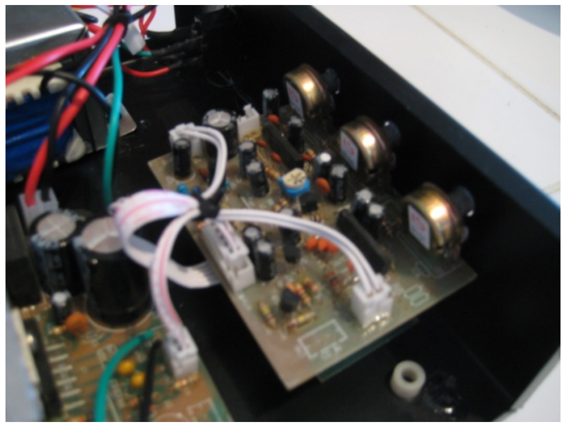

Figure 7: Volume Control Circuit

Figure 8 below shows the front and back panels of the amplifier. The front view shows the 3 available inputs – two “mic” inputs and one auxiliary input. The knobs above the inputs each control the volume for the respective input below it. On the right is the power switch and power indicator LED. The back view shows the power inputs and signal output. The left-most plug-in is for 120V-60Hz AC, the middle plug is the two-wire DC input. The right-most plug is the two-wire speaker output.

Figure 8: Front Panel (left), Back Panel (right)

Figure 9 shows the top-down view of the completed amplifying circuit without top cover.

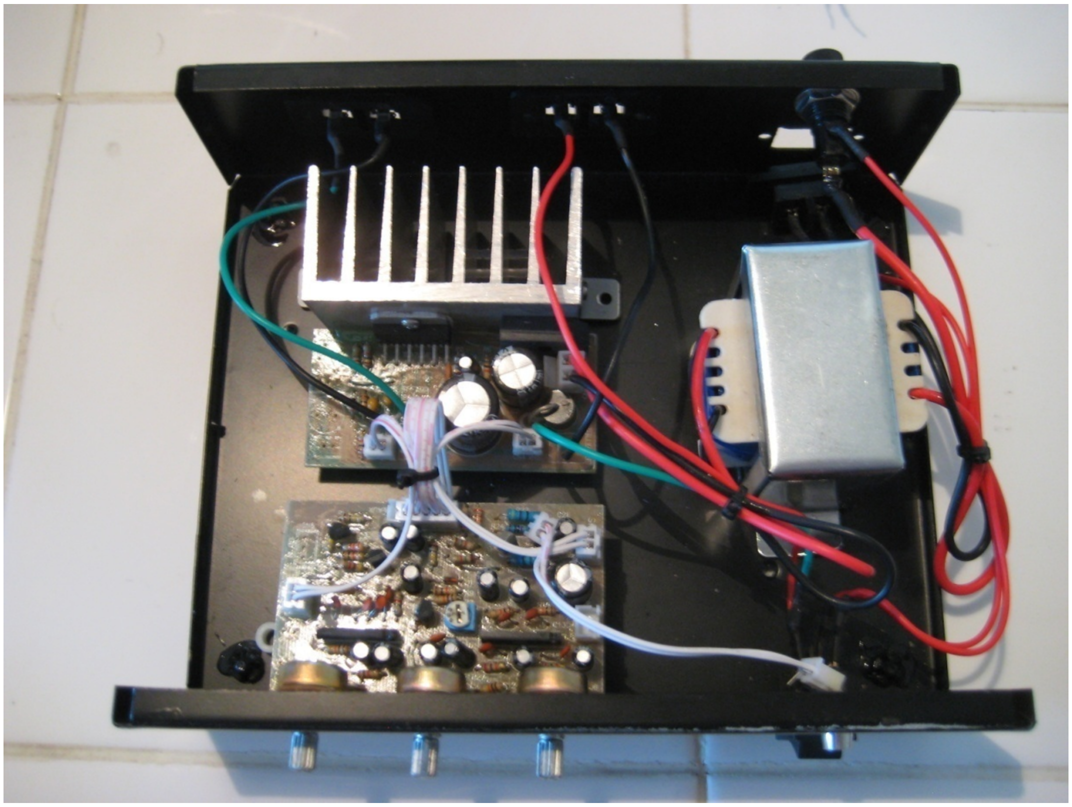

Figure 9: Top-down View of Completed Amplifier

PA Loudspeaker

The output of the audio signal is end goal of the project, but its implementation is relatively straightforward. Since the construction of a loudspeaker is somewhat impractical in terms of the scope of this project, we opted to purchase a horn that would meet the requirements of the system. We found a 100W-8Ω PA loudspeaker that worked quite effectively.

Figure 10: 100W-8Ω PA Loudspeaker

The horn shown in figure 10 outputs at up to 110 decibels, or roughly the equivalent of a rock concert. The physical specifications of the horn helped us meet our size requirements, the horn sits at just over four pounds and is only 8.5”x11”.6.5” in terms of dimensions. Ultimately we may also add a second audio output to our amplifier so that a second horn could be incorporated to effectively increase the range and area coverage of the speaker system.

The connection of the PA loudspeaker is a standard two-wire audio connection, one wire for positive signal and one wire for neutral. We connected these two wires directly into the output panel on the back of our audio amplifier.

System Integration

This section deals with how we assembled the prototype, including the hardware interconnections and the user interaction required to operate the system.

Hardware Integration

We designed each block of the system to retain a simple interface with the other appropriate blocks. As such, integrating the system into its final structure was as easy as connecting a few wires to allow for the transfer of our audio signal. The radio receiver connects to the audio amplifier via a 3.5mm to 6.35mm audio jack as shown in figure 11.

Figure 11: Connection Between Radio and Amplifier

The audio amplifier connects to the PA loudspeaker via a two-wire, positive and neutral, interface. This can be seen in figure 12 below. The power amplifier required a connection to the on-board power supply of the UAV, which in this case is a 12V DC input. This input is connected to the amplifier in the same manner that the speaker is connected, except using the DC input port in the middle of the back panel. Aside from the amplifier's power source, the entire system is self-contained.

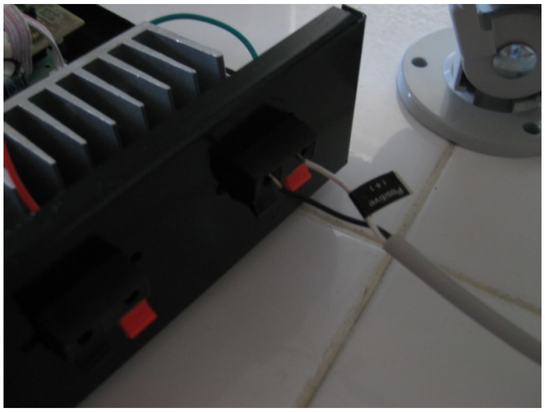

Figure12: Connection Between Amplifier and Loudspeaker

Figure 13 demonstrates the completed system with each piece integrated and implemented.

Figure 13: Completed PA Loudspeaker System

User Interaction

The input into the system starts with the transmitting handheld radio. The user must power on the device and select a channel to operate. Figure 14 shows the screen interface for one of the radios. The 16 on the screen represents the current channel setting and the small little h next to the number represents that the channel selected is a higher power, or 5 watt, channel that operates on the GMRS frequencies.

Figure 14: Radio Interface

The same thing should be done for the receiving radio. The user has access to volume control on both the radios and the audio amplifier via adjustable knobs, but it is advised that the radio volume be kept at a minimum and the amplifier volume control be used to obtain the desired volume. The issue with increasing the radio volume is that it when the amplifier was designed for an input signal of approximately 2.45mV for the mic inputs or 245mV for the auxiliary input and exceeding this value will exponentially increase total harmonic distortion. Once these settings are set, the user may activate the Push-To-Talk button on the side of the transmitting radio and speak into the microphone. The system will handle the rest of the process and output the amplified voice signal from the loudspeaker.

Testing

This section describes how functionality of the system was tested as well as some important parameters that we used when making design decisions.

Radio Testing

Testing of the radio handsets was very basic. Since the radios are pre-packaged and understood to be fully functional, we simply needed to test their limits in relation to their application in our project. The voltage range on the audio out of the radios was found to be approximately 5 volts maximum. However, we worked with a fraction of this in our end design as a 5 volt audio signal generates a lot of distortion when amplified.

Range is one of the most important parameters to consider while constructing the communication stage. The requirements stated we must reach at least five miles, and while this was only a preliminary test with a temporary communication solution, we wanted to be able to reach that goal. Testing of the range was done on Pismo Beach as we would not have to worry about too many obstructions. In this scenario we were able to get approximately seven to eight miles with clear line-of-sight. We were able to transmit across the Cal Poly campus as well, with one radio unit on the top of the parking structure by the performing arts center and the other radio unit next to Engineering IV. While 7-8 miles in prime conditions is a far cry from the advertised 36 mile range on the radios, the values are more than acceptable at this stage of the project. However this does demonstrate how difficult it can be to transmit radio signal over long distances and emphasizes the need for us to utilize local repeater towers on our final design.

Amplifier Testing

The design of the amplifier was the most technically involved for this implementation of the project, and as such was much more difficult to test and tune properly. The gain of the inputs and outputs were very susceptible to minor changes in a variety of different circuit values but references from online web pages were very helpful in pinpointing key areas.

In the end, we found a frequency response of about -3dB for both the mic and line signals, with mic working in the 100Hz-20kHz range and line working in the 30Hz-20kHz range. Signal-to-Noise ratio (SNR) was found to be over 70dB for the mic and over 80dB for the line. The amplifier outputs about 50 watts RMS under normal application settings with a peak value of 100 watts when it's pushed to its limits.

Loudspeaker Testing

The testing of the loudspeaker is fairly subjective. The main question is, given the output of our amplifier, can the loudspeaker output sufficient noise levels to be heard at the distance typical of its application requirements? At one tenth of the maximum volume, we were able to hear the loudspeaker clearly across the Cal Poly G1 parking lots, which is about two or three tenth of a mile. We personally felt that the loudspeaker was sufficiently loud enough to be heard from a UAV several thousand feet in the air, but it's hard to say for sure until we can actually attach the loudspeaker to the UAV and test it. As the value for how loud the system needs to be is largely arbitrary, we will have to wait for an actual UAV demonstration to determine if anything needs adjusting.

Problems During The Process

The project went along fairly smooth, but we did run into a few issues that made us wonder what was going on. However, we were able to learn from these problems and make our design much more solid in the long run.

One of the first things we noticed was after getting our own custom FM receiver functioning. We turned it on and heard some random chatter from other radio users and realized that we had no way of filtering out messages. The radio frequency bands that we are allowed to use are essentially free for anyone to use, so in the event that someone accidentally, or purposefully, hops onto our frequency band, they could misuse our speaker. As a result, we determined that we would have to implement that feature in the future and use a temporary solution since we only had a single quarter for the preliminary design. Hence, two-way hand radios are currently being used in the current project implementation.

Another issue we ran into was working on the amplifier. We had tested the design with lab equipment and determined it to be working properly, with the required gains to power the loudspeaker just fine. However, for some mysterious reason our outputting signal was roughly half of what was intended, but it was only when we attached the radios. What we realized in the end was that we were actually using a 3.5mm stereo-6.35mm stereo adapter for our connection from the radios to the amplifier. The problem is that mic and auxiliary inputs use mono sound, so when given a stereo connection they essentially ignore one of the rings on the adapter. Figure 15 shows the difference between stereo-stereo and stereo-mono adapters. A stereo-mono adapter fixed our issue completely.

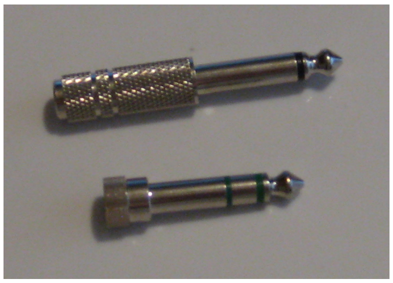

Figure 15: 3.5mm to 6.35mm adapters, stereo-mono (top) and stereo-stereo (bottom)

Future Work

Given that this project has a planned completion date somewhere around December 2011, there are still a few features that need to be completed.

Radio Receiver

First and foremost, the two-way radio communication system will eventually be removed and replaced with a custom built radio receiver. The receiver is based on the Silicon Laboratories Si4374 digital AM/FM/SW/LW radio receiver IC being controlled by an Atmel Atmega328 microcontroller. Both of these chips can be seen in figure 16. The block diagram for the Si4734 can be seen in figure 17.

Figure 16: Si473x IC (left), Atmega328 IC (right)

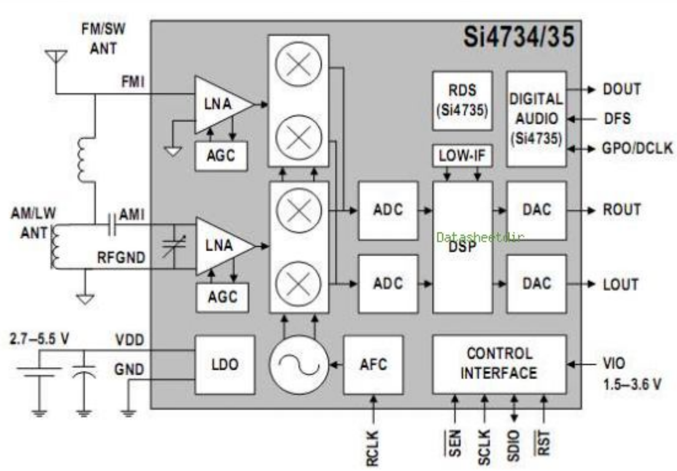

Figure 17: Si4734/35 Hardware Block Diagram

The Si4374 offers support for a wide range of radio frequencies and is easily programmed via a corresponding microcontroller. We have already tested this receiver using a simple whip antenna and headphones to listen to various FM radio stations and found it to be fully functioning. However, it is not currently ready to be implemented on the final design. We need to design an antenna that will offer proper reception for the radio frequency we plan on using for the project. This brings us to the other big problem with designing a radio receiver, what frequency should we plan on using? The FCC holds strict regulation over the allowable frequencies for radio transmitters so the choices are limited. This means that many users could be trying to use the same frequency band which results in our speaker being susceptible to broadcasting random radio chatter. Thus, we need to devise some sort of privacy settings that can encode our audio signal and allow our speaker to broadcast only that which we desire to broadcast.

The plan is to make our receiver versatile enough to operate on a variety of different frequencies, allowing any member of the search-and-rescue team to use the UAV's loudspeaker at their own discretion. Ideally, we would be able to operate on emergency radio frequencies where crosstalk would be minimal. Using this frequency, we could use a variety of different types of radios that search-and-rescue services would already have. In addition, the range of the transmitters would be indefinite, as we can utilize local radio repeater towers to retransmit our signal at higher power levels.

Increasing Sound Range or Quality

While we found the output noise levels of the current implementation to be suitable, it would be possible that the output needs to be increased. This could be done in several ways; the first would be to utilize an extra channel on our audio amplifier to include a second loudspeaker. This would greatly increase the directional capabilities of the current system and would also be very easy to implement.

Sound quality is an issue that will have to be dealt with after the new receiver is installed. At

low volume levels, the signal has been relatively clear, but that is not to say there won't be any distortion when the signal is jumped up to the range of 100 watts utilized by the loudspeaker.

Optimizing Audio Amplifier Design

When building the audio amplifier, we found that we were not always able to access a DC power source with the ratings we needed. Eventually we found an AC transformer laying around that allowed us to operate using the standard 120V-60Hz AC power found in any home. Since the transformer is only implemented as means of convenience and only DC power will be available on the UAV, this component is largely unnecessary and will be removed in the final design. As seen in figure 18, the transformer is quite sizeable.

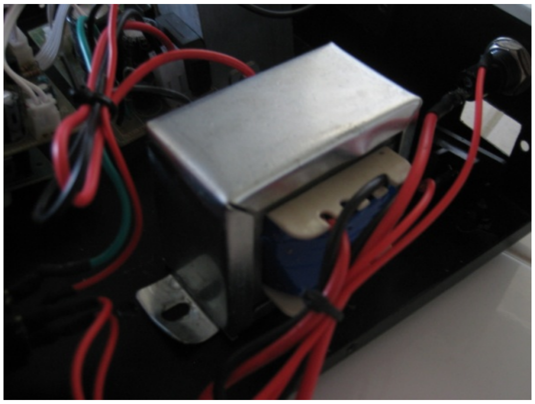

Figure 18: Amplifier Transformer

Redesign Housing

Since the radio receiver will be entirely redesigned from its current implementation, a new housing structure would be ideal. However, with the removal of the AC transformer in the audio amplifier, it may be possible and ideal to simply incorporate the new FM receiver into the pre-existing housing, putting the receiver in the transformer's old location.

Conclusions

The initial requirements for this quarter stated that we must design and implement a wireless PA loudspeaker system that can operate with the on-board power supply, obtain a range of at least five miles, and weigh less than ten pounds. All of the requirements were met and the system is able to solve the problem presented before us.

Based on the requirements for our final design, we are ahead of schedule. We have already tested our custom receiver IC and found it to be fully functional. Once a proper antenna design is found and an algorithm is created to allow for private channel operation, the new receiver block will be completed. Upon the integration of the new receiver, all final project goals will be accomplished and the time remaining can be spent optimizing the design and adding additional functionality.

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Viking Aerospace WeControl UAV Autopilot Systems
http://www.vikingaero.com/uav_autopilot.html

User's Quickstart Guide

The following is a guide to quickly setup and use the PA system. Setup time should be less than one minute.

Step 1: Connecting the Radio and Amplifier - Plug the 3.5mm end of the wire into SPK jack on the receiving radio handset, then plug the 6.35mm end into the input labelled auxiliar or mic on the front panel of the amplifier as shown below.

Figure 19: Connecting the Radio to the Amplifier

Step 2: Connecting the Amplifier and Loudspeaker - Take wire from the back of the loudspeaker and plug it into the back panel of the amplifier. The outlet should be labeled OUT. The white wire is positive and should be placed in the red clip while the black wire is negative and should be placed in the black clip. Figure 20 below depicts what this should look like when connected.

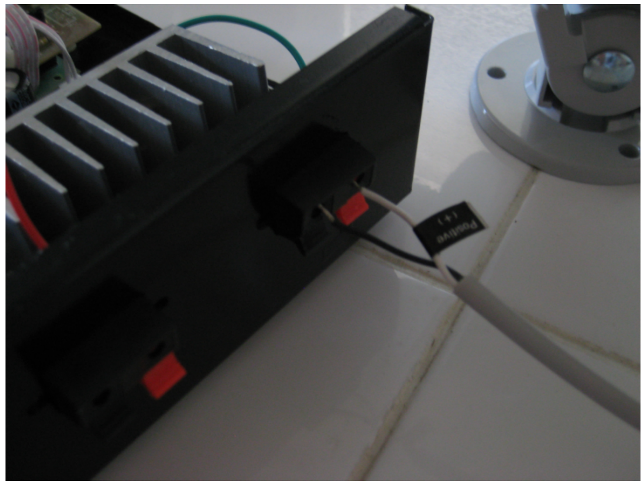

Figure 20: Connecting the Loudspeaker to the Amplifier

Step 3: Setting Up the Radios – Power on the radio by turning the volume adjustment knob on the top of the radio. Volume on the radios should be kept relatively low (around a quarter turn). To change channels on the radios, press the menu button on the middle of the radio. After doing so the number on the screen should be flashing. By pressing the up and down buttons the radio can cycle through the different channels. After the desired channel is selected, press menu until nothing on the screen is flashing. Repeat this whole process for both radios and make sure they are both set to the same channel. The figure below shows each button necessary for setup and use.

Figure 21: Radio Setup – Volume Control (blue), Menu (yellow), Up/Down (red), Push-To-Talk (green)

Step 4: Adjusting the Volume – Volume should be adjusted by turning the knobs on the amplifier. Turn the knob above the desired input to increase or decrease the volume of the output.

Step 5: Using the Loudspeaker – Once all settings are set, operate the radio by pressing and holding the Push-To-Talk button (see figure 21) on the side of the transmitting radio handset. Speak into the radio and once your message is complete, release the button.