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RUSH

March 7, 2008

Dr. Patrick Leung
School of Engineering Science
Simon Fraser University
Burnaby, BC
V5A 1S6

Re: ENSC 440 Design Specifications for a Helmet-Embedded Communications System

Dear Dr. Leung,

Our team is working diligently to construct and assemble an innovative solution to the growing and diverse communication needs of snow-sports enthusiasts. By integrating a communication and location tracking system into a snow-sports helmet, our product will deliver a new level of safety and convenience to winter sport enthusiasts. We have selected design solutions to meet the functional requirements of our product, and outlined them in the attached document, *Functional Specifications for a Helmet-Embedded Communications System*.

The attached design specifications concisely describe how we plan to implement the hardware, firmware, and mechanical components of our product, and include our strict rationale for design and component selection. We also outline a test plan to ensure our product functions correctly and reliably.

Ensuring the success of our proposal is a team of five enthusiastic and talented individuals from the School of Engineering Science: Mathew Bond, Daniel Hessels, Robert Hueber, Darren Jang, and Rob Tyson. You are welcome to contact us by phone at 604-783-9650 or email at ensc440-rush@sfu.ca if you have any questions regarding our project.

Sincerely,

MBond

Mathew Bond, CEO RUSH

Enclosure: Design Specifications for a Helmet-Embedded Communications System

cc: Mr. Steve Whitmore, Mr. Brad Oldham, Mr. Jason Lee

Raven

Design Specifications for a Helmet-Embedded Communications System

Management Team: Mathew Bond
Daniel Hessels
Robert Hueber
Darren Jang
Rob Tyson

Contact: Mathew Bond ensc440-rush@sfu.ca

Submitted to: Dr. Patrick Leung
Mr. Steve Whitmore
Mr. Brad Oldham
Mr. Jason Lee

Issued Date: March 7, 2008

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Executive Summary

The current adoption of personal communication technologies continues to deeply penetrate our social networks. As an indicator of this we are expecting to see the *global* number of cellular telephone users surpass the number of those without cell phones in 2008 [1]. Clearly our dependence on convenient wireless communications has pervaded our consciousness so thoroughly that we constantly rely upon them at home, at work, and on the go.

With the recent increase in the availability of portable media services, outdoor enthusiasts have readily adopted music players, GPS receivers, and FRS radios to enhance their recreational experience. While these technologies have so far existed independently, RUSH now innovatively integrates them together into our fully featured snow-sports helmet that offers users wireless control and uncompromised protection.

Protecting its users against potential head injury is the paramount function of the RUSH Raven. Our design team has taken helmet design to the next level by integrating electronic and mechanical components together to provide enhanced features to the user without compromising safety. With the RUSH Raven, snow-sports enthusiasts can now:

- communicate to others via FRS radio
- log GPS performance data and transfer it to a PC
- listen to external audio without the need for clumsy headphones

Most importantly, all of the enhanced features of the RUSH Raven can be effortlessly accessed and controlled through our ergonomically designed user interface. Users are now able to transmit radio messages and adjust volume without having to stop and remove their gloves.

These design specifications outline the fulfilment of the RUSH Raven's features and detail all of the major components necessary to provide quality functionality to the user.

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Glossary

FRS	Family Radio Service
GPS	Global Positioning System
GGA	Global Positioning System Fix Data
VTG	Course Over Ground and Ground Speed
RMC	Recommended Minimum Specific GPS Data
GSA	GPS DOP and Active Satellites
GSV	GPS Satellites in View
GLL	Latitude, Longitude, UTC and status
Good View of the Sky	This means that GPS satellite signals are not severely blocked by any large structures.
Normal Use	A period of use in which the product is transmitting FRS radio signals 10% of the time
PTT	Push-to-talk

UI	User Interface
OEM	Original Equipment Manufacturer
TQFN	Thin Quad Flat No leads
TSSOP	Thin Shrink Small Outline Package
NMEA	National Marine Electronics Association
SD	Secure Digital
SPI	Serial Peripheral Interface
EUSART	Enhanced Universal Synchronous Asynchronous Receiver Transmitter

1. Introduction

The RUSH Raven is a helmet-embedded communications system that brings together the functionality of handheld GPS units and common two-way radios in the form of an ergonomic and easy to use snow sports helmet.

1.1. Scope

This document outlines the design specifications for a proof-of-concept version of the RUSH Raven. We take care to fully describe how each component of the design meets the functional requirements of our proof of concept prototype. In addition, we provide a detailed description of the implementation of each system component and a thorough test plan, ensuring our product will function as required.

1.2. Intended Audience

This document is intended to guide the members of the RUSH team throughout the process of designing, implementing, testing, and evaluating the RUSH Raven.

2. System Overview

The RUSH Raven, as demonstrated in Figure 1, combines the safety of a snowboard helmet with position tracking from a GPS module, personal communication via FRS radio, and a wireless PTT button to provide the user with an all-in-one Helmet Embedded Communication System. This unified solution simplifies the use of the former subsystems, while adding new functionality and capabilities. The easy-to-use wireless PTT will enable the user to communicate to other FRS users without the frustration of fishing in a pocket for a separate device that can be clumsily dropped by gloved hands. A GPS module will enable the system to inform the user of various parameters like velocity, altitude and compass bearing, while storage of position information on a mircoSD card allows them to transfer data to a personal computer and review and analyze his/her daily performance. All the modules that comprise the system will be replaceable, enhancing the lifetime of our product and enabling the user to repair or upgrade the electronic modules or helmet as they wish.

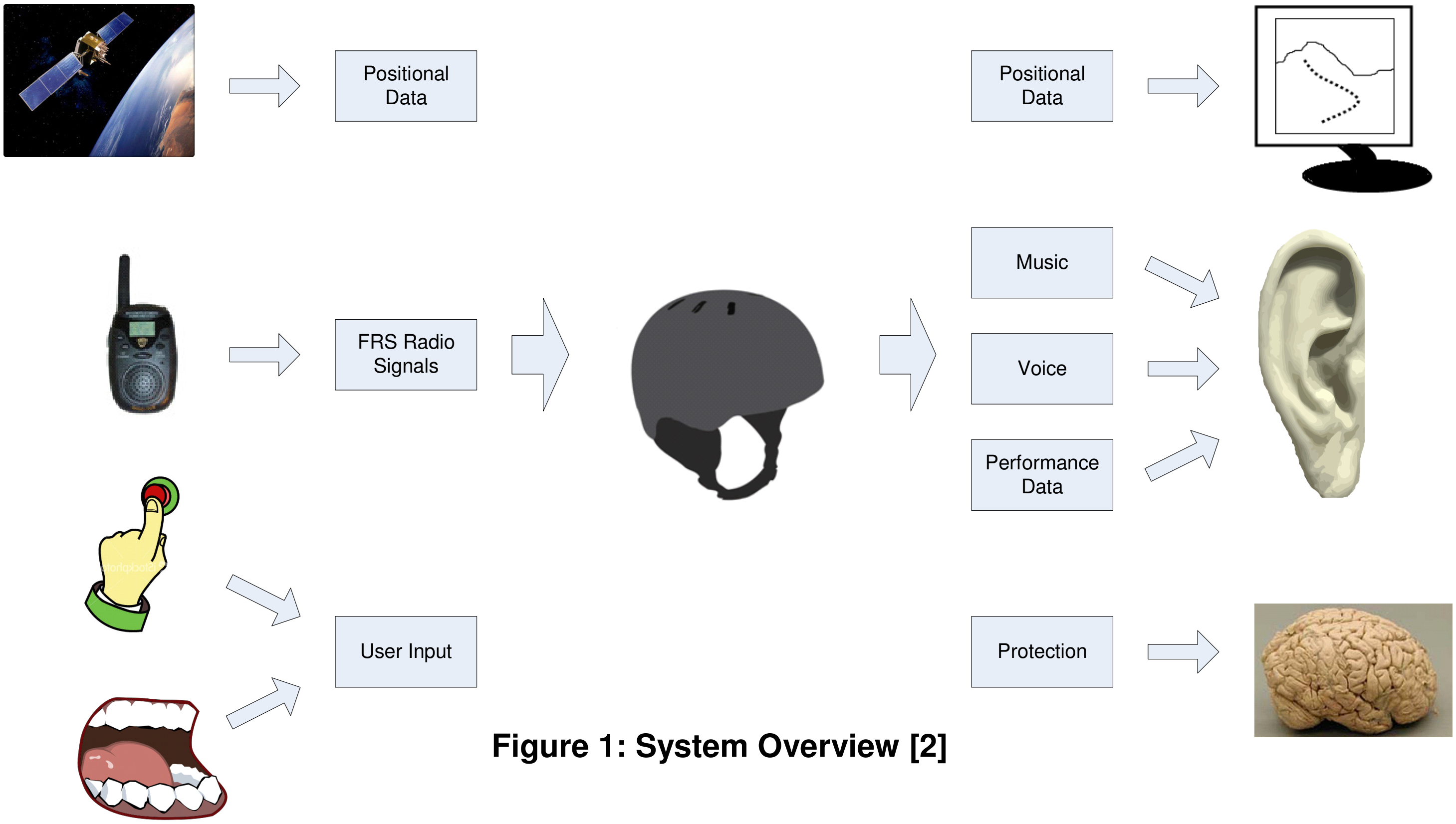


Figure 1: System Overview [2]

3. System Hardware

This section describes the design of the electronic hardware components of the RUSH Raven.

3.1. Hardware Overview

Figure 2 below provides a visual description of all the hardware components of the RUSH Raven and how they will interact.

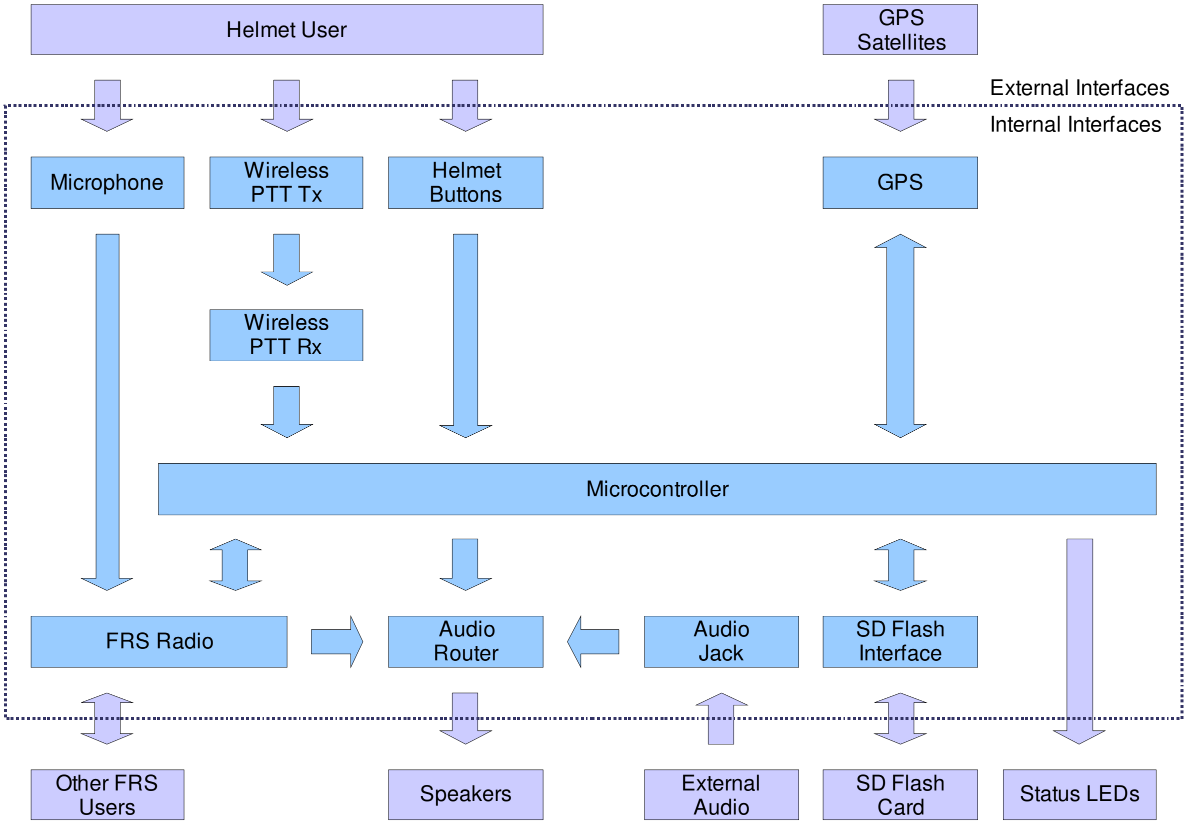


Figure 2: Hardware Overview

3.2. FRS Radio

The two-way walkie-talkie functionality is implemented by an embedded Motorola T6210 FRS radio. For the proof-of-concept build, only the basic features of this commercially available radio module are used to provide the specified functionality of the RUSH Raven concept. The integration of the T6210 radio does not compromise its effectiveness or electrical specifications and as such, it continues to fully comply with all of the consumer product and federal wireless standards and specifications. Specifically, the radio will preserve its ability to communicate on the standard 14 base channels assigned to the FRS radio spectrum as shown in Table 1 below.

Table 1: FRS Channel Frequency Chart [3]

Channel Frequency Chart			
Channel	**MHz**	**Channel**	**MHz**
1	462.5625	8	467.5625
2	462.5875	9	467.5875
3	462.6125	10	467.6125
4	462.6375	11	467.6375
5	462.6625	12	467.6625
6	462.6875	13	467.6875
7	462.7125	14	467.7125

Similarly, the integrated FRS radio will have a range equivalent to the stock T6210 radio. While this operating range is highly dependent on the nature of the user's environment, a slight range advantage may be realized by our placement of the radio's circuitry atop the users head. In doing so, and in combination with an extended ground plane (shielding the user's head from unnecessary EM radiation), the radio is better configured for optimal performance.

In maintaining with the FCC requirement 95.647 that "The antenna of each FRS unit, ..., must be an integral part of the transmitter" [4], the vertically-polarizing OEM antenna of the T6210 transceiver is maintained as an "integral part" of the radio circuitry. The proof-of-concept prototype preserves the T6210 circuit board in its entirety, save for the LCD display and speaker. The T6210 OEM shielding, in addition to supplemental EMI shielding is used, and thus maintains compliance with wireless device standards such as FCC Title 47, Part 15 [5].

Additionally, the T6210 satisfies the following RF emission standards [3]:

- United States Federal Communications Commission, Code of Federal Regulations;47 CFR part 2 sub-part J
- American National Standards Institute (ANSI) / Institute of Electrical and Electronic Engineers (IEEE) C95. 1-1992
- Institute of Electrical and Electronic Engineers (IEEE) C95.1-1999 Edition

- National Council on Radiation Protection and Measurements (NCRP) of the United States, Report 86, 1986
- International Commission on Non-Ionizing Radiation Protection (ICNIRP) 1998
- Ministry of Health (Canada) Safety Code 6. Limits of Human Exposure to Radio Frequency Electromagnetic Fields in the Frequency Range from 3 kHz to 300 GHz, 1999
- National Radiological Protection Board of the United Kingdom 1995

The use of a personal music player will not interfere with the operation of the FRS radio. Since the audio is multiplexed by the MAX9770 IC, which is in turn controlled by microcontroller logic, the auxiliary audio source is interrupted whenever the radio is being operated. This design keeps the respective audio signals from interfering with one another.

3.3. Audio Control

3.3.1. Overview

The RUSH helmet-embedded communications system intelligently integrates the two-way voice communication of a walkie-talkie with the ever popular personal music player. It provides the user with a standard 3.5mm stereo input jack for connection of an auxiliary audio source such as an iPod mp3 player. When the FRS radio receives a transmission, the auxiliary audio source is automatically interrupted to allow the incoming voice to be heard over the headphone speakers. When the user transmits their voice by speaking into the microphone while pressing one of the PTT buttons, the auxiliary audio source is muted to allow undisturbed messaging.

The FRS radio and auxiliary audio source maintain independent volume control. To adjust the radio volume, the user is provided with an intuitive rocker-type switch to either increase or decrease the audio level. The volume control of the auxiliary audio source remains a function of the playback device so as to preserve its native user-interface and control features. Correspondingly, all other features typical to playback devices (such as track selection, power, etc.) will remain unaffected when used in conjunction with the RUSH electronics. A top-level overview of the audio module is shown below in Figure 3.

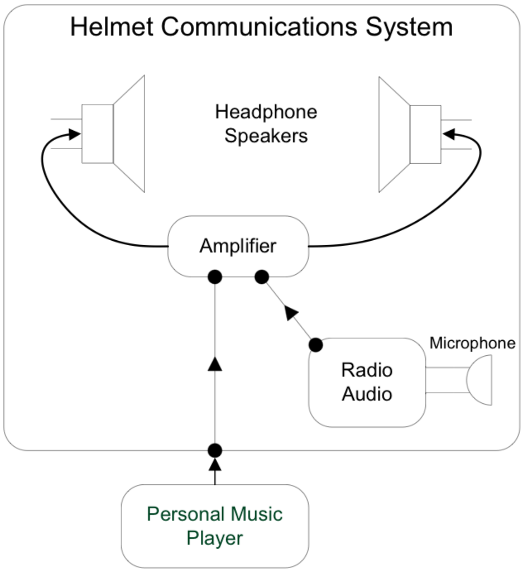


Figure 3: Audio Module Overview

3.3.2. Audio Signal Conditioning

Figure 4 below details the functional connections of the audio routing system.

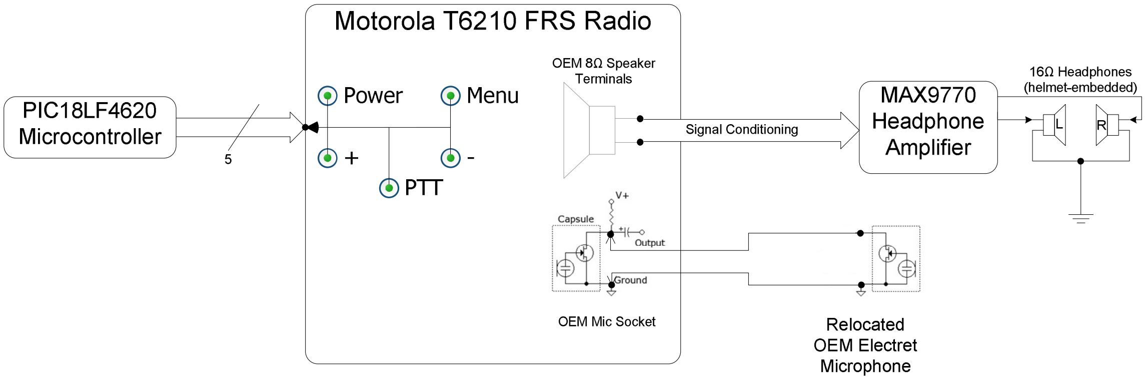


Figure 4: Audio Implementation Schematic [6]

The OEM speaker was implemented in a biased, Bridge-Tied Load configuration, with the output waveform biased at approximately half the supply voltage as shown in Figure 5 below.

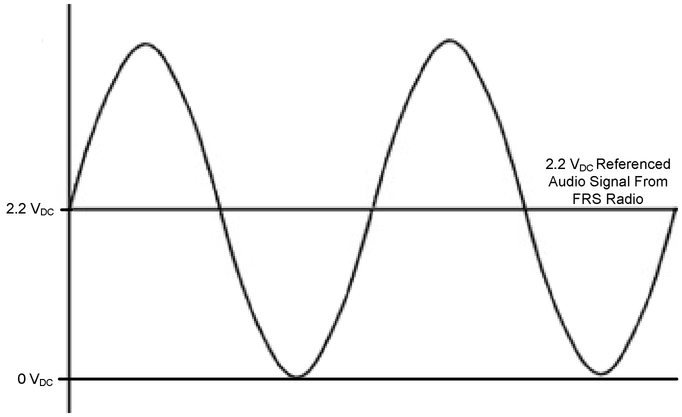


Figure 5: Illustrative Signal Applied to OEM Speaker by T6210 Circuitry [7]

The MAX9770 Headphone amplifier requires a ground-referenced audio signal, so a level-shifter signal conditioning circuit, as shown below in Figure 6, is required.

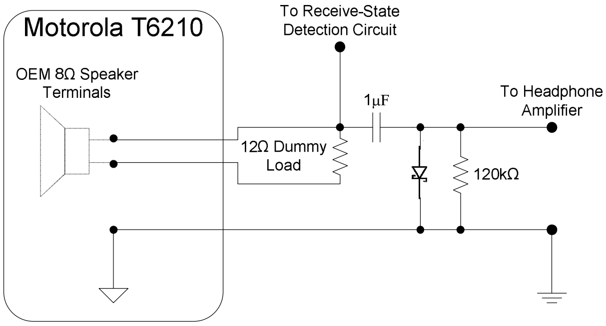


Figure 6: Level-Shifting Signal Conditioner Circuit [8]

A 12Ω dummy load resistor is applied across the speaker terminals to simulate the 8Ω OEM speaker. The received audio signal is then sampled from the voltage developed across the dummy load, and level-shifted by the capacitor, diode, and 120k Ω discharge resistor network to provide a ground-referenced audio signal. The resulting waveform is shown pictorially as Figure 7 below.

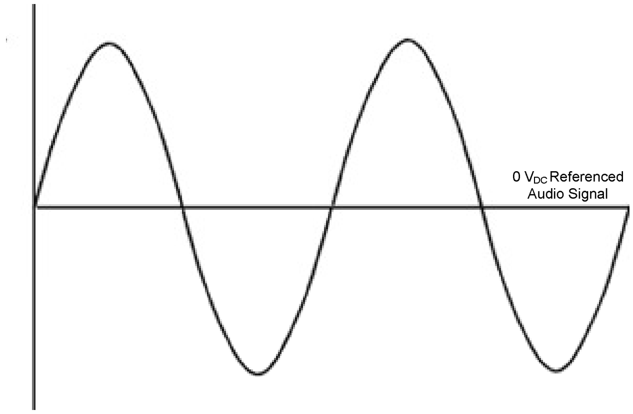


Figure 7: Illustrative ground-referenced waveform [7]

3.3.3. Component Selection and Schematics

To achieve the highly integrated and refined functional performance of the RUSH communications package, the MAXIM MAX9770 audio IC is specified. This full- featured single IC solution provides:

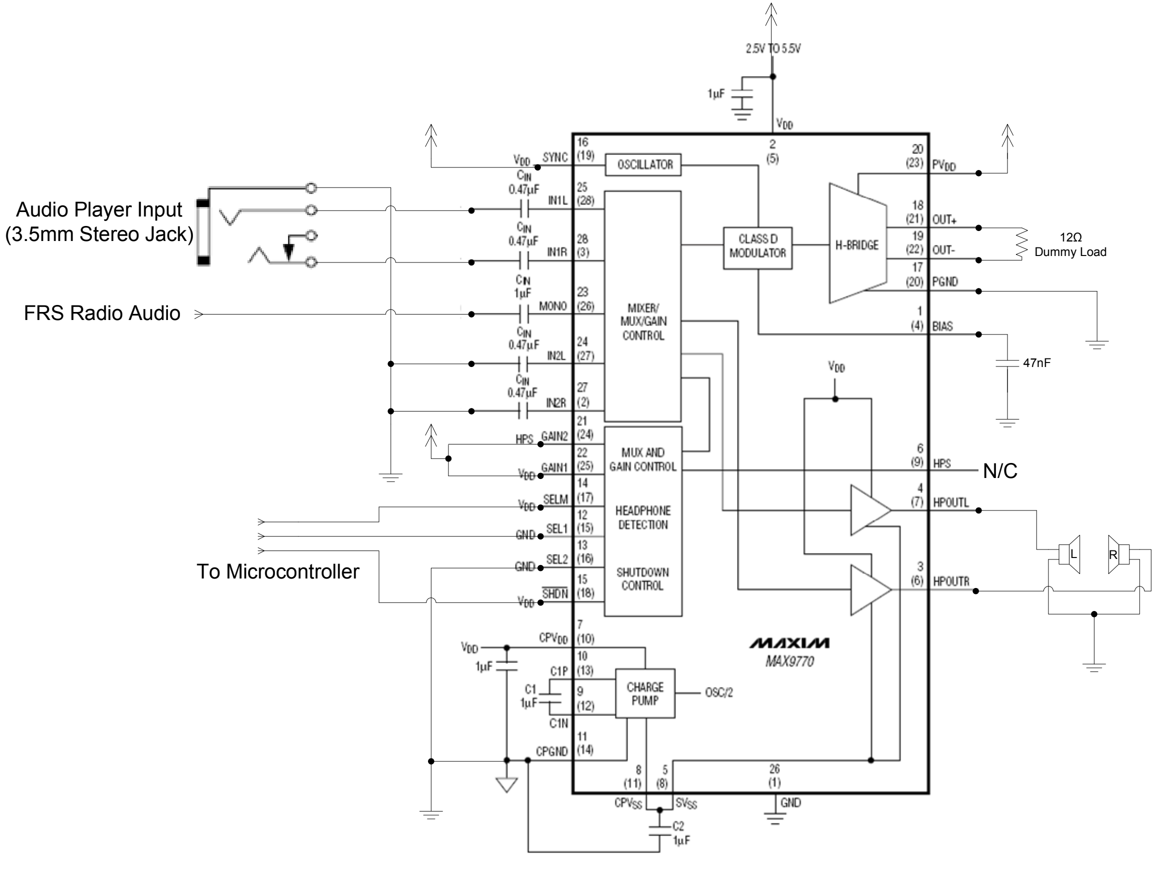
- input multiplexing and mixing
- variable gain
- advanced 'click-and-pop' suppression
- the ability to directly drive output transducers without DC-blocking capacitors.

The audio inputs are silently switched from control signals provided by the microcontroller. We exploit the dedicated MONO input of the MAX9770 to feed the radio audio through to both left and right headphone speakers. The IN1 stereo input used for the music player is connected as shown to its input jack. The third, IN2, input is unused and its input and control (SEL2) lines are correspondingly grounded.

Since volume control is handled by upstream circuits, the programmable gain is set for a headphone gain of 1dB. The MAX9770 also features a mono Class-D loudspeaker amplifier, however this functionality is unused in our design. As such, a 12 Ω dummy load resister is used and the IC is configured for permanent headphone operation by leaving HPS unconnected.

One of the key features of the MAX9770 is its ability to directly drive output transducers. Typical single-supply audio amplifiers require large-value DC-blocking capacitors at their outputs that sacrifice both physical space and low-frequency response. The internal charge-pump negative supply of the MAX9770 yields ground-referenced output signals for improved bass response and simpler, more compact implementation. This so-called “DirectDrive” technology is also a component of the advanced click-and-pop noise suppression functionality that this feature rich IC offers [9].

Figure 8 below shows our modified implementation of the functional blocks of the MAX9770, as adapted from the datasheet typical application.



( ) FOR TSSOP PIN.

Figure 8: MAX9770 Internal Functional Details [9]

The 28-pin TSSOP package is selected for its ease in prototyping, with leads on only two of its sides vs. the quad-sided TQFN alternate packaging. This schematic implementation is shown in Figure 9 below.

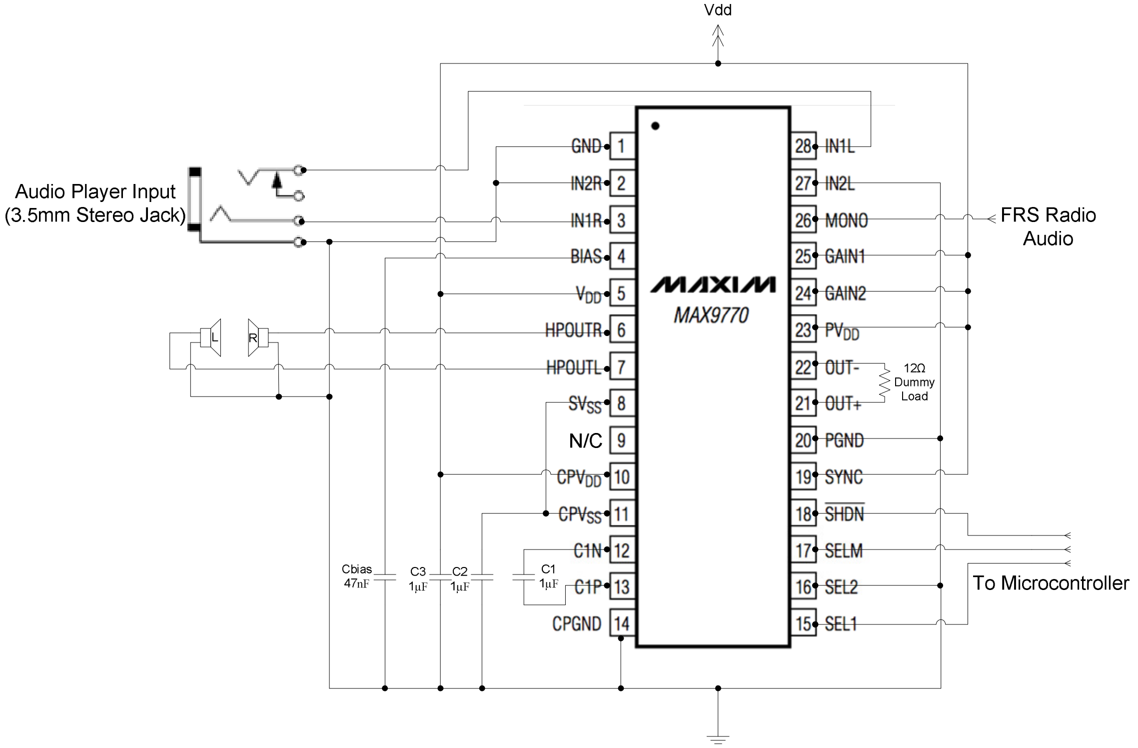


Figure 9: Audio Control Circuit Schematic [9]

The following table lists the key operating specifications of the MAX9770 as they pertain to its application in the RUSH communication system.

Table 2: Key Operating Specs of the MAX9770 Integrated Amplifier IC [9]

General	
Supply Voltage (Nominal)	3.6 V_{DC}
Current Consumption (Typ., @ V_{dd} = 3.3V)	5 mA
Shutdown Current Consumption (Typ.)	0.1 µA
Shutdown to Full Operation	50 ms
Headphone Amplifier (for Gain = -2dB, Vdd = 3.3V)	
Output Offset Voltage (Max.)	± 10 mV
Output Power (Typ., @ 1kHz, THD+N = 1%) R_L = 16Ω R_L = 32Ω	 40 mW 55 mW
Signal to Noise Ratio (Typ.) (R_L = 32Ω, V_{out} = 300mV_{rms}, BW = 22Hz – 22kHz)	101 dB
Electro-Static Discharge Protection (Typ.) (IEC Air Discharge)	± 8 kV

3.4. GPS Module

The function of the GPS subsystem is to provide the user with positional and performance information such as course, speed and time. When selecting a GPS unit the follow characteristics were the most important considerations:

- Simplicity – Requires little or no external circuitry of RF design
- Size
- Cost
- Power consumption
- Quality of documentation.

The two GPS modules that stood out from the rest during research are compared below in Table 3.

Table 3: Comparison of GPS Modules

Criteria	Ublox	Tyco
Simplicity	Antenna included	Need to design one PCB trace
Size	Small	Small
Cost	$200	$130
Power Consumption	Low	Low
Documentation	Very well documented	Difficult to obtain

Due to the large difference in price, our final decision was to use the Tyco Electronics module.

For the implementation of the prototype the evaluation kit will be used directly with the rest of the helmet system. This will make it easy for us to power, access, and debug the functions of interest. The board has six screw terminals and a set of eight DIP switches that must be set correctly depending on its use. For the unit to interface with the microcontroller correctly the switches should be set as shown in Table 4 below.

Table 4: DIP Switch Settings [10]

Switch	Setting
S1	Open
S2	Closed
S3	Closed
S4	Open
S5	Closed
S6	Open
S7	Closed
S8	Open

Connections to the module are accomplished through the six screw terminals, as described below in Table 5. A physical diagram of these connections as well as the antenna connection is included in Figure 10.

Table 5: Screw Terminal Connections

Pin	Port	Connection
1	NMEA in	uC Serial
2	NMEA	uC Serial in
3	1PPS	N/C
4	3.3 V	Power
5	GND	Ground
6	Backup	N/C

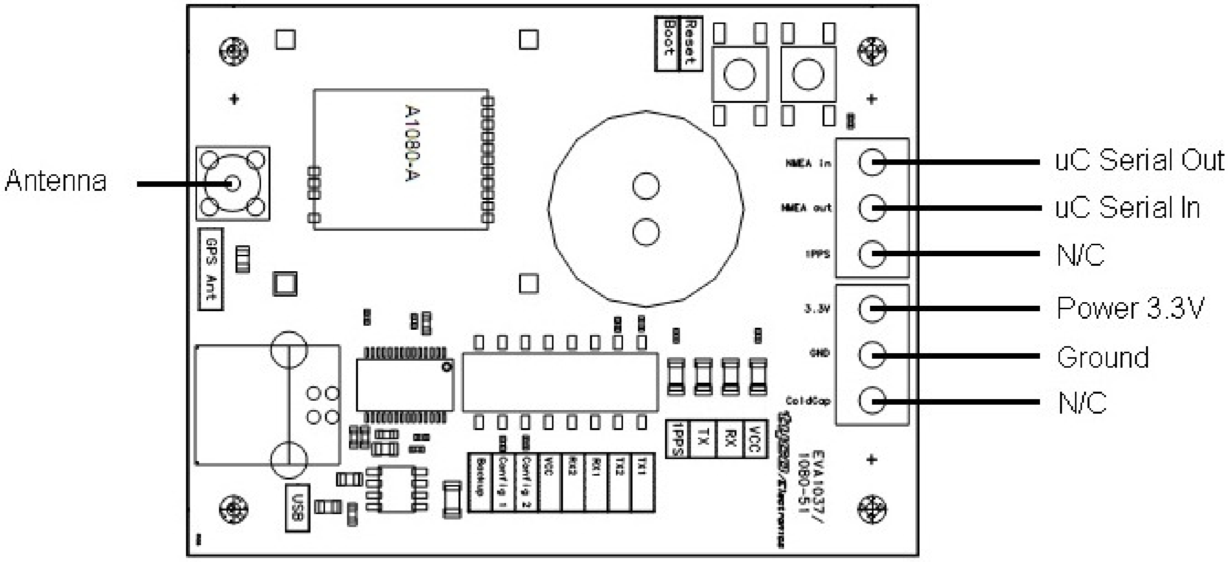


Figure 10: Evaluation Board Connections [10]

The final product will be implemented without the evaluation board, using the A1080-A GPS module with the connections shown below in Figure 11. Our final implementation has two main differences from our prototype implementation. The first is that a passive, rather than an active, antenna is used. Although an active antenna, which requires additional power, is useful for enhancing performance indoors and in urban locations, it is not necessary in an outdoor environment with an excellent view of the sky.

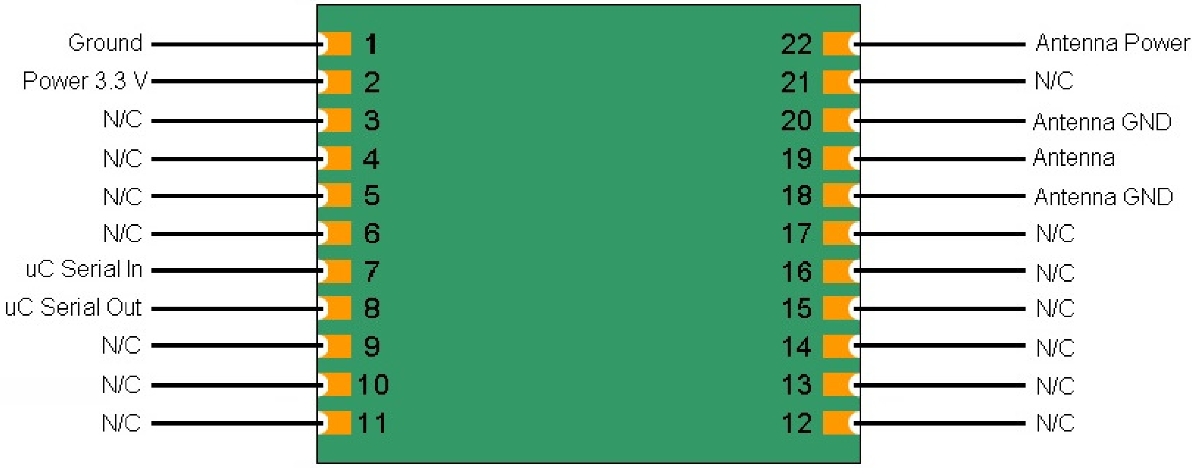


Figure 11: GPS Module Connections [11]

The second is that a strip line must be properly laid out to connect the antenna pin (19) to an antenna jack. The correct design rules are detailed in the user manual and summarized in Figure 12 and Figure 13 below. Most importantly, the width of the strip line must be calculated correctly, that is W = 1.8 X H.

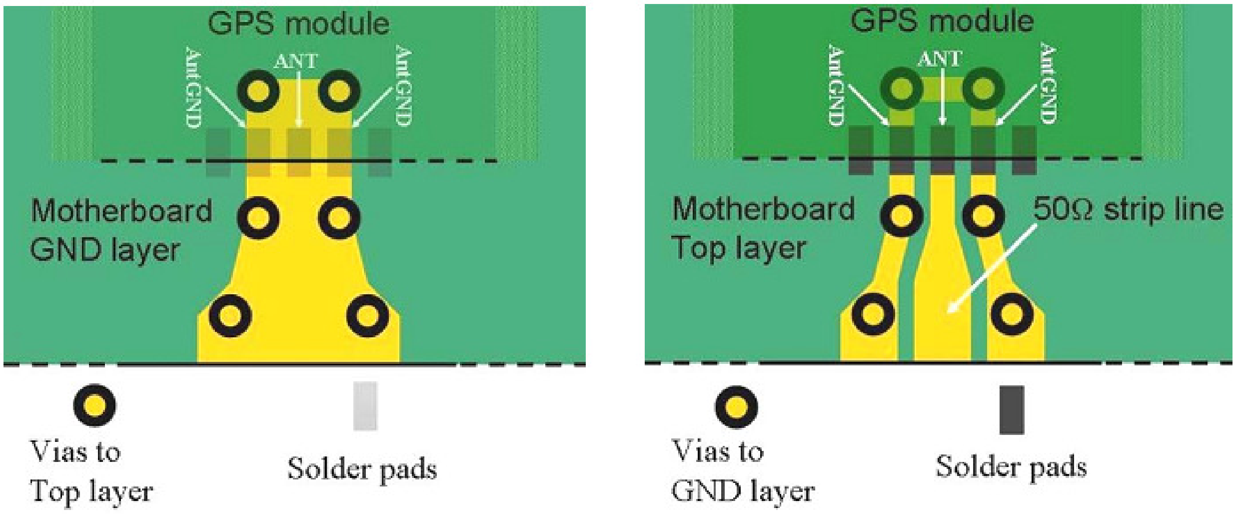


Figure 12: 50Ω Characteristic Strip Line [11]

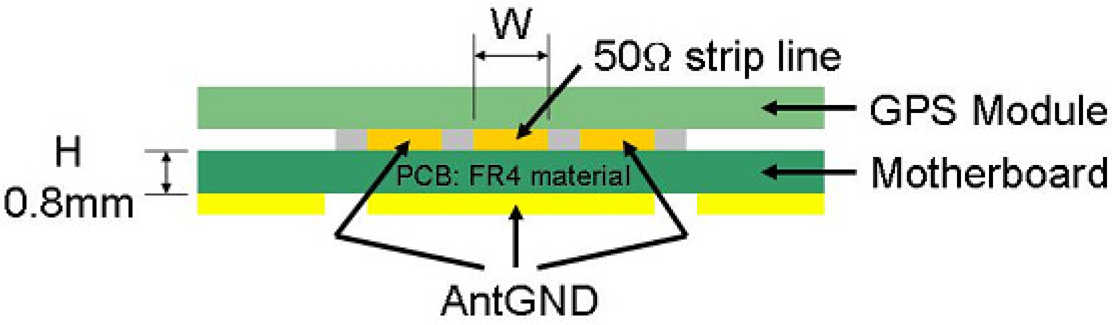


Figure 13: 50Ω Strip Line Cross-Section [11]

For our application we would like to provide the user with information describing their course over the day. To do this we will use longitude, latitude, and altitude to describe position and speed over ground, and direction (compass bearing) to describe velocity. To achieve this we need two types of GPS data: GGA for altitude information and RMC for velocity information [12]. Both types of data supply longitude and latitude.

By default the GPS module outputs four types of data, GGA, RMC, GSA, and GSV, and therefore we will turn off the last two. This will simplify processing of the data and free up time for the microcontroller to do other tasks. Instructions to configure the module can be found in Appendix A.

3.5. PTT Subsystem

3.5.1. Overview

The PTT subsystem alerts the microcontroller when one of the PTT buttons is being held so that the microcontroller can activate the FRS radio. Primarily, it consists of a wireless transmitter, which is mounted in a small package separate from the helmet, and a receiver located in a module on the side of the helmet. The PTT system can be activated via the button on the transmitter package or by a secondary button mounted on the helmet. Due to the user interface constraint that the transmitter package must be usable underneath gloves, only a single button (PTT activation) is implemented on the transmitter.

3.5.2. Component Selection

The main functionality of the PTT subsystem is provided by the Linx KH2 series chipset; specifically, the TXE-315-KH2 transmitter and RXD-315-KH2 receiver. This chipset has several features that make it highly desirable for implementing the PTT subsystem:

- No external RF components are required
- An encoder is integrated into the chip
- Power consumption, particularly during sleep mode, is low
- Its cost is competitive with other solutions
- Maximum range of 900m [13]

The high level of integration offered by the Linx chips greatly simplifies the design by removing the need for extensive RF design or the addition of a microcontroller or discrete encoder to the transmitter circuit. Additionally, the large maximum range allows us to assume that the system will still have sufficient range to meet the performance specification of at least 2m despite the sub-optimal antenna design. Given all the advantages offered by the Linx KH2 chipset, it is a clear choice for the implementation of the PTT subsystem.

3.5.3. Transmitter Design and Schematics

The transmitter circuit is relatively simple, and can be seen below in Figure 14. The power source is a standard 3V lithium CR2032 battery, which can provide up to 220mAh [14] while occupying a relatively small footprint. This battery should allow the transmitter to continue working for over 50 hours with the PTT button continuously pressed (500 hours normal use) and provide practically unlimited standby time. The design includes a power switch mainly intended to avoid accidental activations during storage.

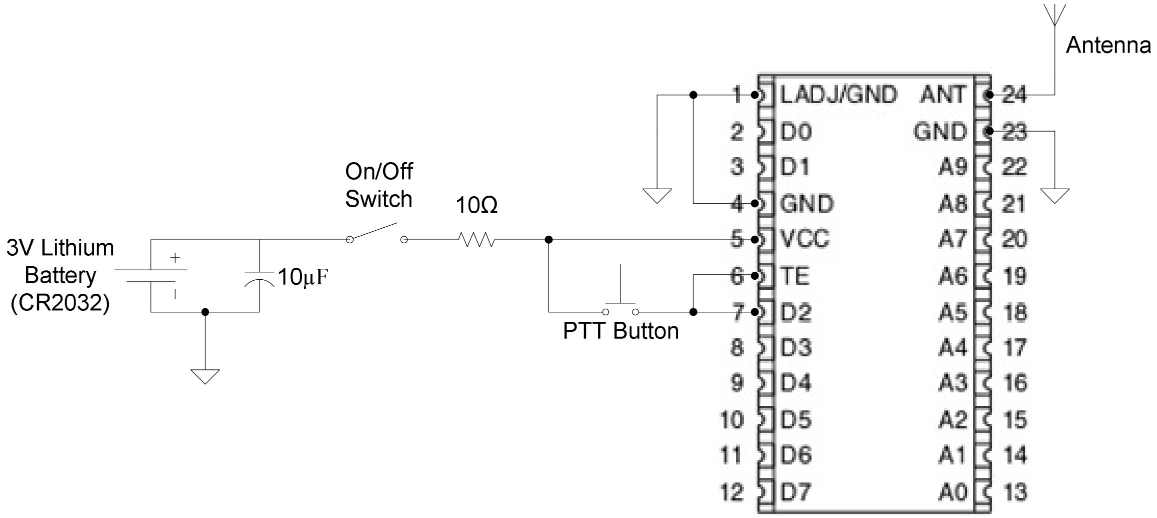


Figure 14: Wireless PTT Transmitter Schematic

3.5.4. Receiver Design and Schematics

The receiver circuit is designed to have a relatively small footprint and to include modular connectors for connecting the power and signal lines to the main electronics module. A schematic of the circuit can be seen below in Figure 15. One of the simplifications made to this design is to use the valid transmission (VT) signal to drive the PTT Active line instead of one of the data outputs; this is possible because only a single button is being encoded by the transmitter. Also of note is the connector for the on-helmet PTT button; pressing this button will short the two lines and drive the PTT Active line high. Finally, the 22.6cm antenna wire will be run through the helmet towards the forehead, where it will be able to receive wireless signals from all possible transmitter locations.

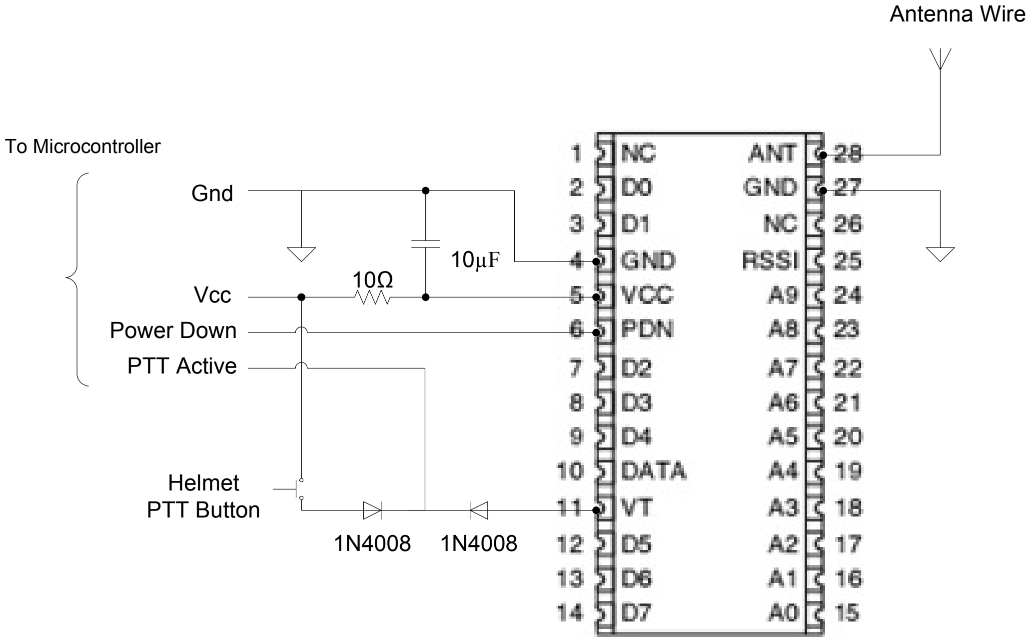


Figure 15: Wireless PTT Receiver Schematics

The main difference between the prototype and final product implementations of these circuits are the address lines. In both of the transmitter and receiver prototype implementations, the address lines (A0-A9) are left floating, which specifies an address of "ZZZZZZZZZZ" for both[1]. In the final product, these lines will be selectively pulled down to ground, via either DIP switches or laser-cut PCB traces. Overall this design for the PTT subsystem should satisfy all of the performance goals of the functional specification while remaining cost-effective and straightforward to implement.

3.6. Buttons and User Interface

Given that user must be able to operate the helmet while wearing heavy gloves, all controls need to be chosen so that they are easily distinguishable from each other by touch.

Volume controls in devices such as TV remotes are often based on a rocker switch design. In order to take advantage of this familiar mapping, we have selected a rocking button that can be mounted to have an inherent "up" and "down" direction.

---

[1] The address lines are trinary and detect three valid states: 1, 0, and Z/Floating

Unlike the volume control, the channel selector would have no feedback if the button was simply an up/down rocker style. Thus, we have chosen a wheel type of control that is distinct from the volume control and will show what channel the radio is currently on.

Electronic devices often have an indicator light to show whether or not the unit is on, so we have chosen power buttons that have an LED built into them to the system's status display to the user.

The most frequently used controls are the helmet-mounted and wireless PTT buttons. The helmet PTT is there so that the unit is usable without the remote and will be a simple push button style. However, the remote PTT is susceptible to accidental activation and thus a button with a high activation force was chosen for this control.

3.7. Flash Memory

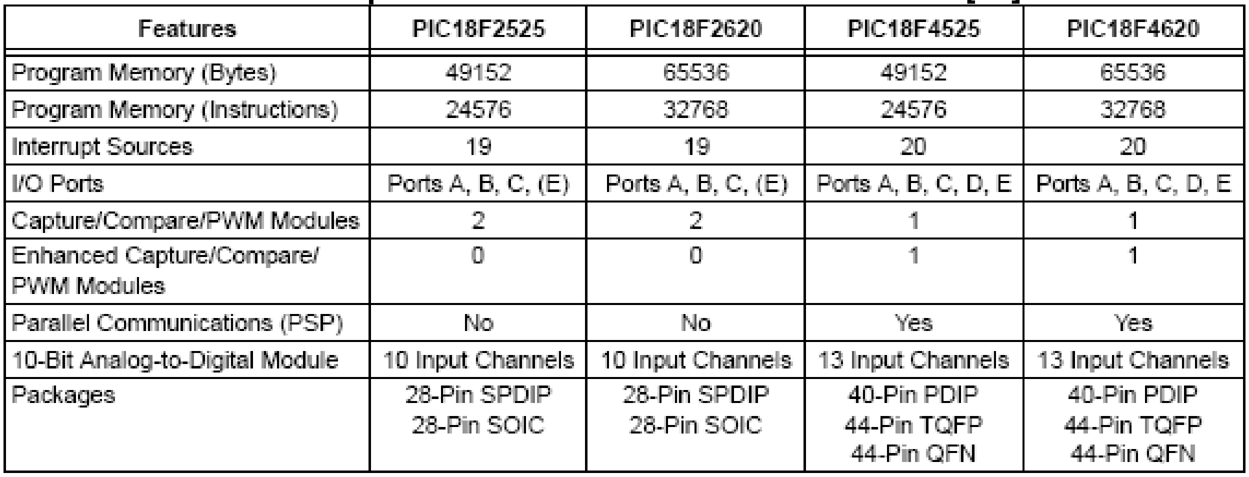
Out of the possible memory styles for our application flash memory is the most attractive due to its compact size, inherent resistance to shock and water, and wide spread use in mobile devices such as phones and cameras. Although we considered several formats, such as CompactFlash, we have chosen to use microSD flash memory. The primary motivation was the simplicity of the interface, as microSD can be communicated with via an SPI. Additionally, the small size of microSD cards was useful due to the space constraints of the helmet electronics module.

3.8. Microcontroller

The RUSH Raven has a large number of buttons, lights, and devices that need to interact with each other and therefore required a microcontroller with a large amount of inputs and outputs to handle all the peripheral components. Two serial ports are also needed for the GPS receiver and microSD card, and a large amount of program memory is also necessary in order to store the very large SD protocol and FAT16 file system drivers.

There are several microcontroller manufacturers but we were already familiar with Microchip's PIC family of processors and were impressed with its efficient power usage and versatility. This led us to the 18F series, a comparison of which is shown below in Table 6.

Table 6: A Comparison of the PIC18F Microcontrollers [15]



Features	PIC18F2525	PIC18F2620	PIC18F4525	PIC18F4620
Program Memory (Bytes)	49152	65536	49152	65536
Program Memory (Instructions)	24576	32768	24576	32768
Interrupt Sources	19	19	20	20
I/O Ports	Ports A, B, C, (E)	Ports A, B, C, (E)	Ports A, B, C, D, E	Ports A, B, C, D, E
Capture/Compare/PWM Modules	2	2	1	1
Enhanced Capture/Compare/ PWM Modules	0	0	1	1
Parallel Communications (PSP)	No	No	Yes	Yes
10-Bit Analog-to-Digital Module	10 Input Channels	10 Input Channels	13 Input Channels	13 Input Channels
Packages	28-Pin SPDIP 28-Pin SOIC	28-Pin SPDIP 28-Pin SOIC	40-Pin PDIP 44-Pin TQFP 44-Pin QFN	40-Pin PDIP 44-Pin TQFP 44-Pin QFN

All of the microcontrollers in this table have a generous quantity of program memory, however, the 4525 and 4620 have more I/O options than the other two. Since the size of the devices does not depend on the size of the program memory, we decided it was best to choose the PIC18LF4620 to avoid resource limitations. Note that the 'L' stands for the wide (or low) voltage range option. The final product will contain the optimum devices once the final memory requirements are known.

3.9. Electrical and Power

To satisfy the rechargeable portable power source requirement, our design will implement the latest 2500mAh Nickel-Metal Hydride AA-size cells from Energizer. Three cells connected in series will provide a nominal 3.6V to power the helmet-embedded communications system. They will occupy 25cm^3 with a mass of 30g [16].

The main power consuming sub-systems are detailed in Figure 16 below. The MICROCHIP MCP1826S-3302E 3.3V linear voltage regulator was selected for its ultra-low dropout voltage of just 250mV. It provides a typical output voltage tolerance of 0.5% while supplying up to 1000mA of current. This high performance IC also features a negligible quiescent current of less than 1mA [17].

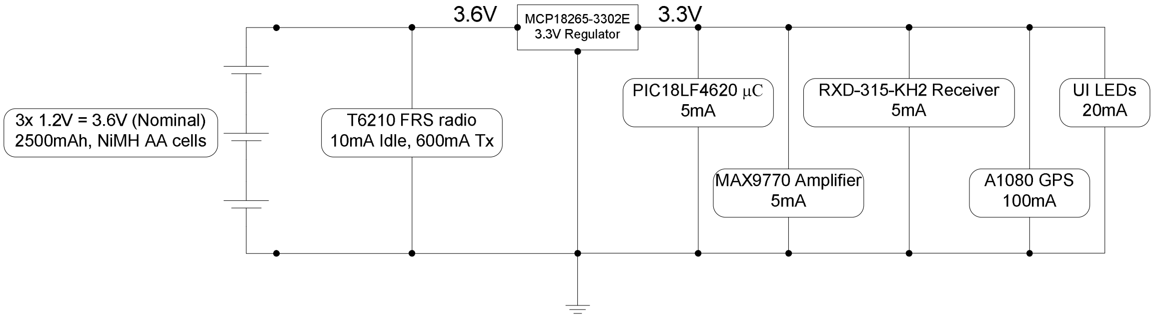


Figure 16: Helmet-Embedded Power Resource and Usage Map

The estimated current draws for all subsystems are listed in Table 7 below. To quantify the estimated battery lifetime, all systems were assumed enabled for the power consumption budget.

Table 7: Power management budget

System	Current Draw
T6210 FRS Radio 10mA idle current, 600mA transmit	For 10% use model: 10*.9 + 600*.1 = **69 mA** normalised average current draw
PIC18LF4620 microcontroller	**5 mA** (typical)
MAX 9770 amplifer	**5 mA** (typical)
RXD-315-KH2 ptt receiver	**5 mA** (typical)
A1080 GPS receiver	**100 mA** (worst case)
UI LEDs (4 @ 5mA)	**20 mA** (typical)
Total for current consumption budget:	**204 mA** (2040 mAh over 10hrs)
Extrapolated battery capacity at 204 mA constant draw to 1.2V/cell	**2175 mAh**

To estimate the battery capacity at the budgeted 204 mA discharge rate, the time to cell discharge to 1.2 V was linearly extrapolated to be 10.66 hours, as shown below in Figure 17. At a constant 204 mA current draw, the estimated battery capacity of 2175 mAh exceeds the budgeted 2040 mAh, thus satisfying our requirement for 10 hour of normal use.

With the low 250mV dropout voltage of the MCP1826S-3302E, 3.55V is the lowest operating limit of the battery. Therefore the absolute minimum cell voltage allowed is 1.18V, which was rounded up for our capacity calculations.

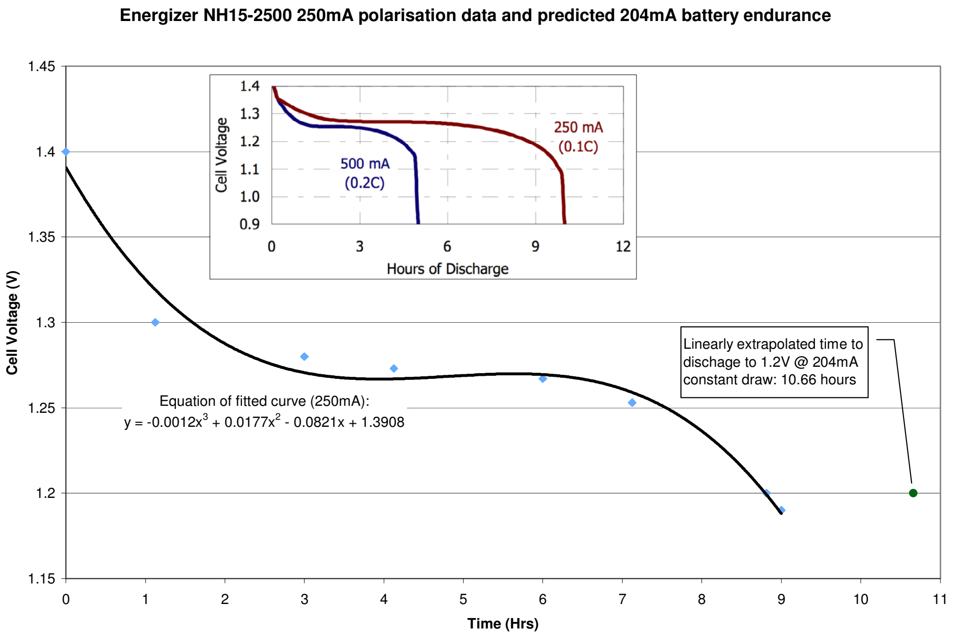


Figure 17: NH15-2500 Battery Performance Characterization for Worst-Case Discharge Rate [16]

Through their respective **SHUTDOWN** or **SLEEP** control lines, the PIC18LF4620 will continuously minimize the total power consumption by disabling any unused subsystem. The microcontroller serves both a supervisory and control function by implementing the desired actions and states as defined by the user's input to the various buttons and switches.

The wireless PTT transmitter is specified for use with the common CR2032 Lithium / Manganese Dioxide coin cell. The Energizer version of this cell has a typical capacity of 240mAh, and should allow the transmitter to continue working for over 50 hours with the PTT button continuously pressed (500 hours typical use) and provide practically unlimited standby time [18].

4. Mechanical and Physical Design

4.1 Helmet Enclosure

4.1.1. Overview

Figure 18 below illustrates the conceptual mechanical design of the RUSH Raven. The complete mechanical design of a market-ready helmet meeting our functional specifications and complying with ASTM F2040-06 and CEM 1077 safety standards is a task beyond our group's capabilities and outside the scope of this project. In light of this, we have chosen an existing helmet as the basis of our prototype and plan on integrating our electronic hardware within this helmet's mechanical enclosure.

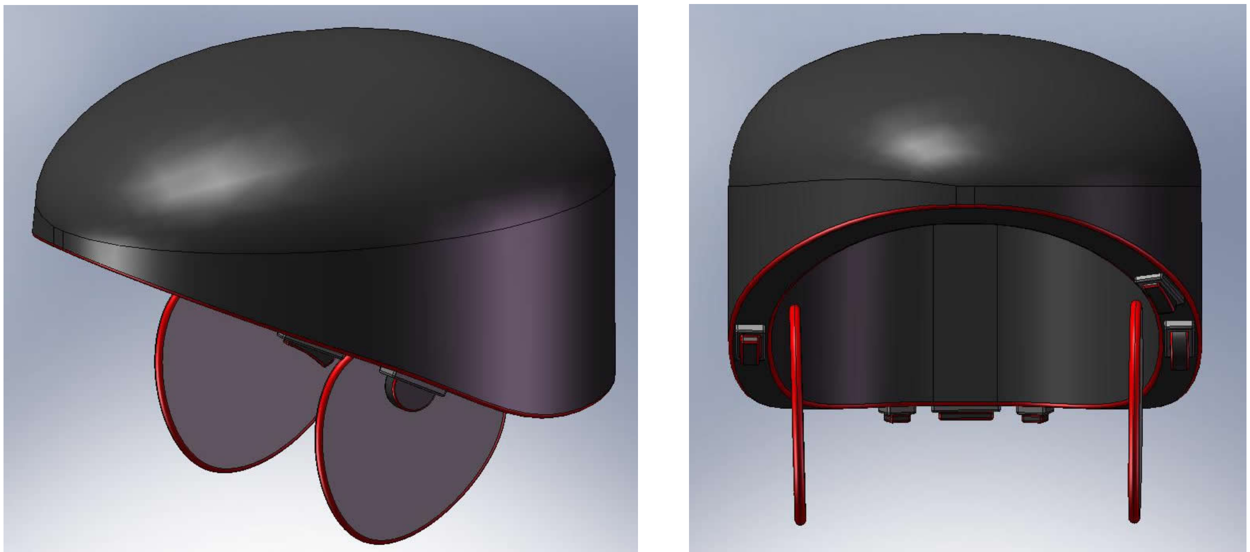


Figure 18: Conceptual Front Views of the RUSH Raven

4.1.2. Location of Controls

A description of the six controls required to effectively operate the RUSH Raven is shown in Table 8 on the following page.

Table 8: Manual Controls of the RUSH Raven

Control	Function
Power	Activates and deactivates main power to the electronics
PTT	When pressed, activates the FRS Radio in transmit mode
Channel	Selects the FRS channel
Volume	Increases or decreases the volume
GPS	Activates or deactivates power to the GPS Module
FRS	Activates or deactivates power to the FRS Radio

The RUSH Raven's user interface has been ergonomically designed to maximize usability and performance. Our design:

- Locates all controls along the lower rim of the helmet to protect against accidental activation
- Logically groups and orders controls based on our studies of actual user association
- Provides visual status feedback in the form of colour coded LED's

The placement of our controls is shown below in Figure 19, which shows a bottom view of the helmet with the power buttons located on the back of the helmet.

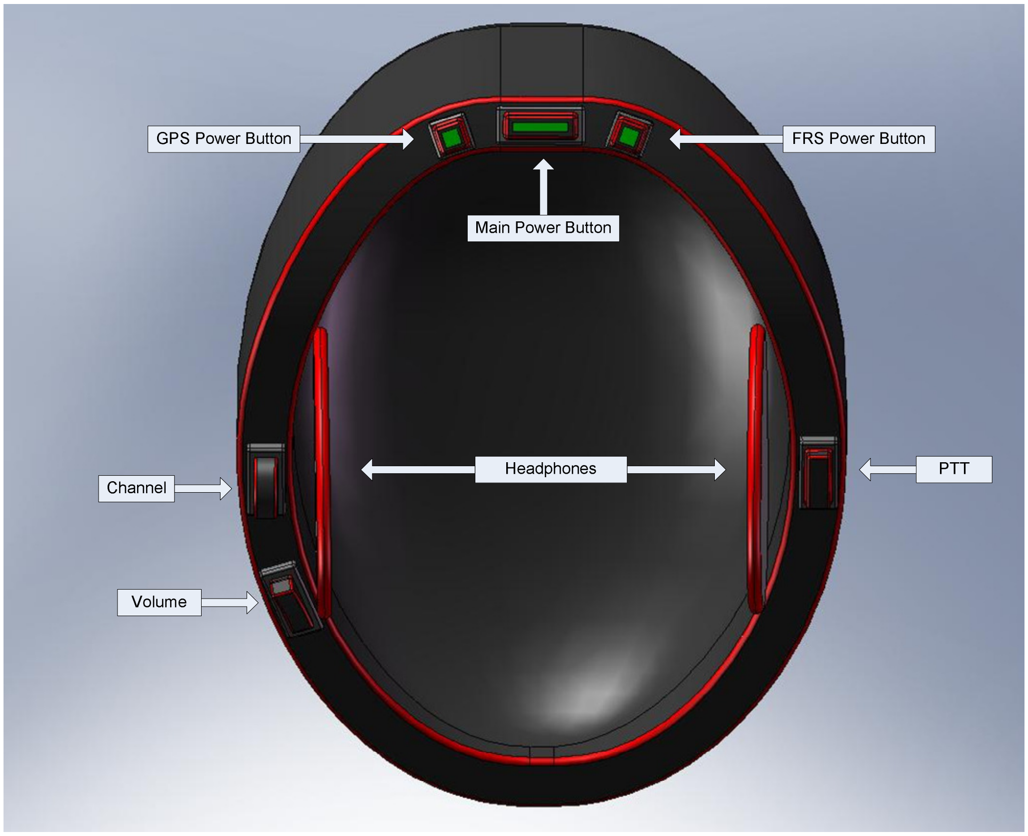


Figure 19: Location of Controls for the RUSH Raven

4.1.3. Electronics Module Location

Instead of implementing all of our hardware on one monolithic board, we have designed a distributed system to incorporate our electronic hardware into the helmet. This system consists of a main board and three daughter boards as described below in Table 9.

Table 9: Description of Component Distribution Among Boards

Board	Components
Main	Microcontroller, GPS Module, Audio Controller, Batteries, SD Socket, Audio Jack, GPS Button, FRS Button, Main Power Button
Controls	Volume, Channel
Communications	PTT Button, PTT Receiver
FRS	FRS Radio

In designing the placement of the boards within the helmet, we considered the following:

- The FRS radio is self-contained on its own board, and will be located separately
- The FRS radio and Wireless PTT receiver will be located separately to reduce RF interference
- Each board is modular and removable by the user, and therefore should be logically located close to it's corresponding user interface
- The main bulk of the electronics should be located in an area where it is easily hidden and does not drastically change the external appearance of the helmet
- The electronics should be distributed in a fashion that maintains balance between sides of the helmet and does not negatively effect overall wearability

The placement of our distributed boards within the helmet is shown below in Figure 20.

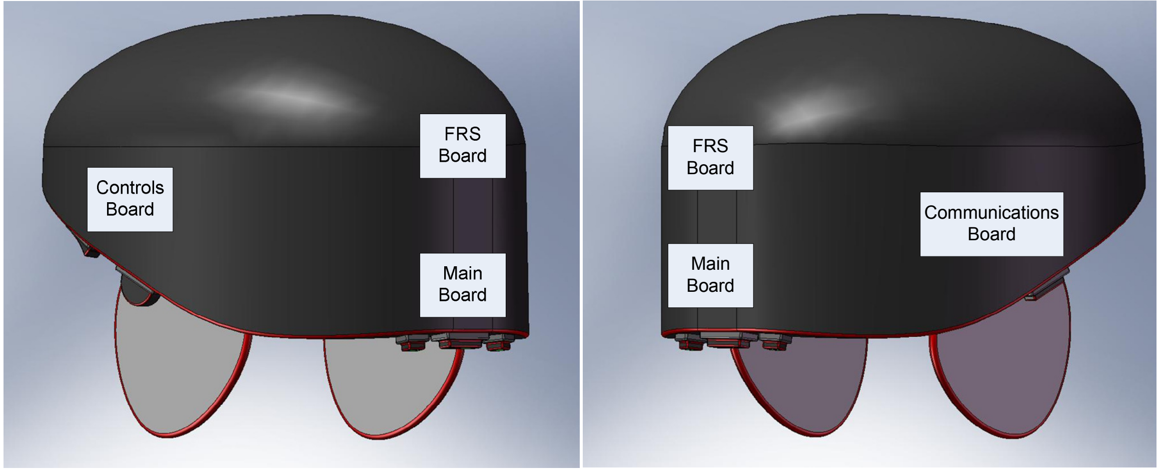


Figure 20: Distributed Board Placement

4.2. Wireless PTT Enclosure

Figure 21 and Figure 22 below describes the mechanical design of the PTT enclosure, which protects and encases the Wireless PTT transmitter circuit as described in Section 3.5.3. Since the transmitter circuit has a very small footprint, the size of the PTT enclosure is primarily limited by the 22.6cm antenna wire. Our preliminary RF performance evaluation has shown that performance remains acceptable when the antenna wire is loosely coiled, allowing us greater design freedom. As such, we have designed the enclosure as shown below.

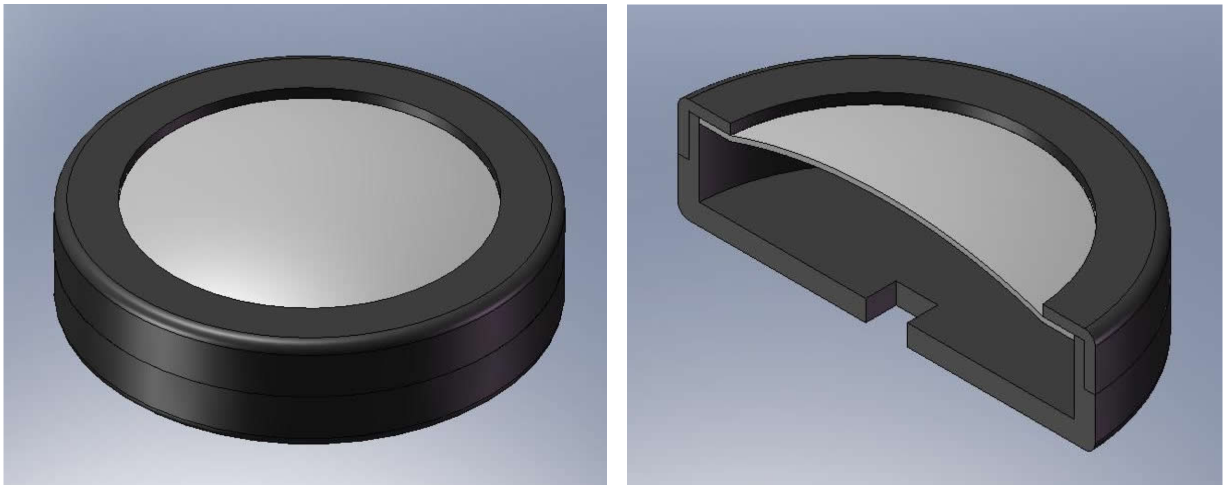


Figure 21: PTT Enclosure

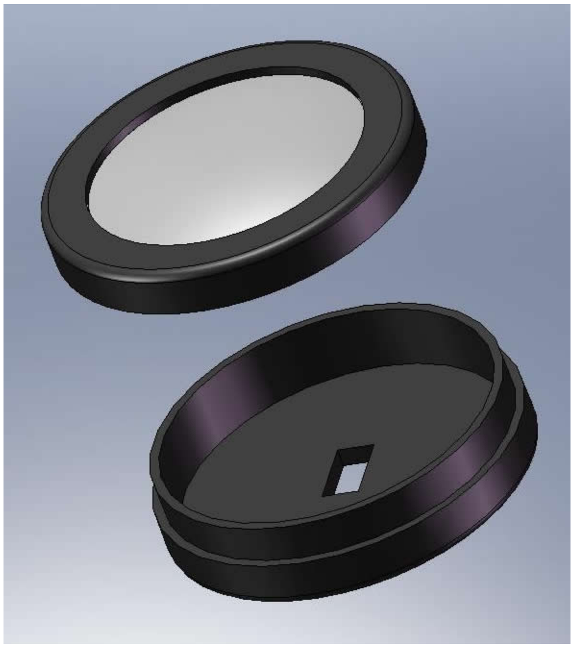


Figure 22: Exploded View of PTT Enclosure

The characteristics of the enclosure are as follows:

- The case will be constructed of hard plastic, due to its low production cost and design flexibility.
- The top will be constructed of a flexible rubberized material to allow for comfortable button activation.
- The case shall come apart to allow replacement of the battery.
- The interface between each half of the case will be sealed by two separate rubber O-rings, to protect against water ingress.
- The electronics shall be securely attached to the bottom half of the case, via mounting screws (not included in diagram).
- The power button shall be accessible through a sealed port in the bottom of the case.

This PTT enclosure can be attached to the user or their clothing via either an adjustable strap that will function much like a watch band or a clip that is mounted on the back of the package. Both of these attachment mechanisms will be removable, and other attachment means such as velcro may also be provided.

5. Firmware Design

The RUSH Raven helmet will rely heavily on firmware control to animate its hardware features. Through the pins of the microcontroller, the firmware will interface with the helmet's subsystems and control their operation. This programmability of hardware behavior opens up a great number of possibilities for feature development and product versioning.

Contained below is a high-level overview of the firmware program. This overview is meant simply as a description of the firmware's overall structure. Subsequent sections will provide more details about the individual stages of the firmware as they pertain to the various hardware subsystems.

5.1. Overview

As can be seen in Figure 23 to the right, the firmware program can be broken down into four separate stages: Device Initialization, Device Activation, Regular Operation, and Device Shutdown. As soon as the helmet has power it must immediately enter the Device Initialization stage, wherein the microcontroller will be configured to interface with all the other hardware subsystems. The device, however, is not on at this point and the microcontroller must enter sleep mode until the user turns the device on and it enters the Device Activation stage. At the start of this stage the helmet has just been turned on, and thus all of its subsystems must be powered up and initialized. Once this is done the helmet may enter Regular Operation during which the helmet must be fully powered with all of its features behaving according to the Functional Specifications. The device will remain in Regular Operation until the user chooses to turn the helmet off. At this point the firmware enters its final stage, Device Shutdown. This stage requires that the firmware complete any unfinished tasks and safely power down the helmet. At the very end of the firmware program the

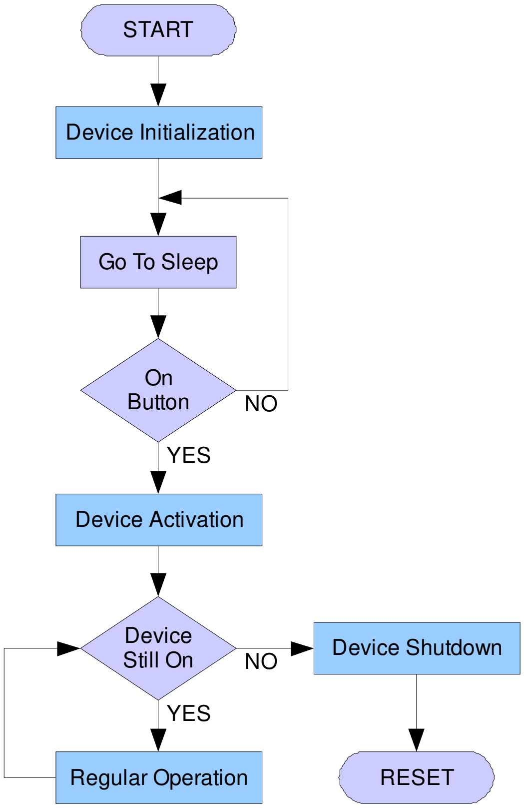


Figure 23: Firmware Overview

microcontroller is reset, causing the firmware to automatically re-enter the Device Initialization stage.

5.2. Device Initialization

Upon receiving power the firmware must initialize all the systems by correctly programming the registers of the microcontroller’s ports and functional blocks to appropriate initial values. To save energy the initialization sequence should not turn on any subsystems within the helmet.

If the user has not yet released the helmet's On/Off button complications could arise from bounce-induced interrupts after the button is finally released. To guard against this possibility the firmware must ensure that the On/Off button has been released before enabling its interrupts, and waiting for the device to be turned on by the user. Figure 24 to the right illustrates one possible implementation of this guard mechanism.

While waiting for the user to turn the helmet on, the firmware should keep all subsystems powered down, and must remain in sleep mode.

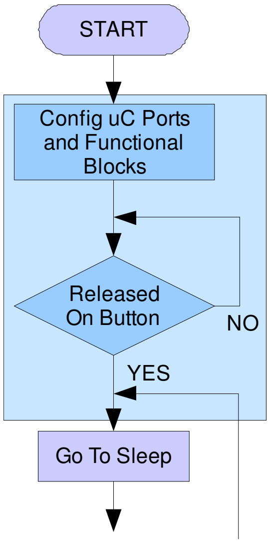


Figure 24: Device Initialization

5.3. Device Activation

The helmet must not wake up, and should keep all subsystems powered down, until the user presses the On/Off button. At this time, the firmware must exit from sleep mode and run the Device Activation sequence depicted in Figure 25 on the right. The first step is to detect important system status information and initialize the helmet's subsystems accordingly. The Device Activation sequence must include the following:

- Recall system status information such as the 'last known' FRS channel and volume from on-chip EEPROM.
- Test the status/presence of the SD Flash memory card.
- Power up all hardware subsystems.

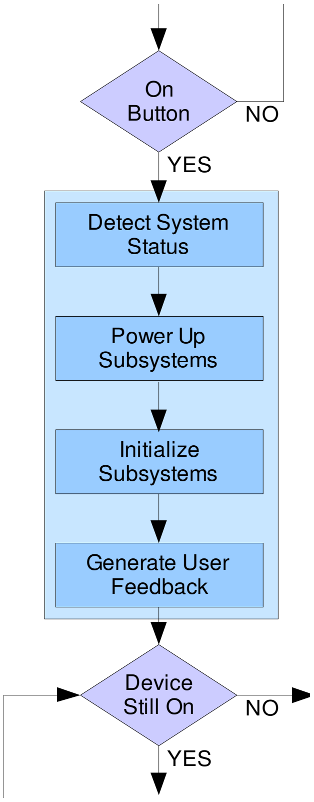


Figure 25: Device Activation

- Initialize all subsystems based on the detected system status.
- Generate user feedback – using LEDs – indicating the detected system status.

Once these steps are completed the system will enter Regular Operation, during which all subsystems in the RUSH Raven helmet should be working as per their functional specifications. The primary task of the firmware is now responding to and managing the different types of hardware events. Finally, the firmware must also provide a high level of robustness, such that no action by the user will cause the device to malfunction. In the following sub-sections, details are given on how the firmware coordinates hardware functionality and addresses certain usability issues for each of the helmet's hardware subsystems.

5.3.1. User Interface

The user interface of the RUSH Raven helmet is the collection of inputs used by the wearer and the status LEDs which provide feedback to the user. To guard against false input events, the firmware must implement de-bounce delays for all buttons, switches, and knobs. Preliminary experiments indicate that a 40ms delay provides reliable performance. To provide adequate user feedback about the status of the helmet system, the firmware must implement the LED status signals listed in Table 10 below.

Table 10: User Interface Feedback

STATUS LED	LED STATE	STATUS INFORMATION
POWER LED	OFF	Helmet power off
	GREEN	Helmet power on
LOW BATTERY LED	OFF	Battery full charge
	YELLOW	Low battery
GPS LED	OFF	GPS module Off
	YELLOW	GPS module On SD card not inserted/ready
	GREEN	GPS module On SD card inserted/ready
FLASH MEMORY LED	OFF	No SD card detected
	GREEN	SD card detected

5.3.2. GPS Module

The GPS module will communicate asynchronously with the microcontroller using a EUSART. The microcontroller must be able to receive 8-bit frames of data over the EUSART serial lines. The firmware must also be able to automatically recognize when a new byte has been received, so that it can store the data in an intermediate location and prevent data collision. Given that the GPS module is expected to send a package of over 100 bytes of data once per second, the firmware must be able to process well over 100 Bytes/sec of data to keep up and also be able to manage other potential hardware events at the same time.

5.3.3. FRS Radio

Owing to our limited development time for this project, the RUSH Raven prototype makes use of an existing radio product for its FRS radio module. Interfacing with this device requires the microcontroller to electrically simulate key strokes on the radio's button pad. Keypad strokes must be simulated as follows:

- Initialize the pin signal to '0' and the pin TRIS register to '1' (High-impedance input)
- Set the TRIS to '0' (Output driven to the signal level of '0')
- Pause for time delay FRS_PUSH_DELAY
- Set the TRIS to '1' (Return to High-impedance)
- Pause for time delay FRS_RELEASE_DELAY

The one exception to this sequence is the FRS radio's On/Off button which must be initialized with a signal value of '1' to simulate power instead of ground.

5.3.4. Audio Router

The microcontroller will have three output lines to the audio router: SEL1, SELM, and !SHDN_ROUTER. The firmware must set !SHDN_ROUTER to '0', in order to turn off the audio router. While the router is on, the firmware must implement the routing functionality shown in Table 11 below.

Table 11: Mandatory Audio Routing Codes

ROUTING SIGNALS		AUDIO OUTPUT	
SEL1	SELM	LEFT SPEAKER	RIGHT SPEAKER
0	0	Mute	Mute
0	1	FRS Radio (Mono)	FRS Radio (Mono)
1	0	External Audio (L Channel)	External Audio (R Channel)

To decide which state the audio routing should be in, the firmware may consider two signals. First, the PTT signal of the helmet may be used to indicate when the user is transmitting a message, and thus the FRS radio should be the only audio source. Second, the firmware may use the positive voltage bias on the speaker signal lines as an indication that an FRS radio message is being received. This again should cause the firmware to block the external audio signal and route only the FRS radio signal. When the user isn't transmitting over the radio and no radio messages are being received, the firmware must use the audio router to pass the external audio signal by default.

5.3.5. SD Flash Memory

Most SD Flash memory cards support both an SD interface and an SPI interface for physical layer communication. The firmware must utilize the microcontroller's on-chip SPI module for this byte-level communication, because the full SD interface would prove prohibitively cumbersome for an embedded microcontroller.

In order to send device commands to the SD card, the firmware must also implement I/O drivers which conform to the SD Physical Layer protocol. Furthermore, to ensure that the GPS data is readable on the average user's home computer, the firmware must implement additional drivers to format the data according to a recognized file system. Given that many SD cards are designed to expect a FAT16 file system, the firmware will implement file I/O operations compatible with a FAT16 file system.

Because flash memory is only rated for a finite number of writes, which are block-based instead of byte-based, the firmware should minimize the frequency of writes to the SD card. This may be implemented in firmware by collecting the GPS data in an intermediate memory area on the microcontroller, and then writing this larger information package to the SD card when it reaches an appropriate size. Ideally this size should be the block size of the SD card, but if that is too large, then a size that will maximize usage of the microcontroller’s RAM.

Finally, in terms of usability considerations, the firmware must support the 'hot swappable' nature of SD memory cards. Many SD sockets contain a 'card insertion' switch. This switch must be used by the firmware to detect the insertion or removal of an SD memory card during any stage of the firmware program. Upon hot insertion, the firmware must initialize the memory card and the drivers which will be used to interact with the SD card's file system. Furthermore, if no file exists on the SD memory card related to the RUSH Raven helmet, then the firmware should contain functionality to create the necessary files and file system records.

5.4. Device Shutdown

The RUSH Raven helmet must feature 'soft off' functionality which triggers a shutdown sequence in firmware when the user wishes to turn the device off. This powerful technique allows the firmware to complete any unfinished tasks before shutting down the system. As indicated in Figure 26 to the right, the Device Shutdown sequence must include the following:

- Transfer any remaining GPS Performance Data to SD Flash memory.
- Store the 'last known' volume and channel FRS settings in non-volatile memory.
- Assert '0' on all Status LEDs lines.
- Assert '0' on each of the !SHDN lines.

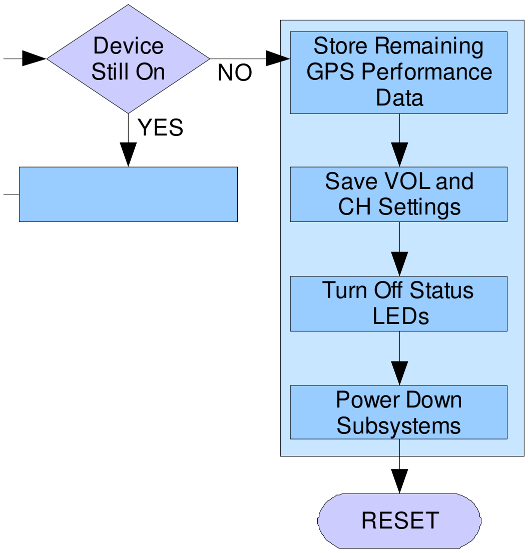


Figure 26: Device Shutdown Sequence

Upon completion of the Device Shutdown sequence, all data will have been saved, all subsystems within the helmet will be powered down, and it will be safe to put the microcontroller in sleep mode.

6. Test Plan

A basic test plan for evaluating the performance of our system has been devised that involves a combination of unit tests and full system tests. The unit tests will serve to evaluate the development of each sub-component, while the full system tests (Basic Acceptance Test) will ensure that all of the prototypes core functionality is operating properly.

6.1. Unit Tests

6.1.1 Basic PTT Reception Test

Preconditions:
The PTT transmitter and receiver are powered on and a measurement device is attached to “PTT Active” line

Procedure:
Press and hold the transmitter button for several seconds, then release

Expected Result:
The “PTT Active” line goes to Vcc shortly after the button is pressed and remains high until the button is released

6.1.2. Advanced PTT Reception Test

Preconditions:
The PTT receiver is connected to the microcontroller, the FRS radio is connected to the microcontroller, the PTT transmitter and receiver are separated by 3m, a human body (or a suitable substitute) is between the PTT transmitter and receiver, and all components are powered on

Procedure:
Press and hold the transmitter button for several seconds, then release

Expected Result:
The FRS radio enters transmit mode shortly after the button is pressed and remains in that mode until the button is released

6.1.3. FRS Communication Test

Preconditions:
The FRS radio is connected to the microcontroller, manual switches are connected to the microcontroller, and all components are powered on

Procedure:
Press the Volume Up manual switch

Expected Result:
FRS radio UI shows volume has increased
Note: Repeat for the Volume Down, PTT, and the channel wheel

6.1.4. Audio Routing

Preconditions:
A source of stereo audio is connected via a 3.5mm jack to the audio routing circuit, the FRS radio's output is connected to the audio routing circuit, the speakers are connected to the audio routing circuit, the audio routing circuit and FRS radio are connected to the microcontroller, manual switches are connected to the microcontroller, another FRS radio ("Radio 2") tuned to the same channel is nearby, and all components are powered on.

Procedure:
Press and hold the manual PTT button, release it, then press and hold the PTT on Radio 2, and then release it.

Expected Result:
The audio from the source is heard, but is muted whenever either PTT button is pressed.
Note: Also observe whether volume levels are acceptable during all phases of the test and whether any "clicks" or "pops" are heard

6.1.5. GPS

Preconditions:
The antenna is connected to the jack on the GPS Evaluation Kit. The output NMEA serial port of the GPS Kit is connected to the serial port of a PC and a 3.3V power supply is connected. Hyperterminal (or another similar program) is loaded and configured for 4800 baud, 8 data bits, no parity, 1 stop bit, no flow control.

Procedure:
Allow the GPS module to run until a valid fix is found. Then, monitor the data for a minute watching for extreme variations in GPS data or a loss of a valid fix. Note that since the unit is stationary during this test the position error of the GPS may be much larger (perhaps +/- 50m instead of 10m). Terminate the serial connection and save at least 5 samples of data in another document.

Expected Result:
The GPS module should be able to acquire a valid fix in less than one minute, providing it has a good view of the sky. The saved data should correspond to the location the test was run within 50 meters.

6.1.6. Flash Memory

Precondition:
The microcontroller is connected to the flash memory socket, a microSD card has been inserted into the socket, a computer capable of reading microSD cards is available, and all components are powered on

Procedure:
Using a program on the microcontroller, write the byte pattern 0xDEADBEEF to a file on the microSD card

Expected Result:
The microSD card is readable by the computer and the expected byte pattern is found within the file

6.2. Basic Acceptance Test

The following test exercises all of the core functionality of the helmet in order to verify that the overall system functions as expected. The procedure and expected results can be seen below in Table 12.

Preconditions: Prototype system is assembled, with both the PTT transmitter and helmet batteries fully charged, a human (or a suitable analogue) is wearing the helmet, the helmet is not powered on, and another FRS radio (“Radio 2”), a handheld GPS unit (“GPS 2”), a computer capable of reading microSD cards, and a stereo audio source are available and powered on.

Table 12: Basic Acceptance Test

Step	Expected Result
Press, hold and then release the power button	Power LED lights up
Connect a stereo audio source to the 3.5mm jack on the helmet	The audio from the source is heard from the helmet speakers
Turn the channel wheel control so that the in-helmet radio is on the same channel as Radio 2	
Press and hold the PTT button on Radio 2 and speak into it, then release the button	The speech is heard from the helmet speakers, stereo audio source is not heard while the button is pressed
Press and hold the PTT button on the PTT transmitter and speak into the helmet microphone, the release the button	The speech is heard on Radio 2, and the stereo audio source is not heard from either the helmet speakers or Radio 2 while the button is pressed
Change the channel on both FRS radios to be different	Radios should not communicate in either direction
Change the channel on both FRS radios to be the same (but different than before)	Radios should again be able to communicate in both directions
Adjust volume on the helmet, first up, then down	The volume of incoming FRS communications should increase then decrease accordingly
Wait until GPS LED indicates a valid fix	Should occur within a few minutes
While wearing the helmet and holding GPS 2, move at least 500m away from your previous position	The GPS LED should continue to indicate a valid fix
Press and hold, then release, the FRS radio power button	The FRS radio should no longer function.
Press and hold, then release, the GPS power button	All GPS LEDs should turn off and no GPS data should exist after this time
Hold the power button to power down the helmet	All LEDs turn off
Remove the microSD card from the helmet and connect it to a computer	The position data is present and in the correct file, and the start and end coordinates of the >500m trip match those recorded by GPS 2 to within 50m

7. Appendices

7.1 Appendix A: NMEA Sentence Notes

7.1.1 Sending Messages

You can send serial messages to the module or evaluation board through the NMEA port labeled “input”.

7.1.2 Checksums

The checksum of an NMEA message is produced by taking the exclusive OR (XOR) of all the characters between $ (start) and * (end).

7.1.3 Configuration

When the configuration of the serial port is changed it is required to restart the unit for the changes to take effect.

The serial port can be changed to a higher baud rate using the following message (in this case 9600):

- Port ‘0’ to 9600: $PSRF100,1,9600,8,1,0*XX

Note: The XX stands for the checksum which I haven’t calculated for these messages.

For our purposes we only need to use the GGA and RMC types of data. The default of the unit is to have GGA, RMC, GSA, GSV turned ON and VTG, GLL turned OFF. Therefore we need to turn off the GSA and GSV types of data. These types give us information about the satellites being tracked, which we don’t need.

- GSA ‘OFF’: $PSRF103,02,00,00,01*XX
- GSV ‘OFF’: $PSRF103,03,00,00,01*XX

In case the GGA and RMC data types aren't ON for some reason or are updating at the wrong rate the following messages will setup the output to 1Hz.

- GGA 'ON': $PSRF103,00,00,01,01*XX
- RMC 'ON': $PSRF103,04,00,01,01*XX

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