Wireless Bear Tracking System

Final Document

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Forward

This document includes information about every aspect of the 2010 Senior Design Project for group 10, Wireless Bear Tracking. This document was pieced together over a two semester period and includes information about the design and then the implementation. This project will need to be completed in another phase of the project, so this document will be important to understand the progress of the project.

The main sections of the document are: Introduction, Design Requirements, Approach and Product Design, Implementation, Test Cases, Schedule, and Resources. The approach section details all of the possibilities for the design that were researched including the actual design that was selected. The implementation section discusses the completed prototype and what parts were finalized as well as any PIC code explanation. The test case section details the different testing procedures that were used to verify the system as well as the results from those testing procedures.

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Definitions

ACK	Acknowledgement
ADC	Analog to digital conversion
AFC	Automatic frequency control
ASK	Amplitude-shift Keying
BER	Bit Error Rate
bps	Bits per second
CRC	Cyclical Redundancy Check
CSMA/CA	Carrier sense multiple access with collision avoidance
dBm	Decibel referenced to milliwatts
ESR	Effective Series Resistance
FCC	Federal Communications Commission
FM	Frequency Modulation
FSK	Frequency-shift Keying
GPS	Global Positioning System
I/O	Input and Output
IF	Intermediate Frequency
ISM	Industrial, Scientific, and Medical Equipment
LEO	Low Earth Orbiting, used in describing satellite orbits
MAC	Media Access Control
MSK	Minimum-shift keying
PA	Power Amplifier
PC	Personal Computer
PIC	Programmable Integrated Circuit

POR	Power on Reset
RF	Radio Frequency
RSSI	Received signal strength indication
RX	Receive
SAR	Specific Absorption Rate
SPOT	Commercially available personal tracking unit, which uses satellites for communication
Sync	Synchronize
TDM	Time Division Multiplexing
TDMA	Time Division Multiple Access
Term	Description
TX	Transmit
UART	Universal asynchronous receiver/transmitter
UHF	Ultra High Frequency, the radio frequency range from 300 MHz to 3 GHz
URL	Uniform Resource Locator
VHF	Very High Frequency, the radio frequency range from 30 MHz to 300 MHz

1. Introduction

The following is an overview of the Wireless Bear Tracking Senior Design Project. This section includes background on the device, the problem statement, possible solutions, and the product deliverables.

1.1.Executive Summary

A non-profit group from northern Minnesota researches a group of twelve mother bears by tracking their movements using RF transmitting collars worn by the bears. These bears are habituated to the researchers and allow them to approach and remove collars as well as take different measurements and notes. The researchers track the mother bears because they are more territorial and will stay within a twenty-five mile by ten mile area. The tree cover in this area is extremely dense. It is important to gather live data of the location of the bears, especially when the bears go into caves during winter to hibernate as well as when they leave the caves in the spring.

The previous solution to this tracking did not even provide live data. The bears had worn collars that transmit on a VHF band. Each collar outputs at a specified frequency, and the researchers were required to travel and locate the bears individually by monitoring the strength of signals transmitted. These collars were very reliable and transmitted well through the trees. The battery life was also superb and lasted nearly five years. The collars would wear through before the batteries were depleted.

This summer, these VHF collars are being phased out by GPS personal tracking devices called SPOT. These devices were modified to continually ping their data and send live location information up to a low earth orbiting satellite and then to the cabin. This system fits well on the collar, but in a dense forest, the signal is often lost for up to two hours. The SPOT units also require a monthly fee. It is also very difficult to get decent battery life, for the collars have batteries that must be changed every week. Still, the researchers prefer the live location data to the old VHF system.

Digi, International has taken the task of providing a new collar for the researchers as a non-profit project. They are supporting the project financially and through their technical expertise and advice.

The goal of this project is to create a new collar that will continually and reliably send location data to the researchers. This unit must run on battery for at least 6 months, and transmit location about every fifteen minutes. It is also important to make the unit durable and smaller than the current SPOT units.

The collar will consist of the basic building blocks of GPS, VHF transceiver, PIC microcontroller, and power electronics, as shown in Figure 5.

The collars will transmit their GPS location via VHF frequencies to various router units. All units will transmit on the same frequency, 217 MHz, and the system will use a time division multiplexing network scheme. The router and collar units will have similar hardware, with minor differences in the VHF antenna and battery. A home base router will output the data serially to be easily plotted as data points on Google maps or similar mapping software.

The current units are very expensive, nearing $2000. The units we are developing will be much less expensive. Estimated unit cost is around $290. Digi, International is providing all of the materials and financing necessary to complete the project.

Prototypes will be available by April so the bears can be collared after they have left hibernation. There will be three collar units and two router units available to test. The mechanical design and the computer mapping interface are not the focus of this stage in the project. In the future these may be developed by another senior design team, or engineers at Digi.

1.2.Acknowledgments

Digi, International is going to supply all of the necessary parts and funding for the project. This is a non-profit task that they have decided to support and are going to help with any aspect of the product. They will provide technical assistance as needed. Technical expertise has been provided by James Puzzo, Jordan Husney, Mark Tekippe, and Jim Stroner.

Technical expertise has been provided by ISU Faculty including Dr. Ahmed Kamal, Dr. Nathan Neihart, Dr. Jiming Song, Dr. Mani Mina, Leland Harker, and Matthew Nelson.

1.3.Problem Statement

Black bears need to be tracked live from a remote location. The area of concern will be approximately a 25 mile by 10 mile plot. It is difficult to transmit a signal in this area due to dense foliage. A collar unit must be developed that can transmit tracking data every ten to fifteen minutes. This unit must be smaller than the current unit and ideally have a battery life of six months. It is also important that the collar be individually identified and easily removed.

1.4.Operating Environment

The unit will be exposed to the harsh conditions of northern Minnesota. Temperatures range from -30 to 70 ºC. The unit must be waterproof and weatherproof. The collar must be comfortable on the bear, or the bear will tear the collar off. The bear cubs also get restless during the hibernation months and will proceed to chew and destroy the collar.

The collar unit must also be easily handled by the researchers. They must be able to simply remove and ID each unit. The researchers are not as familiar with complicated technologies and the unit must be as user friendly as possible.

1.5.Intended Use and Intended Users

The intended use for the product is to track black bear mothers in a 25 by 10 mile area. The collar must function in this area, and if successful, it can be transferred to other wildlife tracking areas as well. The collar will function properly in very dense forests.

The intended users are the bear researchers at the facility in Ely, Minnesota. These researchers are Sue Mansfield and Lynn Rogers.

1.6.Assumptions

There are many assumptions taken into account when working on this project. It is difficult for us to gain access to the forested area, so we must assume how certain signals will react to the forest. We assume that the GPS signals will reach the collar if the collar is properly located on the bear. We also assume that lower frequencies will penetrate the thick forest better than the higher frequencies. We are using the SPOT unit as an acceptable size and weight.

Digi will provide funding and technical advice, and it is assumed that this will continue throughout the project.

After the completion of this project, we do not expect to have much direct contact with the researchers. We have to make the assumption that if the unit is well documented and somewhat simple to use, the researchers will be able to properly use the unit without supervision and guidance.

1.7.Limitations

Our basic limitations on this project are time and experience. We have only one year to develop this prototype and a project such as this could easily be a several year project. All of the group members are Electrical Engineers and our current knowledge base of networking and programming is not as strong as required by this project. We will need to spend extra time researching these technologies.

A second limitation has to do with access to the area. It is a nine hour drive to the forest and we do not have the ability to test our equipment in a similar environment. We will have to estimate and rely on different calculations to determine the best technology.

1.8.Expected End Product and Other Deliverables

At the end of the project the researchers expect three collar tracking units and two router units to be prototyped and ready to field test.

Along with the prototypes, it is important to provide documentation on the device in terms of a user manual and a technical specification document, so that it is easily modified and usable. Suggestions for improving the unit as well as preliminary plans for the next generation are all important deliverables.

2. Design Requirements

The following describes the requirements defined for the project design. Any solution must meet the requirements laid out in this section.

2.1.Functional Requirements

The VHF/UHF terrestrial communication solution will involve transmitters placed on the bears to communicate with routers posted in selected spots within the area of concern. GPS location information would be received by the modules on the collars and then transmitted to the onsite routers. The routers would then relay the bears' GPS location information to an onsite base station. This information would then be processed accordingly by the researchers. See Figure 1.

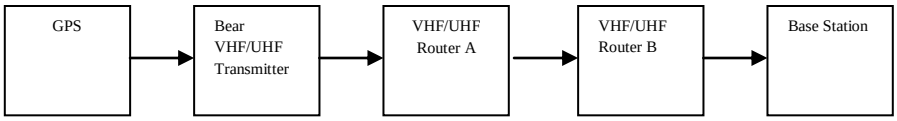


Figure 1: VHF/UHF Solution

The functional requirements pertaining to a VHF/UHF solution are defined below.

A. Local VHF/UHF Solution
    a. Pertaining to the transmitter on the bear
        i. The tracking device is required to receive GPS data via GPS satellites
        ii. The tracking device is required to transmit data to routers, via local VHF/UHF transmitters, stationed within defined area
    b. Pertaining to the routing transceiver
        i. The routing device is required to communicate with mobile units when they are within their communication range.
        ii. The routing device is required to communicate with other routing devices
        iii. Routing devices will cooperate to relay readings received from tracking devices to the end user receiver
    c. Pertaining to the end user receiver
        i. The end device is required to receive data from multiple tracking devices
        ii. The end device is required to receive data from multiple routing devices
        iii. The end device is required to plot location information on a mapping interface

d. Miscellaneous
    i. The battery life of the bear transmitter must be 3 months
    ii. The location must be updated every 15 minutes as a minimum requirement
    iii. Proper care is taken to secure bear location information

2.2.Non-Functional Requirements

The non-functional requirements for the tracking device are defined below.

A. The physical dimensions of each unit (bear transmitter, routing device, and end device) must be appropriate. The bear transmitter must be similar to the currently used SPOT Satellite Messengers
B. The chosen VHF antenna must be appropriately small
C. All devices must be user friendly. This could incorporate features like a 'low battery indication' transmission to let the researchers know when it is appropriate to change batteries.
D. The outer shell of the bear transmitter must be very durable

2.3.Technology Requirements

A. The chosen wireless technology must have the ability to penetrate dense forestry
B. The electrical components must be able to handle extreme environments (approximately -40˚C – 70˚C)
C. The chosen design frequency and output power must be harmless to bears and humans

3. Approach and Product Design Results

The following describes the approach that will be taken to achieve the wireless bear tracking solution. This section describes the overall system and network structure as well as the individual components that will be included in the system. The considered approaches are all evaluated, and the finalized approach is described in detail.

3.1.Overall Bear Tracking Structure

Having a functioning structure for communication is critical. We considered a number of solutions including VHF, satellite, cellular, and Digimesh. From these choices, we narrowed down our options based on pros and cons of each alternative.

3.1.1. VHF Collar Units with VHF Routing Unit

Collar unit will consist of a VHF transceiver that will allow data to transmit and receive over VHF Frequencies to the nearest routing unit. The routing unit will use a predetermined and programming network protocol to send information to collars and to other routers until the information is received at the remote research station.

Pros

- Router and Collar will be very similar designs.
- The routers are able to be mounted in desirable locations to easily transmit.
- VHF can transmit at increased distances using lower power rates.
- VHF frequencies easily penetrate heavily wooded areas.

Cons

- Readily made VHF module is not easily accessible with high power output.
- The network protocol may be difficult to complete.
- Bears may travel outside the range of stationary routers.

3.1.2. VHF Collar Units with OrbCom Routing Unit

Collar unit will consist of a VHF Transceiver that will allow data to transmit and receive over VHF Frequencies. The routing unit will transmit received data to the OrbCom Satellites and the satellites will then transmit to a remote location.

Pros

- VHF can transmit at increased distances using lower power rates.
- VHF frequencies easily penetrate heavily wooded areas.
- OrbCom modules are manufactured by Digi.

Cons

- Readily made VHF module is not easily accessible with high power output.
- OrbCom modules have high power requirements.
- Communication to satellite incurs a monthly fee.
- Modules are more expensive and not currently available from Digi.
- Bears may travel outside the range of stationary routers.

3.1.3. VHF Collar Units with Digi 9Xtend Routing Unit

Collar unit will consist of a VHF transceiver that will allow data to transmit and receive over VHF Frequencies. The routing unit will consist of a Digi 9Xtend (900 MHz) unit and be mounted above the tree line.

Pros

- VHF can transmit at increased distances using lower power rates.
- VHF frequencies easily penetrate heavily wooded areas.
- The 9Xtend module is manufactured by Digi.
- The 9Xtend module will make the network structure very easy to implement.

Cons

- Readily made VHF module is not easily accessible with high power output.
- Bears may travel outside range of stationary routers.
- The transmission of the 9Xtend was only tested to reach approximately 2.5 miles with line of sight.

3.1.4. Other Inappropriate Solutions

The following solutions were looked into for a short period to evaluate their feasibility but were quickly removed from consideration for the given reasons.

Cellular

- Tower coverage is extremely weak in area
- Subscription cost is expensive
- Difficult to certify device
- Signal is too high frequency

IRIDIUM Satellite Communication

- No readily available module
- Too high frequency for good signal reception

Satellite Modem on Collar

- Both IRIDIUM and OrbCom constellations
- Too high of power for collared unit
- Modules too large for collared unit

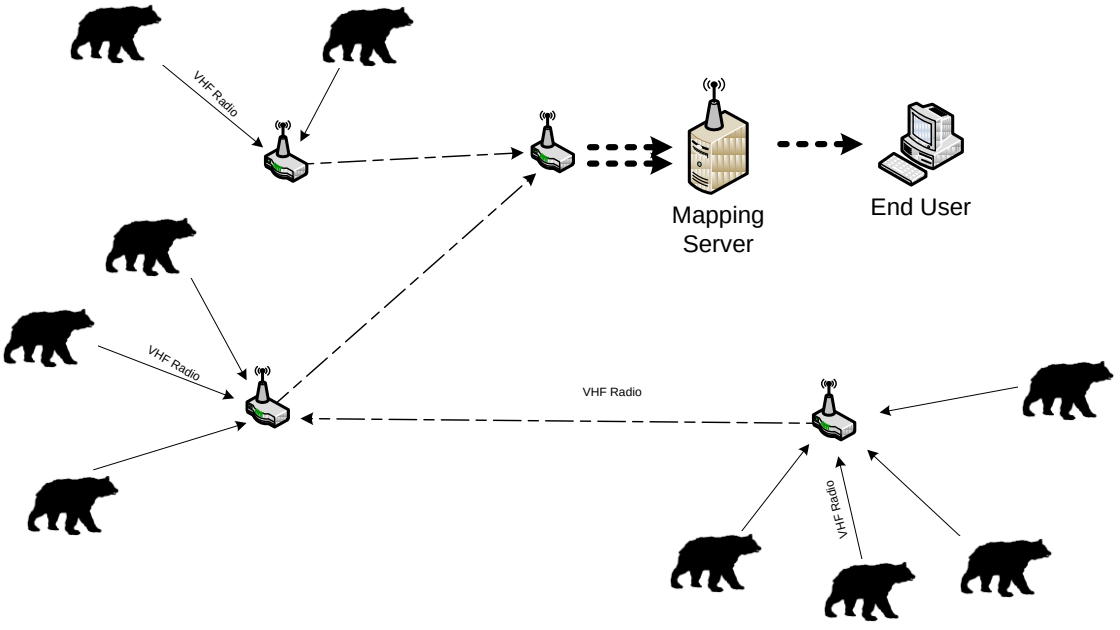
DigiMesh 900MHz Collar Mounted Solution

- Signal power too low to give adequate transmission range.

3.1.5. Detailed Design

The chosen solution was VHF Collar Units with VHF Routing Unit. After evaluating the Orbcom solution, we realized that this was too similar to the solution currently being used by the researchers and incurred the same sort of cost that they are looking to eliminate. Next, we were able to rule out the Digi 9Xtend solution after doing field tests that resulted in an unacceptable 2 mile range from line of sight. This transmission would be drastically reduced in the wooded areas of Minnesota.

The VHF Routing Unit solution allowed for these constraints to be overcome. Not only is it a low cost solution, but it also gives us the ability to choose a frequency that works best for our conditions. With the selected frequency of 217 MHz, we are able to penetrate very dense forestry while still maintaining a reasonable range. This was verified using the Radio Mobile simulation software.



3.2.Network Structure

The following section will define the network routing schemes proposed and why TDMA was chosen as the preferred networking method. The detailed design of the network method is also described.

The sole purpose of this section is to propose a versatile solution to the unit to router communication scheme as well as the router to router communication scheme.

3.2.1. CSMA/CA

CSMA/CA is a networking solution that stands for Carrier Sense Multiple Access with Collision Avoidance. A user will listen to the channel for a period of time before transmitting. If the channel is clear, the user will notify all other users not to transmit and then proceed to transmit the information packet.

3.2.2. TDMA

TDMA will be described in depth in the detailed design section, but its basic concept is that several users will transmit on the same frequency, but for different time slots. The individual user is allocated a time to transmit and during that time period, the channel is clear. After the time has passed, the channel is clear for a second user to transmit.

There were several reasons considered when choosing TDMA over CSMA/CA. CSMA/CA is useful when users' activities are bursty, and also when the number of users of the system varies dynamically. CSMA/CA allows simple adaptation to these conditions. However, since in the current application the system is quasi-static and the number of users does not change (except in rare situations), in addition to the fact those users' activities are deterministic (1 report every 10 minutes), TDMA is better suited for the application. Moreover, with TDMA, the hidden terminal problem can be avoided, the exposed terminal problem can be avoided, and the ad hoc network topology can be supported in a simple way. This strategy will also save energy since it will avoid the collisions that CSMA/CA suffers from. The use of a GPS chip also makes synchronization a simple task.

3.2.3. Detailed Design

This section gives an introduction to the overall network skeleton as well as the network protocol chosen.

3.2.3.1. General Network Skeleton

Consider the case where four routers are placed in predetermined spots within the area of concern. Also consider several units scattered throughout this area but within range of at least one router. This could be described in Figure 2 below.

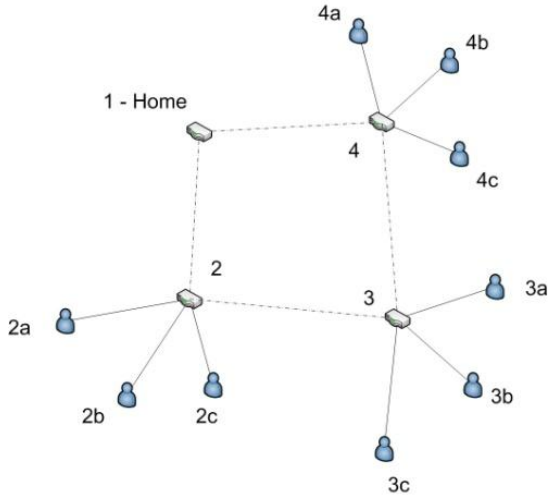


Figure 2. Network Example

In the case above, there are nine users present in the network of four routers, the first being home base. It is required that location data from each bear is routed to home base every 10 to 15 minutes. All units and routers are transmitting and receiving the same frequency, so a fitting modulation scheme needs to be decided upon.

3.2.3.2. General TDM

TDM (Time Division Multiplexing) is a great choice for this application. The idea is that a data stream is divided into separate frames in the time domain. Multiple users then share a piece of that frame (a time slot). Each user is allowed to transmit and receive for the amount of time allotted in the time slot.

For example, consider Figure 3 below. The top section of this figure displays a data stream of which is divided into separate frames. Each frame is then divided into different time slots, in this case four. Thus, there are four possible users that can talk to a host device at very specific times.

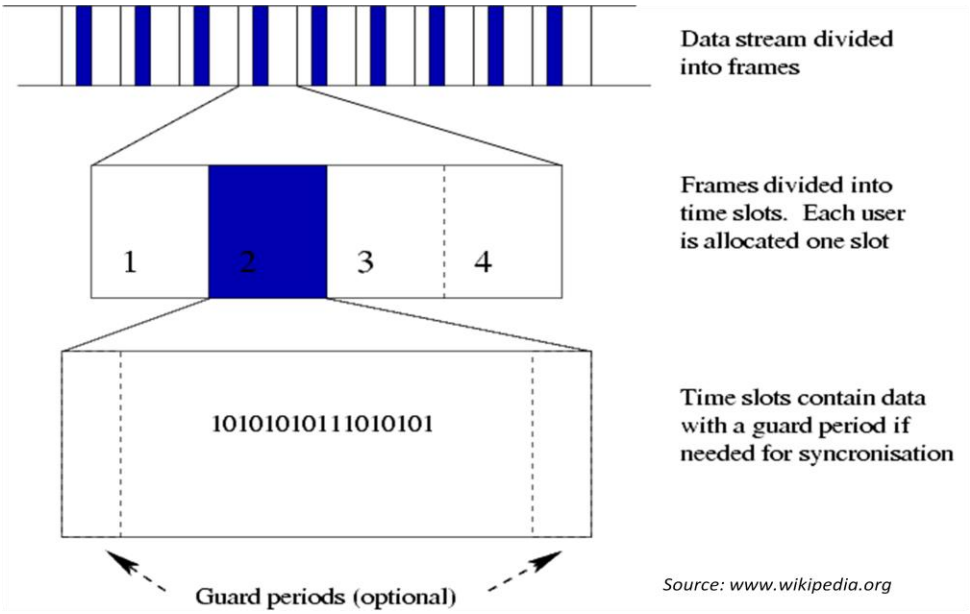


Figure 3. TDM General Diagram

This model assumes that a connection has been previously established and time slots have been assigned to each user. Connection establishment and time slot assignment will be discussed later in this section.

3.2.3.3. General Network Structure

Consider again the example network shown in Figure 2, where nine users have data routed to home base by three different routers. In this system, all routers are constantly listening and do not turn off or sleep. The units only turn on when it is their turn to speak. The unit will know when its turn to speak is based on the time slot given. This timeslot, or specified amount of time where only one particular unit speaks, is given to the unit prior to shipment and is hardcoded.

To determine the number of time slots available, the following equation can be used:

$$TS = \left\| \frac{t_f}{\frac{bpTx}{baud} + 2t_g} \right\|$$

where TS is the number of time slots, *baud* is the bit rate (bits per second), *bpTx* is the number of bits per transmission needed, t_d is the time needed for data transmission (in seconds), and t_g is the guard period (as shown in the previous diagram – two guard periods are needed, one at the beginning and end of the frame, thus resulting in $2t_g$).

The lower the baud, the less number of time slots are available. Lower baud usually results in lower BER and better penetration through the dense woods. The higher the baud, the greater number of time slots available. Higher baud usually results in higher BER and does not allow the signal to penetrate dense forestry as well. So, in selecting the proper baud, tradeoffs need to be considered. The number of bits per transmission should be static.

3.2.3.4. Specific Unit Data Communication

The specific data needed by the router from the unit could be the following:

> *<preamble, data start string, UnitID, MAC, data, flags, CRC, data end string>*

The preamble will consist of 6 bytes of alternating ones and zeros. The purpose of the preamble is to all the transceiver to synchronize with this incoming message. Data start string is a unique set of characters that differentiates this message from any other message. UnitID is the unit's identifier which can be changed in software. MAC is the unit's unique MAC address; this is hardcoded and will never change. Data is the information required to locate the bear. Flags are the bytes needed to let the router know the status of the unit. CRC is the data needed for bit error checking and

correcting. Data end string is the set of bits that lets the router know it has reached the end of the message.

The unit will require an acknowledgment from the router letting the unit know that the data was successfully received. This acknowledgment message sent by the router is described as the following:

<preamble, ACK start string, MAC, time, CRC, ACK end string>

ACK start string is a unique set of characters that differentiates this message from any other message. MAC is the address of the unit receiving the acknowledgement. The time of the received GPS data is resent back to the collar unit for extra verification that the ACK message corresponds to the recent message sent. CRC is the data needed for bit error checking and correcting. ACK end string is the set of bits that lets the router know it has reached the end of the message.

The transceiver can handle up to 8 bits of a constant one or zero. After this, the performance starts to degrade. To address this issue, 8B/10B encoding scheme was chosen. All packets will be encoding using this scheme.

It is predicted that at most 150 bytes will be needed for the unit to router data message, and at most 25 bytes will be needed for the router to unit acknowledgment message. So the total number of bytes needed for data transmission is 175 bytes. This is a very high overestimate to prepare for a worst case scenario.

Referring to the previous equation, the number of time slots available can be determined. The baud chosen initially is was 300. If 0.5 ms is allocated for the guard periods, and 175 bytes are needed for data transmission only, then the time needed for each time slot is:

$$\frac{175\ bytes \times 9\ bits/byte}{300\ \ bits/sec} + 2(0.5\ ms) = \ 5.251\ seconds$$

Nine bits per byte is used to account for the parity bit. If each frame is 10 minutes long, the number of time slots available is:

$$\left\| \frac{10min \times 60\ sec/min}{5.251sec} \right\| = 114$$

Here, it is shown that there are 114 time slots in a length of time equal to 10 minutes. Each collar is given three time slots in order to achieve a successful transmission. If the first attempt is successful, the collar will sleep for the additional two time slots it is assigned. If each collar uses three time slots, this allows for 38 collars in this static case of the system.

As location must arrive at the home base every fifteen minutes, the last five minutes of the TDM allows for router to router communication. A later section defines how the routers register with each other to transmit the information to the home base. Routers will relay their unit information forward to the home base in a chain, until the home base has received all of the data. The time slot for each router is assumed to be the worst case scenario where it must send location information for all 38 collars.

After the routers have relayed the information to the home base, the 15 minute TDM cycle will repeat.

3.2.3.5. Time Slot Recognition

Assigning a time slot to a unit is a simple programming task, but introducing the unit to the network with the assurance the unit properly utilizes the time slot is a more difficult task. The unit can know precisely when to start and stop transmitting only if it knows the current time of day. This can be known by using the GPS time.

3.2.3.6. Initial Unit Perception of Time

Consider a unit that needs to begin transmitting on the :00, :10, :20, :30, :40, and :50 mark of every hour. This is hardcoded. By turning on the unit and allowing it to receive a GPS signal, the time of day can be obtained, and a timer can be set to begin waiting for the next time to reach its time slot. To be clear, say the time obtained is 12:15:25. The controller would then set a timer for 00:04:35 to begin transmitting.

3.2.3.7. Specific Time Slot Assignment

To ensure minimal unit interruption, the time slot assignment for the collar units will be staggered along the ten minute allotted time, allowing for ample wait time between time slots.

For example, consider a system that has eight allowed time slots for units to occupy. Assume that only three units are registered to the system. Units 1, 2, and 3 would be assigned time slots 1, 7, and 3 respectively. The diagram below illustrates this.

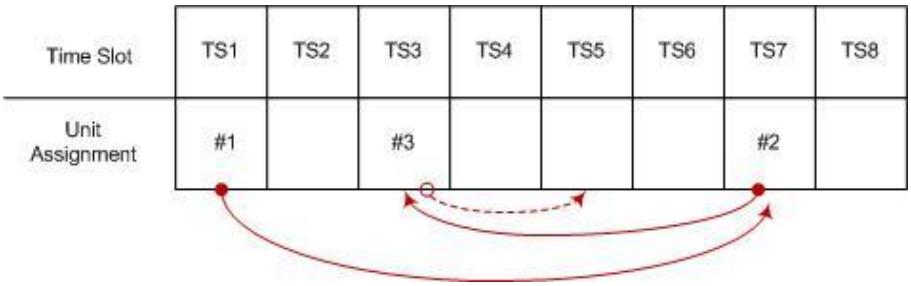


Figure 4. Time Slot Assignment

3.2.3.8. Router Registration

The routers will be required to dynamically set up an appropriate network for transferring the information from routers back to the home router. This section describes that registration and initial set-up.

The router registration will execute the following:

- Router will find the nearest adjacent router in the direction of the home base.
- Router will know how many routers the information will transfer through to arrive at the base router. This will determine the router number.
- Router will define its time slot based on its router number
- Router should know physical location of all other routers in system.

With this information, the steps that will be taken for the router registration are as follows:

- The home router, hardcoded as Router #01 will be registered as Router A.
- Router A will send out a signal asking that all appropriate routers register, along with the time the signal was sent.
- Any router that receives the signal will wait a certain number of seconds, based on the individual router number, and then send the unit's GPS location. This allows Router A to store the GPS coordinates for the routers within range.
- Once the number of router time slots has passed, Router B will do a similar process. This will once again allow Router B to know all of the GPS coordinates for the routers within range.
- This process will continue in an avalanche type of process until each router knows the location of all of the other routers.

Because the location of the home computer is already known, the routers can each calculate which router is the closest router to the path back to the home computer. The router will know that it must then transmit to this router. By only sending it to the closest router to the path back to the home computer, it will save time and allow for fewer transmissions, therefore saving battery power. The receiving router will store the data until it is its turn to transmit the data. This process will continue for a length of time that is dependent on the number of routers. Each router will not have its own time slot, because the amount of data that each router needs to send is dependent on the number of bears in range of the router, as well as the amount of data that was forwarded to the router by the previous routers.

3.2.3.9. Bear to Router Communication

With this solution, when a bear collar transmits its location, multiple routers could receive the location. Each router will know the location of the other routers, so the closest router will send the acknowledgement to the bear. One exception to this would be if the closest router did not receive the bear's transmission. Since the bear will not receive the acknowledgement, according to the conditions laid out above, the bear will retransmit the signal. When the router receives the bear's transmission for a second time, the second closest router will then try to send the acknowledgement. This condition is in place because if two routers attempt to send the acknowledgement simultaneously, the signals could interfere with each other and be ignored by the bear.

After all bears have transmitted their location, the routers will then transmit locations back to the home computer in the order from the furthest router towards the closest router. Once again, the distances will be calculated according to the GPS locations. This will be the method used to get the locations of all the bears back to the home router.

3.3.VHF Transceiver

The chosen design will make use of a VHF Transceiver. The following section describes the frequency selection, transceiver selection, and detailed design for the selected transceiver.

3.3.1. Frequency Selection

In order to achieve better distances in the dense woods, frequencies in the VHF spectrum were considered in both the unlicensed and licensed bands. These bands were the unlicensed band at 174 to 216 MHz, ISM band at 40 MHz, and the licensed band at 216 to 220 MHz.

The first band we considered was the unlicensed band at 174 to 216 MHz. This band allowed a bandwidth of 200 kHz and maximum field strength of emissions of 1500 microvolts/meter at 3 meters. The field strength was calculated to limit our transmission power to -32 dBm of power to the antenna. For our application, this was not enough power (Federal Communications Commission- Part 15).

The second band we considered was the ISM band at 40 MHz. This band allowed a high power transmission. However, at a frequency of 40 MHz, our antenna for the VHF would require an antenna length of 6.2 ft which is too long for the units on the bears (Federal Communications Commission- Part 18).

The final band we consider was the licensed band at 216 to 220 MHz. The band allows a maximum output power of 2 watts and bandwidths of 6.25, 12.5, 25 and 50 kHz. The band is assigned to applicants that establish eligibility in the Industrial/Business Pool. The Industrial/Business Pool includes uses in the operation of educational institutions which our final product would qualify for. The downside to this band is that it would require certification from the FCC (Federal Communications Commission- Part 90).

In the end, we chose the license band at 216 to 220 MHz. More specifically, the exact frequency the units will operate at is 217.025 MHz. The band is in the VHF spectrum and will allow us to transmit at power levels that are needed. With the requirement of needing a license, our client informed us that we do not need to certify our product and any certification needed would be done by them.

3.3.2. Transceiver Selection

Due to time constraints of the project and the availability of VHF transceiver modules, our team decided to consider only VHF transceiver modules instead of trying to build our own transceiver. We considered three different modules: Radiometrix UHX1, Melexis TH7122, and Analog Devices ADF7021.

Radiometrix UHX1 operated at a frequency of 140 to 175 MHz and allowed output power of 1 mW to 500 mW. It used FM modulation with channel spacing of 12.5 and 25 kHz. The temperature rating on the device was from -30 to 75 °C. With the temperature only going down to -30 °C, choosing to use the 216 to 220 MHz band, and a cost of $266, this transceiver was not a valid option

Melexis TH7122 transceiver allowed frequency range of 27 to 930 MHz. It is digitally programmable with modulation schemes of FSK, FM, and ASK. The chip has an adjustable output power of -20 to 10 dBm which means that an external power amplifier

would be needed to achieve an output power of 1 watt. The transceiver has an operating temperature range of -40 to 85 °C and can transmit at a data rate as low as DC with external components and as high as 20 kbps. Narrowband operation required more external components to improve performance. TH7122 had a sensitivity of -107 dBm and had a cost of $13.40.

The last transceiver we considered was Analog Devices ADF7021. The ADF7021 had a frequency range of 80 to 950 MHz. It is digitally programmable with modulation schemes of FSK, 3FSK, 4FSK, and MSK. The chip has an adjustable output power of -16 dBm to 13 dBm which means that an external power amplifier would be needed to achieve an output power of 1 watt. The transceiver has an operating temperature range of -40 to 85 °C and can transmit at a data rate of 50 bps to 32.8 kbps without any external components. The transceiver is designed as a narrowband transceiver with programmable bandwidths of 12.5, 18.75, and 25 kHz. ADF7021 has a receiver sensitivity of -130 dBm at 100 bps with on-chip image rejection calibration. It also had an on-board temperature sensor and battery strength indicator.

We decided to use the Analog Devices ADF7021. It required fewer external components compared to the Melexis TH7122. It also came with software that helped design the component values of the external circuitry, performed simulations of the chip, and gave register values to be programmed into the ADF7021 all based on our frequency, external oscillator frequency, and bandwidth. The chip was also the cheapest at $5.76.

3.3.3. Detailed Design

The following section describes the detailed design for the VHF transceiver. This includes diagrams, schematics, and simulation data.

3.3.3.1. VHF Overview

The Analog Devices ADF7021 transceiver performs the modulation and demodulation of the data sent from the microcontroller. ADF7021 outputs the modulated data at a digitally programmable power range of -16 dBm to 13 dBm to an external power amplifier SPA-1118 made by RFMD. This power amplifier has a fixed gain of 17.2 db and an output power at 1db compression of 29.5 dBm. SPA-1118 outputs to RF switch SKY13270-92LF made by Skyworks which connects the RF output and RF input to a single 50 ohm antenna. For a block diagram, see Figure 5.

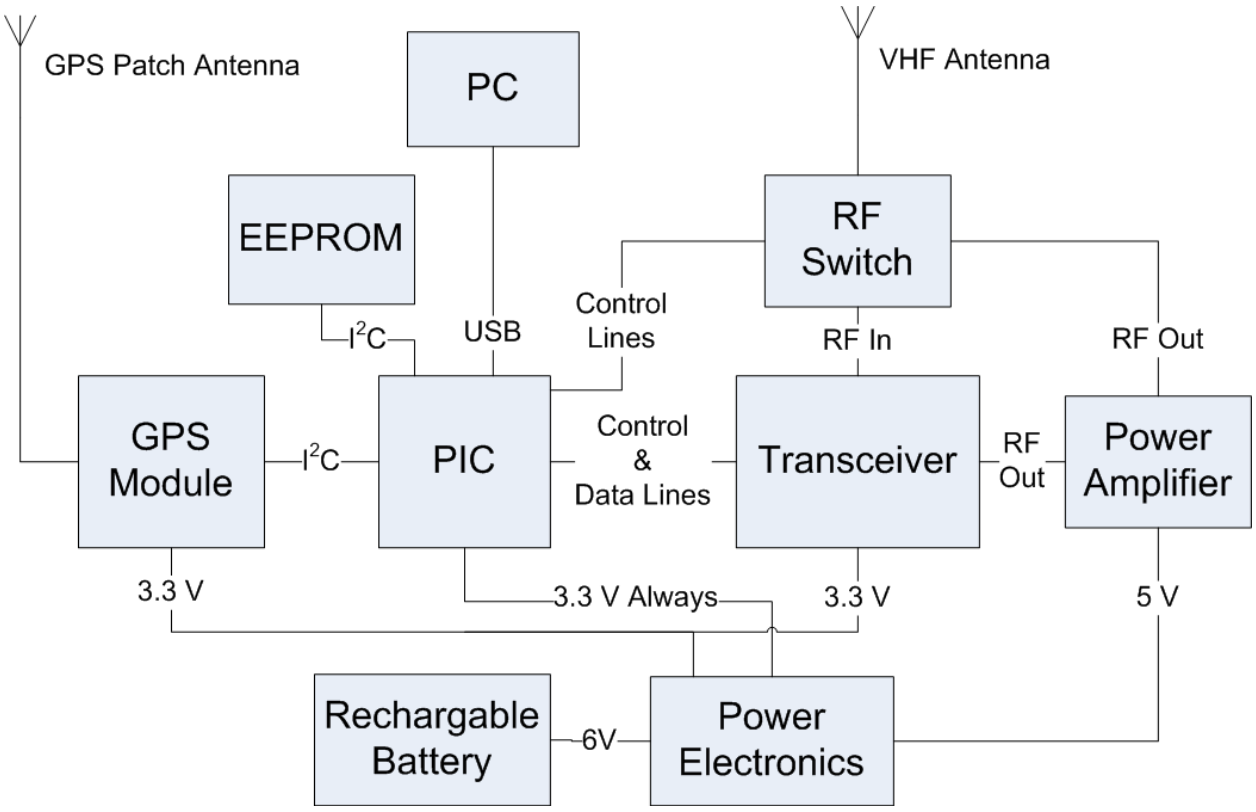


Figure 5. System Block Diagram

3.3.3.2. VHF Transceiver ADF7021

The ADF7021 has been configured to have a bandwidth of 25 kHz, a carrier frequency of 217.025 MHz, transmit at a data rate of 300 bps, and use FSK modulation.

3.3.3.3. Microcontroller Interface

The data to be transmitted and received by the transceiver is interfaced with the USART of the microcontroller. The transceiver's registers are configured by the microcontroller's USART. The transceiver has three lines (VHF_CE, VHF_SWD, and VHF_MUXOUT) that interface with the general I/O of the microcontroller. A description of each line can be seen in Table 1.

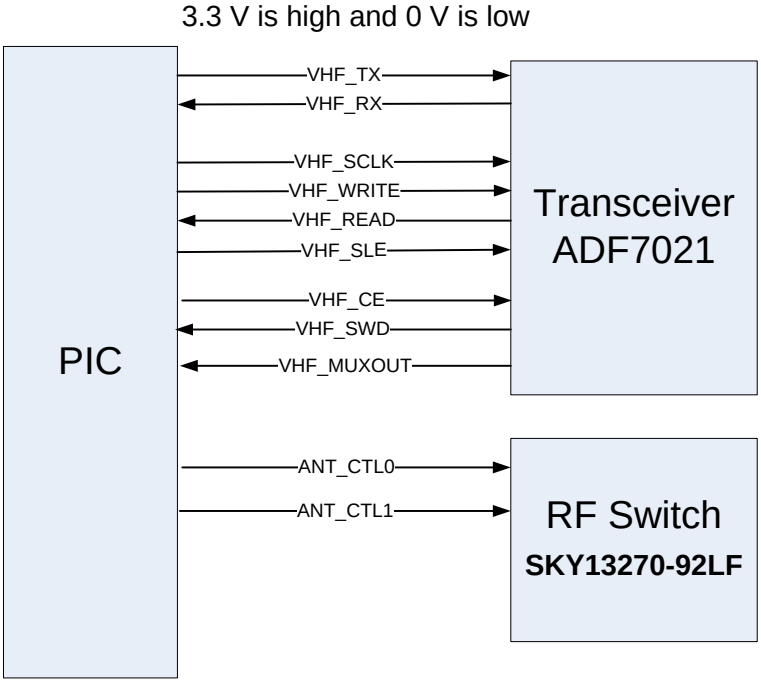


Figure 6. Interface of Transceiver and RF Switch to Microcontroller

Table 1: VHF to PIC I/O Descriptions

VHF_TX	Serial data that is sent to be transmitted
VHF_RX	VHF received data from another device
VHF_SCLK	Serial clock input for writing and reading to the registers of the transceiver
VHF_WRITE	Serial data input, data to be loaded into the registers of the transceiver
VHF_READ	Serial data output, register data of the transceiver
VHF_SLE	Load enable input, set high to load data into register
VHF_CE	Chip enable, low puts transceiver in power-down and register values are lost
VHF_SWD	Sync word detect, high when a match for the sync word sequence found
VHF_MUXOUT	Digital pin that can be set to read various set conditions. Default is Regulator_Ready – pin is set high when the regulator is ready on power up
ANT_CTL0	Antenna Control bit 0 of the antenna switch. Set 0 for TX and 1 for RX
ANT_CTL1	Antenna Control bit 1 of the antenna switch. Set 1 for TX and 0 for RX

To write to the transceiver's register, the data is read in on the rising edge of the VHF_SCLK. The registers are 32 bits in length and are fed in most significant bit to least significant bit. During this time VHF_SLE must be held low. After the last bit rising clock has been read in, VHF_SLE must be raised high for at least 20 ns to move the data into the registers. Table 2 and Figure 7 below from the ADF7021 datasheet show the timing requirements.

Parameter	Limit at T_{MIN} to T_{MAX}	Unit	Test Conditions/Comments
t_1	>10	ns	SDATA to SCLK setup time
t_2	>10	ns	SDATA to SCLK hold time
t_3	>25	ns	SCLK high duration
t_4	>25	ns	SCLK low duration
t_5	>10	ns	SCLK to SLE setup time
t_6	>20	ns	SLE pulse width
t_8	<25	ns	SCLK to SREAD data valid, readback
t_9	<25	ns	SREAD hold time after SCLK, readback
t_{10}	>10	ns	SCLK to SLE disable time, readback

Table 2: Timing Table for ADF7021 (Analog Devices, 2009)

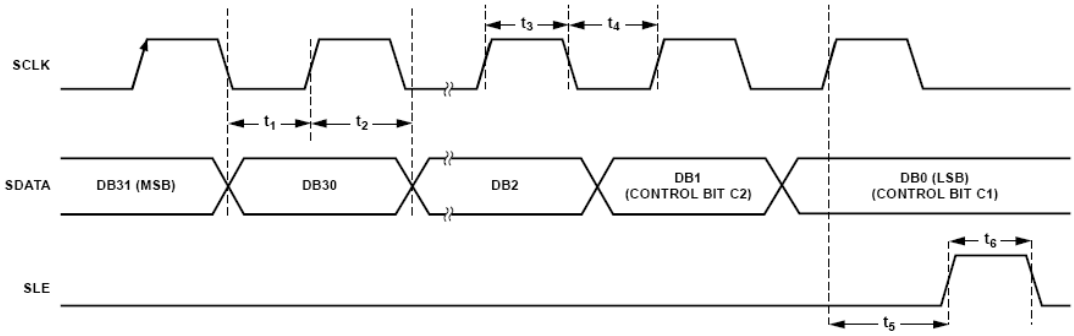


Figure 7. Timing Diagram for Writing to ADF7021 Registers (Analog Devices)

Readback from the ADF7021 can be performed to read back the follow seven values: AFC, RSSI, battery voltage, temperature, external ADC, filter bandwidth calibration, and silicon revision. To read back this data, the readback enable bit in register 7 must be set to 1. VHF_SLE must go high to write the data to register 7. The data appearing one clock cycle after VHF_SLE goes high must be ignored. After this ignored clock cycle, the valid data will appear starting with the most significant bit (bit 15). After bit 0 has been read, one clock cycle should pass before setting VHF_SLE low to allow for the SREAD pin to be set back to tristate. Figure 8 below from the datasheet shows the timing for readback.

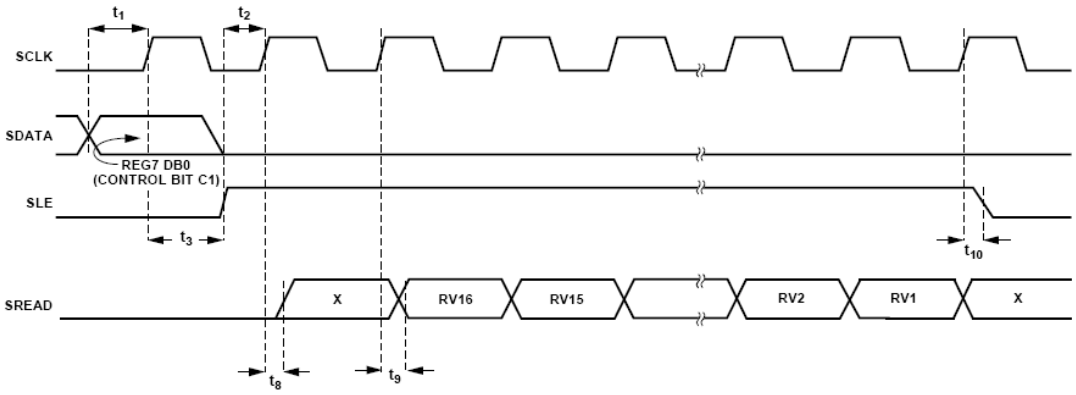


Figure 8. Timing Diagram for Readback (Analog Devices)

Data to be transmitted is sent on VHF_TX and data received is received on VHF_RX. These lines are asynchronous and will be sent at the bit rate set in the transceiver.

3.3.3.4. Programming after Initial Power-Up

After VHF_CE is brought high, the registers in the transceiver must be reprogrammed.

Figure 9 and Figure 10 are the suggested programming sequences for transmitting and receiving from the ADF7021 datasheet.

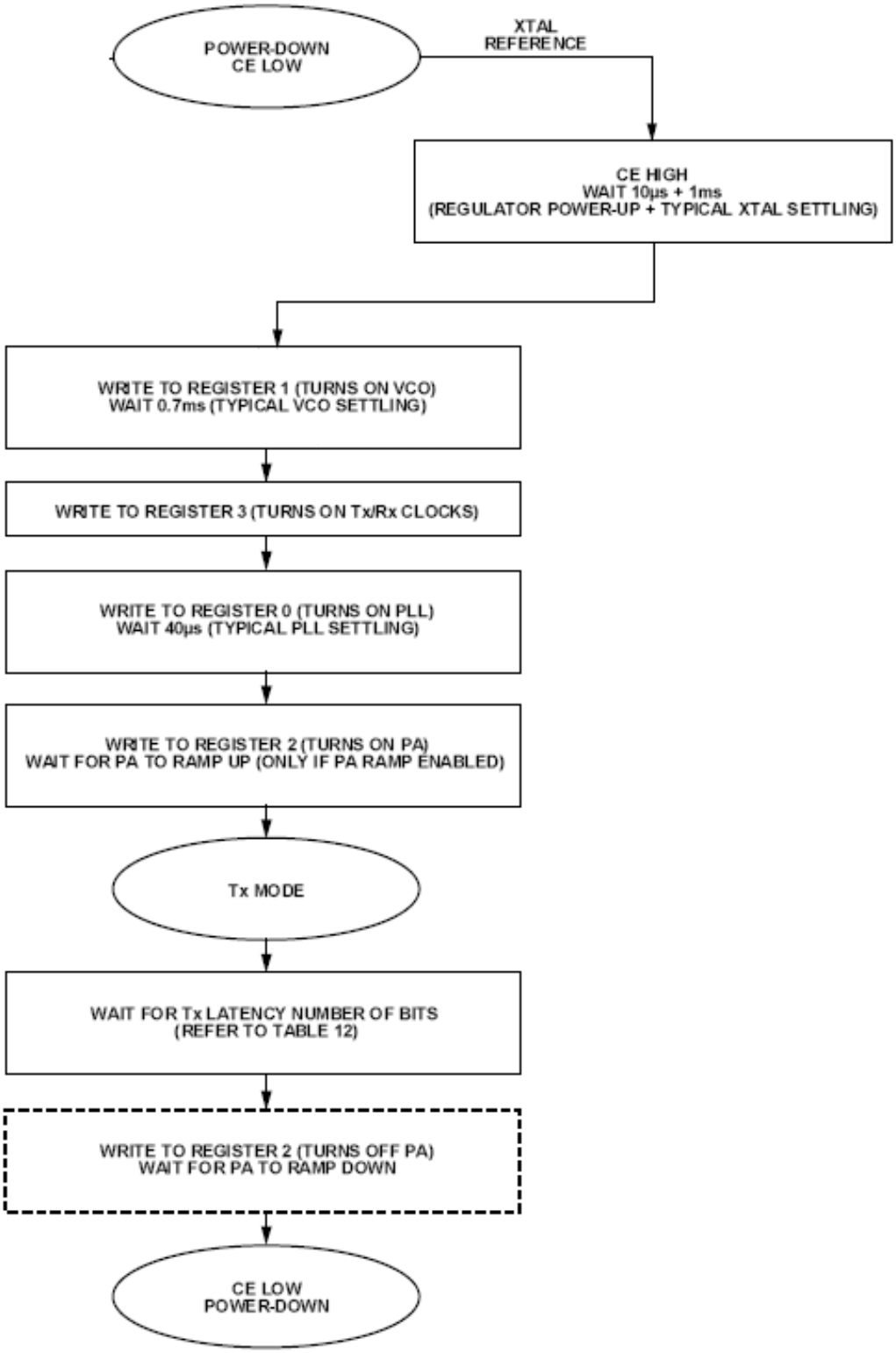


Figure 9. Transmit sequence after power up (Analog Devices, 2009)

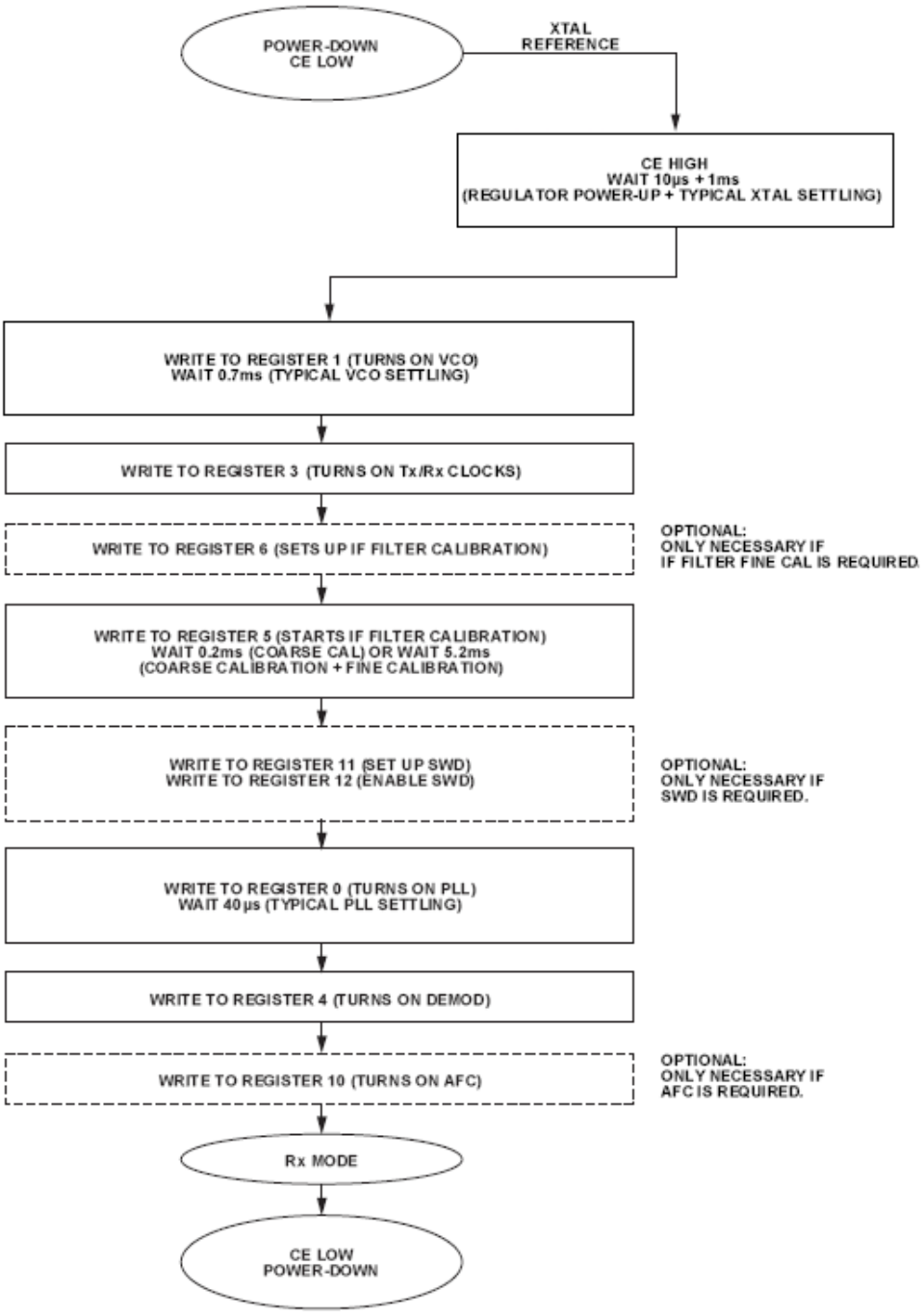


Figure 10. Receive sequence after power up (Analog Devices, 2009)

3.3.3.5. Automatic Sync Word Detection

The ADF7021 can be set to detect a user defined sync word which can be 12, 16, 20, or 24 bits long. When the transceiver detects the defined sync word, VHF_SWD is set high.

3.3.3.6. Loop Filter Design

The loop filter design from pin 1 to pin 42 was designed using Analog Devices' software ADIsimSRD Design Studio. This software takes the user inputs of frequency, bandwidth, and crystal oscillator frequency and automatically calculates the values of the loop filter.

3.3.3.7. Crystal Oscillator Design

The crystal oscillator frequency was chosen based on the SRD ADIsimSRD Design Studio. This crystal frequency allowed the transceiver to have the exact carrier frequency of 217.025 MHz and a bandwidth of 25 kHz. The crystal oscillator frequency was also chosen because it was an available crystal to buy and gave us the exact carrier frequency when multiplied internally. The crystal that was chosen is made by Citizen and has a temperature range of -40 to 85 °C and a load capacitance of 18.0 pF. Two capacitances were needed to be put in shunt with the crystal oscillator to achieve the 18.0 pF load capacitance. The value of these two capacitors (C_1 and C_2) can be approximate using the following formula.

$$CL = \frac{C1 \times C2}{C1 + C2} + Cstray$$

C_1 and C_2 are the load capacitors. C_L is the load capacitance specified in the crystal's datasheet and C_{stray} is the total parasitic capacitances on the crystal. C_{stray} was estimated at 5 pF. Using this value of C_{stray} and the available capacitor values available for purchase, C1 and C2 were picked to be 20 and 36 pF.

3.3.3.8. Matching Network

The RF output of the transceiver was matched to 50 ohm load impedance. From the application notes, the input impedance at 220 MHz can be modeled as 159.75 + j53.16. Using the high pass matching network that was suggested, the capacitor and inductor values were found as shown in Figure 11. A 100.0 pF capacitor was placed in shunt with the 3.3 voltage supply to prevent the RF from propagating to the voltage supply. The simulation of the matching network can be seen in Figure 12. As one can see, the reflected power at 217 MHz is -40 db.

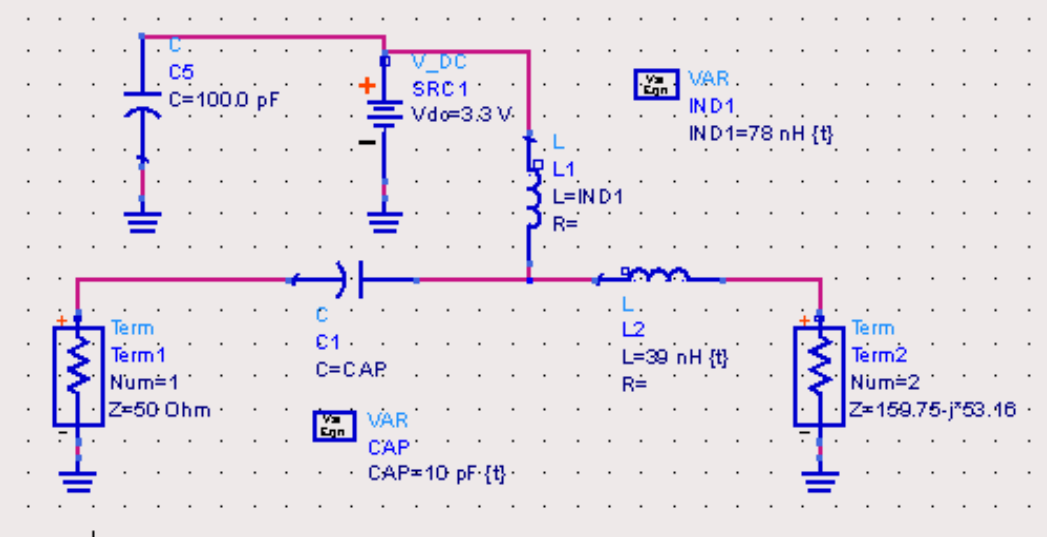


Figure 11. RF Output Matching Network

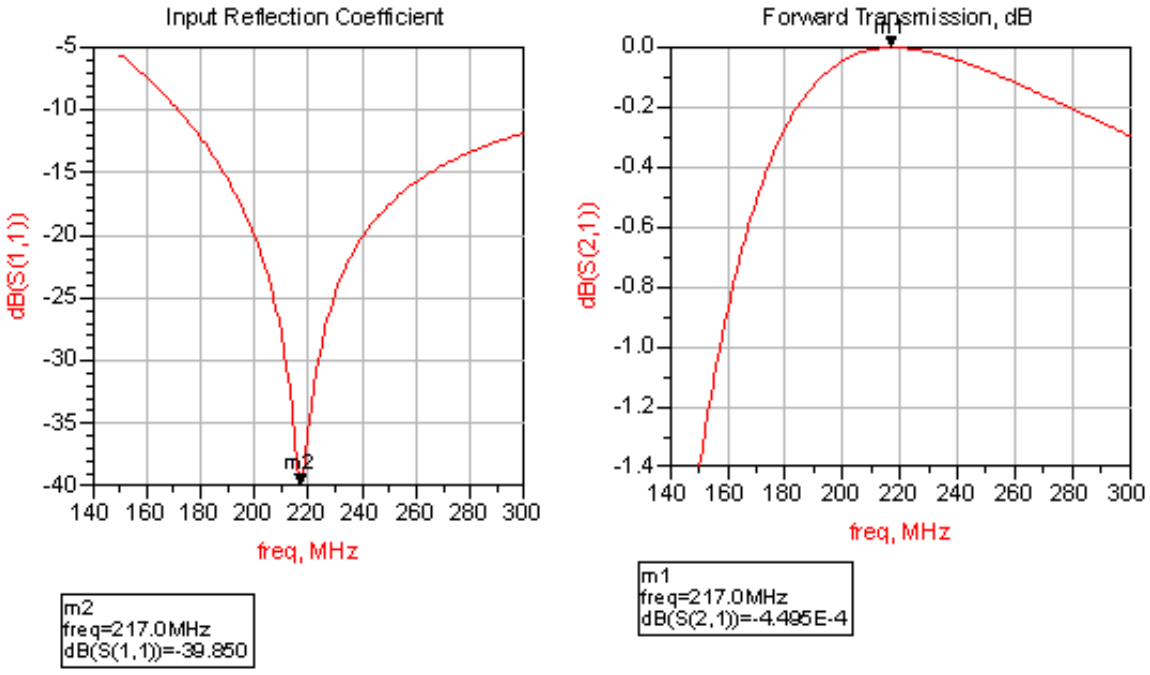


Figure 12. RF Output Matching Network Simulation

The RF input of the transceiver was matched to 50 ohms. From the application notes, the input of the transceiver was modeled at 220 MHz. Using the suggested matching network and the approximate values for a matching network at 150 MHz, the matching network was able to be tuned to get a match to 50 ohms. The matching network (C_3, C_4, L_2, and L_3) can be seen in Figure 13. Simulating the circuit (see Figure 14), the reflected power was -51 db at 217 MHz with an input impedance of 50.182 + j0.215.

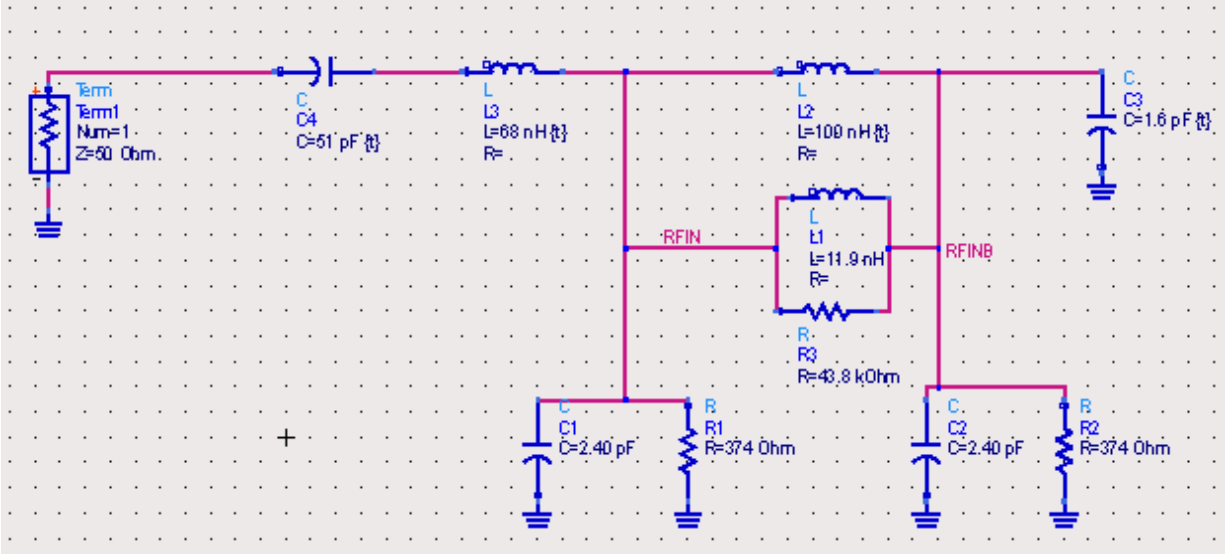


Figure 13. RF Input Matching Network

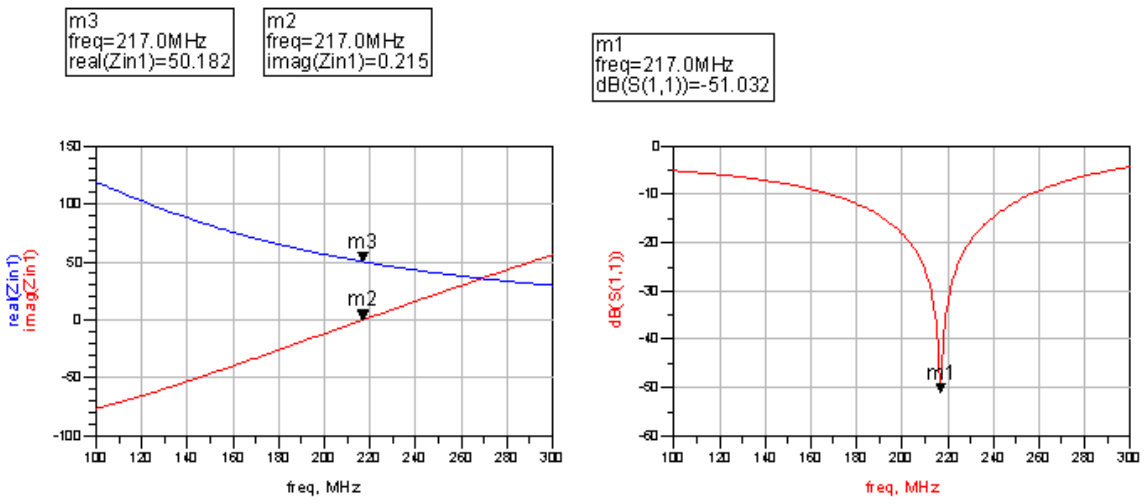


Figure 14. RF Input Matching Network Simulation

3.3.3.9. ADF7021 Simulation

Using ADIsimSRD Design Studio provided by Analog Devices, simulations were performed to simulate the performance of the transceiver's output using the values of the loop filter, oscillator, and 50 ohm load. The results of these simulations can be found in Figure 15.

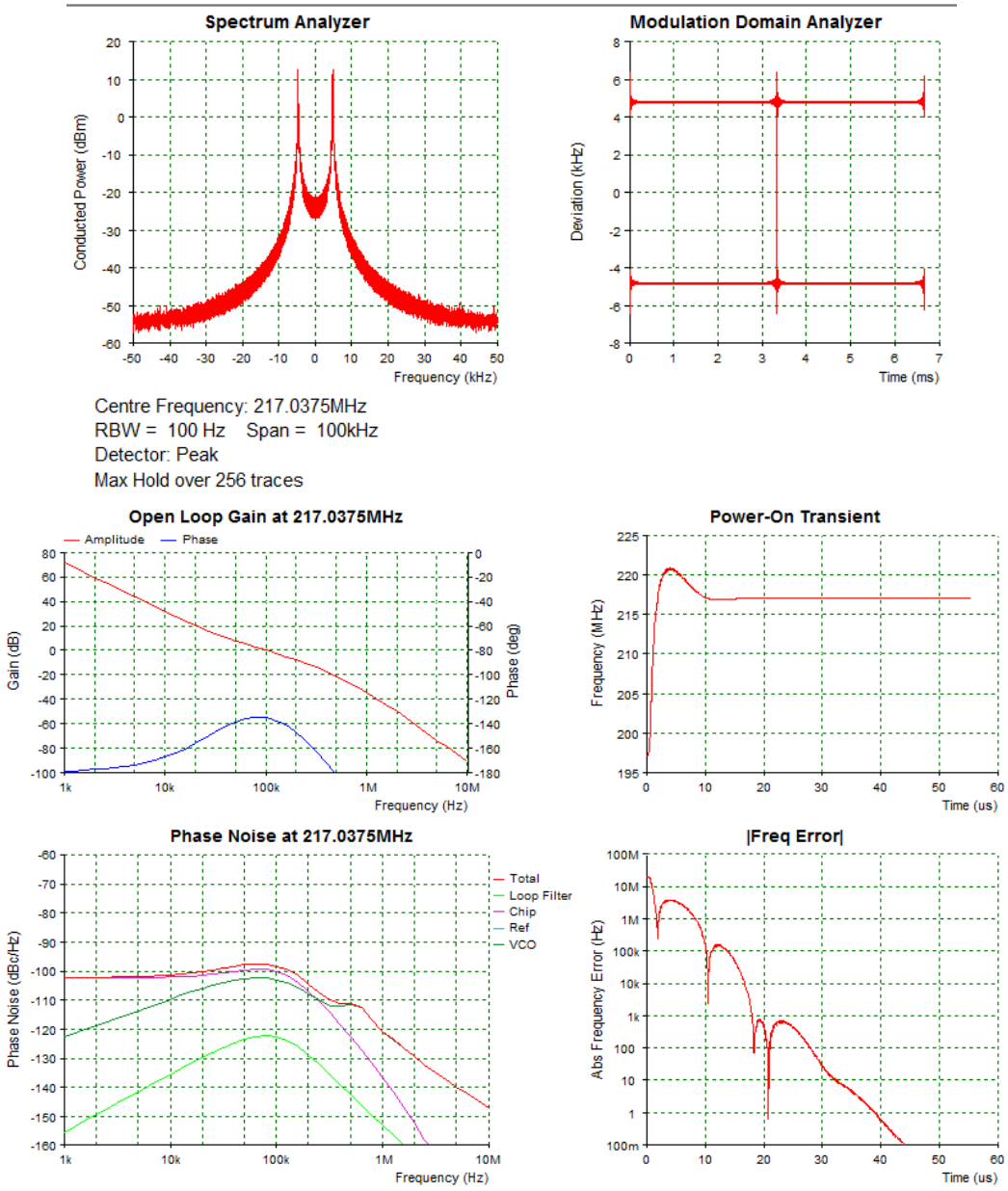


Figure 15. ADF7021 Simulations

3.3.3.10. External Power Amplifier

The output from the ADF7021 is fed into an external power amplifier made by RFMD (SPA-1118). This external power amplifier amplifies the power by 17.2 dB and has a 1 dB compression of 29.5 dB. The matching network and bias network was supplied by RFMD. The values of the external components were optimized for a frequency of 240 MHz and are matched to 50 ohms. The application engineer from RFMD suggested starting with the values and then slightly adjusting them once the board is built to achieve an optimal match.

3.3.3.11. RF Switch

A RF switch connects the output RF of the external power amplifier and the RF input of the transceiver to the common antenna. The RF switch is made my Skyworks (SKY13270-92LF). The switch has a 0.1 db compression point of 37 dBm and can handle up to 6 watts of power. The switch isolates the high power transmission from the RF input of the transceiver. The isolation helps prevent any damaging to the RF input of the transceiver.

ANT_CTL0 and ANT_CTL1 are the control lines from the microcontroller.
 shows the control lines settings for transmitting and receiving.

Table 3: RF Switch Control Lines

	ANT_CTL0	ANT_CTL1
Transmit	1	0
Receive	0	1

3.4.VHF Antenna

The antenna design at the collar and base station is very important in order for the signals to be transmitted at the distances necessary for the bear tracking system. The collar and the routing unit will both have different antenna types and styles due to the different restrictions. The combination of the two antenna types should have a transmission distance in the wooded landscape of nearly five miles.

The antenna at the collar is very restricted in size and shape. The antenna must fit on the collar and be able to withstand the bear's abuse. The antenna should be sewn into the collar as much as possible, and if it protrudes, it must be very minor as to avoid damage by the bears. Curvature of the antenna around the collar and proximity to the bear will greatly affect the performance of the antenna.

The router antenna can be much more sizable which will also allow for a larger antenna gain. It is necessary in order to receive the signals sent by the collar antenna which may be restricted due to different obstructions. It can be assumed that the router will be placed in a relatively clear and higher elevated location.

Wireless communication can be summed up in the following equation, sometimes called the link equation, or link budget equation.

$$P_R = P_T G_T G_R \left(\frac{\lambda}{4\pi R}\right)^2$$

The P_T and P_R are the power transmitted and the power received. G_T and G_R are the gain of the transmitting and receiving antennas. Note that this is not in dB, but is a direct ratio of the max directional gain of the antenna. λ is the wavelength of the transmitted signal and R is the distance between the two antennas.

In this system, due to the poor gain of the antenna on the bear collar, the antenna gain for the router antenna will have to be much higher. The following describes several different antenna types and then the detailed design will incorporate the final selection of collar and router antenna.

3.4.1. ¼ Wavelength Whip Antenna

The ¼ wavelength whip antenna would enter the unit under the neck of the bear and wrap around the bear's neck stitched into the collar. At the defined frequency of 217 MHz, the length of this antenna would be approximately 12.07 inches. This would wrap around the bear's neck stitched into the collar and slightly protrude near the top of the collar.

The monopole antenna would require a large ground plane, which the small unit may not be able to provide. The large ground plane is the reference for the signals that will be transmitted to the antenna. It will be necessary in this situation to have an entire ground plane on the printed circuit board.

The antenna would be connected directly to the transceiver. This antenna would not require any transmission line, but the entire wire connecting the antenna to the transceiver will act as part of the antenna. Other signals will need to be shielded from this antenna portion.

The antenna extended along inside the collar will be made from stranded steel aircraft cable. This is a similar material to other wildlife telemetry antennas. There are several different types of aircraft cable, but the most important quality is thickness. The stranded cable allows for it to be flexible as it wraps around the neck. The diameter of the cable must be wide enough to account for the bandwidth of the signal. As the cable of the antenna widens, the higher bandwidth capability of the antenna will increase.

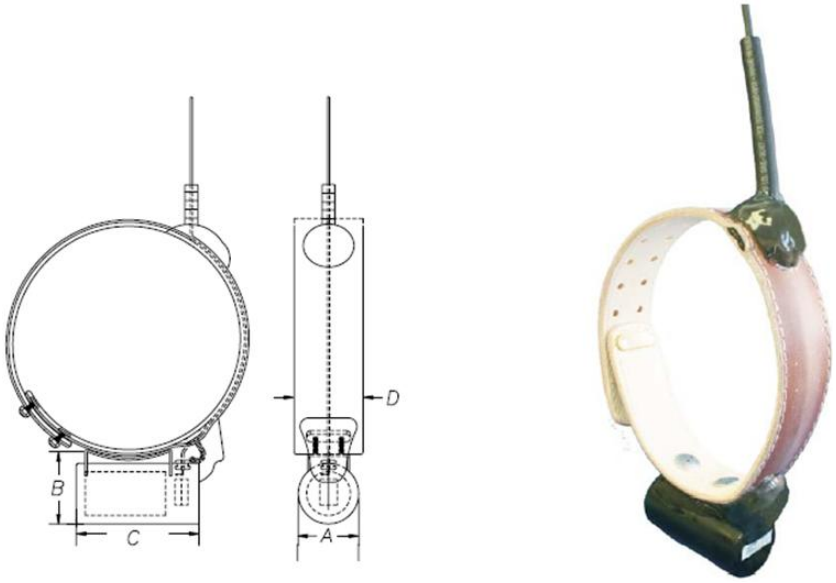


Figure 16. Example Whip Collar Antenna(Advanced Telemetry Systems)

Pros

- Antenna is easily made
- Very inexpensive
- Very flexible around the neck of the bear
- Does not protrude out of the collar
- Can match the impedance with discrete components

Cons

- Antenna is not shielded properly and will also accept a lot of noise
- The curvature of the antenna will not allow for the ground plane to be perpendicular to the antenna and possibly allow interesting results
- Research has shown that the ground plane should be several wavelengths long to produce a stable impedance input

3.4.2. ½ Wavelength Whip Antenna

This antenna is very similar to the ¼ wavelength, except it will have a much longer physical length. This increase in length will also allow a higher antenna gain. The increase in length will also be more cumbersome for the bear to fit in the collar.

Pros

- Antenna is easily made
- Very inexpensive
- Very flexible around the neck of the bear
- Has a high antenna gain compared to the ¼ wavelength antenna
- Can match the impedance with discrete components

Cons

- Antenna will protrude out of collar and be subject to damage by the bears
- Antenna is not shielded properly and will also accept a lot of noise
- The curvature of the antenna will not allow for the ground plane to be perpendicular to the antenna and possibly allow interesting results
- Research has shown that the ground plane should be several wavelengths long to produce a stable impedance input

3.4.3. Sleeve Dipole Antenna

The sleeve dipole antenna is the solution to the unwanted noise possibilities involved in an unshielded whip antenna. A conductive sleeve surrounds the coaxial transmission line for a certain portion of the antenna. The conductive sleeve then connects to the outer shell of the coaxial transmission line and the inner conductor continues as the antenna.

The length of outer conductor, diameter of the conductor, and type of dielectric in between the coaxial transmission line and this conductor all affect the antenna. This sleeve works to filter out unwanted frequencies.

The sleeve dipole antennas available have mostly a hard metal sleeves which make it difficult to wrap around the neck of the bear. Also, the researched designs include the total length to be around ½ wavelength, which is difficult to keep contained inside of the collar.

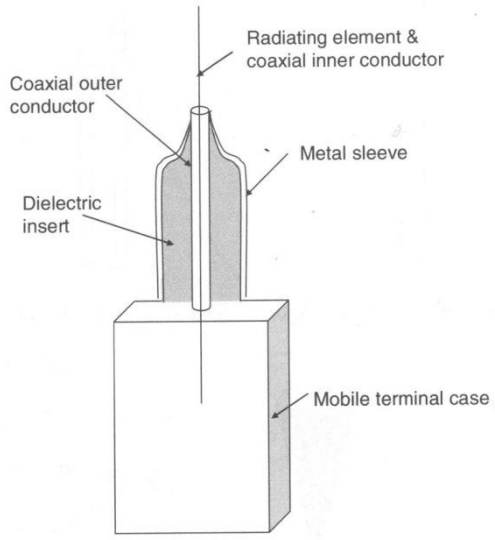


Figure 17. Sleeve Dipole Antenna(Saunders and Aragon-Zavala)

Pros

- Antenna is inexpensive
- More reliable impedance matching than alternative antennas
- Coaxial transmission line will give more accurate results
- Has a high antenna gain compared to the ¼ wavelength antenna

Cons

- Antenna will protrude out of collar and be subject to damage by the bears
- The curvature of the antenna will not allow for the ground plane to be perpendicular to the antenna and possibly allow interesting results
- Antenna is difficult to make and more expensive than alternatives
- Antenna sleeve length and style is difficult to measure and calculate

3.4.4. Normal Mode Helical Antenna

A helical antenna is a coiled antenna that allows the antenna size to be compressed. The electrical length of the antenna is still half wavelength, but the physical length of the antenna is much less than that. This antenna in the normal mode will radiate out normal to the axis of the antenna. It operates in normal mode when the diameter of the antenna is much less than that of the wavelength of the receive signal.

This antenna would be incorporated into the collar and possibly directly into the unit itself. It would be difficult to keep the antenna oriented in the correct direction due to its size.

Pros

- Antenna is inexpensive
- Size is much smaller than other antennas
- Has a high antenna gain compared to the ¼ wavelength antenna
- Impedance can be matched using discrete components

Cons

- The ground plane will not be directly perpendicular to the antenna which may lead to interesting results
- Antenna is not available in size from a manufacturer
- Difficult to manufacture uniform antennas for collars
- Difficult to orient antenna on collar for maximum reception

3.4.5. Rotating Directional Antenna

The previous antennas have been designed for use on the collar. The following antennas will be of use on the router unit. These antennas will need to have much higher gain and therefore will not be omnidirectional. The directional antenna allows there to be higher gain over a more condensed area, yet it is necessary to receive signals from all directions as bear can be traveling at any position.

One option is to build a highly directional antenna and have it rotate to pick up signals in all directions using a small motor. This would allow there to only be one antenna on the router with high gain and it would receive from all directions horizontally.

Pros

- Antenna is very directional and has high gain
- There will be less antenna components than other router antennas

Cons

- The motor will allow for more possibilities of mechanical failure
- The motor will consume battery
- The rotation of the antenna may possibly miss signals when they are sent

3.4.6. Helical Antenna Array

Instead of a rotating antenna, several directional antennas can be set up with their antennas connected in parallel. One simple directional antenna is a helical antenna. Above the helical antenna was used in normal mode as a possible collar antenna. Here the helical antenna will be used in axial mode because the diameter of the loops (shown as variable D in Figure 18) will be much larger than the wave length of the transmitted signal.

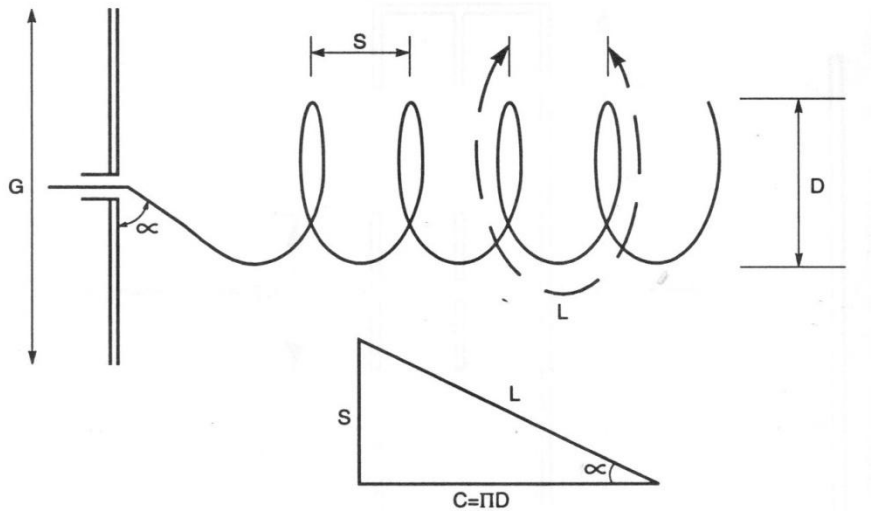


Figure 18. Helical Antenna (Burberry)

The radiation pattern for each instance of the helical antenna will overlap so that in all directions horizontally there is a high gain pattern. Typical gains for Axial Mode Helical antennas are between 10 and 15 dB compared to an isotopic radiator. The radiation pattern is very narrow which will contribute to several antennas necessary for the array.

Pros

- Antenna is relatively inexpensive and can be hand made
- Has a very high gain up to 15 dB
- Impedance can be matched using discrete components

Cons

- The antenna has a very narrow aperture and will require several antennae to build an effective array
- The axial mode antenna are difficult to support especially in harsh climate

3.4.7. Yagi Antenna Array

An antenna array can be made similar to the helical antenna described above, but it can be made with a Yagi antenna. A Yagi antenna consists of a simple dipole antenna, along with several conducting directing elements and a reflecting element. The Yagi antenna can vary in gain based on the length of the elements and the number of elements, but Yagi antennae consistently can have gains for 8 to 11 dB. More antenna elements will increase gain, but also decrease directivity, resulting in more antennas necessary to cover the pattern (Burberry).

The Yagi Antenna can be constructed out of very simple materials including conducting rods and PVC or other plastic tubing. Below is an example of a Yagi antenna.

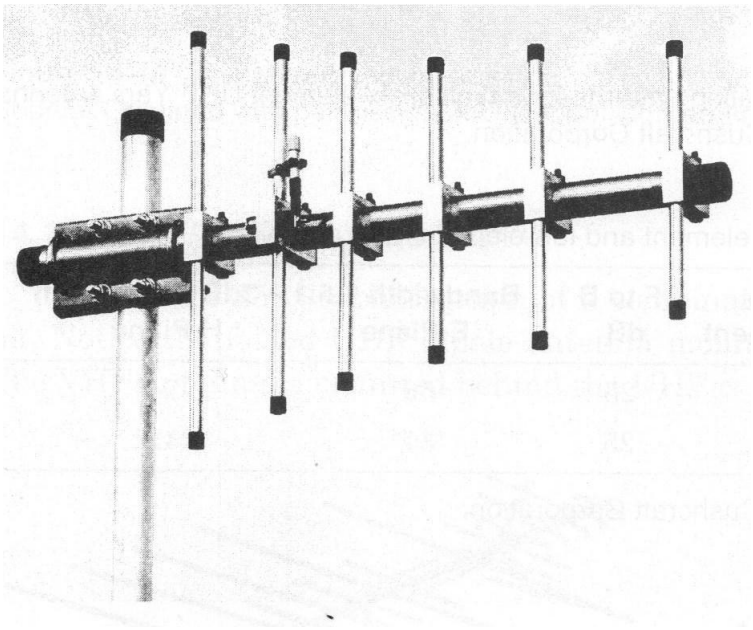


Figure 19. Six Element Yagi Antenna(Setian)

Pros

- Antenna is inexpensive.
- Antenna can be easily constructed.
- Gain is higher than most antennas, can be as high as 11 dB.
- Antenna will withstand the harsh environmental conditions.
- Impedance can be matched using discrete components

Cons

- High gain is achieved at the cost of directivity.
- Antenna may consist of several different components.

3.4.8. Detailed Design

The bear communication solution will consist of a ¼ wavelength whip antenna and a Yagi antenna array solution.

The ¼ wavelength antenna will constructed from a coaxial cable with the outer casing stripped back. The inner wire left exposed will be equal to approximately ¼ wavelength of the transmitted signal. The coax can be then directly mounted to the PCB with the appropriate connector. The PCB will need to be a 4 layer board in order to receive the necessary grounding capabilities for the best antenna performance.

The router antenna will be the Yagi antenna because of its easy of construction and ability to better withstand the elements than the axial mode helical antenna. There will be three or more element Yagi antennas and just as many separate antennas in the system in order for the antenna to view all directions.

Using the link budget equation at the beginning of this section we can determine the amount of power that will be delivered to the router from a bear.

$$P_R = P_T G_T G_R \left(\frac{\lambda}{4\pi R}\right)^2$$

In the system that we will use, the PT will be equal to 1 Watt. The GT is the gain of the ideal omnidirectional whip antenna, which by definition is 1. The GR is the gain of the router antenna, which we will estimate to be 10 dB or a numerical gain of 3.2. The wavelength at 217 MHz is 1.38 meters. We will assume that the distance needed to transmit is about 8 km. A compensation factor of ½ is placed in the equation as well to account for terrain and tree obstructions.

$$P_R = \frac{1}{2} * 1Watt * 1 * 3.2 * \left(\frac{1.38m}{4\pi * 8000m}\right)^2$$

$$P_R = 3.01E^{-10}\ Watts$$

At the baud rate of the system, the receiver can sense at levels down to -130 dBm or 1E-16 Watts. The received power, even with the compensation factor, is much above the transceiver's ability to receive.

Wireless network propagation simulation software called Radio Mobile is available free online and used by many amateur network designers to test the connections and transmission characteristics of the wireless signals. This software uses a model for radio propagation called the Longley-Rice model. The software allows land cover and elevation data to be mapped in the system and simulate the actual terrain for the devices.

The area of land that the bears will travel, between Ely and Tower, Minnesota is loaded into the program along with the characteristics for the router antenna and the collar antenna. The calculated radiation pattern, antenna gain, line loss, transmission power, and antenna sensitivity all factor in to the outcome of this model. Figure 20 below shows the map of the terrain and then three units. Two of the units are to simulate bears, and the third unit will simulate the router. In Figure 21 you can see the Router unit transmit its signal and you can see that in this simulation, the coverage of one router unit nearly covers the entire area at one watt of transmission.

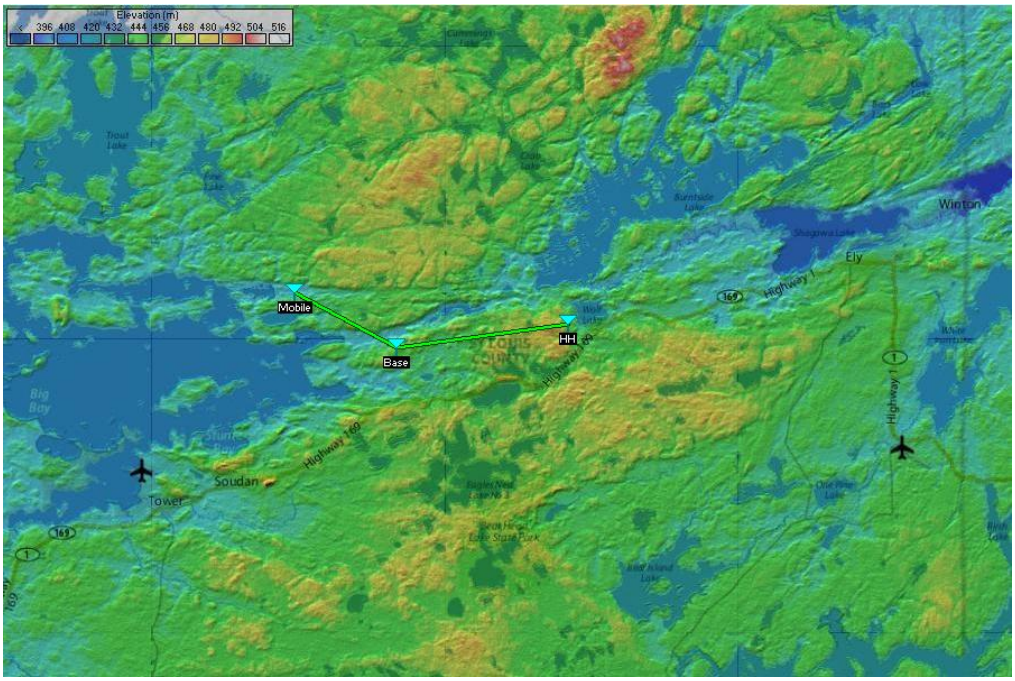


Figure 20. Radio Mobile Area of Concern

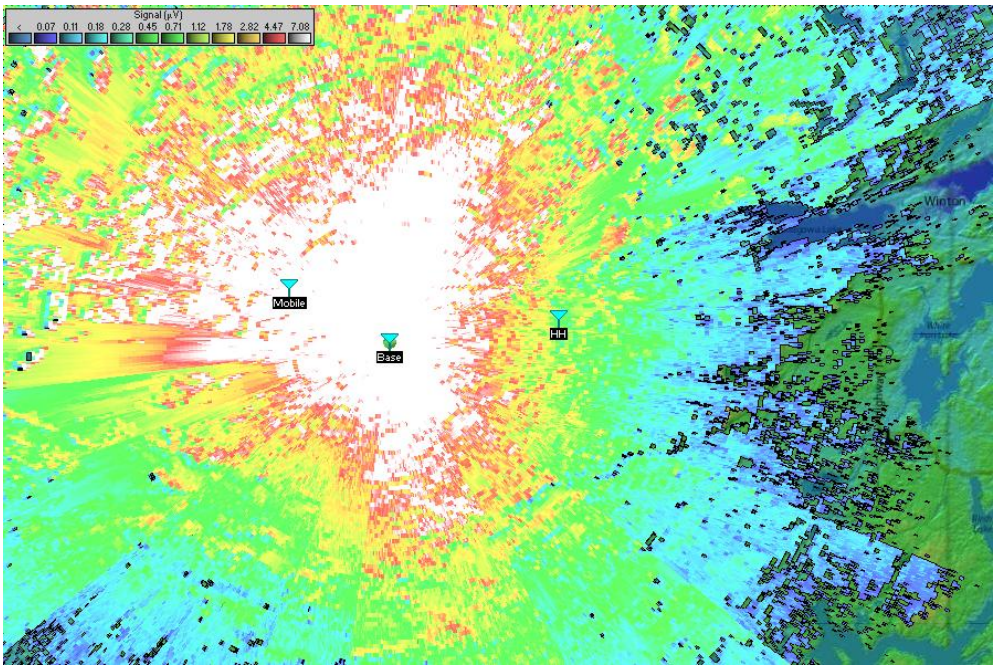


Figure 21. Radio Mobile Router Station Propagation

3.5.GPS Module

The GPS Module chosen was the Ublox NEO-5Q. This was chosen because of its 'kickstart' weak signal acquisition technology, its compatible I2C interface, its package size, its low power modes, and lower cost due to Digi buying in bulk.

Other modules were considered including the Trimble Copernicus and Trimble Condor. Neither the Copernicus nor the Condor had an I2C interface, and both were larger packages than the Ublox. The Trimble units did, however, trump the Ublox module in accuracy, update frequency, tracking mode power consumption. These features were only slightly better than the Ublox, and thus expendable. Overall, the Ublox NEO-5Q was a much more suitable choice.

3.6.GPS Antenna

Unlike the VHF antenna, only one GPS antenna solution is necessary. While both bear collars and routers will require GPS antennas, the each will be receiving GPS information in similar conditions and restrictions.

The antenna will:

- Receive GPS data through thick cover of forestry
- Appropriate sizing constraint to fit inside device casing
- Low cost
- Durable in conditions seen in Northern Minnesota

3.6.1. GPS Helix Antenna

A GPS helix antenna provides the best performance out of all GPS antennas. This is especially true when tracking satellites near the horizon when the GPS antenna is facing up into the sky. Unfortunately, in order to get this type of performance, the helix antenna requires a large amount of space to get the correct wavelength for GPS signals. In our case, the size required and space it takes up exceeds what we are hoping to fit inside of our case. The base of the helix antenna is greater than 40 centimeters in length, the circumference of the helix antenna is 19 centimeters, and the height is nearly 40 centimeters as well. While one of these would be simple enough for us to build ourselves, the sizing of the unit exceeds our devices sizing constraint. (Gulley)

3.6.2. Passive GPS Patch Antenna

In an effort to try to keep costs low, the next possibility for a GPS antenna was the passive GPS patch antenna. With this solution, we could either design and build our own again, or buy one from another manufacturer. The advantage of the passive GPS patch antenna is that no additional power is used in locating and getting a fix on GPS satellites. The disadvantage of a passive antenna versus an active antenna is that it can take longer to find the GPS satellites, requiring the device to be powered on longer and therefore using more power anyway.

While a passive GPS patch antenna would be simple to design and print on to a printed circuit board, it requires a larger size because the dielectric material is air. Most manufacturers use a different dielectric material in order to reduce the size of the antenna. Therefore it would be beneficial to use a manufactured GPS antenna unit rather than an antenna we would build ourselves. The cost of purchasing an antenna is less than $15 per unit. Going with a purchased unit would also save time and money invested in creating a do-it-yourself type of antenna. (Mehaffey)

3.6.3. Active GPS Patch Antenna

Since a manufactured passive GPS patch antenna was already being considered, we also looked at purchasing an active GPS patch antenna. Research showed that active GPS antennas have the same physical dimensions as passive GPS antennas. Even with this same size, since they are powered they can locate satellites quicker than their passive counterparts. They can also track satellites better through the dense forestry that the bears in Northern Minnesota habitat. Even with the advantages of the active GPS patch antenna, the cost is the same as the passive GPS patch antenna; also less than $15 per unit.

3.6.4. Detailed Design

The active GPS patch antenna was chosen because of its theoretical ability to receive GPS satellite signals through the dense foliage cover in the Northern Minnesota forestry. Also it will be cheaper and less time consuming to purchase an antenna rather than researching, designing, and building our own antenna. Taoglas is a reputable GPS patch antenna manufacturer, which produces both active and passive GPS antennas. After communicating with a representative of the company, it was determined that the Taoglas AP25b would be the best antenna for our device. This antenna is only 35 millimeters square, with a thickness of 4.5 millimeters. It also has a gain of 16 dB. This antenna also comes with a coaxial cable connection. This will be able to connect directly to a connection on the GPS chip that we will include.

3.7.Microcontroller

Several types of controllers were considered, but PIC was chosen over others such as Atmel or a processor because of the great combination of versatility and ease of use.

The microcontroller chosen was the PIC18F46J11. This basis for this choice was its low power features, multiple communication ports, large program memory, I/O count, and price. It is an 8-bit microcontroller of the PIC18 family. 16-bit and 32-bit controllers were considered, but it was found that 8-bit would be sufficient. Choosing 8-bit restricted the choices to the PIC 10, 12, 16, and 18 families. There were several controllers among these families that suited the needs of the application, but there were limited availabilities. The controllers that were best suited and readily available were among the PIC18 family. The PIC18F46J11 was found to meet all essential needs with the exception of EEPROM. This was compensated for by selecting an external EEPROM chip 24FC512, manufactured by Microchip.

C programming was chosen again due to versatility and ease of use. There are other easier languages to use such as PICBASIC, but it would limit the functionality of the controller as well as efficiency. There are more efficient, low-level languages that could have been chosen, such as assembly, but using this would complicate the programs needed to be written far too greatly.

3.8.Chassis

The chassis took into account a number of parameters in choosing the optimal solution. The chassis needs to be able to withstand the rugged environment (i.e. shock and vibe, waterproof, temperature) as well as the bears themselves. We were informed that the bear cubs tend to chew on the collars during the hibernation time. Therefore, we needed an encapsulation that was small enough but could still endure the effects of its use as well as one that could contain circuitry without having any effect on the circuit's performance.

3.8.1. Commercial Cases

These plastic cases are meant to hold cell phones, wallets, and cameras. Their focus is for personal use for protection of the users valuables.

Pros

- Waterproof
- Crushproof
- Buoyant Case
- Environmentally friendly
- Cheap

Cons

- Dimensions and layout aren't customizable.
- Simple latch for closing

3.8.2. Industrial Cases

These polycarbonate cases meet industry standards and are meant for housing electronics.

Pros

- Waterproof
- Buoyant case
- Customizable shape and layout.
- Premade cases
- Environmentally friendly.
- Cheap

Cons

- Unknown lead time if customized design

3.8.3. Detailed Design

The industrial cases were chosen because of their required fulfillment of industry standards. The cases meet National Electrical Manufacturers Association (NEMA) standards 1, 2, 4, 4x, 12, and 13. These standards are shown in Table 4.

Standard	Description
NEMA 1	Enclosures constructed for indoor use to provide a degree of protection to personnel against incidental contact with the enclosed equipment and to provide a degree of protection against falling dirt.
NEMA 2	Same as NEMA 1 including protection against dripping and light splashing of liquids.
NEMA 4	Enclosures constructed for either indoor or outdoor use to provide a degree of protection to personnel against incidental contact with the enclosed equipment; to provide a degree of protection against falling dirt, rain, sleet, snow, windblown dust, splashing water, and hose-directed water; and that will be undamaged by the external formation of ice on the enclosure.
NEMA 4X	Same as NEMA 4 including protection against corrosion.
NEMA 12	Enclosures constructed (without knockouts) for indoor use to provide a degree of protection to personnel against incidental contact with the enclosed equipment; to provide a degree of protection against falling dirt; against circulating dust, lint, fibers, and flyings; and against dripping and light splashing of liquids.
NEMA 13	Enclosures constructed for indoor use to provide a degree of protection to personnel against incidental contact with the enclosed equipment; to provide a degree of protection against falling dirt; against circulating dust, lint, fibers, and flyings; and against the spraying, splashing, and seepage of water, oil, and non-corrosive coolants.

Table 4: Nema Case Standards (Computer Dynamics)

These cases can also be equipped with heavy duty waterproof prevention options. This will ensure no intrusion of water. Also, because they are composed of polycarbonate they have a very high tolerance to impact and wear over time.

3.9.Power Supply Circuitry

The power supply section will take the power from the battery and allow it to be readily available to all components in the system at the power allowances necessary. Table 5 shows the components in the unit and the power requirements for each of these components.

Component	Maximum Required Current	Required Voltage
PIC microcontroller	15 mA	3.3 V
UBLOX GPS Module	80 mA	3.3 V
Analog Devices Transceiver	23.5 mA	3.3 V
Power Amplifier	330 mA	5 V

Table 5: Power Requirements

Essentially, after much research it was decided that four AA batteries would serve as the input to three high efficiency buck converters. These step-down regulators would be used to provide the 5V and two 3.3V power lines. A tap directly on the 6V output would be stepped down with a voltage divider whose output would serve as the input to an A/D converter on the PIC18F46J11. This voltage tap would provide for low-battery detection.

Several voltage regulators were considered for the power supply circuitry. This subsection will describe the different types and models considered as well as the chosen solution.

3.9.1. Linear Regulators

Initially, linear regulators were considered. Specifically, the LM317 was the linear regulator of choice. This regulator provided the required current, allowed for a large input voltage range, was adjustable for a large output voltage range, and was readily available. It was unfortunately very inefficient and thus dismissed as an option.

Figure 22. LM317

3.9.2. Switching Regulators

In researching more efficient regulators, it was found that switching regulators should be used in our design. Several regulators of this type were considered.

The first considered was the LM2717. This device was very suitable as its current output was beyond the requirement, it had a dual output such that 3.3V and 5V could be obtained on the same chip, and separate shutdown pins were available. Unfortunately, the input voltage needed to meet our current output was not sufficient.

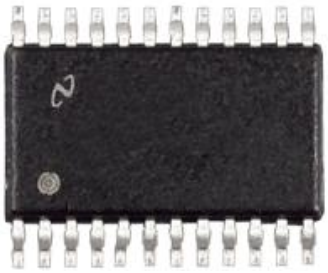


Figure 23. LM2717

The second considered was the MAX863. This device also gave very high output current capabilities, a dual output of 3.3V and 5V were available on the same chip, separate shutdown pins were available, and even a low-battery detect pin was provided. The input voltage needed to meet our current output requirement was again the problem the downfall of this part, as well as the lack of availability.

Figure 24. MAX863

The third and chosen solution was the ADP3050 series. These step-down buck converters are available in 3.3V and 5.0V fixed outputs which are both used in the design. Both permit very wide input rages, separate shutdown pins were available, and the input voltage allowed current outputs well above the requirement. These devices also required very little external circuitry and are readily available, unlike the previously considered.

Figure 25. ADP3050

3.9.3. Detailed Design

The chosen design is based around an ADP3050 step-down buck converter. Three of these are used, one for the 5V output and two for the 3.3V output.

3.9.3.1. General Circuit

The circuit to be used with the ADP3050 is the fixed output version. The applications information suggests the following circuit. This general circuit will be used in the design but the specific values shown below in Figure 26 are not necessarily the same.

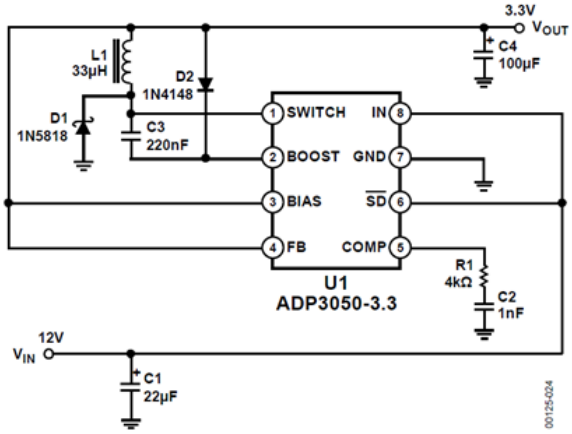


Figure 26. ADP3050 General Circuit

3.9.3.2. Switching Inductor and Output Capacitor Choice for GPS Unit

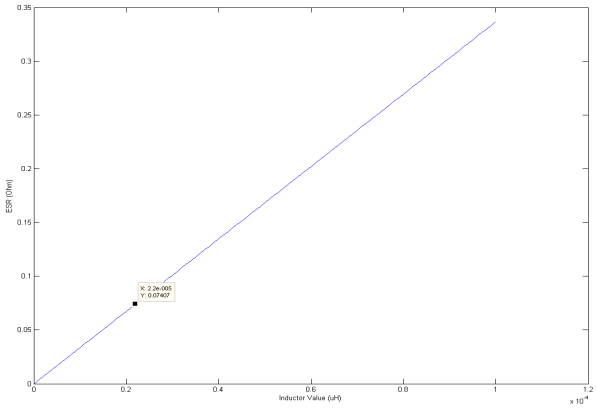
The GPS unit requires an input of 3.3V with a maximum ripple voltage of 50mVPP. Thus, the switching regulator must be designed to meet these conditions. To be safe, the regulator was designed such that the output ripple voltage is 25mVPP. For the ADP3050, the output Vripple depends on the inductor value chosen as well as the ESR of the output capacitor. The equations for this are the following:

$$\text{Vripple} \approx \text{ESR} \times \frac{\text{Vin} - \text{Vout}}{\text{L}} \times \frac{1}{\text{fsw}} \times \frac{\text{Vout}}{\text{Vin}}$$

$$\text{Iripple} \approx \frac{\text{Vin} - \text{Vout}}{\text{L}} \times \frac{1}{\text{fsw}} \times \frac{\text{Vout}}{\text{Vin}}$$

where L is the inductor value chosen, Vin is the input voltage, Vout is the output voltage, fsw is the switching frequency (fixed at 200kHz for this device), ESR is the effective series resistance, Vripple is the output ripple voltage, and Iripple is the output current ripple.

For the 3.3V step-down design, the input voltage is 1.5V*4 = 6V, the output voltage is 3.3V, and the switching frequency is 200kHz. Using MATLAB, the ESR of the output capacitor was plotted as a function of inductor choice. The code and output are below in Figure 27.




```
Vin = 6;
fsw = 200e3;
L = [0:1e-6:100e-6];
Vout33 = 3.3;
Iripple33 = ((Vin -
Vout33)./L).*(1/fsw).*(Vout33/Vin);
ESR33 = 25e-3./Iripple33;
plot(L,ESR33)
xlabel('Inductor Value (uH)'),
ylabel('ESR (Ohm)')
```

Figure 27. 3.3V ESR Calculations

From the graph above, it is shown that selecting a 22uH inductor will result in the choice of capacitor having an ESR of about 74mΩ. After much research it was found that the best choices were a 22uH inductor and a 100uF tantalum capacitor with 75mΩ ESR. Using these values, the new Vripple is:

$$\text{Vripple} \approx 75\text{m}\Omega \times \frac{6-3.3}{22\text{uH}} \times \frac{1}{200\text{kHz}} \times \frac{3.3}{6} = 25.3\text{mVpp}$$

The inductor chosen must be able to handle the proper current draw. The 3.3V supply is estimated to draw between 250mA and 300mA. For worst-case scenario, we will assume the regulator draws 120mA. According to the ADP3050 datasheet, the inductor must be able to handle 20% more than the peak switching current. The calculations for this are shown below.

$$\text{Isw(pk)} = \text{Iout(max)} + \frac{1}{2}\text{Iripple} = 120\text{mA} + 0.5 \times 337.5\text{mA} = 0.28875\text{A}$$

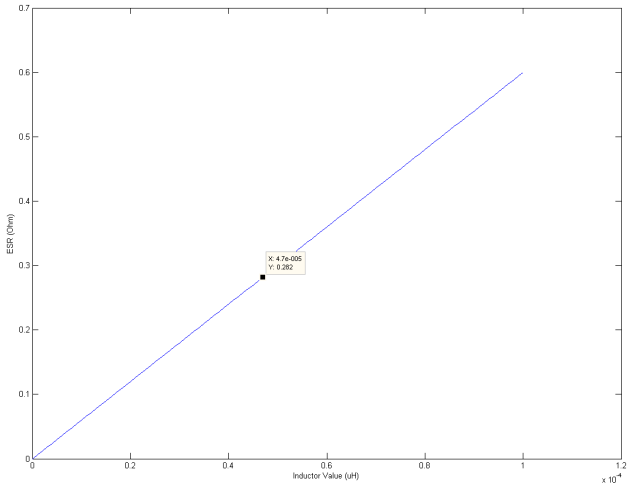
$$1.20 \times \text{Isw(pk)} = 1.20 \times 0.28875 = 0.3465\text{A}$$

where Isw(pk) is the peak swing current, Iout(max) is the expected maximum output current, and Iripple is the output ripple current. After much research, it was found that a 22uH inductor with 350mA current rating was sufficient.

The values for the passive components calculated above will be used for both 3.3V regulators.

3.9.3.3. Switching Inductor and Output Capacitor Choice for PA

The power amplifier requires an input of 5V without a specified maximum ripple voltage. For consistency, a maximum ripple voltage of 25mVPP. Thus, the switching regulator must be designed to meet these conditions. The equations used previously are repeated, and the MATLAB plot was redone using the output voltage of 5V. The code and output for this is shown below in Figure 28.




```
Vin = 6;
fsw = 200e3;
L = [0:1e-6:100e-6];
Vout5 = 5;
Iripple5 = ((Vin -
Vout5)./L).*(1/fsw).*(Vout5/Vin);
ESR5 = 25e-3./Iripple5;

plot(L,ESR5)
xlabel('Inductor Value (uH)'),
ylabel('ESR (Ohm)')
```

Figure 28. 5V ESR Calculations

From the graph above, it is shown that selecting a 47uH inductor will result in the choice of capacitor having an ESR of about 282mΩ. After much research it was found that the best choices were a 47uH inductor and a 47uF tantalum capacitor with 300mΩ ESR.

The inductor chosen must be able to handle the proper current draw. The 5V supply is estimated to draw up to 330mA. For worst-case scenario, we will assume the regulator draws 120mA. According to the ADP3050 datasheet, the inductor must be able to handle 20% more than the peak switching current. The calculations for this are shown below.

$$\mathrm{Isw(pk)} = \mathrm{Iout(max)} + \frac{1}{2}\mathrm{Iripple} = 330\mathrm{mA} + 0.5 \times 337.5\mathrm{mA} = 0.49875\mathrm{A}$$

$$1.20 \times \mathrm{Isw(pk)} = 1.20 \times 0.49875 = 0.5985\mathrm{A}$$

where Isw(pk) is the peak swing current, Iout(max) is the expected maximum output current, and Iripple is the output ripple current. After much research, it was found that a 47uH inductor with 600mA current rating was sufficient.

3.9.3.4. Final Power Circuit

As stated before, three regulators provide three different power lines. The +3.3V ALWAYS line powers the Microchip PIC18F46J11 as well as the backup voltage for the GPS unit. This line should never be shut off. The +3.3V line powers the GPS unit. This can be shut off by the PIC when the GPS unit is not in use. The +5V line powers

the power amplifier of the VHF transceiver. This can also be shut off when the power amplifier is not in use. The resistor divider at the bottom steps down the input to 3V so that the PIC's A/D can monitor the voltage. When the voltage gets below 2.8V (which means the input voltage dropped to 5.6V), the PIC will detect a low battery. This value was chosen based on the ADP3050 datasheet. It specifies that the 5V regulator will not supply the required current below a 5.5V input.

3.10. Battery

The choice for battery had a lot of things to consider. It must be able to withstand the harsh environment of the Minnesota woodlands, both terrain and climate. In addition, it must be able to last at least 3 months without a replacement. Finally, it must be able to deliver the required voltage to power the components.

3.10.1. Nickel Metal Hydride (NiMH)

The Nickel Metal Hydride battery is composed of a hydrogen-absorbing alloy for the negative electrode.

Pros

- High capacity.
- Many recharge cycles.
- Very good performance in high-drain devices.

Cons

- High self-discharge rate.
- Does not function well at low temperatures.
- Memory effect.

3.10.2. Lithium Ion (Li-ion)

A lithium ion battery is composed of a lithium anode and a carbon cathode.

Pros

- Much lighter than other batteries.
- No memory effect.
- High capacity.
- Very good performance in high-drain devices.
- Very slow self-discharge rate.
- Function better than other types at extreme temperatures.
- Capable of withstanding environmental effects
- Environmentally friendly.

Cons

- More expensive than other types
- Lower shelf life than other types
- Due to high capacity, can be hazardous if short circuited

3.10.3. Detailed Design

Because environmental conditions are a huge part of the project, we decided to go with the Li-ion battery because it has much better performance at low temperatures. Regardless of the chosen solution, there were tradeoffs. The higher quality battery will be more expensive; overall this will be more beneficial because of the longevity they have over the alternatives.

4. Implementation

The second semester of the project, two PCB's were designed, populated, and tested. Our team narrowed our focus to the hardware development and low-level programming, leaving high level networking protocols to be implemented in the future. The following section defines the implementation of the hardware and software used in the project.

4.1.Hardware

This section describes the assembly and implementation of the hardware, including design changes. The basic hardware includes two populated PCB's, two VHF antennas, one GPS antenna, the USB interconnect, and the power cables.

4.1.1. Printed Circuit Board Layout

The PCB layout was done using Cadence Layout Plus. Each component on our board has an associated footprint. Most of the footprints were included in the standard library but some of the footprints had to be created manually. Because of budget constraints, we designed a two layer PCB. For testing purposes, we kept all components on the top side of the PCB and included extra test points and connectors.

The general strategy for the layout was to keep the VHF and GPS portions as far apart as possible. Figure 29 shows the general layout structure of our board. Because RF performance greatly depends on the ground plane, the PCB board has copper pour everywhere on the board that does not have any components or traces; these areas are on both the top and bottom layer of the PCB. To try to keep away from breaking up the ground plane with traces, we alternated between the top and bottom layer on longer length traces.

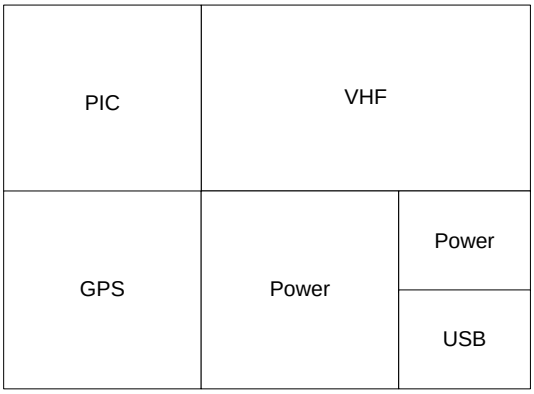


Figure 29: PCB Layout Structure

When starting the layout, the most attention was put on the RF portions of the VHF and GPS section. The reason for this is because adding more traces changes the characteristic impedances of the circuit which will result in the parts not being matched to 50 ohms. It should be noted that on the VHF portion, we had to create two transmission lines because we were not able to keep transceiver and RF switch as close as possible. Using Advanced Design System's (ADS) LineCalc and the characteristic of our PCB as shown in Table 6, we were able to calculate that a 50 ohm transmission line had a width of 109 mils.

PCB Material	FR4
H	64 mils
Er	4.8
Mur	1
Cond	$5.8x10^{7}$
Hu	$3.9x10^{14}$
T	1.4 mils

Table 6: PCB Characteristics

Once we had the RF portions layout using the least amount of traces, we laid out the rest of the PCB trying to make the board as compact as possible and avoid breaking up the ground plane. Plated through holes were also added at various areas to connect the top and bottom ground planes. We also kept all the external connecters on the same side. Copper areas were used on each of the three buck converters to help with dissipating heat. Using the large copper areas was suggested by the manufacturer. The transceiver and power amplifier both have ground planes underneath of their packages which are used for RF performance along with helping dissipate heat. We used copper areas to make these connections. Once we had the layout done, we used Advanced Circuits (www.4pcb.com/) to manufacture our circuit board because they have a special offer where we can build our boards for $33 each with no minimum quantity.

It should be noted that after we made these boards, we realized that we inadvertently did not add the solder mask layer for the power amplifier's and transceiver's ground pad. The revision A PCB layout has this fixed. Also, the crystal was bigger than the package outline. However, in the new design, the current crystal is not being used. Another consideration in changing the layout is with the inductance of L10. By changing the

lengths of the traces from L10 to the transceiver's pins 44 and 46, the inductance value of L10 may need adjustment (See Section 4.2.1)

4.1.2. Populated Board

All parts were ordered and soldered onto the board as shown in Figure 30.

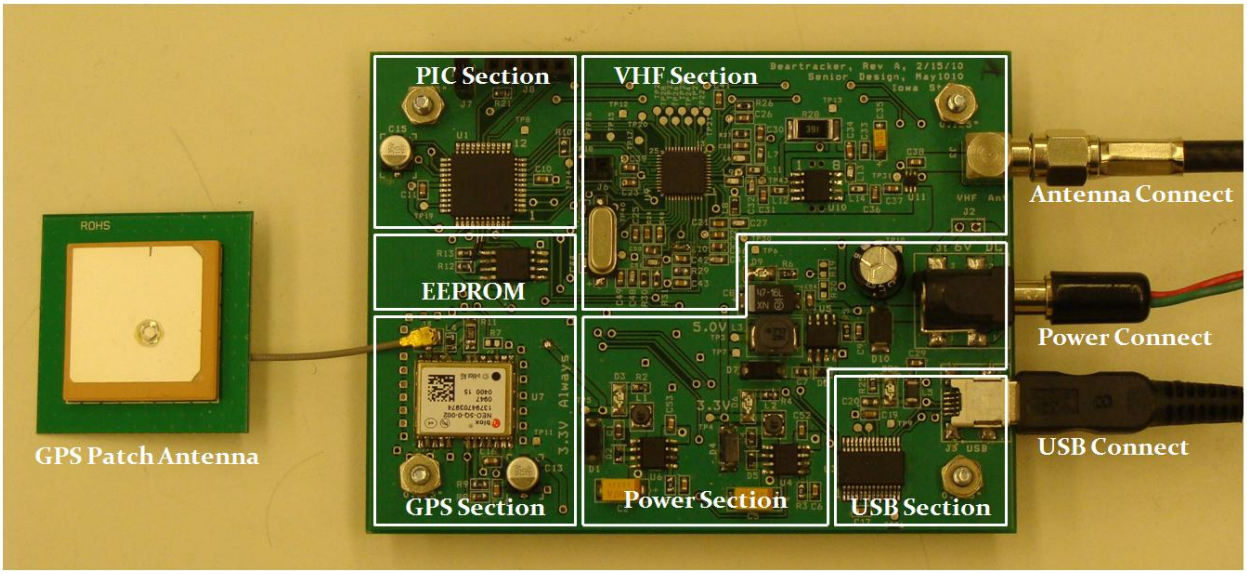


Figure 30: Populated Printed Circuit Board

4.1.3. ADF-7021 Register Configuration

The ADF-7021 uses registers to configure it in either transmit or receive mode. There is a sequence to follow to configure the transceiver in transmit or receive mode which can be seen in Figure 9 and Figure 10.

It should be noted that a lot of these values are based on the current hardware, Revision A. If the crystal oscillator is changed to a voltage controlled oscillator with a better frequency accuracy as suggested, the register values will change.

4.1.3.1. Transmit Mode

The following steps show the order for configuring the transceiver in transmit mode.

1. Set VHF_CE High
   Setting the VHF_CE high turns on the transceiver.

2. Wait around 1.1 ms
   This required delayed is necessary to allow the power regulators to power up. VHF_MUXOUT will be asserted high when the regulators are ready.

3. Write to Register 1- VCO/Oscillator Register

1	00	0011	0	1	11	00	1	0	0000	001	0001
External VCO, Yes	VCO Center, Nominal	VCO-Bias given from Table 9, 0.75mA	RF divide by 2, off	VCO Enable, ON	CP-Current, Set to 2.1 mA	XTAL Bias, 20uA, higher current, faster power up	XOSC Enable, Yes using external crystal	XTAL Doubler, NO	Clock out divide, off	R-Counter, Set to 1	Address bits

Table 7: TX Register 1 value

The phase frequency detector (PFD) is given by the following formula based on whether the RF divide by 2 is on or off.

If XTAL_DOUBLER = 0,

$$PFD = \frac{XTAL}{R\_COUNTER}$$

If XTAL_DOUBLER =1,

$$PFD = \frac{XTAL \times 2}{R\_COUNTER}$$

(Analog Devices)

Maximizing the PFD frequency reduces the N value which will reduce the noise multiplied at a rate of $20\log_{10}(N)$. The PFD frequency is used in the carrier frequency and frequency modulation. Analog software, ADIsimSRD, also gave a lot of the values needed based on our configuration, ADIsimSRD also suggested a PDF frequency of 4.032 MHz.

The charge pump current was set to the highest value to have the fastest charge rate.

4. Wait at least 0.7 ms
5. Write to Register 3- Transmit/Receive Clock Register

00 1010	0010 1000	1101 0010	0010	00	0011
AGC-CLK-Divide, 10	SEQ-CLK-Divide, 40	CDR-Clk-Divide, 210	DEM-CLK-Divide, 2	BBOS Clk Divide, 4	Address

Table 8: TX Register 3 value

Baseband offset clock frequency (BBOS CLK) must be greater than 1 MHz and less than 2 MHz where BBOS CLK is given by the following equation where BBOS_CLK_Divide equal to 4 gave us the desired frequency.

$$\frac{XTAL\_Frequency}{BBOS\_CLK\_Divide} = \frac{4.032MHz}{4} = 1.008MHz$$

The demodulation clock needed to be set between 2 MHz and 15 MHz. The demodulation clock is given by the following equation where a value of 2 gave us the desired frequency.

$$\frac{XTAL\_Frequency}{DEMOD\_CLK\_Divide} = \frac{4.032MHz}{2} = 2.016MHz$$

For 2FSK, the data/clock recovery frequency (CDR CLK) needs to be within 2% of 32 times the data rate. In our case, the data rate was 300 bits/sec given a CDR CLK of 9.6 kHz. The CDR CLK is given by the following equation where CDR_CLK_DIVIDE needs to be a value of 210.

$$\frac{DEMOD\_CLK}{CDR\_CLK\_Divide} = \frac{2.016MHz}{210} = 9.6kHz$$

Sequencer clock (SEQ CLK) supplies the clock to the digital receiver block and should be close to 100 kHz as possible. The SEQ CLK is given by the following equation with a value of SEQ_CLK_DIVIDE being 40 giving us the closest value to 100.

$$\frac{XTAL}{SEQ\_CLK\_Divide} = \frac{4.032MHz}{40} = 100.8kHz\,.$$

AGC step to settle is determined by the AGC update rate. It should be set close to 10 kHz. The AGC update rate is given by the following equation with a value of AGC_CLK_DIVIDE of 10 given us the closest value to 10 kHz.

$$\frac{SEQ\_CLK}{AGC\_CLK\_Divide} = \frac{100.8kHz}{10} = 10.08kHz$$

6. Write to Register 0- N Register

000	0	0	0011 0101	110 1010 0001 0100	0000
Muxout - Regulator Ready	UART Mode, No = 0	Tx/Rx, TX = 0	Integer-N, 53	Fractional-N, 27156	Address Bits

Table 9: TX Register 0 value

The RF output frequency is calculated by the following equations depending on if RF divide by 2 is set which in our case it is not set to be on.

For the direct output

$$RF_{OUT} = PFD \times \left(Integer\_N + \frac{Fractional\_N}{2^{15}} \right)$$

For the RF_DIVIDE_BY_2 (DB18) selected

$$RF_{OUT} = PFD \times 0.5 \times \left(Integer\_N + \frac{Fractional\_N}{2^{15}} \right)$$

(Analog Devices)

An Integer-N and Fractional-N value of 53 and 27,156 gives us the center frequency of 217.0375 MHz. It should be noted that a when the Fractional-N is used, spurs can appear on the VCO output spectrum at an offset frequency that corresponds to the difference frequency between an integer multiple of the reference frequency and the VCO frequency.

Muxout sets the output on the VHF_Muxout line. Muxout is a digital value and can indicate the different components shown in Table 10.

M3	M2	M1	MUXOUT
0	0	0	REGULATOR_READY (DEFAULT)
0	0	1	FILTER_CAL_COMPLETE
0	1	0	DIGITAL_LOCK_DETECT
0	1	1	RSSI_READY
1	0	0	Tx_Rx
1	0	1	LOGIC_ZERO
1	1	0	TRISTATE
1	1	1	LOGIC_ONE

Table 10: VHF Muxout Settings

7. Wait 40 us
8. Write to Register 2- Transmit Modulation Register

0	10	0 0100 1110	10 0100	11	011	0	000	0010
Raised Cosine Alpha, Default	Tx-Data-Invert, Inverted Data	Tx-F_{dev}, 78	PA output power, 36	PA-Bias, 11 uA	PA-Ramp, 64 codes/ bit	PA-Enable, Off = 0	Modulation Scheme, 2FSK	Address

Table 11: TX Register 2 value

If the power amplifier (PA) is enabled/disabled by PA_Enable, it ramps up at the programmed rate but turns off hard. If the PA is enabled/disabled by Tx/Rx (R0_DB27), it ramps up and down at the programmed rate. PA Ramp prevents spectral splattering or spurs in the output spectrum. By gradually ramping the PA on and off, PA transient spurs are minimized. Setting to 64 codes per bit which is approximately 1/300 = 3.33 ms ramp time. Less codes per bit causes a more gradual ramp.

PA Bias current is recommended to be 11 uA when power greater than 10 dBm is required.

The external power amplifier has a gain between 19 and 24 dB at our current frequency with a 1 db compression point of 29.5 dBm. The internal power amplifier is set by, writing the corresponding value seen in Table 12: PA output power into register two.

P6	.	.	P2	P1	PA LEVEL
0	.	.	0	0	0 (PA OFF)
0	.	.	0	1	1 (–16.0 dBm)
0	.	.	1	0	2
0	.	.	1	1	3
.	.	.	.	.	.
.	.	.	.	.	.
1	1	.	1	1	63 (13 dBm)

Table 12: PA output power

The estimated power output at the SMA connector can be given by the following equation.

Output Power in dBm = 0.467742*PA_Level + 0.7323 – Loss in Circuit in dBm

The output power should not exceed more than 29 dBm to avoid non-linearity.

The desired frequency deviation is 4.80 kHz. This frequency deviation allows us to stay in the 25 kHz channel and allows the spectrum output to drop off. This frequency deviation was also calculated by ADIsimSRD based on the channel width and the baud rate. The frequency deviation is given by the following formula from the datasheet.

$$Frequency\ Deviation\ [\text{Hz}] = \frac{Tx\_FREQUENCY\_DEVIATION \times PFD}{2^{16}}$$

(Analog Devices)

By setting TX_FREQUENCY_DEVIATION to 78, it gives us a frequency deviation of 4.798 kHz where PFD frequency is 4.032 MHz given in Register 1.

The data is set to be inverted because in receive mode the transceiver needs to be set to be inverted to correctly set the correlator. Thus, to have the PIC receive non-inverted data, we are inverting the data when we send it.

9. Wait at least 3.33 ms

10. Transmit Data
11. Wait 3.4 ms before power down
    The delay is needed because of bit latency as shown in Table 13. A latency of 1 bit means that 1/bit rate should be waited before powering down. In this case, it is 1/300 which is 3.33 ms.

Modulation	Latency
2FSK	1 bit
GFSK	4 bits
RC2FSK, Alpha = 0.5	5 bits
RC2FSK, Alpha = 0.7	4 bits

Table 13: TX Bit Latency

12. Set Register 0 - PA power down

000	0	1	0011 0101	110 1010 0001 0100	0000
Muxout - Regulator Ready	UART Mode, No = 0	Tx/Rx, RX = 1	Integer-N, 53	Fractional-N, 27156	Address Bits

Table 14: TX Register 0 power down value

    By switching TX/RX bit to 1, the power amplifier will ramp down which will minimize spectral splattering as explained in TX Register 2 description.

13. Wait at least 3.33 ms
    This delay allows time for the PA to power down.

14. Set VHF_CE to 0
    By setting VHF_CE to 0, it will turn off the transceiver.

4.1.3.2. Receive Mode

The following steps show the order for configuring the transceiver in receive mode.

1. Set VHF_CE High
   Setting the VHF_CE high turns on the transceiver.

2. Wait at least 1.1 ms
   This required delay is necessary to allow the power regulators to power up. VHF_MUXOUT will be asserted high when the regulators are ready.

3. Write to Register 1 - VCO/Oscillator Register

1	00	0011	0	1	11	00	1	0	0000	001	0001
External VCO, Yes	VCO Center, Nominal	VCO-Bias given from Table 9, 0.75mA	RF divide by 2, off	VCO Enable, ON	CP-Current, Set to 2.1 mA	XTAL Bias, 20uA, higher current, faster power up	XOSC Enable, Yes using external crystal	XTAL Doubler, NO	Clock out divide, off	R-Counter, Set to 1	Address bits

Table 15: RX Register 1 value

See Section 4.1.3.1: Transmit Mode for details.

4. Wait at least 0.7 ms
5. Write to Register 3- Transmit/Receive Clock Register

00 1010	0010 1000	1101 0010	0010	00	0011
AGC-CLK-Divide, 10	SEQ-CLK-Divide, 40	CDR-Clk-Divide, 210	DEM-CLK-Divide, 2	BBOS Clk Divide, 4	Address

Table 16: RX Register 3 value

See Section 4.1.3.1: Transmit Mode for details.

6. Write to Register 6 - IF Fine Cal Setup

0	11	011 0011	0000 1111	0001 1111	1	0110
IR Cal Source divide 2, OFF	IR-Cal-Source-Drive-Level, High	IF-Cal-Dwell-Time, 51	IF-Cal-Upper-Tone-Divide, 15	IF-Cal-Lower-Tone-Divide, 31	Enable IF Fine Cal	Address

Table 17: RX Register 6 value

The ADF-7021 has an intermediate-frequency (IF) bandwidth calibration which should be calibrated on every power-up in receive mode to correct for errors in the bandwidth and filter center frequency due to process variations. There are two different calibrations available: Coarse and Fine Calibration. In the cases where the receive signal bandwidth is very close to the bandwidth of the IF filter, it is recommended to perform a fine filter calibration every time the unit powers up which is the case in our design. IF Fine calibration is setup in Register 6 and is started by writing to Register 5.

IF_Cal_Lower_Tone_Divide and IF_Cal_Upper_Tone_Divide are given by the following formulas.

$$\frac{XTAL}{IF\_CAL\_LOWER\_TONE\_DIVIDE \times 2} = 65.8\,\text{kHz}$$

$$\frac{XTAL}{IF\_CAL\_UPPER\_TONE\_DIVIDE \times 2} = 131.5\,\text{kHz}$$

(Analog Devices)

In our case, IF_CAL_LOWER_TONE_DIVIDE and IF_CAL_UPPER_TONE_DIVIDE should be 31 and 15.

IF Tone calibration Time is recommended to be at least 500 µs which is given by the following equation.

$$IF\ Tone\ Calibration\ Time = \frac{IF\_CAL\_DWELL\_TIME}{SEQ\ CLK}$$

(Analog Devices)

The SEQ Clk is equal to 100.8 kHz which is given in Register 3 which makes the IF_CAL_DWELL_TIME to be at least 51 to have at least a 500 µs calibration time.

The total time for a fine IF filter calibration is IF Tone Calibration Time times 10 which is around 5.06 ms.

7. Write to Register 5- IF Filter Setup Register

0	0	0 0000	0	0000	00 0000	0 0101 0001	1	0101
IR-Gain-Adjust-UP/DN,	IR-Gain-Adjust-I/Q,	IR-Gain-Adjust-Mag,	IR-Phase-Adjust-I/Q,	IR-Phase-Adjust-Mag,	IF_Filter-Adjust, 0	IF-Filter-Divider, 81	IF-Cal-Coarse, Do Calibration	Address

Table 18: RX Register 5 value

Register 5 sets up the Coarse calibration.

IF_Filter_Divider is given by the following equation which a value of 81 gives us the closest value to 50 kHz.

$$\frac{XTAL}{IF\_FILTER\_DIVIDER} = 50\,\text{kHz}$$

(Analog Devices)

IF_Filter_Adjust is automatically adjusted when the Calibration is performed. This could be set manually if desired.

IR portion is used for image rejection calibration which can be used with an external microcontroller to calibrate the image rejection. We are currently are not calibrating.

8. Wait at least 5.2 ms for IF calibration
9. Write to Register 11- Sync Word Detect

0000 0000 0101 1101 1010 1011	01	01	1011
Sync byte Sequence, 0x5DAB but must be loaded least significant bit to most significant bit and inverted	Matching Tolerance- Accept 1 Error	Sync Byte Length- 16 bits	Address, 11

Table 19: RX Register 11 value

The transceiver can be set to look for a certain sequence of bits and when this sequence is found, the VHF_SWD is asserted high. In our application, we use the sync word to act as a start sequence that tells us that a valid transmission is coming. We chose a start sequence of 0xBAD5. However, in when the PIC uses synchronous transmission, it sends the least significant bit first at 8 bits at a time. Because of this, the transceiver must look for 0x5DAB.

The transceiver also allows for a matching tolerance which is the number of errors in the sync word that are allowed in the detection.

10. Write to Register 12- SWD/Threshold Setup Register

0001 0011	10	10	1100
Data_packet_length, 19	SWD Mode- SWD Pin High after next sync word for data packet length	Lock threshold mode – Lock threshold after next sync word for data packet length	Address, 12

Table 20: RX Register 12 value

The lock threshold locks the automatic frequency correction (AFC) and automatic gain correction. We set this lock to last as long as the data packet length.

11. Write to Register 0- N Register

010	0	1	0011 0101	110 1010 0001 0100	0000
Muxout - Digital-Lock-Detect	UART Mode, No = 0	Tx/Rx, RX = 1	Integer-N, 53	Fractional-N, 27156	Address Bits

Table 21: RX Register 0 value

Digital Lock Detect indicates when the PLL has locked. When the phase error on five consecutive cycles is less than 15 ns, lock detect is set high and remains high until a 25 ns phase error is detected at the PFD.

See Section 4.1.3.1: Transmit Mode for details.

12. Wait 40 us
13. Write to Register 4- Demod Register

10	00 0000 0001	00 0110 1010	10	1	001	0100
IF-BW, 25kHz	Post-Demod-BW, 1	Discriminator-BW, 106	Rx-Invert, Invert Data	Product	DeMod Scheme, 2FSK Correlator	Address

Table 22: RX Register 4 value

Demodulation Scheme is set to 2FSK Correlator which is used for 2FSK and has better performance than the Linear Demodulator for 2FSK.

The Discriminator BW is given from the following equations.

$$DISCRIMINATOR\_BW = \frac{(DEMOD\,CLK \times K)}{400 \times 10^3}, \quad K = Round\left(\frac{100 \times 10^3}{f_{DEV}}\right)$$

(Analog Devices)

In our case the Demod Clk is equal to 2.016 MHz (from Register 3) and f_{dev} is equal to 4.80 kHz (from Register 2). Using the above equation, we get a K value of 21 which results in a DISCRIMINATOR_BW of 106.

To optimize the coefficients of the correlator, Product and Rx-Invert must be assigned. The value of these bits depends on whether K is odd or even. The assignment is given in the following table.

Table 17. Assignment of Correlator K Value for 2FSK and 3FSK

K	K/2	(K + 1)/2	R4_DB7	R4_DB[8:9]
Even	Even	N/A	0	00
Even	Odd	N/A	0	10
Odd	N/A	Even	1	00
Odd	N/A	Odd	1	10

(Analog Devices)

In our case, K and (K+1)/2 is also odd. This makes Product = 1 and RX-Invert =0b10.

Post Demodulator BW should be set according to the following equation and table.

$$POST\_DEMOD\_BW = \frac{2^{11} \times \pi \times f_{CUTOFF}}{DEMOD\,CLK}$$

where f_{CUTOFF} is the target 3 dB bandwidth in Hz of the post demodulator filter.

Table 19. Post Demodulator Filter Bandwidth Settings for 2FSK/3FSK/4FSK Modulation Schemes

Received Modulation	Post Demodulator Filter Bandwidth, f_{CUTOFF} (Hz)
2FSK	0.75 × data rate
3FSK	1 × data rate
4FSK	1.6 × symbol rate (= 0.8 × data rate)

(Analog Devices)

In our case, the data rate is 300 so f_{cutoff} is 225 and with Demod clk equal to 2.016 MHz (from Register 3), we get a POST_DEMOD_BW equal to 1.

14. Write to Register 10 - AFC Register

0011 0010	100	1011	1000 0010 0001	1	1010
Max-AFC-Range,50	KP	KI	AFC Scaling Factor, 2081	AFC Enable, On	Address

Table 23: RX Register 10 value

AFC is used to remove frequency errors due to mismatches between the transmit and receive crystals.

The AFC Scaling Factor is given by the following equation.

$$AFC\_SCALING\_FACTOR = Round\left(\frac{2^{24} \times 500}{XTAL}\right)$$

(Analog Devices)

In our case, the XTAL is 4.032 MHz which results in a AFC_Scaling_Factor equal to 2081

KI equal 11 (1011) and KP equal to 4 (100) are the recommended settings to give optimal AFC performance.

The MAX AFC correction range should be less than or equal to 1.5 IF filter Bandwidth. From Register 4, our IF filter BW is equal to 25 kHz resulting in a MAX AFC Correction of less than or equal to 37.5 kHz. The MAX_AFC_RANGE is given by the following equation.

$$AFC\ Correction\ Range = MAX\_AFC\_RANGE \times 500\ \text{Hz}$$

(Analog Devices)

Setting the AFC correction range at 25 kHz gives us a MAX_AFC_RANGE of 50.

15. RX Mode
16. Set VHF_CE low to power down

4.1.4. Matching Networks

With the PCB design completed, we re-simulated our matching networks for the transceiver with non-ideal parts and traces using Advanced Design System 2009. We used models for the inductors and capacitors from Murata and Panasonic, and PCB board characteristics given in Table 6. From these simulations, we only needed to increase L8 inductance to maintain our 50 ohm matches. Figure 31, Figure 32, Figure 33, and Figure 34 all show the circuits used in ADS and their corresponding simulations.

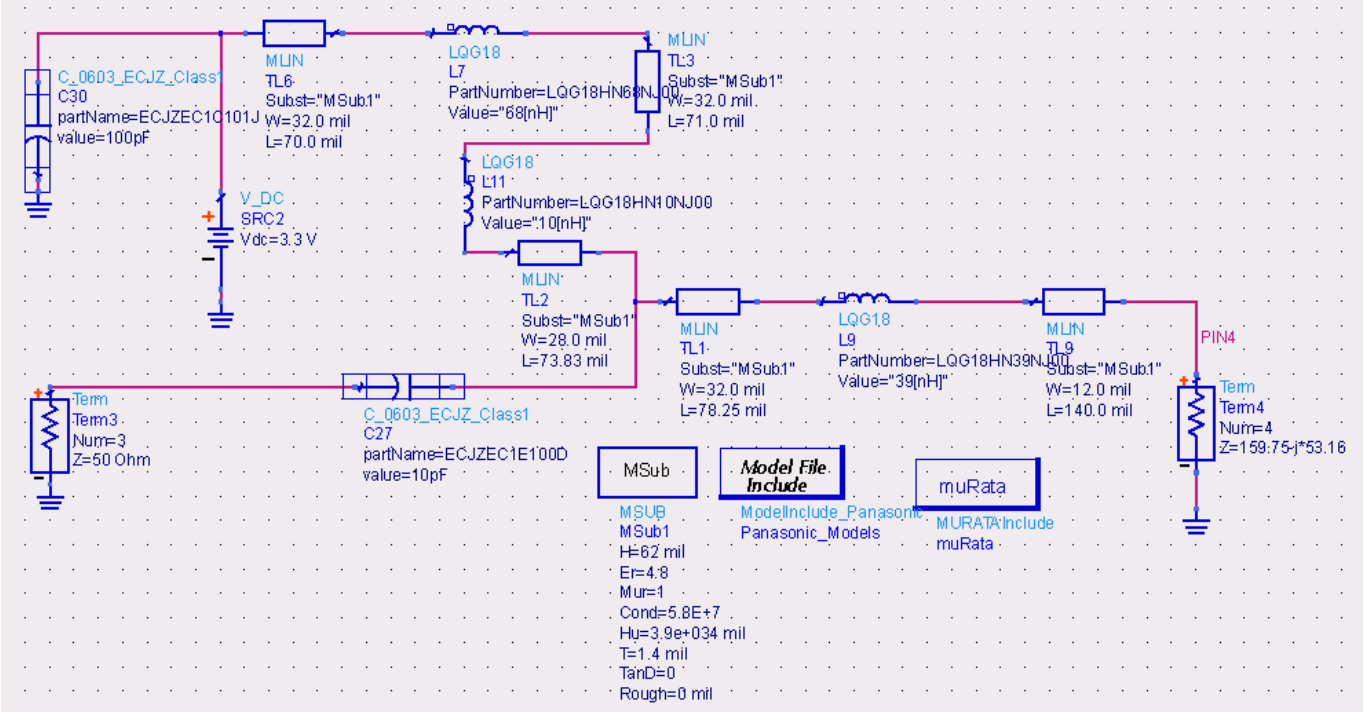


Figure 31: Transceiver output matching network simulation circuit with non-ideals

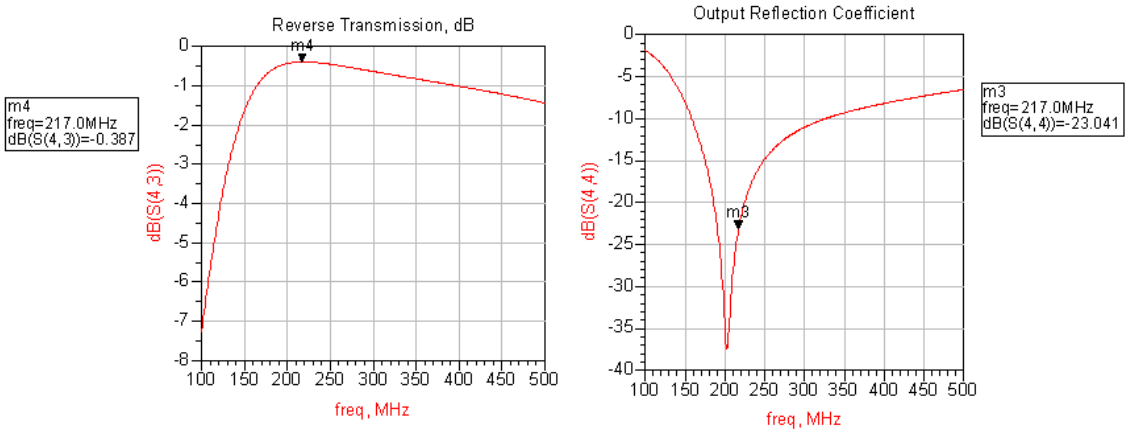


Figure 32: Transceiver output matching network simulation with non-ideals

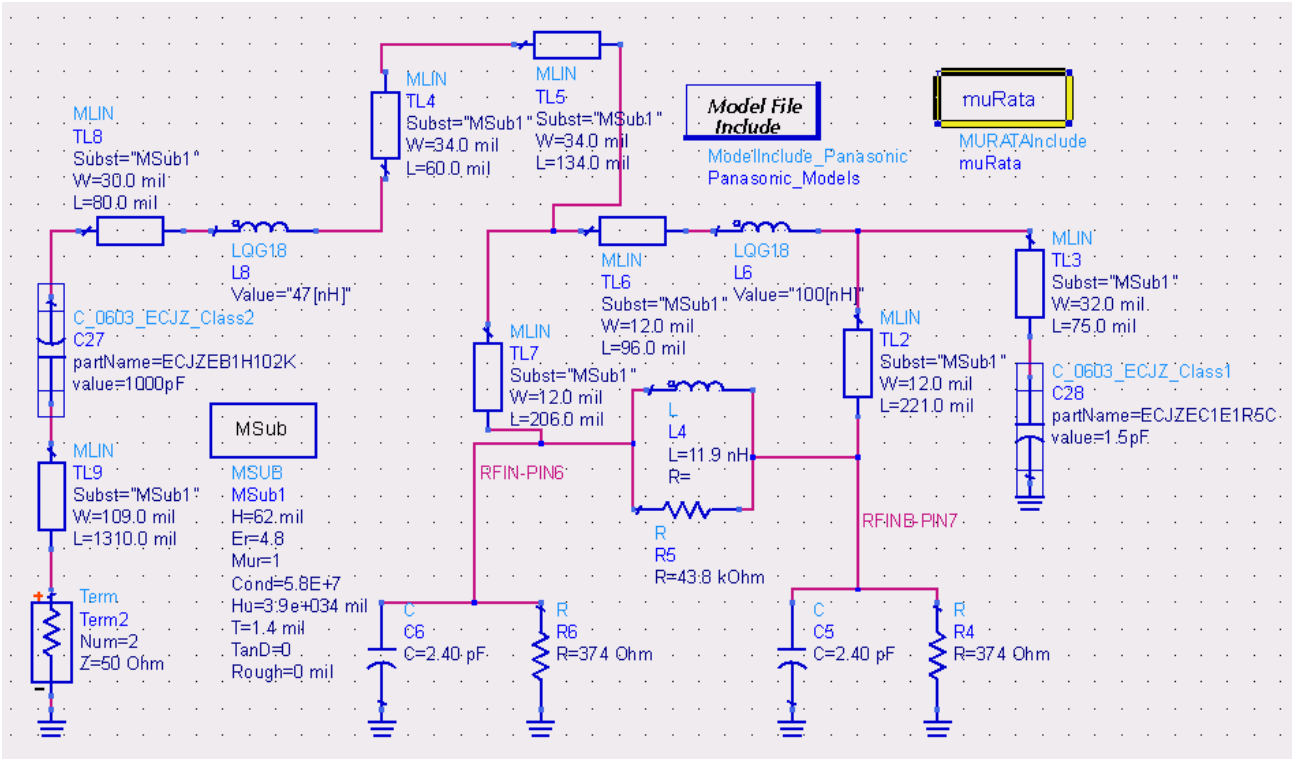


Figure 33: Transceiver input matching network circuit with non-ideals

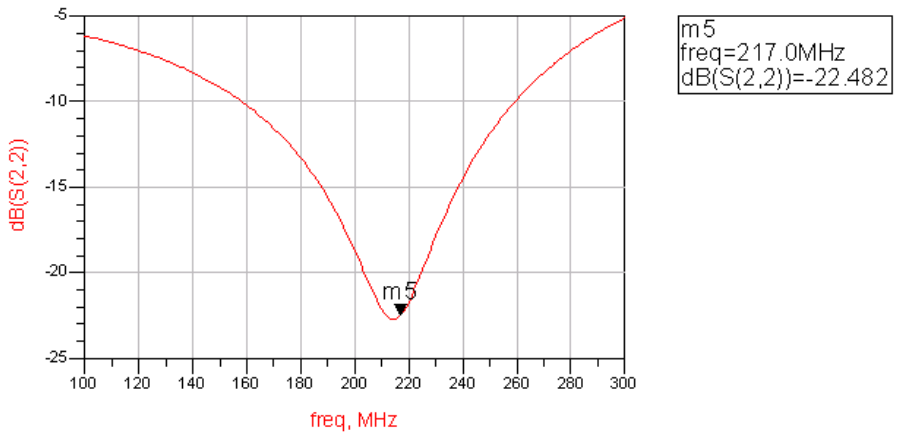


Figure 34: Transceiver input matching network simulation with non-ideals

4.2.Hardware Modifications

The following section defines the modifications made to the original design post PCB fabrication, and the reasons for such modifications.

4.2.1. External Inductor L10

The frequency range of the transceiver is determined by an external inductor between pin 44 and pin 46. Figure 35 shows the RF output verses total external inductance between pin 44 and 46 of the transceiver.

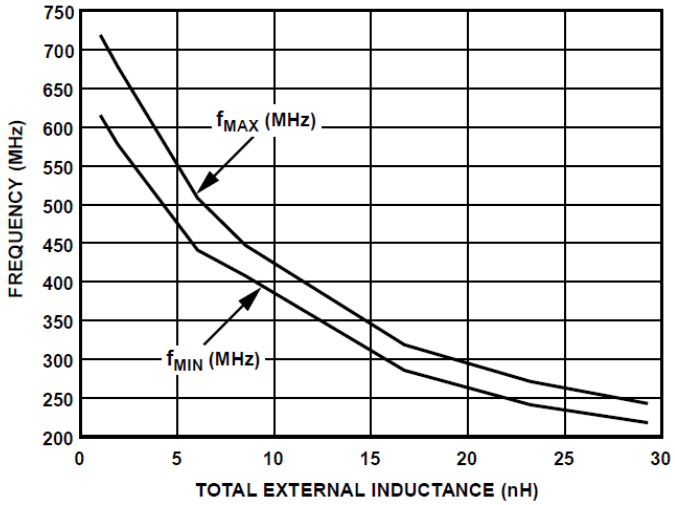


Figure 35: RF output vs. total external inductance (Analog Devices, 2009)

The inductance value was given by ADIsimSRD at a value of 38.5 nH based on our center frequency of 217.0375 MHz. We initially used an inductance value of 39 nH (L10). However, we were only able to get a max frequency of 200 MHz, which meant we needed a smaller inductor. In our initial design, we did not include the inductance of the traces to get to the desired inductance of 38.5 nH. After trying different values of inductance, a 30 nH inductor gave us the desired frequency that we need. It should be noted that if the PCB layout is changed with respect to L10, the external inductance will change depending on the length of the traces from pin 44 and pin 46 to L10.

4.2.2. PIC Connection to Transceiver

The PIC has two different connections to the transceiver: one for configuring the transceiver's registers and the other for sending and receiving data wirelessly. To configure the transceiver's registers, we generated our own procedure that produced the desired sequence as explained in Section 3.3.3.3. The procedure is explained in more detail in the transceiver software Section 4.3.2.3.6.

To send data, we used the PIC's USART. It should be noted that the USART lines for TX and RX to the PIC and ADF7021 were switched around in using USART 1. PIC PIN 44 should be connected to TXRXCLK Pin 35. PIC PIN 1 should be connected to TXRXDATA Pin 34 of the transceiver. On the current revision A, we worked around this issue by using USART 2 which can be programmed to PIC Pin 1 and 44 and this issue has been switched in the revised schematic. Using USART 2, we configured the PIC's USART to act as the slave. The transceiver provides the clock to output the data on the rising edge. More details on this can be seen in Section 4.3.2.2 and 4.3.2.3

In receive mode, we do not use the PIC's USART. Instead, we use the transceiver's sync word functionality. The transceiver is programmed to look for a specific start sequence of bits which in our case is 0x5DAB. Once the transceiver sees this sequence of bits, it sets the VHF_SWD_INT high which tells the PIC to start to read the bits on the rising edge of the transceiver's outputted clock. Once the whole packet is read in, the VHF_SWD_INT is set low until the next start sequence.

4.2.3. Transceiver External Crystal

The current crystal that was picked out has a frequency tolerance of 30ppm. The recommended tolerance rate for narrow-band applications, which is given on page 22 of the transceiver data sheet is to have a <=10ppm. Digikey does not stock crystasl with these specs. However, there are voltage controlled oscillators (VCXO) that have this specification. A possible replacement is Digikey part number 631-1068-1-ND. This VCXO has a frequency tolerance of 1.5 ppm at frequency of 12 MHz which will still allow us to have exactly a 300 baud rate. It should be noted that if this VCXO is used

instead of the current crystal, the values in the registers will have to be changed based on this new frequency of 12 MHz.

4.2.4. I2C

The I2C lines were used by the PIC to operate an EEPROM memory chip and a UBLOX NEO-5Q module. Both units operated on different SCL and SDA lines so that each unit could be debugged separately. The I2C modules are available on the PIC and code was supplied by Microchip. However, each unit required debugging, especially the UBLOX module.

In I2C the unit has to address the slave on the line and then wait for the slave to respond with valuable information. The EEPROM would respond with the data stored in its memory. The UBLOX GPS chip would respond with NMEA and proprietary UBX data messages. The UBLOX Protocol Specifications document outlined all the data messages and how they would be configured.

The EEPROM I2C lines were accidentally switched in the original PCB fabrication. Jumper lines had to be soldered in order to switch the two lines. Future PCBs will be updated to this modification.

4.2.5. Power

Coupling between the 3.3V line and an unknown source was detected; therefore, it appeared that the 3.3V line does not fully shut down. There is a possibility that devices which use 3.3V line may still be powered even though we prompt it to shut down.

4.2.6. Antenna

A base station antenna was never constructed due to time limitations and material cost. However, a small whip antenna was constructed for the bear collar. This antenna consisted of a RG 58A/U coaxial cable terminating at the unit in a 50 Ω SMA connector.

The coaxial cable's outer conductor was stripped away for a quarter-wave antenna. At the radiating frequency of 217.0375 MHz, this length was 34.52 cm. There was also a quarter-wave of coax left on the cable. This cable helped to match the impedance of the unit and lengthened the antenna for a better fit on the bear collar.

This construction also leads to a poor interface between the coaxial termination and the radiator. This is due to the mismatch between input impedance of the quarter-wave antenna and the intrinsic impedance of the coaxial line. Some reflection is expected in the S11 parameter of the antenna.

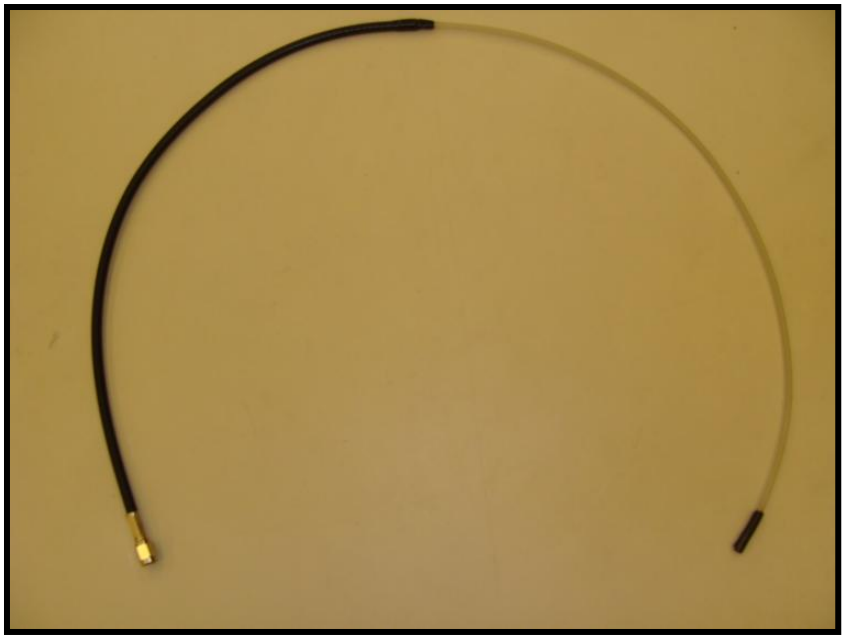


Figure 36. Quarter-Wave Antenna Construction

4.3.Software

The following section describes the functionality and scope of the software portion of the project.

4.3.1. PC Code

This portion describes the mapping of GPS coordinates onto Google Maps.

4.3.1.1. Google Mappping Code

Google Maps is a handy and user friendly tool that we thought would give the researchers a better way to locate the bears and have a better visualization of that location. So, using the scripting language Python, we wrote a code that will extract the GPS data sent by the PIC and automatically launch a browser and plot those coordinates on Google Maps. This code can be seen in Appendix 6. Initially, the set up of the port is needed. Since we are using serial communication we were able to implement the pySerial API. This makes it very easy to access the ports needed and also allows us to set the various parameters.

```
ser = serial.Serial(port=6, baudrate=2400, bytesize=EIGHTBITS,
parity=PARITY_NONE, stopbits=STOPBITS_ONE,timeout=None, xonxoff=0,
rtscts=0, interCharTimeout=None)
```

The only thing that needs to be monitored is the port number. Since a computer may already be using port 6 it may require some modifications to read from the correct

port that the board is connected to via USB. In order to view the COM port being used after plugging in the device open the Device Manager application and double click "Ports (COM & LPT)". This will list all ports being used on your computer. From there, the correct port number may be found and the Python code may be updated as appropriate.

Once the GPS coordinates have been read through the port in decimal form, the program separates the latitude and longitude coordinates with a comma. This allows the program to distinguish the coordinates. Then, it implants the coordinates into the basic URL structure and opens the browser to that URL.

4.3.2. PIC Code

This part of the document describes the files as well as the high level and low level functions written for the PIC18F46J11 microcontroller for Revision A. The tools used to program this microcontroller are the following:

- **IDE:** MPLAB
- **Programmer:** PICKIT2 or MPLAB ICD2
- **Compiler:** MPLAB C for PIC18 MCUs (MCC18)

The MPLAB project currently used is the following:

- TDMANetwork.mcp

4.3.2.1. main.c

This file configures and initializes the PIC18F46J11, and serves as the skeleton for the TDMA network.

4.3.2.1.1. main()

This function calls the initialization functions and then runs the deep sleep handler function. It is then decided whether the power on reset (POR) was pure, meaning it is the first power up, or was an awake from deep sleep. Proper actions are then taken based on the decision.

4.3.2.1.2. activate_unit()

This function is called when the PIC has fully wakened from deep sleep. It is where communication with the GPS, VHF transceiver, and EEPROM will take place. This is where communication with other units will take place (one frame in

the TDMA network). After all networking logic is complete, data is written to the deep sleep save registers and the PIC goes back to sleep.

4.3.2.1.3. maintenance()

This function performs ‘maintenance’ on the peripherals of the PIC. Its purpose is to make sure all devices are working correctly.

4.3.2.1.4. tx_test()

This function runs the procedure needed to put the VHF section in transmission mode. This is used for testing purposes.

4.3.2.1.5. rx_test()

This function runs the procedure needed to put the VHF section in reception mode. This is used for testing purposes.

4.3.2.2. init.c

This file contains functions that initialize communication ports, I/O ports, the oscillator, etc.

4.3.2.2.1. eusart2USB_remap()

This function remaps the EUSART2 pins Rx2 and Tx2 to pins 14 and 15 respectively. This allows the FTDI USB to Serial converter chip to talk to the PIC.

4.3.2.2.2. syc_eusart2VHF_remap()

This procedure sets up the reprogrammable pins needed VHF transmission or reception. In TX mode, USART 2 clock and data lines are mapped to Pin 1 and Pin 44 of the PIC respectively. In receive mode, external interrupt 1 and 2 are programmed to Pin 4 and Pin 1 respectively. Interrupt 1 is used to detect when the VHF_SWD_INT goes high and external interrupt 2 is used to detect the rising edge of the receive clock of the transceiver

4.3.2.2.3. eusart2_init()

This function initializes all registers required to communicate serial data asynchronously over the EUSART2 module.

4.3.2.2.4. syc_eusart2_init()

This procedure initializes the synchronous transmission and reception. In transmission mode, the synchronous USART 2 is used to send the data. The USART is set up in synchronous and slave mode and disables transmission interrupts. The transceiver acts as the master and outputs the clock to shift the data out.

In receive mode, the USART is not used. Instead, the receive procedure uses interrupts. Two interrupts are needed: one for the sync word detection and the other for the rising edge of the transceiver clock. External interrupt 1 and 2 are tied to the sync word detection and transceiver data clock respectively. Thus, in receive mode, this procedure sets up external interrupt 1 and 2 to be activated on the rising edge. External interrupt 1 is the only interrupt that is activated right away because we do not need to start clocking in data until the start character has been detected. Lastly, the procedure calls global_var_init which initializes the received data array and count variables to zero.

4.3.2.2.5. osc_init()

This function initializes all registers required for the PIC's internal oscillator to oscillate properly.

4.3.2.2.6. io_init()

This function initializes all GPIO pins to be either digital or analog inputs or outputs.

4.3.2.2.7. vhf_init()

This procedure configures the transceiver to be in either transmit or receive mode. The procedure contains the register values needed to be written to the transceiver. For more information on the registers values, see Section ADF-7021 Register Configuration4.1.3. The register values are passed to the procedure send_gpio() which writes the values to the transceiver's registers. The for loops are added to make the required delays as defined in Section 4.1.3.

4.3.2.3. handler.c

This file contains functions that perform any type of data handling. This involves the deep sleep functionality, sending eusart data, sending data via I/O ports, and other functions for peripheral testing purposes.

4.3.2.3.1. ds_handler()

This function is called to *decide* whether or not the power on reset (POR) was pure or if it was from a deep sleep wake.

4.3.2.3.2. dpslp_chk()

This function is called to *determine* whether or not the power on reset (POR) was pure or if it was from a deep sleep wake.

4.3.2.3.3. go_to_sleep()

This function is called if a wake from a deep sleep has occurred, but the wake is not at the beginning of a TDMA network frame. When this function is called, it increments a counter by calling the sleep_count() function. It then writes this counter information to the deep sleep save registers, and puts the PIC back into deep sleep.

4.3.2.3.4. send_eusart1()

This function sends the user inputted integer value via USART 1. It checks to make sure that the buffer it not full before sending the next byte of data.

4.3.2.3.5. send_esuart2()

This function sends the user inputted integer value via USART 2. It checks to make sure that the buffer it not full before sending the next byte of data.

4.3.2.3.6. send_gpio()

This procedure writes the specific register value to the transceiver. It takes in the register value and shifts each bit into an array. These bits are then fed from most significant bit to least to the transceiver. The procedure sets up the bit's value on the VHFW line and then toggles the VHF_SCLK to generate the required clock. The procedure performs this for all 32 bits. After the last bit is read by the transceiver, the VHF_SLE is set high for a period to latch the data into the transceiver and then finally set low again. For timing requirements on this procedure, Section 3.3.3.3 contains more details.

4.3.2.3.7. eusart_test()

This function tests the eusart port by calling the send_eusart() function to send specific values (from 0x00 to 0x03).

4.3.2.3.8. sleep_count()

This function increments the counter variables count1 and count2. These variables are set at zero when a pure POR has occurred. When counter1 passes 255, it resets to zero and increments counter 2. The maximum value these counters can increment to is 255^2 or 65,025.

4.3.2.3.9. power_33()

This function sets the proper I/O pin high or low to turn the 3.3V power supply on or off respectively.

4.3.2.3.10. power_5()

This function sets the proper I/O pin high or low to turn the 5V power supply on or off respectively.

4.3.2.3.11. vhf_trx()

This function sets the proper I/O pin high or low to turn the VHF transceiver on or off respectively.

4.3.2.3.12. switch_ctrl()

This function is called to control the RF switch to be in either receive or transmit mode. This function has an unsigned character as a parameter. If the argument passed through this function is 0, the switch is off. If the argument passed through this function is 1, the switch is in transmit mode. If the argument passed through this function is 2, the switch is in receive mode.

4.3.2.3.13. swd()

This procedure is called when external interrupt 1 is detected which means the transceiver has found the start sequence and the data packet is going to be outputted. This procedure disables external interrupt 1 (SWD interrupt), clears external interrupt 2's flag, and enables external interrupt 2 (Data Clock). By enabling external interrupt 2, the PIC is setting up to read the data outputted by the transceiver on the rising edge of the transceiver's data clock (TXRXCLK).

4.3.2.3.14. VHF_data_rx()

This procedure is called when external interrupt 2 is detected which means a rising edge was detected on the transceiver's data clock. This procedure is used to read the data packet and format it in array VHF_buff. The data is sent out from the PIC least significant bit first and thus as the bits are received, they have to be shifted to the left to form the byte of data. Once the fixed packet length is read in, the procedure enables external interrupt 1 (SWD) and disables external interrupt 2 (Data Clock).

4.3.2.3.15. global_var_init()

This procedure initializes the VHF receive global variables VHF_bit_count, VHF_byte_count, and VHF_buff to 0.

4.3.2.3.16. VHF_read_back()

This function writes to the VHF transceiver register 7 which sets up the read_back function of the transceiver. For more information on the specifications on read back, more details can be found in Section 3.3.3.3. Register 7's value is written to the transceiver in the same manner as the procedure send_gpio(). Once the VHF_SLE is raised high, the transceiver will output data on the rising edge of the clock on line VHF_SCLK. The first bit of data is to be ignored. The PIC reads in the data on the lower edge of the clock to ensure the data has had time to settle. After the 16 bits have been read in, the VHF_SLE is lowered and one more clock cycle is produced to allow the transceiver to exit readback mode.

4.3.2.3.17. VHF_AFC_RB()

This function reads back the automatic frequency correction and outputs corrected frequency. A frequency output of 100 kHz means there is no frequency errors. The AFC when enabled automatically adjusts the value of the fractional-n to get a frequency of 100 kHz. The equation for the frequency read back is the follow equation where DEMOD_CLK is given from register 3 at 2.016 MHz.

$$\frac{(AFC_{READBACK})(DEMOD_{CLK})}{2^{18}} = AFC_{READBACK} * 7.69043$$

4.3.2.3.18. VHF_Silicon_Rev_RB()

This function returns the silicon revision of the transceiver. The current silicon revision is 0x2104.

4.3.2.3.19. VHF_RSSI_RB()

This function reads the received signal strength indication (RSSI) value from the transceiver and returns the RSSI in dBm. The signal strength in dBm can be calculated using the following equation.

$$Input\ Power\ [\text{dBm}] = -130\ \text{dBm} + (Readback\ Code + Gain\ Mode\ Correction) \times 0.5$$

The readback code is the first 7 bits of the readback value. The gain mode correction is given by the next 4 bits and gives a correction value based on the following table.

LNA Gain (LG2, LG1)	Filter Gain (FG2, FG1)	Gain Mode Correction
H (1, 0)	H (1, 0)	0
M (0, 1)	H (1, 0)	24
M (0, 1)	M (0, 1)	38
M (0, 1)	L (0, 0)	58
L (0, 0)	L (0, 0)	86

Table 24: Gain Mode Correction (Analog Devices)

4.3.2.3.20. VHF_Filter_Cal_RB()

This function reads back the filter bandwidth calibration of the transceiver after the fine and coarse filter calibration has been performed. These values can be used to manually set the filter calibration without having to run the automatic filter calibration. The manual adjustment should only be done when the transceiver has only been powered down for a short period of time. The following equation gives the filter adjustment value that can be programmed into register 5.

$$IF\_FILTER\_ADJUST = FILTER\_CAL\_READBACK - 128$$

(Analog Devices)

4.3.2.3.21. VHF_Battery_RB()

This function returns the battery voltage as measured at PIN VDD4. The analog to digital conversion (ADC) needs to be turned on to read the battery value which is performed by writing to register 8. Once the ADC is turned on, the battery readback can be performed. The following equation is used to calculate the voltage at the battery.

$$V_{Battery} = \frac{BATTERY\_VOLTAGE\_READBACK}{21.1}$$

4.3.2.3.22. VHF_Temperture_RB()

This function returns the outside temperature in degree Celsius. Just like the battery readback, the ADC must be turned on before performing the temperature readback which is performed by writing to register 8. Once the ADC is turned on, the temperature readback value can be performed and the temperature can be calculated using the following equation.

$$Temp\ [°C] = -40 + (68.4 - TEMP\_READBACK) \times 9.32$$

(Analog Devices)

4.3.2.4. interrupts.c

This file contains all functions needed for handling interrupts on the PIC18F46J11.

4.3.2.4.1. high_vector_table()

If a 'sync word detect' interrupt has been enabled (external interrupt 1), this function calls the swd() function. If external interrupt 2 has been enabled (VHF RX data clock), this function calls the VHF_data_rx() function. If there is incoming data from the FTDI USB to Serial converter, this function calls the esuart2_rx_int().

4.3.2.4.2. low_vector_table()

This function is not implemented yet because no low priority interrupts are set up.

4.3.2.4.3. eusart2_rx_int()

This function stores the value that was received in an array called eusart2_buff. If the data received exceeds the length of eusart2_buff, the rx2 pointer is reset to the beginning of the buffer so that data is overwritten.

4.3.2.4.4. high_vector()

When a high priority interrupt occurs, the program arrives at this function. This function then directs the program counter (PC) to the high_vector_table() function using assembly code.

4.3.2.4.5. low_vector()

When a low priority interrupt occurs, the program arrives at this function. This function then directs the program counter (PC) to the low_vector_table() function using assembly code.

4.3.2.5. user.c

This file contains all the functions necessary to run the user interface on a PC. Its purpose is to serve as a gateway for the user to access all PIC functionalities.

4.3.2.5.1. user_ctrl()

This function should be run through a while(1) loop to constantly check for user interaction. A user will open a HyperTerminal and set it up to connect to the proper COM port with 2400 baud. In the terminal, the user will type '+++' (without quotations) and the PIC will print a welcome string as well as a set of choices to the terminal. The user will choose a command and based on that choice the PIC will make decisions and perform the required actions.

4.3.2.5.2. chk_33()

This function is called if the user selects the '3.3V Line On' or '3.3V Line Off' choice. This function turns the 3.3V power line on or off.

4.3.2.5.3. chk_5()

This function is called if the user selects the '5V Line On' or '5V Line Off' choice. This function turns the 5V power line on or off.

4.3.2.5.4. chk_eeprom()

This function is called if the 'EEPROM Status' choice is selected. Once implemented, this function will check the status of the EEPROM chip and report back to the user on its findings.

4.3.2.5.5. chk_gps()

This function is called if the 'GPS Status' choice is selected. Once implemented, this function will check the status of the GPS chip and report back to the user on its findings.

4.3.2.5.6. chk_trx()

This function is called if the 'Transceiver Enable' or 'Transceiver Disable' choice is selected. This function enables or disables the transceiver.

4.3.2.5.7. chk_trx_cfg()

This function is called if the ‘Configure Transceiver’ choice is selected. Once implemented, this function will run through the procedure needed to properly configure the transceiver for transmission or reception mode.

4.3.2.5.8. send_data()

This function is called if the ‘Send Data via Transceiver’ choice is selected. Once implemented, this function will send data to the transceiver that is then sent by RF.

4.3.2.5.9. gps_test()

This function is called if the ‘GPS Testing Program’ choice is selected. This function outputs a static GPS coordinate an infinite amount of times. This is used when using the Google Map interface.

4.3.2.5.10. choice_disp1()

This function is called by user_ctrl() to display the first set of choices once a user types ‘+++’ in the HyperTerminal.

4.3.2.5.11. choice_disp2()

This function is called by user_ctrl() to display the second set of choices once a user types ‘+++’ in the HyperTerminal.

4.3.2.5.12. choice_disp3()

This function is called by user_ctrl() to display the third set of choices once a user types ‘+++’ in the HyperTerminal.

4.3.2.5.13. reset_buff2()

This function resets the user input buffer.

4.3.2.5.14. print()

This function takes a string and prints it to the HyperTerminal. It sends data byte by byte using the EUSART2 module. It then sends two more bytes – a return carriage and a new line indicator.

4.3.2.5.15. print_mod()

This function is used for the gps_test() function to print location data without any user visual formatting. In other words, it is the same as print() without sending the last

4.3.2.6. Eeprom_i2c.c

The eeprom_i2c.c file includes all the necessary protocols to communicate to the external EEPROM memory.

4.3.2.6.1. eeprom_i2c_init()

This function initializes the PIC to communicate via the second I2C lines. The pins 38 and 39 on the PIC are set as inputs in order for this to function properly. This initialization happens at a 100 kHz I2C clock which is based off of the 4MHz oscillator clock.

4.3.2.6.2. eeprom_write_byte()

In the case that only one byte of data needs to be written to the EEPROM, this function allows that. The inputs must be a single byte, as well as which memory block (1 or 0), and the address of memory that the data will be written.

4.3.2.6.3. eeprom_read()

The EEPROM can be read simply with this function. An array or pointer must be passed in as *rdptr and this location is where the EEPROM data will be located locally. The address and memory block (1 or 0) must also be input. The length of string to be read is also necessary

4.3.2.6.4. eeprom_ack_polling()

There is no way for the PIC to know when the EEPROM is completed with the writing stages of its operation. In order to know when it's done the PIC operates a polling mechanism. It waits until the EEPROM responds to an address, and then the unit is available for a second write.

4.3.2.6.5. eeprom_write()

This function is formatted very similar to the read function. It takes all the same parameters, but this time the dataptr has values to be written to the EEPROM instead of available space to be written to.

4.3.2.7. gps_i2c.c

This file contains all the initialization and basic functionality for the first pair of I2C lines on the PIC which communicate to the GPS.

4.3.2.7.1. gps_i2c_init()

This function initializes the UBLOX I2C lines to 31.25 kHz if the internal oscillator is properly tuned to 4 MHz. The I2C lines communicate on pins 37 and 42 of the PIC and these are both configured as inputs. Another important bit to set is the Slew Rate Control Bit, which allows the signals to be properly recognized by the GPS. The UBLOX initially configures itself as master to an external EEPROM. This function waits 300ms in order for this sequence to complete before initialization.

4.3.2.7.2. gps_read()

This function will read the message stream on the UBLOX chip. The chip does not always have data available, and this may not print any values in the rdptr. This function also returns the length of the data that was read, which is important when looping for data as this function is often used.

4.3.2.7.3. gps_write()

This function is used to write a message to the UBLOX. Messages are not often written to the GPS, only for the purposes of configuration. Therefore, this message will often not be used by itself, but by another configuration function.

4.3.2.7.4. gps_read_loop()

At times the UBLOX may not respond to an address, but this function will loop and end with a read request after the UBLOX acknowledges. This function is not often used outside of the gps_read function.

4.3.2.7.5. gps_write_loop()

At times the UBLOX may not respond to an address, but this function will loop and end with a write request after the UBLOX acknowledges. This function is not often used outside of the gps_write function.

4.3.2.8. Ublox_cfg.c

This file contains all of the configuration messages used to set up the UBLOX NEO-5 for the bear application. The functions package a correct configuration message and then write it to the GPS.

4.3.2.8.1. ubx_cfg_port_poll()

A request is made for the UBLOX to output its current port configuration on the output Data Stream to be read by the PIC.

4.3.2.8.2. ubx_cfg_port()

This sends a configuration message to the UBLOX. The only important setting is that this message changes the protocol from NMEA to UBX protocol.

4.3.2.8.3. ubx_cfg_msg_off()

Different message types are outputted automatically to the data stream as a boot-time configuration of the UBLOX NEO-5. This function turns off a message of the above class and id as inputs.

4.3.2.8.4. ubx_cfg_msg_on()

Some messages do not default output to the data stream. This function will take a class and id of a message and have that message type be output to the stream each time it is available.

4.3.2.8.5. ubx_cfg_inf_off()

The UBLOX has many different error messages available to send to the PIC. This function turns off all information messages including errors and warnings.

4.3.2.9. Packet Formatting

4.3.2.9.1. Preamble

The preamble consists of a series of 48 alternating 1's and 0's. This is required by the VHF transceiver in order to lock on to the signal.

4.3.2.9.2. Start bit

The start bit that we used is 0xBA, 0xD5. This is the signal that the information is about to be sent, so the receiver can be ready to receive the data.

4.3.2.9.3. Information

For the actual information contained in the packet, we included Longitude, Latitude, Time, Status, and a Bear ID number.

4.3.2.9.4. Encoding

For the encoding of the message itself, we decided to use 4B/5B encoding. This would eliminate the issue of having any series of eight 1's or eight 0's consecutively. The problem with having eight 1's or eight 0's consecutively is that the transceiver can lose the lock on the signal. While other encoding methods would have worked as well, we decided to use 4B/5B because of its simplicity. This functionality uses Table 25 to assign 5 bits of encoding to every 4 bits of data.

Hex	4 Bits	5 Bits
0	0000	11110
1	0001	01001
2	0010	10100
3	0011	10101
4	0100	01010
5	0101	01011
6	0110	01110
7	0111	01111
8	1000	10010
9	1001	10011
A	1010	10110
B	1011	10111
C	1100	11010
D	1101	11011
E	1110	11100
F	1111	11101

Table 25: 4B/5B Encoding

4.3.2.9.5. Checksum

The checksum is an important piece of information to include in the packet because it allows the receiving unit to check to see if the data it is received is

actually valid. To compute the checksum, we summed all of the encoded data, and then encoded the checks.

4.3.2.9.6. Shifting

In order to reduce the amount of bytes transmitted, it was necessary to shift the data so we could transfer 8 data bits, instead of 5 data bits and 3 "filler" bits.

4.3.2.9.7. Sending through VHF

Once the packet has been formatted, it is ready to be sent. This is done with a function that will send the data synchronously.

4.3.2.9.8. Decoding

Once the data has been received, it is necessary for it to be decoded in order to actually read the data and convert it in to useful information. Each set of values gets decoded separately; Longitude, Latitude, Time, Status, and Bear ID. The decoding has to take each set of 5 bits, decode it to 4 bits, then recombine two 2 sets of 4 bits to make a byte. Longitude and Latitude are signed long (4 bytes), Time is unsigned long (4 bytes), Status and Bear ID are unsigned characters (1 byte).

Longitude	signed long	4 bytes
Latitude	signed long	4 bytes
Time	unsigned long	4 bytes
Status	unsigned char	1 byte
Bear ID	unsigned char	1 byte

Table 26: Packet Format Size Before Encoding

4.3.2.9.9. Checksum Decode

The checksum is how the receiver checks the validity of the data it receives. It computes the checksum by taking the last 12 bits of the received, decoding 10 of those bits, and shifting the other 2 bits to the most significant positions.

5. System and Unit Level Test Cases

The following section defines the test cases to which the design will adhere. There are unit level tests to confirm the individual components capabilities, as well as system level tests to confirm that the overall bear tracking system will meet requirements.

5.1.VHF Transceiver Unit Level Test Cases

Impedance matching will be tested between the RF output of the transceiver and input of the external power amplifier. Impedance matching will also be checked between the output of the external power amplifier and the antenna port.

The external oscillator will need to be measured to ensure that it is oscillating at the desired frequency. If the oscillation frequency is high, the load capacitors should be increased to lower the frequency. If the frequency is low, the load capacitor values should be decreased.

Writing and reading to the registers of the transceiver from the microcontroller will also be tested to ensure the microcontroller is able to configure the transceiver.

The output RF spectrum will be tested at the output of the transceiver and at the antenna port. The spectrum will be checked to make sure that the frequencies outside of our 25 kHz bandwidth at our center frequency is below the FCC mask requirements.

Transceiver to transceiver communication will be tested. Data will be send from one transceiver and read from another to ensure that communication has been made between the two units.

5.2.VHF Antenna Unit Level Test Cases

Each collar and router will be tested under ideal conditions, and then it will be tested under conditions representative of operational use. The router antenna will be as ideal as possible in the real application, but the collar antenna will also be tested under different curvature settings as well as with a simulated bear to block signal reception.

Measure the input impedance of the antenna using a network analyzer. The input impedance should be matched over the desired frequency range to minimize the reflection coefficient of the antenna.

Use the university's antenna lab equipment to measure the radiation pattern for the antenna. Both the router antenna array and the collar antenna must be as omnidirectional as possible.

Collar antenna must easily flex around the neck of the bear without drastically affecting performance.

5.3.GPS Module Unit Level Test Cases

This section describes the testing process that will be undergone once the board has been fabricated. The microcontroller will output data to a PC when needed. The GPS chip will output data to the microcontroller which will then output data to the PC (through debugging), indicating the PC whether or not the GPS is responsive or the outputted data is valid.

Hardware

- All physical connections are sound
- VCC levels are correct
- < 50mV$_{PP}$ ripple is observed at VCC pin
    - I/O levels are correct
- Unused I/O ports are high impedance

Functionality

- Status acknowledgment will be requested by the microcontroller to the GPS module, acknowledgment will be expected from the GPS module.
- GPS data request by the microcontroller shall result in an array of pertinent GPS data received by the microcontroller.
- Bytes will be counted and compared to the predicted set of data as to calculate an accurate time slot pertaining to the network design.
- GPS status will be checked in times of low power mode to get an accurate low-power consumption rate.

5.4.Microcontroller Unit Level Test Cases

This section describes the testing process that will be undergone once the board has been fabricated. The microcontroller will output data to a PC when needed. The GPS chip will output data to the microcontroller which will then output data to the PC (through debugging), indicating the PC whether or not the GPS is responsive or the outputted data is valid.

Hardware

- All physical connections are sound
- VCC levels are correct
- I/O levels are correct
- Unused I/O ports are high impedance

Functionality

- Serial data activity is exhibited in times of serial communication – serial ports will be observed using an oscilloscope.
- Controller status will be checked in times of low power mode to get an accurate low-power consumption rate.

5.5.Chassis Unit Level Test Cases

In order to test the durability and resistivity of the cases to the environments a variety of tests can be performed.

- Realistic and measurable force impact on the case at room temperature as well as cold and hot temperatures.
- Submersion in a variety of materials (dirt, sand, rock) as well as submersion in water.
- Shock and vibration tests at realistic g-forces, with a circuit encapsulated within the case to test the functionality of a circuit in the rugged conditions that may be encountered.

5.6.Battery Unit Level Test Cases

To verify their functionality at the extreme temperatures, we would test the battery's properties while using a temperature chamber. By starting at 80˚C and decreasing the temperature by 5˚C every ten minutes, we can take a reading to test the voltage and current. This will help us get an idea for the temperature at which the battery functionality becomes unreliable.

5.7.Power Supply Circuit Unit Level Test Cases

Verify the power supply circuitry through the following test cases:

- There is no short to ground on any power line.
- A 3.3V line is properly regulated.
- A 5V line is properly regulated.
- All lines can supply current defined in Table 5.
- System will successfully power down and suppress all voltages on the bus lines, and send flag to microcontroller when power up is complete.

5.8.System Test Cases

The final deliverables will include two router units and three collar units. The following tests will be performed with these completed units.

Unit System Level Tests

- The unit will successfully power down all systems and power up after a predetermined amount of time. While the unit is in sleep mode, it will consume less power.
- The unit will successfully power up and gain a GPS signal lock.

Unit to Router Communication

- The router will recognize the unit sending a packet of information and download this information. The router will recognize the unit within three attempts by the unit and will download all correct information. We will test the range of the unit to router communication in an open area.
- In a heavily forested area, the router will recognize the unit sending a packet of information and download this information. The router will recognize the unit within three transmission attempts by the unit and will down load all correct information. We will test the range of the unit to router communication in a heavily forested area.

Router to Router Communication

- The router will recognize another router sending a packet of information and download this information. The router will recognize the router within three transmission attempts and will down load all correct information. We will test the range of router to router communication in an open area.
- Information received from another router will be successfully downloaded and concatenated to the information already available. This complete information will be readily available for serial download from router.

Networking Communication

- Time Division multiplexing will successfully allow the position of a collar unit to be sent to router 1 and this information will successfully be forwarded to router 2. If one collar position is sent to more than one router, only one router will send a confirmation ACK to the collar unit.
- Time Division multiplexing will successfully allow the position of two collar units to be sent to router 1 and this information will successfully be forwarded to router 2. If one collar position is sent to more than one router, only one router will send a confirmation ACK to the collar unit.
- Time Division multiplexing will successfully allow the position of three collar units to be sent to router 1 and this information will successfully be forwarded to router 2.

If one collar position is sent to more than one router, only one router will send a confirmation ACK to the collar unit.

- Time Division multiplexing will successfully allow the position of two collar units to be sent to router 1 and one collar unit to router 2. The information from router 1 will successfully be forwarded to router 2. If one collar position is sent to more than one router, only one router will send a confirmation ACK to the collar unit.

Optimization and Initialization Routines

- The base router, when notified by the user, will successfully communicate to all available routers and determine their GPS location. Based on this location, the router will optimize a networking pattern. The pattern must be the most efficient and the base router must locate every other router in the system.
- When the base router is notified by user, it can determine all of the routers that are in use in the field.

6. System and Unit Level Test Case Results

The following section is the results from the tests recommended in Section 0. Not all test cases were implemented due to time and feasibility constraints.

6.1.VHF Spectrum

With the transceiver configured to 2FSK, we measured the output spectrum using a spectrum analyzer. The first time we measured the output spectrum, we noticed that we were not getting the power amplification that we should be getting. With the transceiver set at a power level of 36 (around 0 dBm), we were only seeing around 0 dBm. We believed that a possible reason for the power amplifier for not working correctly is because there was too much resistance to ground. In our PCB design, we forgot to add a copper area on the solder mask for the ground plane of the power amplifier; the only connection to ground is on the underside of the power amplifier. To test this, we removed the power amplifier from board B and scrapped off the insulation until we got to the top copper ground plane. After doing this, we put a new power amplifier onto the board which should allow a full connection to the ground pad on the power amplifier.

With board A having a power amplifier with only plated through hole connections to ground and board B with a full connection to ground, we measured the spectrum again of the two boards at three different power levels: 1 (-16 dBm), 36 (~0 dBm), and 63 (13 dBm). Figure 37, Figure 38, Figure 39, and Figure 40 show the screen shots for board A. As one can see, we never achieved the amplification that we required. These screen shots did verify that our boards are modulating using FSK with a frequency deviation of 4.8 kHz. We did observe that when we turned the power of the transceiver to maximum (PA level 63), we were seeing the gain dropping tremendously and losing the modulation all together as seen in Figure 40. Contacting the PA manufacturer (RFMD), they believed that the issue was because of not having a good connection to ground and also not having a high Q choke and low resistant inductor on L13. RFMD suggested that we use Coilcraft 1008CS inductor. Because of time issues, we were not able to see if changing the choke inductor would fix the PA issue.

We also observed images of the FSK modulation at 4.8 kHz from each impulse as seen in Figure 38 and also 200 kHz from the center frequency as seen in Figure 39. These images can be cause by using a high number on the fractional-n as explained in the transceiver TX register 0.

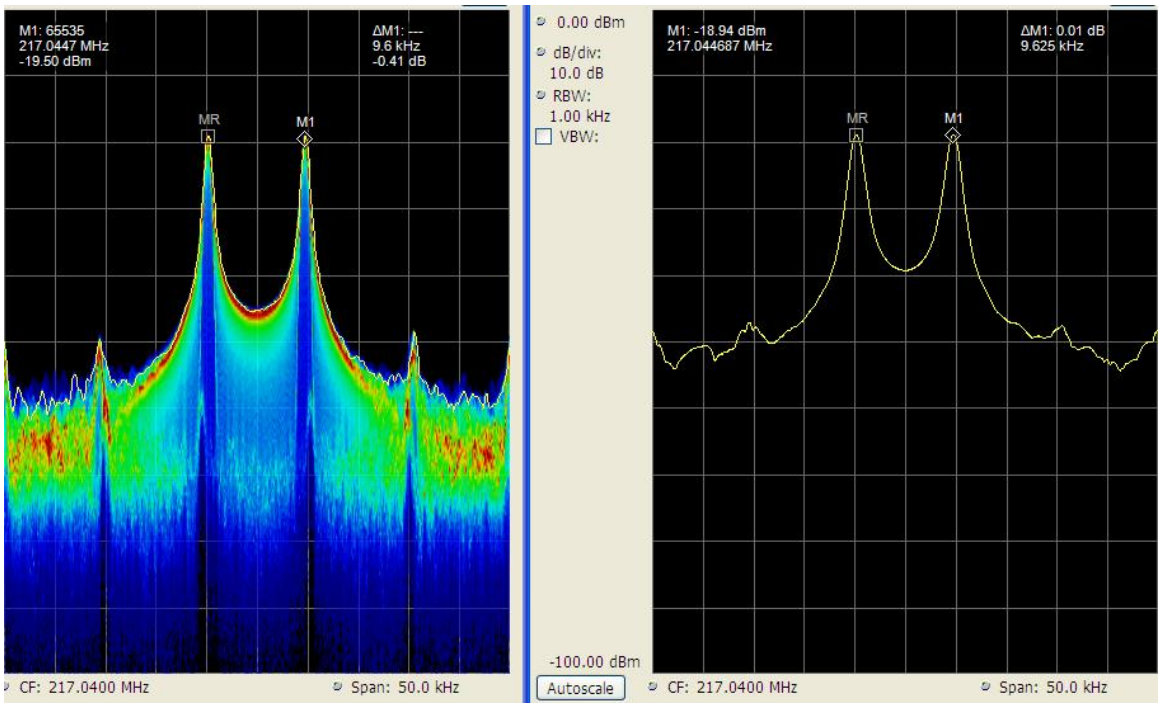


Figure 37: Output Spectrum of board A with transceiver set at level 1 power (-16 dBm)

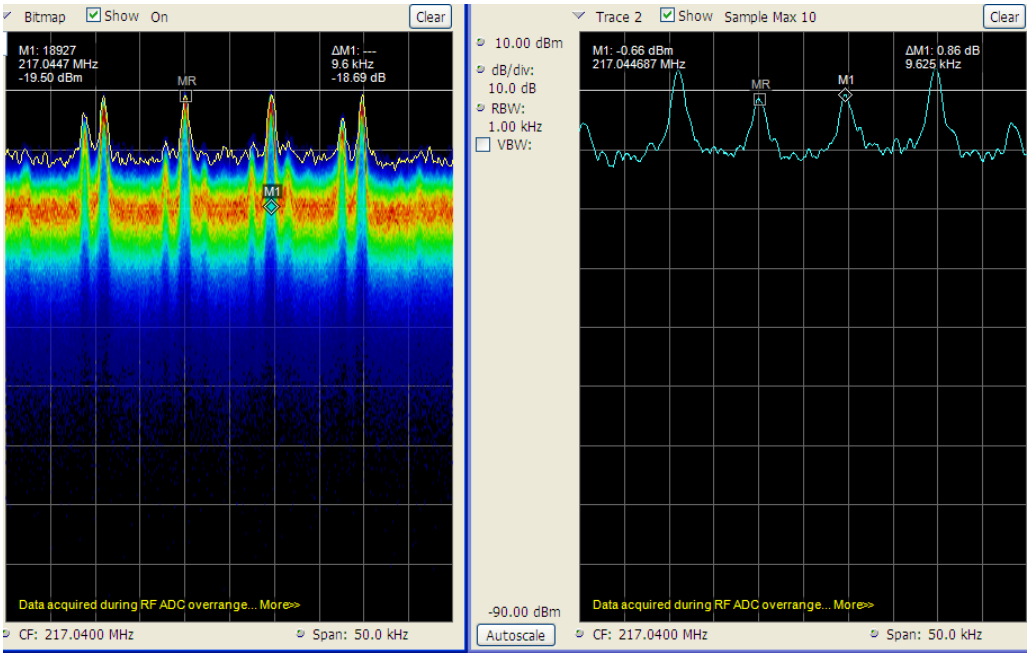


Figure 38: Output Spectrum of board A with transceiver set at level 36 power (~0 dBm) with span 50 kHz

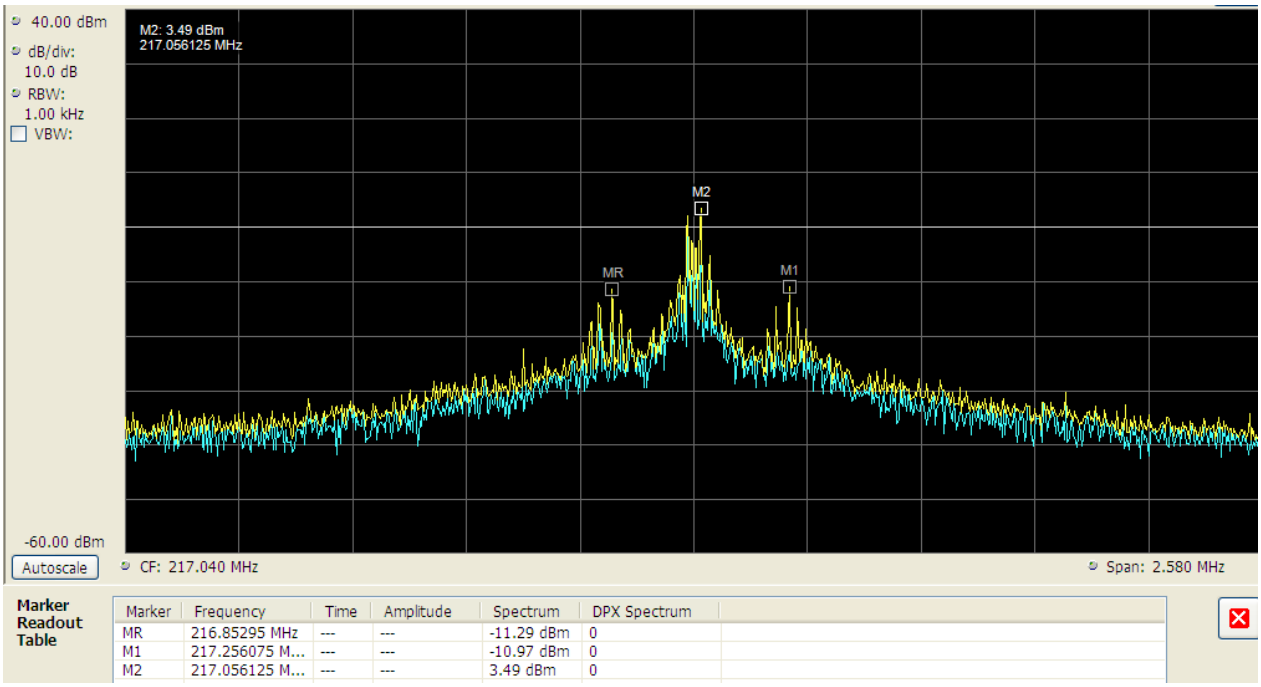


Figure 39: Output Spectrum of board A with transceiver set at level 36 power (~0 dBm) with Span 2.6 MHz

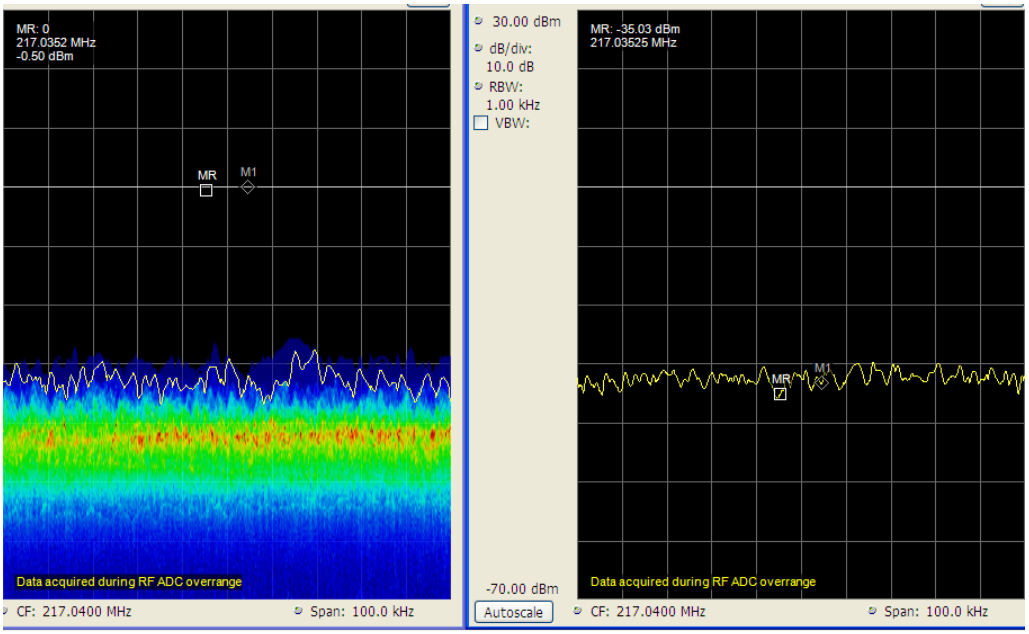


Figure 40: Output Spectrum of board A with transceiver set at level 63 power (13 dBm)

With the modification to the ground connection of board B, we saw the output was attenuated as seen in Figure 41, Figure 42, and Figure 43. When we had the power level of the transceiver at its highest, we observed an increase in spectral content as seen in Figure 43. The increase in spectral content may be caused if the power amplifier was not

acting as a linear device. We believe that the PA on board B is no longer in a state of functionality which is why there is so much attenuation.

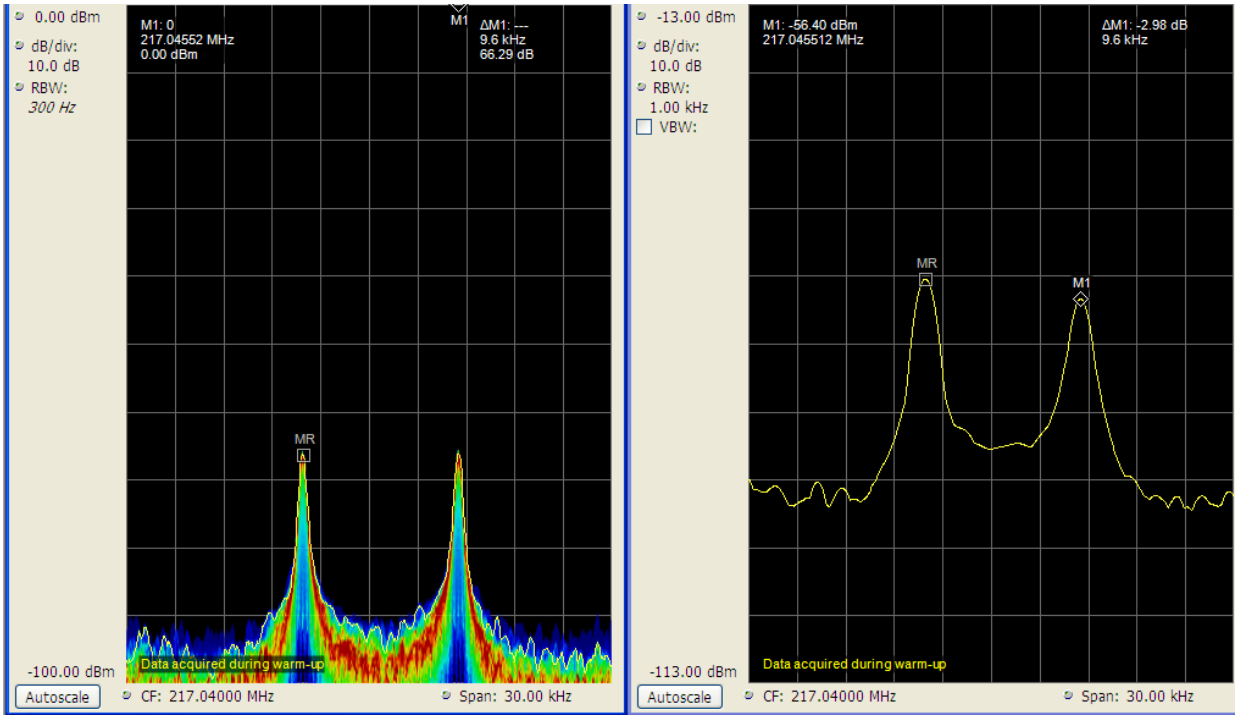


Figure 41: Spectrum of board B with modification and transceiver output power level of 1 (-16 dBm)

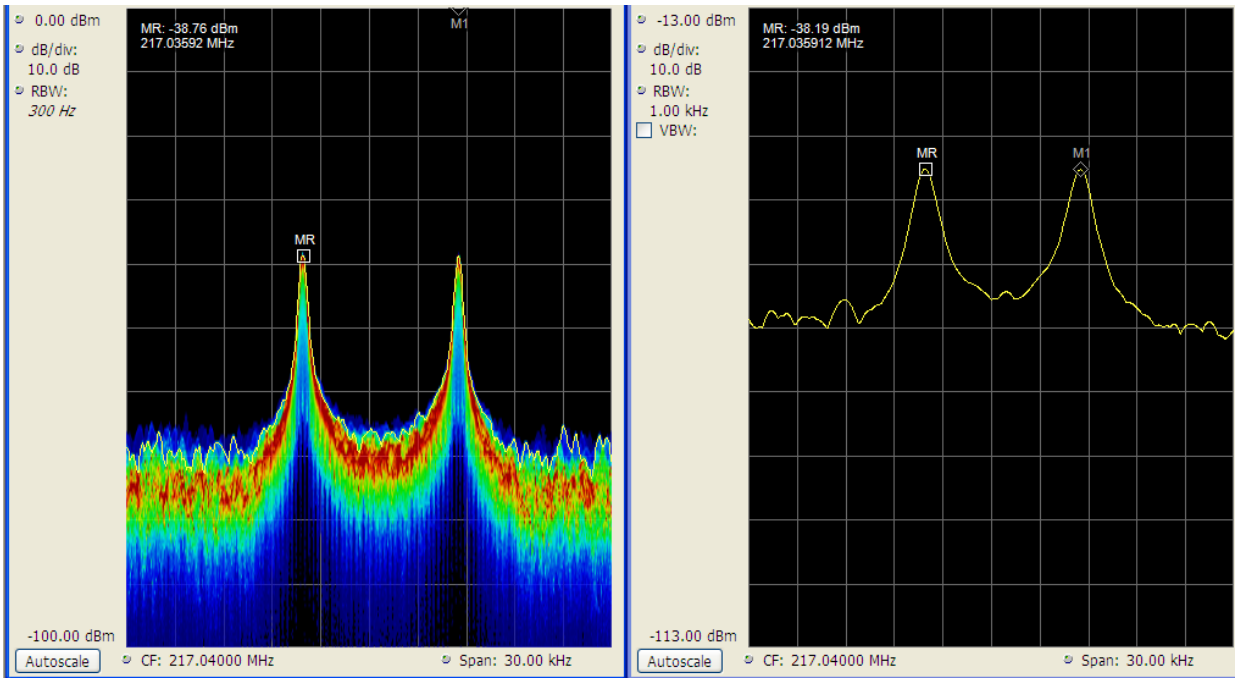


Figure 42: Spectrum of board B with modification and transceiver output power level of 36 (~0 dBm)

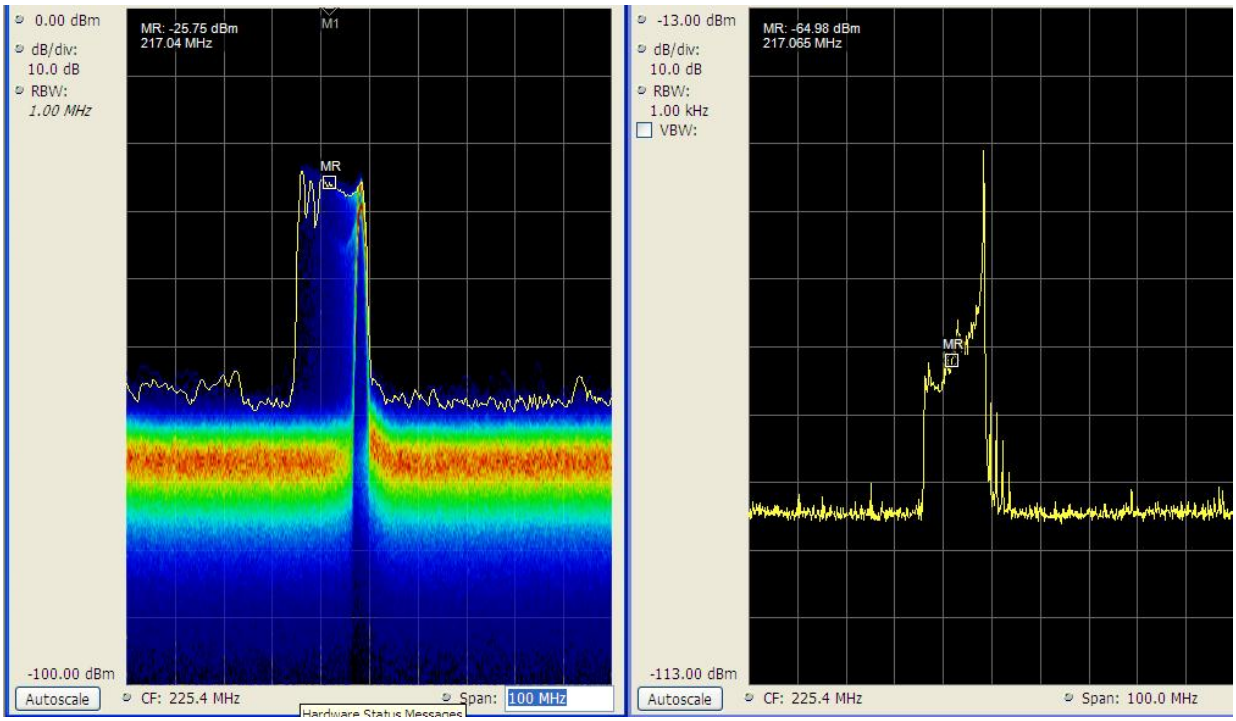


Figure 43: Spectrum of board B with modification and transceiver output power level of 63 (13 dBm)

6.2.Antenna

The RF transmission of the board was initially tested using a quarter-wave coaxial cable to connect the two units. After acceptable transmission rate was achieved, the quarter-wave antennas were used in testing.

To test the performance of the quarter-wave antenna we used a network analyzer to test the reflection S-Parameters. The antenna had tuned frequencies that were slightly off of accepted, and the desired frequency was almost entirely reflected.

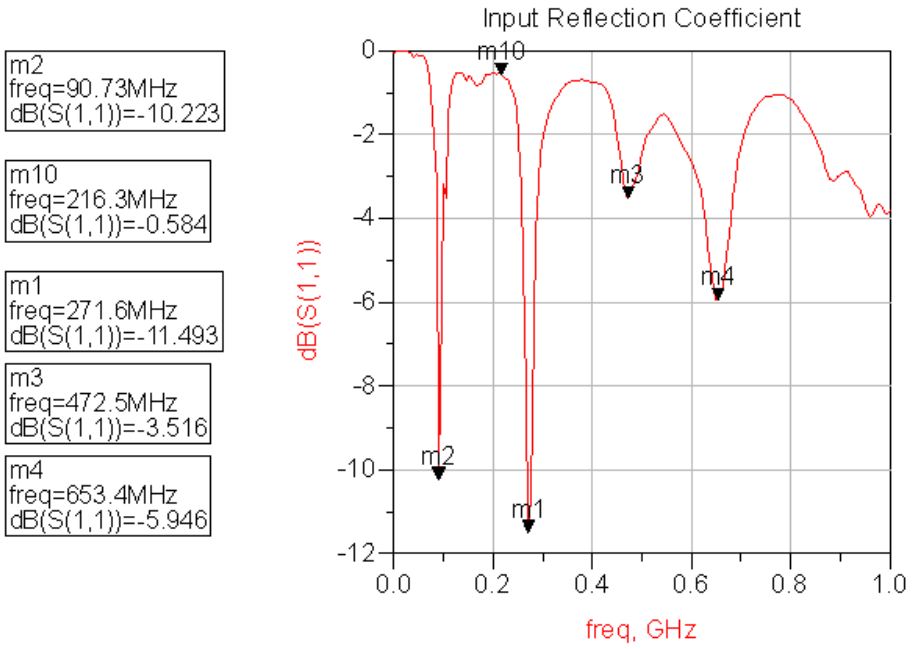


Figure 44. Antenna A - S11 Parameters

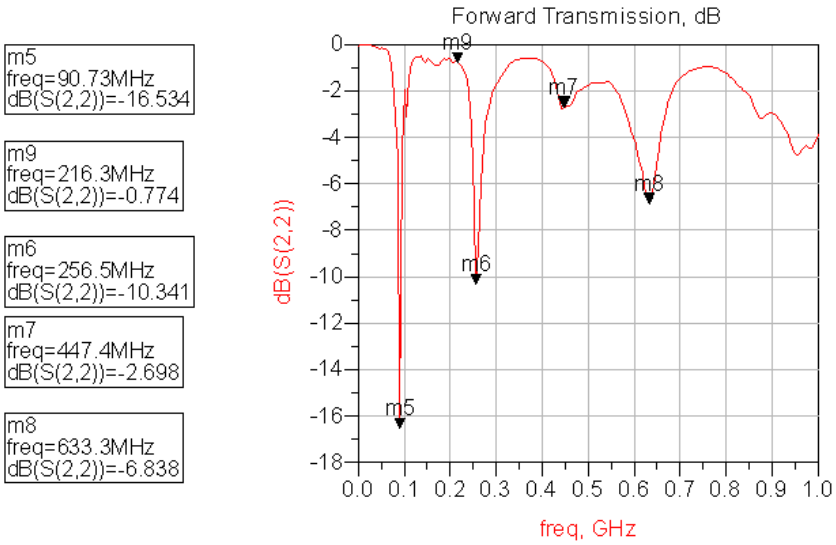


Figure 45. Antenna 2 - S11 Parameters

The antennas were very sensitive to movement and any adjustment in curvature would affect the S11 parameters of the antenna. At the angle that the antenna will be on the bear's collar, there were the distinct frequencies as displayed in the above graph.

New antennas were constructed to better meet the required frequency. The new antenna is trimmed in length to adjust the tuned frequency of the system at 217.0375MHz. The following antenna had a small coax portion and then a length of 21 cm. This antenna had a nice bandwidth around the necessary frequency.

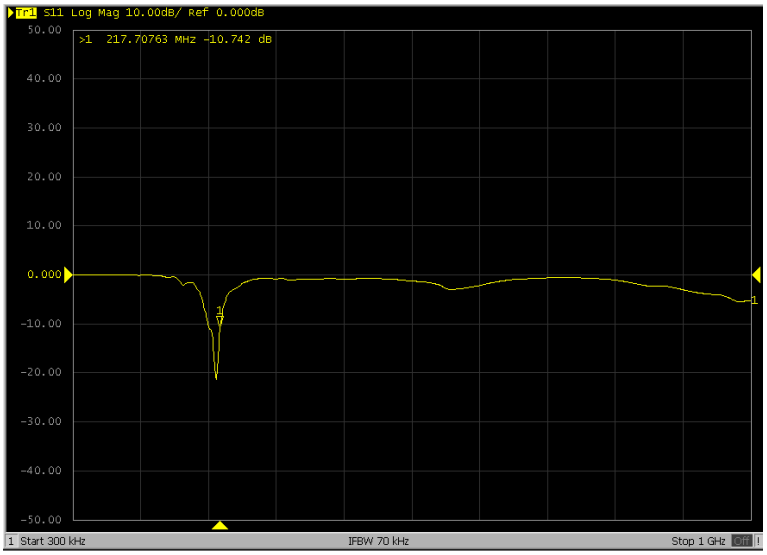


Figure 46. Finalized Antenna - S11 Parameters

6.3.Google Maps

During the testing of this code, it initially let the user input coordinates so that it was able to verify the correct format of the URL implant and the launching of the browser. Once the formatting of the URL was correct, we set up a communication link with Putty. Putty is an open source terminal emulation application that can act as a client for a number of computing protocols. To simulate GPS coordinates, we set up the PIC to continually output the same string of fake coordinates. This was to ensure our port parameters were set up correctly to allow for communication via USB. Once we knew what COM port we were communicating with, we set the baud rate to 2400, bit size of 8, no parity, and one stop bit.

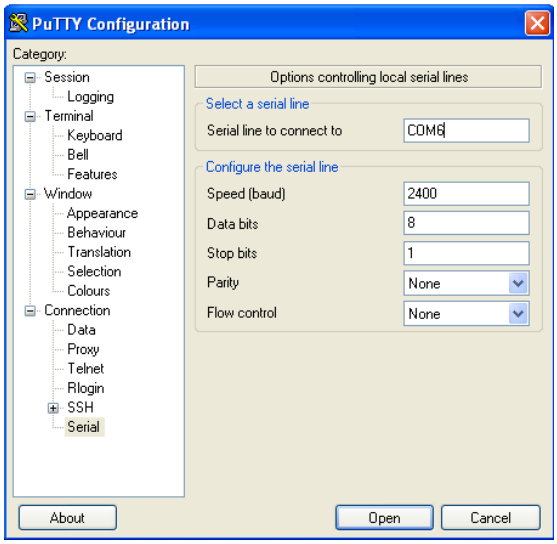


Figure 47 Port parameters for communication to PC for Google Map testing

6.4.Specific Absorption Rate Safety

The specific absorption rate is a way to measure the amount of energy being absorbed by bodily tissue due to exposure to radio frequency electromagnetic fields. It is important for us to take this into account so that we don't injure the bear. Since the collar is so close to the bear's head, we have to ensure that our outputted power is safe. SAR is measured in Watts/Kilogram and, in our case, needs to be evaluated over the mass of the bear's head. The FCC requires that all cell phones have a SAR no greater than 1.6W/kg. Therefore, with our system outputting about 1W, the bear's head would have to weigh less than 1kg. This condition will not be a factor our group will encounter since it is safe to say that the average bears head weighs roughly 5-15kg. Also, contributing to the safety of our system is the amount of time in which we are transmitting. It is such a short time of exposure that the effects are very minimal.

7. Recommendation for Project Continuation

This section will describe our groups suggestions for future changes to the project.

7.1.VHF Recommendations

In a future design, the image rejection calibration in the ADF-7021 register 5 should be implemented. By performing this, the transceiver will be able to reject the image frequency at a higher attenuation which should decrease the bit error rate. Pages 39 to 40 of the ADF-7021 datasheet explain the procedure to calibrate the image rejection.

A bandpass filter should be added to the output of the RF switch. The band-pass should allow the frequency range of 216 to 221 MHz to pass. A much narrower filter design would be infeasible with the given fractional bandwidth. This filter will help clean up the out of band spectrum content and help reject the image frequency. By adding the filter, it should help lower the bit error rate and clean up the output band content.

In future PCB layouts, the power amplifier and transceiver ground pad should have a copper area on the solder mask along with the plated through holes to ground. These copper areas will help with RF performance along with helping dissipate heat. Section 4.1.1 should also be read in detail to maintain the same RF strategy and knowing to adjust the external inductor of the transceiver.

7.2.Power Section Recommendations

Previously, three buck converters were used in the power section for a 3.3V always power line, a 3.3V selectable power line, and a 5V selectable power line. The purpose for using buck converters was to allow for an efficient step down from the 6V battery supply, as well as a wide range of input voltages for when a wall transformer is used. This proved to be a waste of space for only a small save in efficiency as well as an expensive alternative. The new design replaces these buck converters with selectable LDO regulators. Very few components are need for these supplies and their efficiencies are comparable to the buck converters at the input voltages being used. They are also much less expensive.

7.3.USB Section Recommendations

For the USB section in the previous design, an FTDI chip was used for USB to serial conversion. This was an excellent choice for its capabilities, but it still took up a lot of space and used several components. A new chip, the Silicon Labs CP2102 is now used, costing the same amount but having a smaller package size and requiring less external components. This will again save board space and cost.

7.4.GPS Section Recommendations

The NEO-5Q GPS chip is replaced with the EM-408 module and antenna package. Instead of being integrated into the board as before, this module will plug into a connector mounted on the board and be a completely separate entity. This module greatly reduces cost and complication. It further saves design time in that it communicates via UART which is very easy to implement in the controller chosen (PIC18F46J11). The integrated patch antenna can be bypassed if required; the EM-408 has an MMCX connector for an optional external antenna.

7.5.General Design Recommendations

Few changes were needed based off of flaws found in the previous revision. First, the SDA and SCL communication lines were switched on the EEPROM to PIC interface and are corrected in this design. Secondly, the VHF_RX and VHF_TX lines need to be switched to be able to use USART1. Also, a different crystal oscillator was used for the VHF transceiver to account for the required frequency tolerance.

8. Statement of Work

The project will be broken down into seven tasks (Table 27) and every member of the team will contribute to complete these tasks.

Table 27: Tasks to be accomplished

Task 1 - Problem Definition
- Subtask 1.1 - Problem Definition Completion
- Subtask 1.2 - Constraint Identification
- Subtask 1.3 - End User Identification

Task 2 - Technology Research and Selection
- Subtask 2.1 - Communication and Antenna
- Subtask 2.2 – GPS and Antenna
- Subtask 2.3 - Battery
- Subtask 2.4 – Microcontroller Hardware & Software
- Subtask 2.5 – Chassis
- Subtask 2.6 – Network Structure
- Subtask 2.7 - Security

Task 3 - End-Product Design
- Subtask 3.1 - Electrical Hardware
- Subtask 3.2 - Embedded Programming
- Subtask 3.3 - Software Design
- Subtask 3.4 - Chassis

Task 4 - End-Product Prototype Development
- Subtask 4.1 - Acquire Materials for Prototypes
- Subtask 4.2 - Assemble Prototypes

Task 5 - End-Product Testing
- Subtask 5.1 - Test Planning
- Subtask 5.2 - Test Development
- Subtask 5.3 - Test Implementation

Task 6 - Presentations
- Subtask 6.1 - Project Plan
- Subtask 6.2 - Design Review
- Subtask 6.3 - Client
- Subtask 6.4 - Industry Review Panel

Task 7 - Product Documentation
- Subtask 7.1 - Project Plan Development
- Subtask 7.2 - Design Document Development
- Subtask 7.3 - Project Poster
- Subtask 7.4 - Project Final Report Development
- Subtask 7.5 - Weekly Status Email

8.1.Task 1 - Problem Definition

The objective of Task 1 is to clearly define the problem, constraints, and end users that the client has presented. We will meet with the client to fully understand the problem and ask for clarification when needed. At the end of this task, we will clearly understand the client's expectations of the project.

8.1.1. Subtask 1.1 - Problem Definition Completion

The objective of Subtask 1.1 is to clearly define the problem the client has presented. We will approach this task by meeting with the client and performing research on current wildlife tracking methods.

8.1.2. Subtask 1.2 - Constraint Identification

The objective of Subtask 1.2 is to define the constraints of the project. We will approach this task by meeting with the client to identify the constraints of the project.

8.1.3. Subtask 1.3 - End User Identification

The objective of Subtask 1.3 is to identify who will be using the end product. We will approach this task by meeting with the client to discuss the end use of product.

8.2.Task 2 - Technology Research and Selection

The objective of Task 2 is to find the best technology to use in the project. We will approach this task by separating the different technologies among the team and performing research on different options within that technology. After the research has been performed, the results will be present to the team as whole. At the end of this task, we will have the technology selected for the project.

8.2.1. Subtask 2.1 - Communication and Antenna

The objective of Subtask 2.1 is to select the method of communication and corresponding appropriate antenna. The method of communication is the technology that we will use to send the GPS data from the bears to the end user (i.e. VHF, Satellite, ect.). Along with picking the technology, we will decide if we will purchase a module or complete a new hardware design. At the end of the task, we will know the method of communication between the bears and the end user and whether we are designing the communication hardware or purchasing a completed module.

8.2.2. Subtask 2.2 – GPS and Antenna

The objective of Subtask 2.2 is to select the best GPS module and antenna. We will approach this task by researching the different modules and antennas available and picking the best GPS module and antenna for this project.

8.2.3. Subtask 2.3 - Battery

The objective of Subtask 2.3 is to select the best battery technology and vendor for our application. We will approach this task by researching the different battery technologies and vendors and picking the appropriate battery technology.

8.2.4. Subtask 2.4 – Microcontroller Hardware & Software

The objective of Subtask 2.4 is to select the microcontroller, programming hardware and software, and any necessary operating systems needed to run on the microcontroller. Depending on the microcontroller selected, we will decide if external memory will be needed and if so, the appropriate memory will be researched and selected. We will also select the appropriate hardware and software needed to program the microcontroller. Lastly, we will decide if we will need an operating system and if so will pick the best operating system for our project.

8.2.5. Subtask 2.5 – Chassis

The objective of Subtask 2.5 is to select the appropriate material for the chassis. We will research our different options and pick the appropriate material.

8.2.6. Subtask 2.6 – Network Structure

The objective of Subtask 2.6 is to select the appropriate network structure. The network structure includes the protocol that will be used in the wireless communication and how the information will go from the bear to the end user. We will research different methods and pick the appropriate method.

8.2.7. Subtask 2.7 - Security

The objective of Subtask 2.7 is to select the necessary security of the wireless communication to prevent unauthorized access to the transmitted data. We will approach this task by determining the appropriate amount of security and the method to protect the data.

8.3.Task 3 - End-Product Design

The objective of Task 3 is to develop the design of the end-product. The design will be of the unit on the bear and any necessary routers. The design includes both hardware and software. We will approach this task by dividing the necessary work between the members of the team based on expertise and desire to work on a specific task.

8.3.1. Subtask 3.1 - Electrical Hardware

The objective of Subtask 3.1 is to design the electrical hardware of the unit on the bear and any necessary routers. In this task, we will create block diagrams and schematics to show the electrical layout of all the parts. We will run any necessary simulations to test our designs. We will also create the printed circuit board layout which will be used to fabricate the printed circuit board. We will acquire sample parts in order for us to test initial part performance to make sure the part is applicable to our project.

8.3.2. Subtask 3.2 - Embedded Programming

The objective of Subtask 3.2 is to design the logic and structure of the embedded software. We will design the logic structure and necessary configurations needed for our microcontroller on both the unit on the bear and any necessary routers. We will also develop the necessary configurations of any other device in our hardware design. We will start initial coding necessary to perform part performance testing done in Subtask 3.1.

8.3.3. Subtask 3.3 - Software Design

The objective of Subtask 3.3 is to design the necessary software needed to allow the user to obtain the information from the bears on a computer. At the least, the software will allow the user retrieve the raw data from the bear on a computer. If time allows, more sophisticated software may be developed to map the data of each bear on a map.

8.3.4. Subtask 3.4 - Chassis

The objective of Subtask 3.4 is to design the physical layout of the chassis of the unit on the bear and any necessary routers. We will also determine how and where we will be making the chassis.

8.4.Task 4 - End-Product Prototype Development

The objective of Task 4 is to build the necessary prototypes. At the end of this task, we will have created multiple prototypes of our design in Task 3.

8.4.1. Subtask 4.1 - Acquire Materials for Prototypes

The objective of Subtask 4.1 is to create a list of necessary parts and materials to build the prototypes and acquire these parts and materials. This task also includes acquiring any necessary tools needed to build the prototypes.

8.4.2. Subtask 4.2 - Assemble Prototypes

The objective of Subtask 4.2 is to build the prototypes and finish any embedded programming code and end user software. At the end of this task, we will have built prototypes that are programmed and ready for testing.

8.5.Task 5 - End-Product Testing

The objective of Task 5 is to create and implement tests to ensure the end-product meets the necessary functional and non-functional requirements.

8.5.1. Subtask 5.1 - Test Planning

The objective of Subtask 5.1 is to create a list of tests necessary to ensure the end-product meets the necessary requirements. This task includes creating a list of necessary tools needed to perform the tests.

8.5.2. Subtask 5.2 - Test Development

The objective of Subtask 5.2 is to create the test procedures and any test hardware and/or software necessary to accomplish the tests defined in Subtask 5.1.

8.5.3. Subtask 5.3 - Test Implementation

The objective of Subtask 5.3 is to use the tests created in Subtask 5.2 to test the requirements and functionality of the prototypes. The test implementation includes any necessary debugging and modifying of the design in order to successfully fulfill the defined requirements.

8.6.Task 6 – Presentations

The objective of Task 6 is to make the required presentations for the Senior Design course and to demonstrate the end-product to the client.

8.6.1. Subtask 6.1 - Project Plan

The objective of Subtask 6.1 is to create a power point presentation of our project plan and present this presentation to the Senior Design class. The presentation will cover the main aspects of our project plan document.

8.6.2. Subtask 6.2 - Design Review

The objective of Subtask 6.2 is to create a power point presentation of our design and present this presentation to the Senior Design class and review committee. The presentation will cover the main aspects of our design from Task 3.

8.6.3. Subtask 6.3 - Client

The objective of Subtask 6.3 is to demonstrate the end-product to the client. We will demonstrate the capabilities of the end-product and the fulfillment of requirements.

8.6.4. Subtask 6.4 - Industry Review Panel

The objective of Subtask 6.4 is to create a power point presentation of the main aspects of our final end-product and present the presentation to the industry review panel.

8.7.Task 7 - Product Documentation

The objective of Task 7 is to create necessary documentation to plan the project and record the initial and final designs of our end-product.

8.7.1. Subtask 7.1 - Project Plan Development

The objective of subtask 7.1 is to create a document that captures the requirements and plans necessary to create the end-product. The document will guide our decisions in the development of the product.

8.7.2. Subtask 7.2 - Design Document Development

The objective of Subtask 7.2 is to create a document that explains the design of our end-product. The design document describes the logic of our design, how we plan to build our end-product, and how the end-product will operate.

8.7.3. Subtask 7.3 - Project Poster

The objective of Subtask 7.3 is to create a poster to show the development of our end-product. It will show the problem, our solution, and the effort in developing the solution.

8.7.4. Subtask 7.4 - Project Final Report Development

The objective of Subtask 7.4 is to create a final document that records the end-product in both final design and functionality.

8.7.5. Subtask 7.5 - Weekly Status Email

The objective of Subtask 7.5 is to send a weekly status email to all members of the team, our advisor, and the instructors of Senior Design. The emails will include the team's progress for the week, meetings held during the week, plan for the upcoming week, and individual hours worked on the project for the week.

9. Resources and Schedule

We estimate the single unit material cost to be $210 and development labor cost to be $21,380. The development labor costs are being donated by the team, and the material costs are being covered by the client.

Section 9.2 outlines the schedule of the entire project. The schedule consists of all the tasks and subtasks from Section 8.2. The schedule was produced to ensure an on-time completion of the project.

9.1.Resources

Based on initial research and our conceptual diagram, we estimated the unit material cost to be $210 (see Table 28). The unit material cost represents more of a worst case scenario of having to use more expensive technology to achieve the performance. In the design stage, we hope to reduce the single unit cost. The material costs will be covered by the client.

Table 28: Single Unit Estimated Cost

Item	Estimate Cost
VHF Communication	$22.00
VHF Antenna	$5.00
GPS	$100.00
GPS Antenna	$11.00
Battery	$6.00
Microcontroller	$17.00
Connectors	$7.00
Printed Wiring Board	$33.00
Power Electronics	$9.00
Total	$210.00

The development labor hours required to complete the project was 1069 hours (see Table 28). With an hourly rate of $20 per hour, the development labor cost for the project is $21,380. However, for this project, our team will donate the development labor cost. The total cost for the project is $21,800. The total cost includes building two prototypes (see Table 29).

Table 29: Project Costs

Description	Estimated Unit Cost	Estimated Qty	Extended Cost
Prototypes	$210.00	2	$420
Development Labor Costs	$20.00	1069	$21,380
Total			$21,800

9.2.Schedule

A schedule was developed to ensure that the project will be completed on time. The completion date of each subtask was based on datelines given to us by the Senior Design class and the estimated amount of time needed for each task. Figure 48 shows the schedule for the project.

Task Name	Duration	Start	Finish
Problem Definition	**8 days?**	**Thu 9/24/09**	**Mon 10/5/09**
Problem Definition Completion	8 days?	Thu 9/24/09	Mon 10/5/09
Constraint Identification	8 days?	Thu 9/24/09	Mon 10/5/09
End User Identification	8 days?	Thu 9/24/09	Mon 10/5/09
Technology Research and Selection	**28 days?**	**Thu 9/24/09**	**Mon 11/2/09**
Communication and Antenna	8 days?	Thu 9/24/09	Mon 10/5/09
GPS and Antenna	8 days?	Thu 9/24/09	Mon 10/5/09
Battery	28 days?	Thu 9/24/09	Mon 11/2/09
Microcontroller Hardware & Software	8 days?	Thu 9/24/09	Mon 10/5/09
Chassis	28 days?	Thu 9/24/09	Mon 11/2/09
Network Structure	18 days?	Thu 9/24/09	Mon 10/19/09
Security	28 days?	Thu 9/24/09	Mon 11/2/09
End-Product Design	**31 days?**	**Mon 10/5/09**	**Mon 11/16/09**
Electrical Hardware	31 days?	Mon 10/5/09	Mon 11/16/09
Embedded Programming	31 days?	Mon 10/5/09	Mon 11/16/09
Software Interface	31 days?	Mon 10/5/09	Mon 11/16/09
Chassis	11 days?	Mon 11/2/09	Mon 11/16/09
End-Product Prototype Development	**76 days?**	**Mon 11/16/09**	**Mon 3/1/10**
Acquire Materials for Prototype	41 days?	Mon 11/16/09	Mon 1/11/10
Assemble Prototype	36 days?	Mon 1/11/10	Mon 3/1/10
End-Product Testing	**121 days?**	**Mon 11/2/09**	**Mon 4/19/10**
Test Planning	11 days?	Mon 11/2/09	Mon 11/16/09
Test Development	16 days?	Mon 1/11/10	Mon 2/1/10
Test implementation	56 days?	Mon 2/1/10	Mon 4/19/10
Presentations	**158 days?**	**Thu 9/24/09**	**Mon 5/3/10**
Project Plan	4 days?	Thu 9/24/09	Tue 9/29/09
Design Review	6 days?	Mon 11/9/09	Mon 11/16/09
Client	6 days?	Mon 4/12/10	Mon 4/19/10
Industry Review Panel	11 days?	Mon 4/19/10	Mon 5/3/10
Product Documentation	**158 days?**	**Thu 9/24/09**	**Mon 5/3/10**
Project Plan	12 days	Thu 9/24/09	Fri 10/9/09
Design Document	11 days?	Mon 11/16/09	Mon 11/30/09
Project Poster	11 days?	Mon 3/29/10	Mon 4/12/10
Project Final Report	16 days	Mon 4/12/10	Mon 5/3/10
Weekly Status Emails	158 days?	Thu 9/24/09	Mon 5/3/10

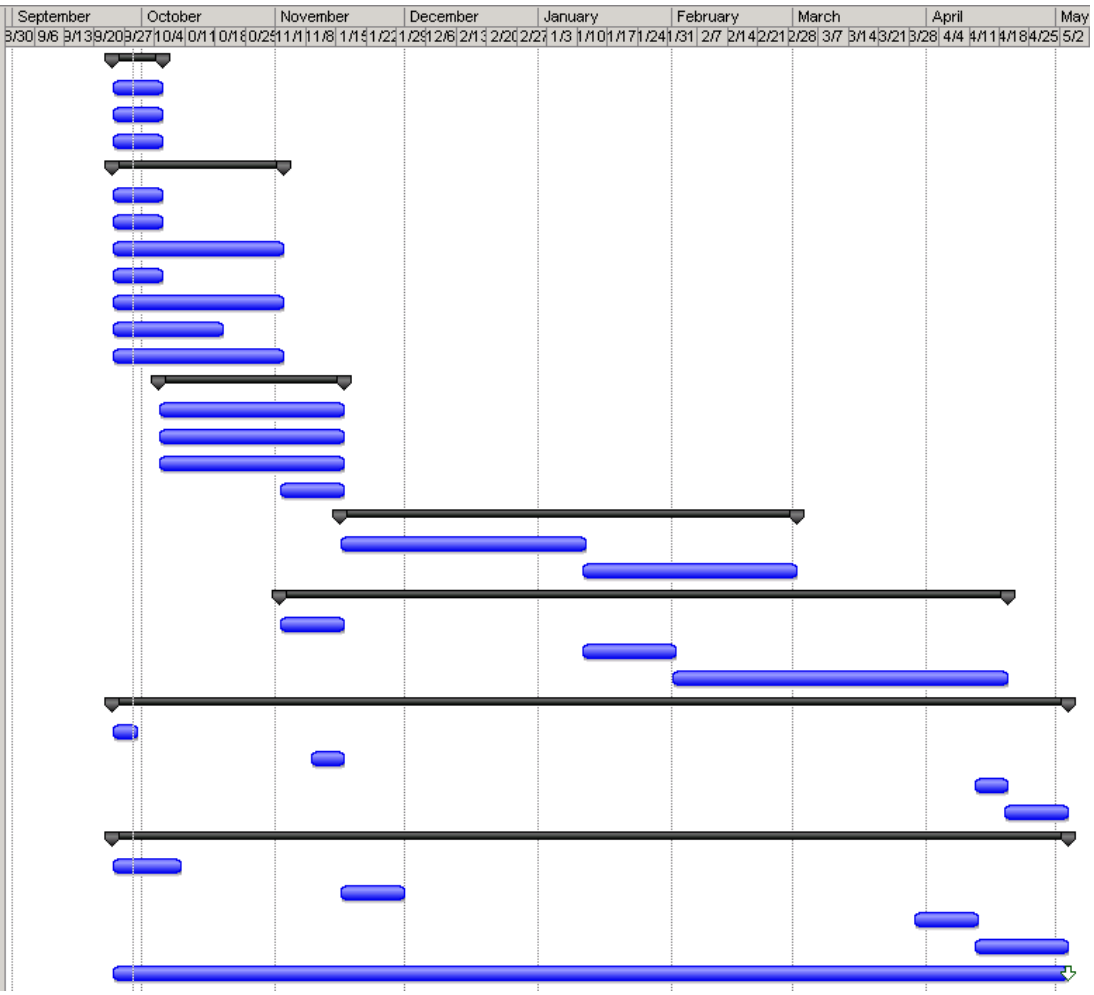


Figure 48: Schedule for Project

10.Closure Material

Outlined in this section is the contact information of the client, faculty advisor, and student team. The closure material also contains a brief summary of the project plan.

10.1. Project Contact Information

The following contains the contact information of the client, faculty advisor, and student team.

10.1.1. Client Information

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10.1.2. Faculty Advisor Information

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10.1.3. Student Team Information

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10.2. Closing Summary

Digi International has presented a problem to our team to find an effective method of tracking the location of bears in Northern Minnesota. With current products being expensive, we will provide cheaper end-product that will provide nearly live location information of bears when possible for researchers who use our end-product. At a unit material cost of $210 and development labor costs of $21,380, we have provided a proof of concept for Digi International that meets their requirements for the project.

Due to the complexity of this project, we strongly recommend that this project be continued for a second phase.

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Operation Manual of the System

Senior Design 491

Joe Lane

April 23, 2010

Project title: Wireless Mesh Bear Tracking
Project team: Zach Bruce – team leader, Blane Chesnut – Webmaster, Chris Donnelly, John Pritchard – Communications Liaison, Adam Rasmussen, Dr. Ahmed E. Kamal – Advisor, Mark Tekippe (Digi International) – Client.

1 High-level Objective

Wirelessly track the location and movements of black bears for the researchers at the Wildlife Research Institute. To improve the efficiency and cost of the research the team is tasked with replacing the current scheme of scanning large forested areas manually with a system that can relay data off-site via cell or satellite.

2 Key Functional Requirements

- Point location every 15 minutes
- Weatherproof device
- Tough shell that will withstand bear cub jaws
- 25 by 10 mile signal coverage

3 State of Implementation

The team has a working prototype board with all hardware included. The parts on the board are a PIC microcontroller, GPS device, external EEPROM memory, radio transceiver, radio switch, power amplifier, power supply section. At our meeting they had everything confirmed working with the exception of the GPS device.
The team has also implemented a debugging program on the microcontroller that enables

them to connect a computer to the prototype board and harvest debugging information. Also they have fabricated a 1/4th wave antenna.

4 System Setup

- Open MPLAB
- Plug in programmer and connect to it
- Verify no errors occurred
- `Programmer→Build All` , to compile program
- Verify no errors occurred
- `Programmer→Program`, to load program onto microcontroller
- Verify no errors occurred
- Plug in power supply
- Plug in USB cable from computer to board
- Check that board power and USB LED is lit
- On computer find the port that the FTDI chip uses as virtual com port
- Connect to found serial port with putty @ 2400 baud
- Send "+++" to enter debug mode
- Turn 3.3v line on with (b) option
- Enable transceiver with (f) option
- Put in transmit mode with (l) option

5 Tests observed

I observed the setup of the system to transmit as outlined in the System Setup section. I also observed a picture of the radio spectrum that they are operating on collected by a spectrum analyzer. They have also seen successful modulation of data and the transceiver successfully demodulate the data. They have verified that the power supply has a voltage ripple of less than 50mV P-P which is within specifications of chosen transceiver. The group has had successful writes to the external EEPROM memory chip.

6 Critique

6.1 Strengths and Weaknesses

- Programmed debugging functionality into microcontroller code
- Careful layout of component sections in prototype board
- Could be hard to debug some features
- Implementing media access control manually

6.2 Does the Implementation Meet Specification

Of what the group has accomplished so far I believe that they are within spec. They have included all the necessary hardware to fulfill the requirements of their project. However it is to earlier in the project as a whole to tell if what they will do in the future will be able to fulfill the other requirements such as range since it is currently to early to test.

6.3 Suggestions

I really admire this group and have little suggestions for them other than maybe they could have thought about using a transceiver that would have been easier to work with as far as media access control and such.

Wireless Bear Tracking
Senior Design Group MAY10-10
Team: Blane Chesnut, Chris Donnelly,
Adam Rasmussen, John Pritchard, Zach Bruce
Advisor: Dr. Ahmed E. Kamal
Client: Digi
Auhor: Jamin Hitchcock

1 Overview

The Wireless Bear Tracking project's goal is to design a system to track the location of bears in the wild. The system uses GPS to determine the bear's location and a VHF transmitter to send data to recievers. The system would be built into a collar worn by the bears.

2 Requirements

The main functional requirements are that the unit must be able to recieve GPS data to determine the bears location. The unit must be able to transmit that data to a reciever so that they can be used by researchers. The battery life of the unit must be at least 3 months. The unit must send location data to the reciever at least once every 15 minutes. The physical dimensions of the device cannot exceed 3.7" x 2.6" x 1".

3 Implementation

So far a test board has been designed and assembled for the bear tracking unit. The board consists of 6 main sections. The PIC microcontroller section has the microcontroller that acts as the main controller of all other systems on the board. The EEPROM section has an EEPROM chip to provide extra memory. The VHF section controls the sending and recieving of data over the VHF wireless signal. The GPS section houses the GPS chip which processes GPS location data. The power section handles converting the 6V DC input to the various voltages required by the system components. The USB section has a USB controller that allows the PIC to be accessed from a computer.

The team has also written the software for the PIC microcontroller that controls the system. The software allows the controller to turn power on and off to parts of the board. It also controls the wireless transciever and GPS. The controller provides an interface through the USB so that a user can issue commands to the microcontroller.

Currently the power, USB, PIC, and EEPROM sections are working. Additional debugging is needed for for transceiver and GPS sections.

4 System Setup

The following instructions explain how to set up and test the USB interface to the PIC controller.

1. Start the MPLAB software on the computer. MPLAB is the integrated development environment for the PIC microcontroller.
2. Plug the programmer cable into the board.
3. In MPLAB connect to the board by selecting Programmer→Connect.
4. Build the project by selecting Project→Build All.
5. Program the microcontroller by selecting Programmer→Program.
6. Unplug the programmer cable from the board.
7. Plug in the 6V DC power cable. Verify the board has power by observing the small green LED.
8. Plug the USB cable into the board.
9. Open a terminal program such as HyperTerminal or Putty on the computer.
10. Look up the COM port of the USB on the computer.
11. Set the speed in the terminal to 2400 Baud.
12. Log in to the PIC by sending three "+" characters.
13. The menu presented shows the various commands that can be sent to the controller.
14. To start transceiver mode turn on the 3.3V line by selecting option b. Verify the 3.3V line is on by making sure he green LED near it is on.
15. Enable the transceiver with option f.
16. Set transceiver mode with option m.

5 Testing

After the board was assembled important traces were observed using the oscilloscope to verify the behavior was correct. The oscilloscope was also used to ensure the transceiver was properly modulating and demodulating data. The power line was tested to make sure the ripple was within $50mV$ peak to peak also using an oscilloscope. The antennae connector was hooked up to a spectrum analyzer to test the functioning of the transceiver.

6 Project Critique

The projects strengths were:

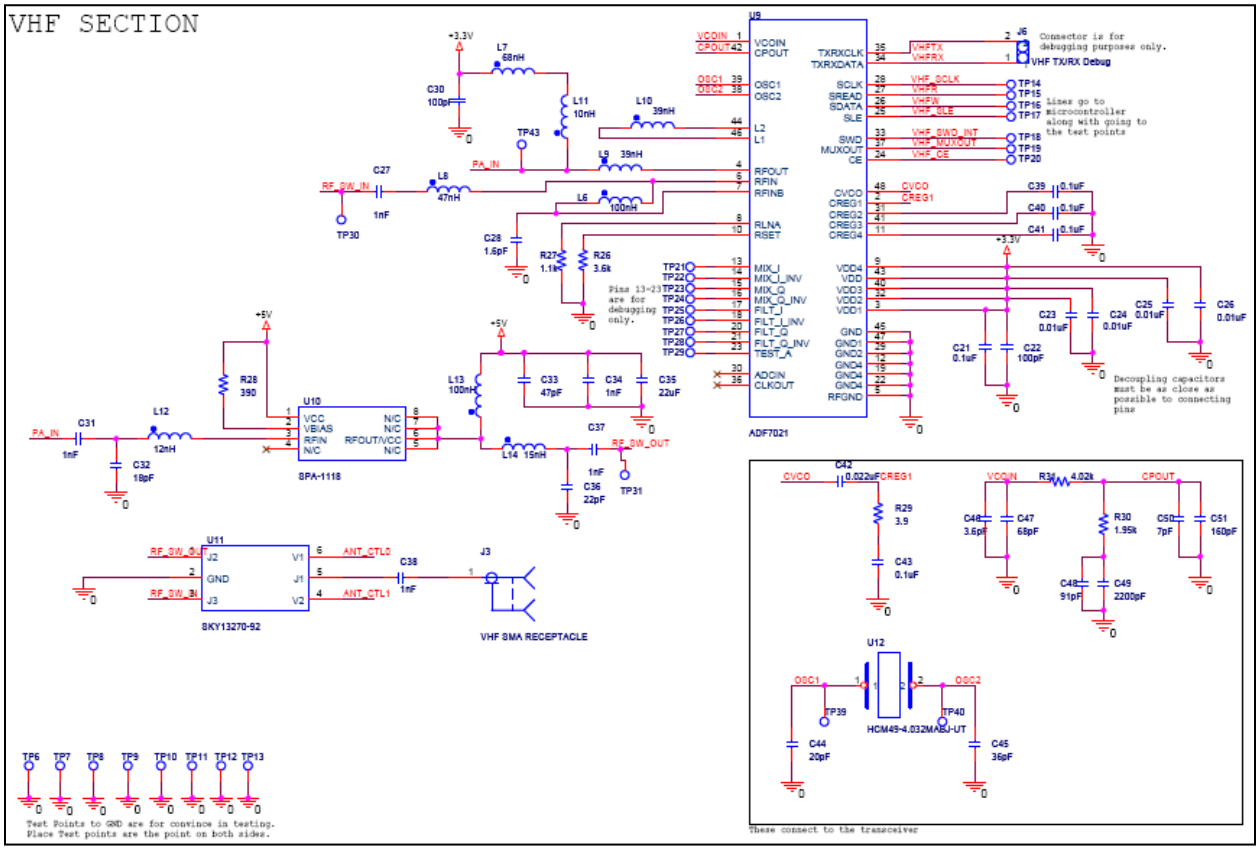
- The design is thoroughly documented.
- The sytem was designed in a modular fashion with each subsytem clearly separated on the board.

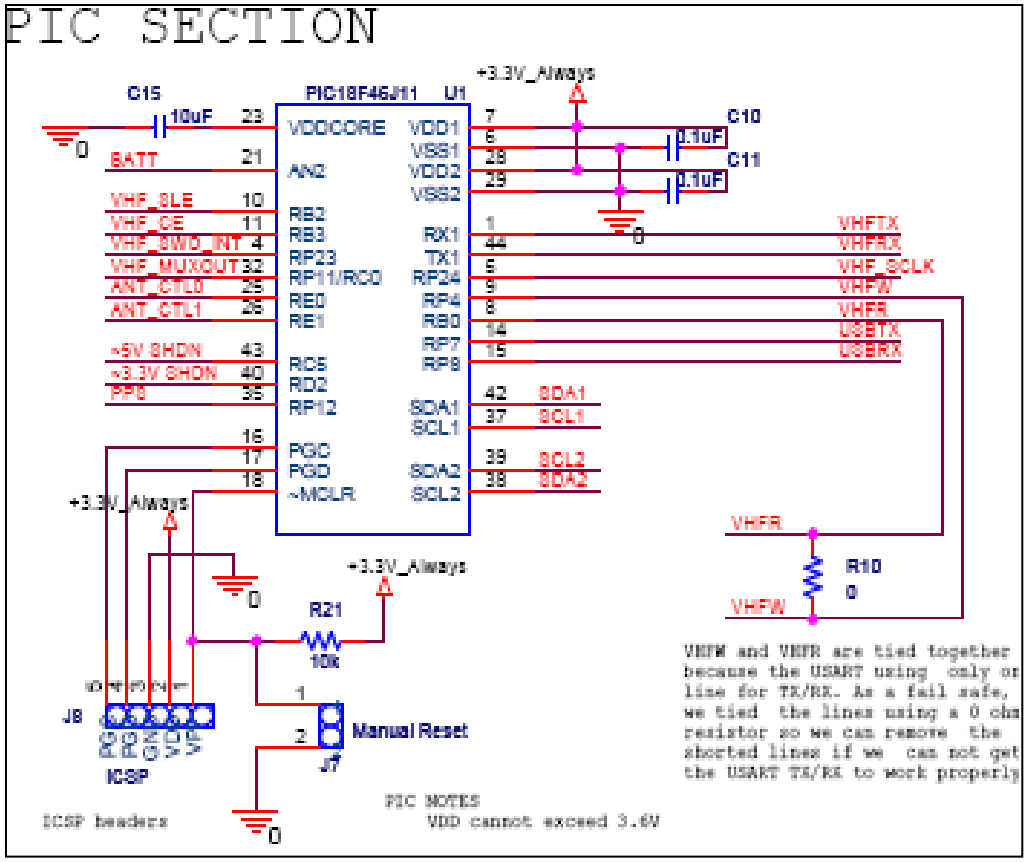
The projects weaknesses were:

- The requirements could have been more quantifiable. For example the team could have specified under what conditions the system could be expected to work in, the number of devices the receiver should be able to handle, and what level of EM radiation is safe for humans and bears.

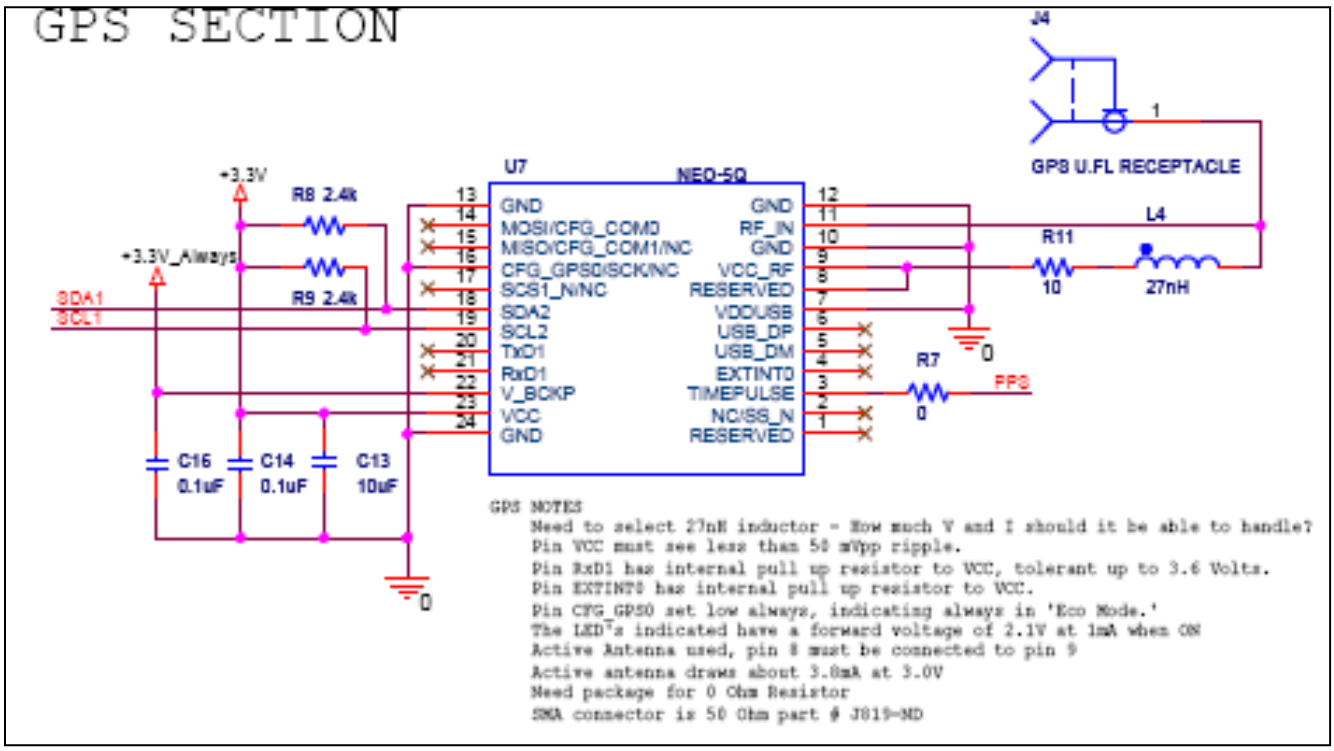
Currently the system has all the components necessary to meet the specifications of the project. The transceiver and GPS modules are not functioning yet and additional debugging is needed before the system will work. Once those problems are identified and fixed the system should be able to meet all the requirements.

Appendix 3: VHF and Power Amplifier Revision A Schematic

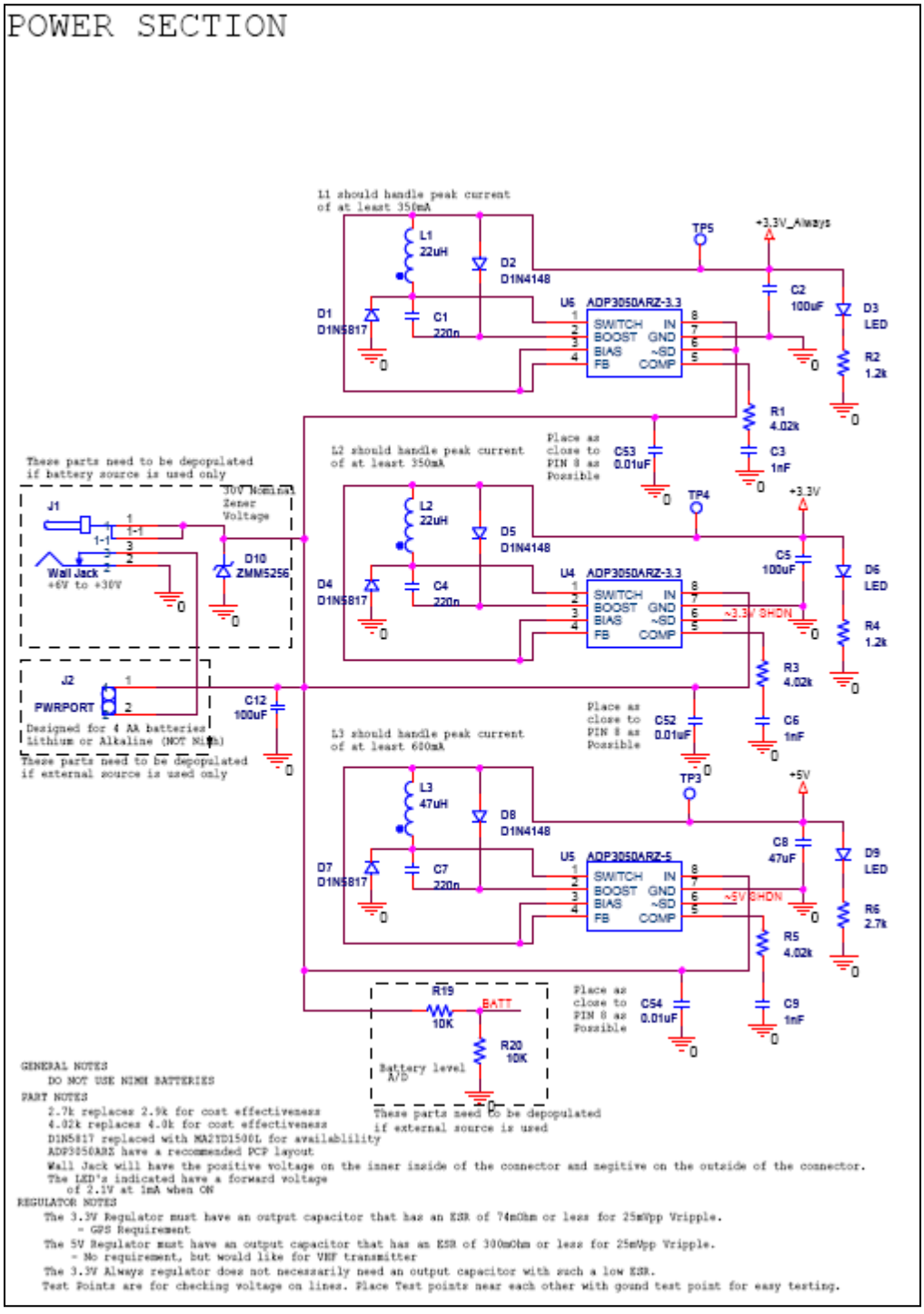



PIC SECTION
PIC18F46J11 U1
C15
10uF
BATT
VHF_BLE
VHF_CE
VHF_SWD_INT
VHF_MUXOUT
ANT_CTL0
ANT_CTL1
~5V SHDN
~3.3V SHDN
PPS
VDDCORE
AN2
RB2
RB3
RP23
RP11/RC0
RE0
RE1
RC5
RD2
RP12
PGC
PGD
~MCLR
VDD1
VSS1
VDD2
VSS2
RX1
TX1
RP24
RP4
RB0
RP7
RP8
SDA1
SCL1
SDA2
SCL2
+3.3V_Always
C10
0.1uF
C11
0.1uF
VHFTX
VHFRX
VHF_SCLK
VHFW
VHFR
USBTX
USBRX
SDA1
SCL1
SCL2
SDA2
VHFR
R10
0
VHFW
R21
10k
J8
ICSP
Manual Reset
J7
ICSP headers
PIC NOTES
VDD cannot exceed 3.6V
VHFW and VHFR are tied together because the USART using only on line for TX/RX. As a fail safe, we tied the lines using a 0 ohm resistor so we can remove the shorted lines if we can not get the USART TX/RX to work properly

Appendix 5: GPS Revision A Schematic



Appendix 6: Power Supply



Appendix 7: PCB Layout Layers

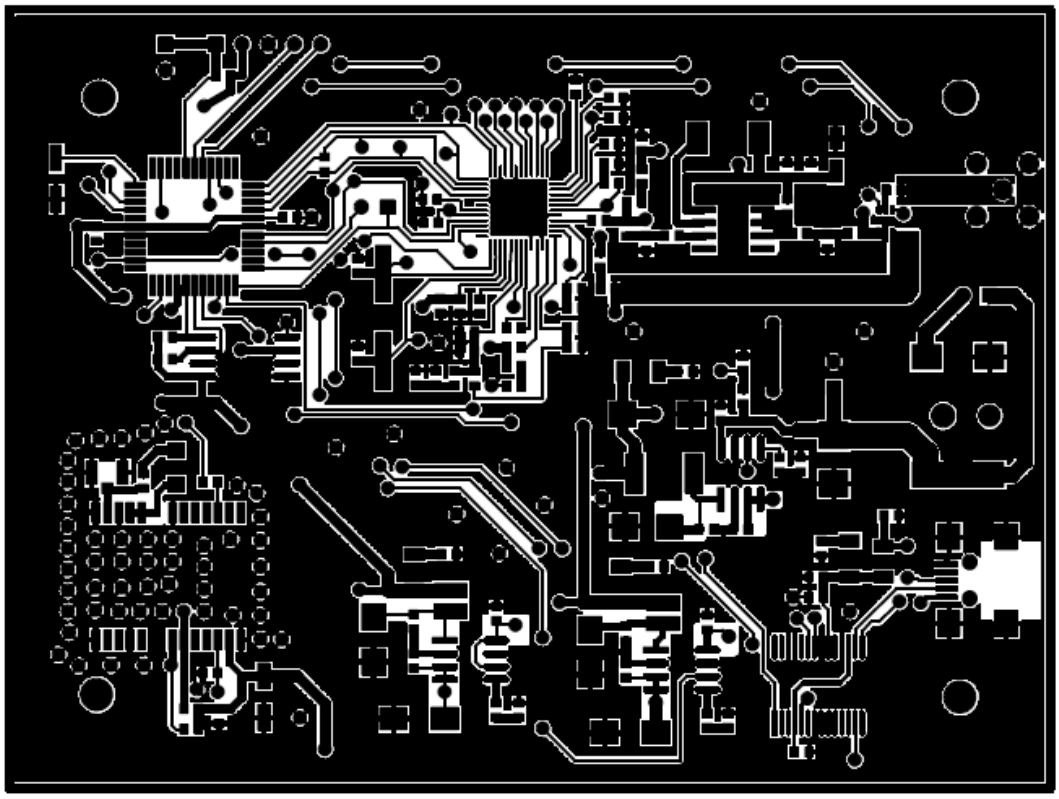


Figure 49: Top Copper Layer

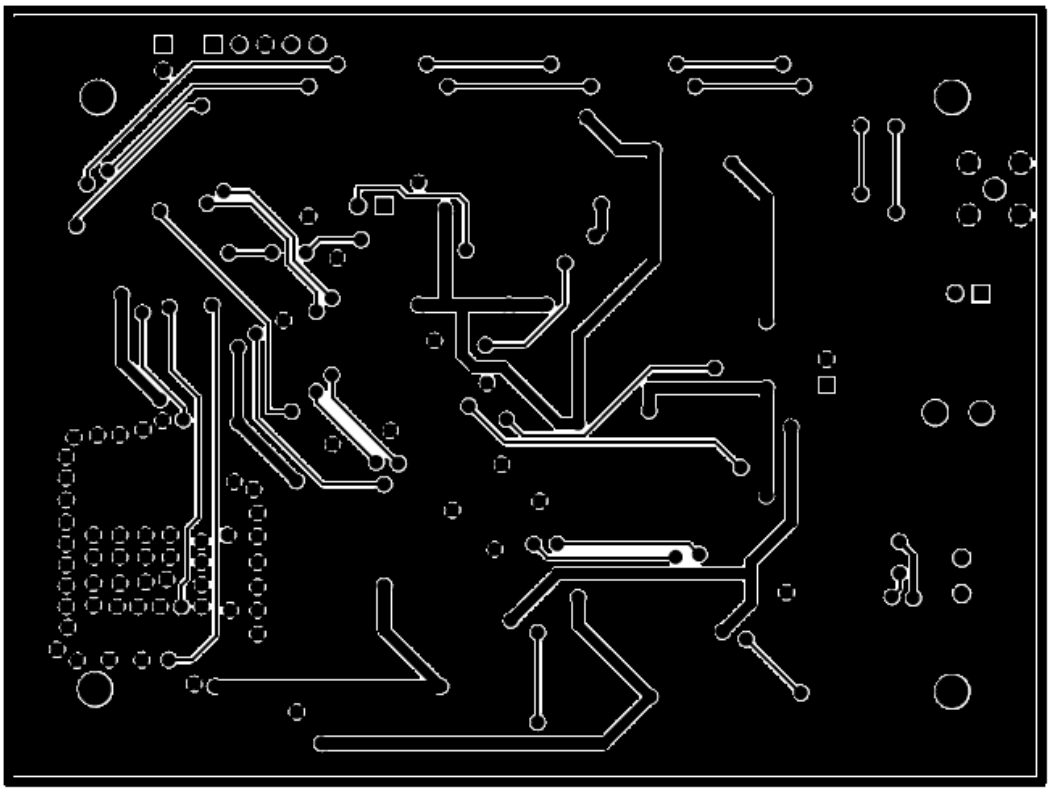


Figure 50: Bottom Copper Layer

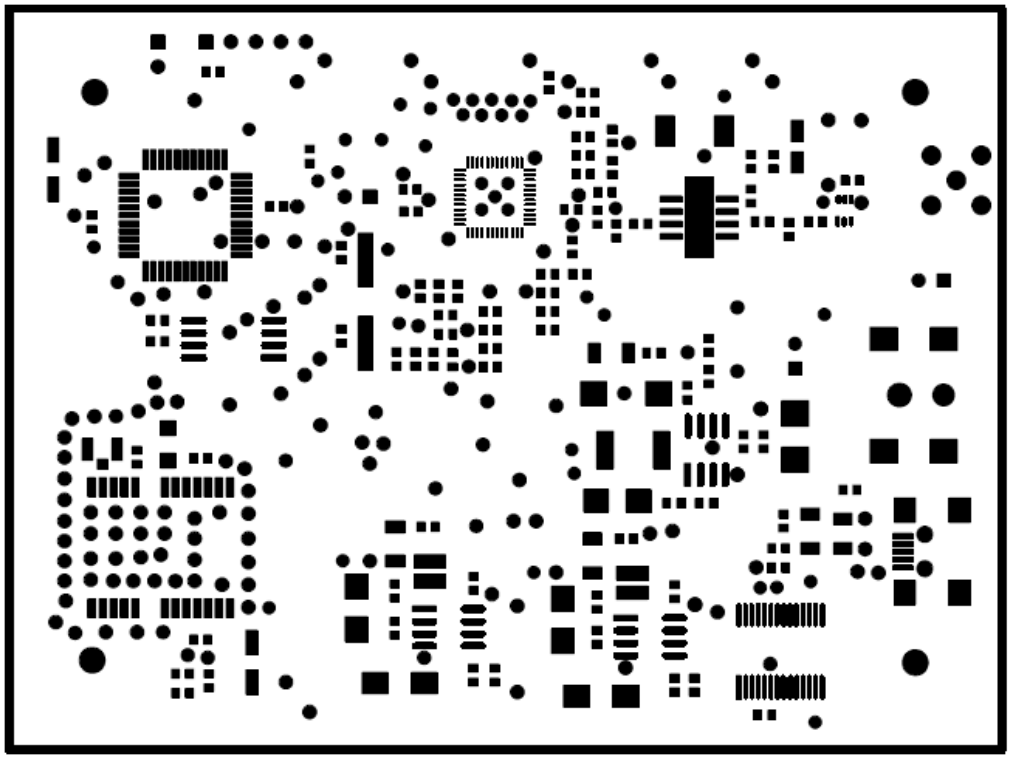


Figure 51: Top Solder Mask

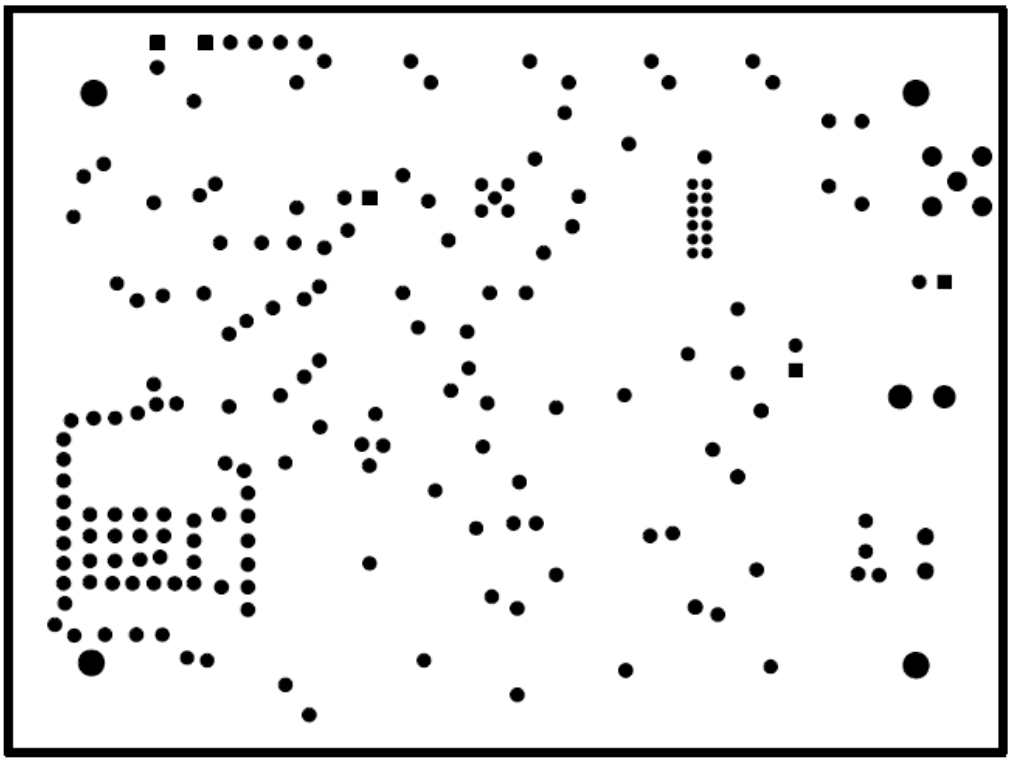


Figure 52: Bottom Solder Mask

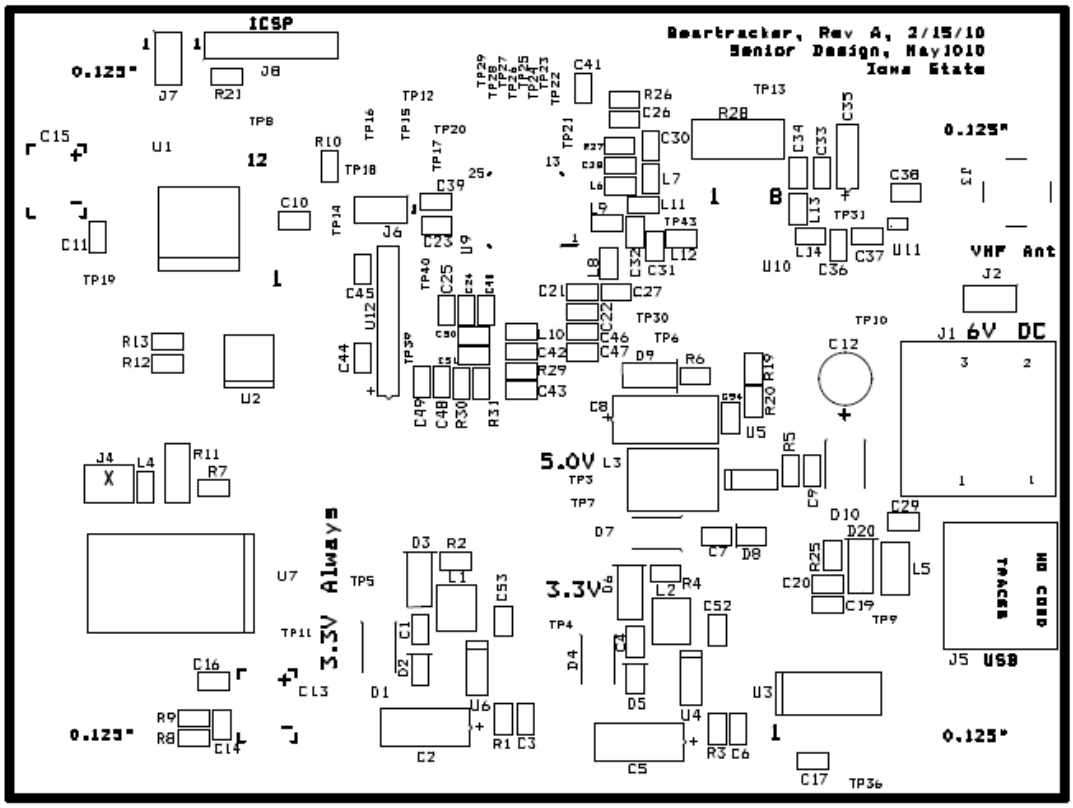


Figure 53: Top Silk Screen

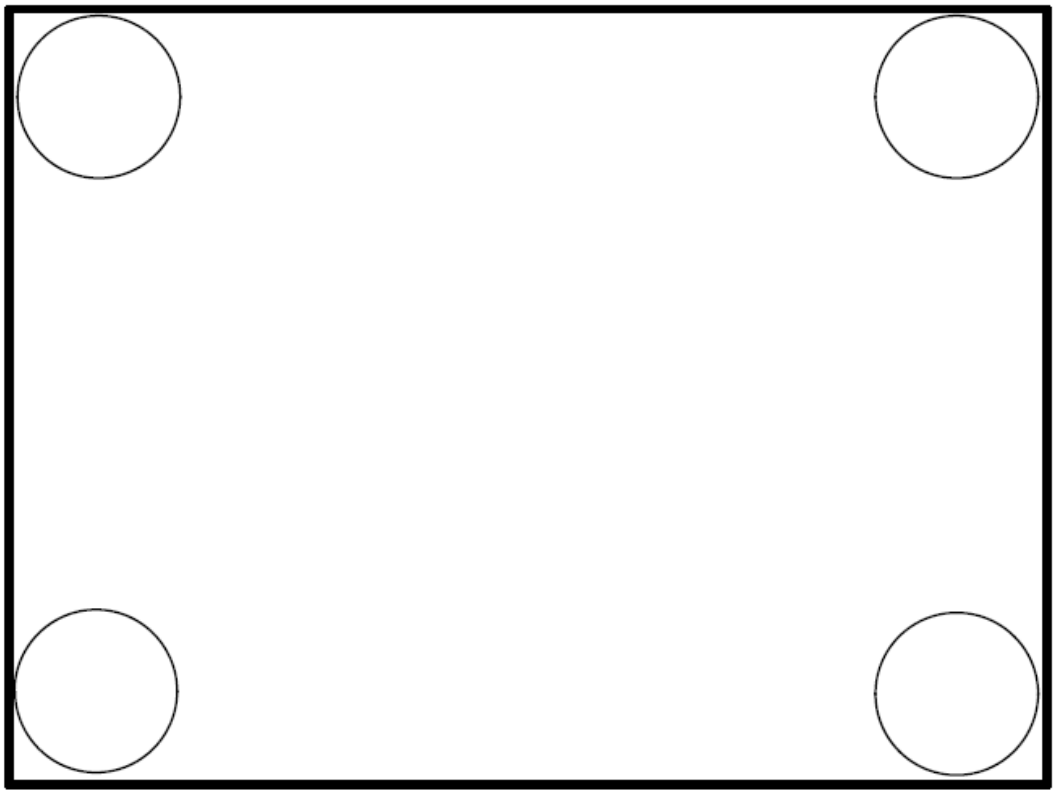
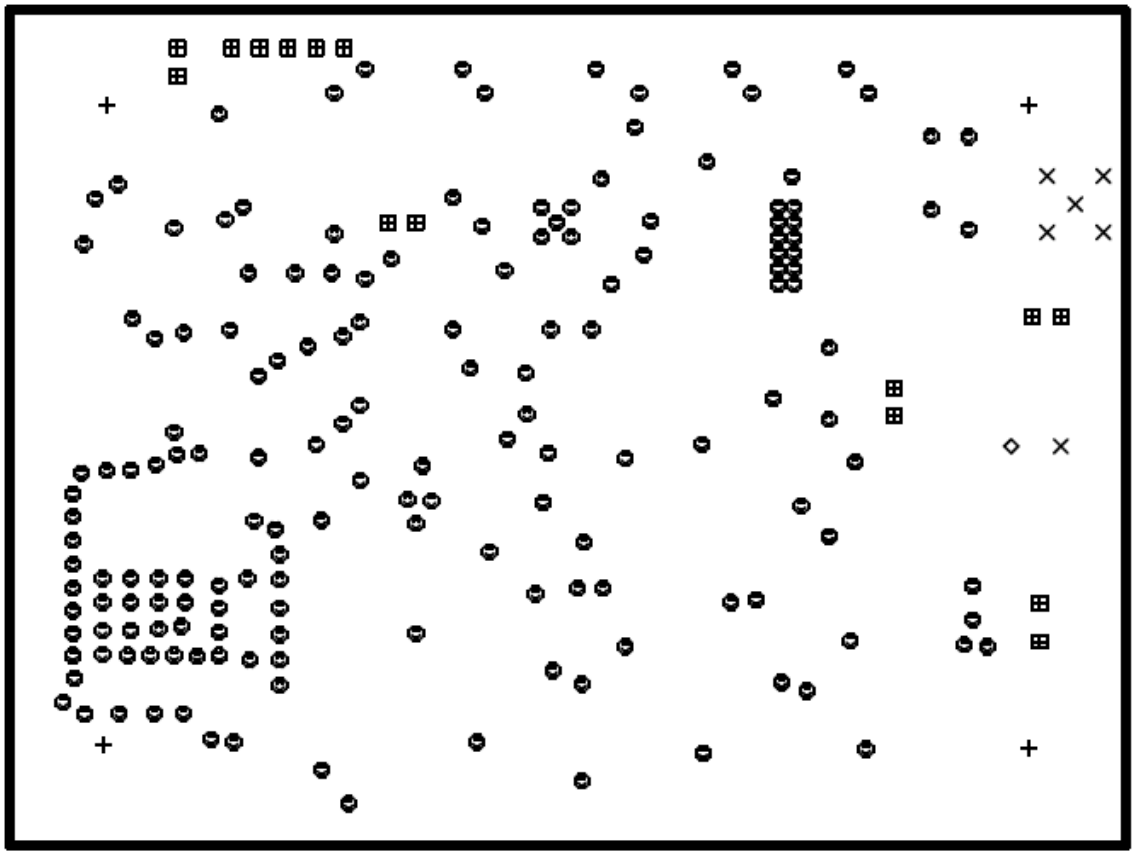


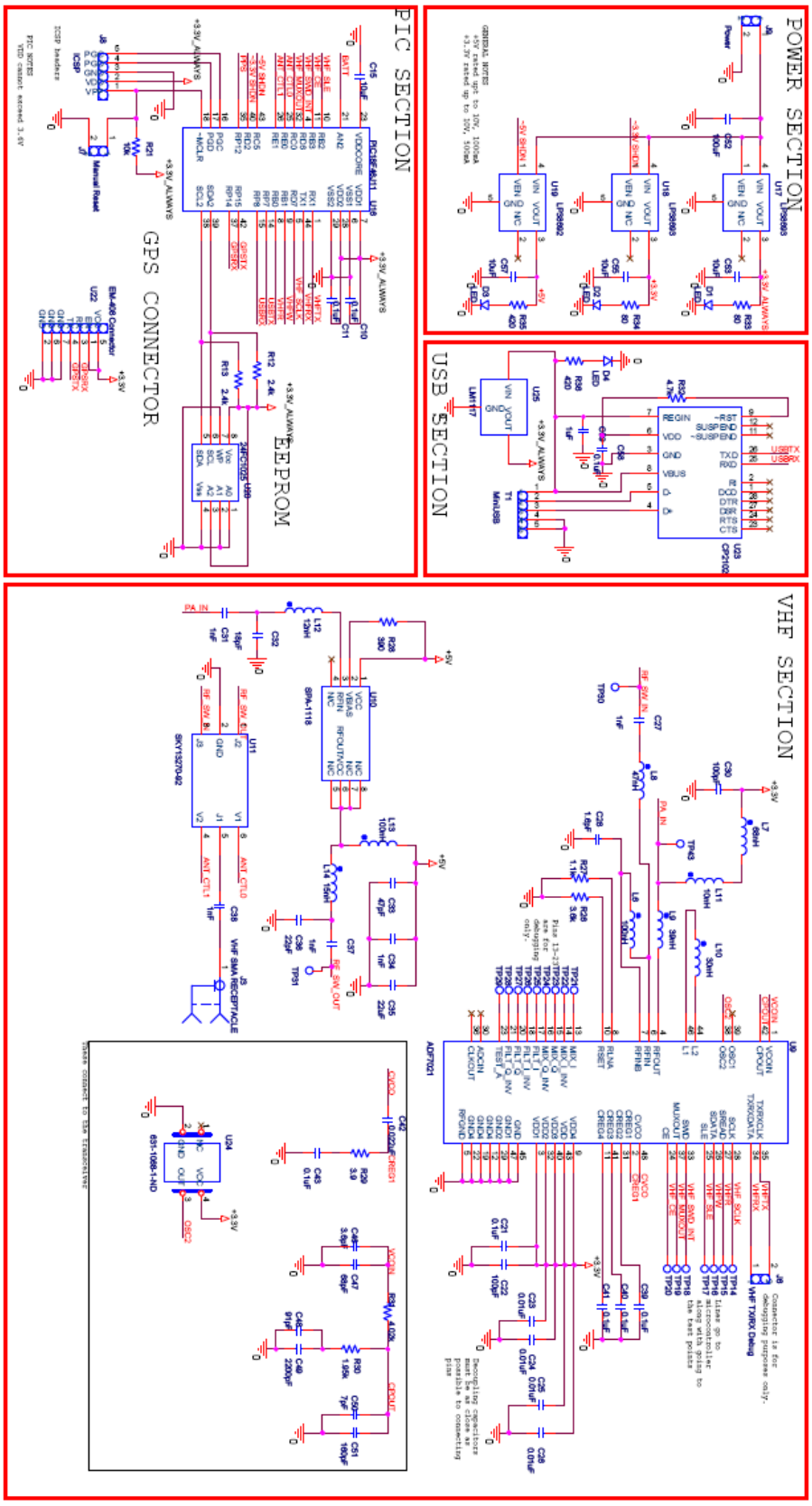
Figure 54: Bottom Silk Screen



DRILL CHART				
SYM	DIAM	TOL	QTY	NOTE
⊖	0.028		168	
⊞	0.035		15	
×	0.063		6	
◇	0.071		1	
+	0.125		4	
TOTAL			194	

Figure 55: Drill Chart

Appendix 8: Revision B Schematic



Appendix 9: PC Code

```
import os,urllib
import serial

while 1:
    addr = ''
    #Set up serial port
    ser = serial.Serial(port=7, baudrate=2400, bytesize=serial.EIGHTBITS,
parity=serial.PARITY_NONE,stopbits=serial.STOPBITS_ONE,timeout=None,
xonxoff=0, rtscts=0, interCharTimeout=None)
    addr=ser.read(size=25)

    #addr = raw_input('\nAddress or (Lat,Long): ')
    if addr <> '':
        url = ''
        if addr[0]=='(':
            center = addr.replace('(','').replace(')','')
            lat,lng = center.split(',')
            url = 'http://maps.google.com/maps?q=%s+%s' % (lat,lng)
        else:
            # Encode query string into URL
            url = 'http://maps.google.com/?q=' + urllib.quote(addr) +
            '&output=js'
            print '\nQuery: %s' % (url)

            # Get XML location
            xml = urllib.urlopen(url).read()

            if '<error>' in xml:
               print '\nGoogle cannot interpret the address.'
            else:
                # Strip lat/long coordinates from XML
                lat,lng = 0.0,0.0
                  center = xml[xml.find('{center')+13:xml.find('}
            ',xml.find('{center'))]
                center = center.replace('lat:',' ').replace('lng:',' ')
                lat,lng = center.split(',')
                url = 'http://maps.google.com/maps?q=%s+%s' % (lat,lng)

        if url<>'':
            print 'Map: %s' % (url)
            os.startfile(url)

    ser.flush()
    ser.flushInput()

    ser.close()
```

Appendix 10: PIC Code – main.c

```
//====================deep_sleep.c=====================================//
//    file: deep_sleep.c                                              //
//    author: John Pritchard                                          //
//    project: Bear Tracker Project                                   //
//    date: Spring 2010                                               //
//                                                                    //
//    Desc: This file configures and initializes the PIC18F26J11. Its   //
//    purpose right now is to serve as a template for the TDMA          //
//    networking scheme. This program initializes the PIC, sets a time//
//    interval, then sleeps for that interval. The PIC then wakes,      //
//    flashes a set of LEDs, then goes back to sleep.                   //
//====================================================================//
#include "main.h"
#include "datatypes.h"
#include "interrupts.h"
#include "init.h"
#include "handler.h"
#include "user.h"
#include "encoding.h"
#include "ublox_read.h"
#include "gps_i2c.h"
#include "eeprom_i2c.h"
#include <string.h>


//Set configuration bits (see datasheet for details)
#if defined(__18F26J11) || defined(__18F46J11)
#pragma config WDTEN = OFF, XINST = OFF, OSC = INTOSC
#pragma config T1DIG = ON, LPT1OSC = OFF, DSWDTOSC = INTOSCREF
#pragma config RTCOSC = INTOSCREF, DSBOREN = ON, DSWDTEN = ON
#pragma config DSWDTPS = DSPER, FCMEN = OFF, IESO = OFF
#endif


#define ON 1
#define OFF 0
#define TX 1
#define RX 2
#define VHF 0
#define USB 1

//used for testing purposes to determine the transmission error rate
int error=0,trans=0;
```

```
/*-----------Main ----------------------------------------------------/
*     function: main()                                                *
*                                                                     *
*     desc: This is the main function that initializes registers        *
*     required for the PIC to function properly. It also is where the*
*     deep sleep wakeup is checked. If is just powering up (for the     *
*     first time), then it did not wake from a deep sleep and will      *
*     perform normal Power On Reset (POR) actions. If the PIC wakes     *
*     from being in deep sleep, logic is set in place to determine      *
*     the proper course of action.                                      *
*                                                                     *
/---------------------------------------------------------------------*/
void main(void)
{
      int activate_chk = 0;

      //Do some initialization maintenance first.+
      osc_init();       //do this first
      io_init();        //do this before any com port inits


      //activate_chk = ds_handler();      //Run DS handler to see if normal
POR or deep sleep POR
      activate_unit();
      if(activate_chk == 1)               //If it is a pure POR, do this...
      {
            Write_DSGPR(0x00,0x00);       //write zeros to the registers that
retain values in deep sleep. We will store counter data here.
            maintenance();                      //perform first startup
maintenance
            go_to_sleep();                      //call the "go_to_sleep"
function in the handler file
      }
      if(activate_chk == 2)               //If it is a deep sleep increment
wake (multiple of a DSWDT postscalar), do this...
      {
            go_to_sleep();
      }
      if(activate_chk == 3)               //If it is a deep sleep final wake
(final multiple of a DSWDT postscalar), do this...
      {
            activate_unit();
      }
      else
            Nop();
      while(1);
      return;
}
```

```
/*-----------Activate Unit-----------------------------------------/
*     function: activate_unit()                                    *
*                                                                  *
*     desc: This function serves to manage the unit's activities once   *
*     it is fully awake. This means that in this function the unit      *
*     will receive GPS data, manipulate it, and send it to the          *
*     transceiver. Future activities will need to be implemented.       *
*                                                                  *
/------------------------------------------------------------------*/

void activate_unit(void)
{



//    KEEP THESE NEXT TWO LINES. Write zeros to the registers that retain
values in deep sleep. We will store counter data here.
//    Write_DSGPR(0x00,0x00);
//    go_to_sleep();

      return;

}

//Used for Demo, makes the unit a transmitter only
void TX_unit(){
      unsigned int k;

//    gps_i2c_init();   //initializes the GPS

      while(1){
            //Get GPS data and send it
            VHF_TX_Mode();

            //Delay to allow time for the power amplifier to cool down
            for(k = 0; k < 30000; k++); //delay
            for(k = 0; k < 30000; k++); //delay
      }
}

void RX_unit(void){
      unsigned char valid = 0;
      signed long lat=0, lon =0;    //latitude and longitude
      unsigned long time = 0;       //Time in ms of week
      unsigned char status=0, ID;   //Status byte and ID of unit
      int k,i;

      //Configures the PIC for transciver RX mode
      syc_eusart2VHF_remap(RX);
      syc_eusart2_init(RX);

      //Turns on the 3.3 line and makes sure the 5V line is OFF
      power_33(ON);
      power_5(OFF);

      //turns on the transceiver and switches the RF switch to RX mode
```

```
	vhf_trx(ON);
	switch_ctrl(RX);

	//Delay to allow the transciever to power up
	for(k = 0; k < 90; k++); //delay for ~3.6 ms

	//Configures the receiver to RX mode
	vhf_init(RX);

	while(1){
		//configures transciever in RX mode and waits until data is
received
		valid = VHF_RX_Mode();
		trans++;

		//Checks to see if valid data is available. 1 = Valid data
		if(valid==1){

			//Gets the decoded lat, lon, time, status, and ID
			lat = get_lat();	//gets the latitude
			lon = get_lon();	//gets the longitude
			time = get_time();		//gets the time
			status = get_status();	//gets the status
			ID = get_ID();			//gets the ID

			//sets up the port for USB interface
			eusart2USB_remap();
			eusart2_init(USB);

			//Sends the Data to the PC for mapping to google maps
			gps_map(lat,lon);

			syc_eusart2VHF_remap(RX);
			syc_eusart2_init(RX);

		}else{
			error++;
		}
		if(trans==20)
			trans = trans;
	}
}
```

```
/*-----------Maintenance-----------------------------------------------/
*     function: maintenance()                                          *
*                                                                  *
*     desc: This function serves to perform maintenance at final wake.*
*     Duties include checking if all peripherals are not faulty and     *
*     also setting the required startup registers for the peripherals.*
*                                                                      *
/---------------------------------------------------------------------*/

void maintenance(void)
{
      Nop();
      return;
}


void tx_test(void){

      int k;

      syc_eusart2VHF_remap(TX);
      syc_eusart2_init(TX);

      power_33(ON);
      power_5(ON);
      vhf_trx(ON);
      switch_ctrl(TX);

      for(k = 0; k < 90; k++); //delay for ~3.6 ms
      vhf_init(TX);
      for(k = 0; k < 20; k++); //delay 0.840 ms

            send_eusart2(0xAA);
            send_eusart2(0xAA);
            send_eusart2(0xAA);
            send_eusart2(0xAA);
            send_eusart2(0xAA);
            send_eusart2(0xAA);
            send_eusart2(0xAA);
            send_eusart2(0xBA);
            send_eusart2(0xD5);
            send_eusart2(0xAC);
            send_eusart2(0xAD);
            send_eusart2(0xAE);
            send_eusart2(0xAF);
            send_eusart2(0x55);
            while(!TXSTA2bits.TRMT);
            for(k = 0; k < 8000; k++); //delay 0.840 ms

            power_5(OFF);
            vhf_trx(OFF);


      return;
}
```

```
void rx_test(void){

	int k;
	int i=0, j=1;
	float temp=0;
	long Silicon_Rev;
	float AFC[10];
	float Avg_AFC=0;

	syc_eusart2VHF_remap(RX);
	syc_eusart2_init(RX);

	power_33(ON);
	power_5(OFF);
	vhf_trx(ON);
	switch_ctrl(RX);

	for(k = 0; k < 90; k++); //delay for ~3.6 ms
	vhf_init(RX);

	while(1){
		//Find_RX_Data();
		AFC[i] = VHF_AFC_RB();
		Avg_AFC = (Avg_AFC + AFC[i])/2;

		j++;
		i++;
		if (i==10)
			i=0;
		if(j==600){
			j = 0;
			Avg_AFC = 0;
		}
		for(k = 0; k < 1000; k++);
	}
	return;
}
*/
```

Appendix 11: PIC Code – main.h

```
#ifndef _MAIN_H_
#define _MAIN_H_

/*=====================================================;
;   Deep Sleep Watchdog Postscaler :                                  ;
;     DSWDTPS = 2          1:2 (2.1 ms)                          ;
;     DSWDTPS = 8          1:8 (8.3 ms)                          ;
;     DSWDTPS = 32         1:32 (33 ms)                          ;
;     DSWDTPS = 128        1:128 (132 ms)                        ;
;     DSWDTPS = 512        1:512 (528 ms)                        ;
;     DSWDTPS = 2048       1:2,048 (2.1 seconds)           ;
;     DSWDTPS = 8192       1:8,192 (8.5 seconds)           ;
;     DSWDTPS = K32        1:32,768 (34 seconds)           ;
;     DSWDTPS = K131       1:131,072 (135 seconds)         ;
;     DSWDTPS = K524       1:524,288 (9 minutes)           ;
;     DSWDTPS = M2         1:2,097,152 (36 minutes)   ;
;     DSWDTPS = M8         1:8,388,608 (2.4 hours)         ;
;     DSWDTPS = M33        1:33,554,432 (9.6 hours)   ;
;     DSWDTPS = M134       1:134,217,728 (38.5 hours) ;
;     DSWDTPS = M536       1:536,870,912 (6.4 days)   ;
;     DSWDTPS = G2         1:2,147,483,648 (25.7 days);
=====================================================*/

#include "p18cxxx.h"
#include "dpslp.h"
#include "datatypes.h"
#define TRUE 1
#define DSPER 32        //this is the sleep period postscalar



//Function Prototypes
void activate_unit(void); //the function that activates all peripheral
functionality
void maintenance(void);
void TX_unit(void);     //for demo purposes
void RX_unit(void);     //for demo purposes
void tx_test(void);     //testing purposes only
void rx_test(void);     //testing purposes only


#endif
```

Appendix 12: PIC Code – init.c

```
//====================init.c=========================================//
//    file: deep_sleep.c                                             //
//    author: John Pritchard                                              //
//    project: Bear Tracker Project                                  //
//    date: Spring 2010                                                   //
//                                                                        //
//    Desc: This file initializes all ports needed                   //
//                                                                        //
//====================================================================//
#include "p18cxxx.h"
#include "init.h"
#include "datatypes.h"
#include "handler.h"


//----->this function remaps the eusart2 pins to RP7(RX) and RP8(TX)<-----//
void eusart2USB_remap(void)
{
      //************************************
      // Unlock Registers
      //************************************
      _asm
      MOVLB 0x0E
      MOVLW 0x55
      MOVWF EECON2, 0
      MOVLW 0xAA
      MOVWF EECON2, 0
      BCF PPSCON, 0, BANKED
      _endasm
      //***************************
      // Configure Input Functions
      // (See Table 9-13)
      //***************************
      //***************************
      // Assign RX2 To Pin RP7
      //***************************
      _asm
      MOVLW 0x07
      MOVWF RPINR16, BANKED
      _endasm
      //***************************
      // Configure Output Functions
      // (See Table 9-14)
      //***************************
      //***************************
      // Assign TX2 To Pin RP8
      //***************************
      _asm
      MOVLW 0x05
      MOVWF RPOR8, BANKED
      _endasm
      //************************************
      // Lock Registers
      //************************************
      _asm
      MOVLW 0x55
```

```
	MOVWF EECON2, 0
	MOVLW 0xAA
	MOVWF EECON2, 0
	BSF PPSCON, 0, BANKED
	_endasm

	return;
}

//Maps the programmable pins to be set up for VHF Syncrounous TX/RX
void syc_eusart2VHF_remap(byte mode)
{
	//*************************************
	// Unlock Registers
	//*************************************
	_asm
	MOVLB 0x0E
	MOVLW 0x55
	MOVWF EECON2, 0
	MOVLW 0xAA
	MOVWF EECON2, 0
	BCF PPSCON, 0, BANKED
	_endasm
	//****************************
	// Configure I/O Functions
	// (See Table 9-13)
	//****************************

	if(mode ==1){	//TX Mode
		//Assigns Pin 44 as the TX data line for USART 2
		//Assigns Pin 1, RP18 as input clock for USART 2
		_asm
		MOVLW 0x06
		MOVWF RPOR17, BANKED

		MOVLW 0x12
		MOVWF RPINR17, BANKED
		_endasm
	}
	else{		//RX Mode
		//Assigns External Interrupt 1 to Pin 4, RP23 for SWD
		//Assigns External Interrupt 2 to Pin 1, RP18 for CLK
		_asm
		MOVLW 0x17
		MOVWF RPINR1, BANKED

		MOVLW 0x12
		MOVWF RPINR2, BANKED
		_endasm
	}

	//*************************************
	// Lock Registers
	//*************************************
	_asm
	MOVLW 0x55
	MOVWF EECON2, 0
```

```
      MOVLW 0xAA
      MOVWF EECON2, 0
      BSF PPSCON, 0, BANKED
      _endasm

      return;
}

//----->this function sets up all regesters required for eusart2 transmission
and reception<-----//
void eusart2_init(byte mode)
{
      if(mode == 1){SPBRG2 = 25;}               //Baud rate (25 = 2400 baud)
- (Use SYNC=0,BRGH=0,BRG16=0 to determine SPBRG2
      if(mode == 0){SPBRG2 = 207;}        //Baud rate (207 = 300 baud) - (Use
SYNC=0,BRGH=0,BRG16=0 to determine SPBRG2
                                          //Keep below 9600 for an accurate
reading
      BAUDCON2bits.TXCKP = 0;
      TXSTA2bits.SYNC = 0;    //Required for TX/RX setup
      TXSTA2bits.TXEN = 1;    //enable transmission
      RCSTA2bits.SPEN = 1;    //Required for TX/RX setup

      PIE3bits.TX2IE = 0;           //No transmission interrupts
      PIE3bits.RC2IE = 1;           //Set receive interrupts
      IPR3bits.RC2IP = 1;           //set receive interrupt as high prioity
      INTCONbits.GIEL = 1;    //Enable global low priority interrupts
      INTCONbits.GIEH = 1;    //Enable global high priority interrupts

      RCSTA2bits.CREN = 1;    //RX setup

      TRISCbits.TRISC6 = 1;   //Set RX pin as input
      TRISCbits.TRISC7 = 0;   //Set TX pin as output

      return;

}

//Sets up the registers of the pic to be used for Syncrounous TX/RX
void syc_eusart2_init(byte mode){

      if(mode == 1){          //TX MODE
            TRISCbits.TRISC7 = 1;   //Set CLK pin as input
            TRISCbits.TRISC6 = 0;   //Set TX pin as output

//          BAUDCON2bits.TXCKP  = 0;      //1= noninverted, 0= inverted

            TXSTA2bits.SYNC = 1;    //Synchronous mode
            RCSTA2bits.SPEN = 1;    //Enables serial port
            TXSTA2bits.CSRC = 0;    //Slave mode

            RCSTA2bits.CREN = 0;    //disables continuous receive
            RCSTA2bits.SREN = 0;    //don't care

            PIE3bits.TX2IE = 0;           //No transmission interrupts
            TXSTA2bits.TXEN = 1;    //enables transmission
```

```
      }else if(mode ==2){           //RX Mode

//These settings are used for Ayscrounous Transmission and are not need at
this time for Syncrous transmission
/*          TRISCbits.TRISC7 = 1;   //Set CLK pin as output
            TRISCbits.TRISC6 = 1;   //Set RX pin as output

            BAUDCON2bits.RXDTP      = 0;        //received data is inverted
from transciever (active-low)

            TXSTA2bits.SYNC = 1;    //Synchronous mode
            RCSTA2bits.SPEN = 1;    //Enables serial port
            TXSTA2bits.CSRC = 0;    //Slave mode

            PIE3bits.RC2IE = 1;           //Set receive interrupts
            IPR3bits.RC2IP = 1;           //set receive interrupt as high
prioity
            INTCONbits.GIEL = 1;    //Enable global low priority interrupts
            INTCONbits.GIEH = 1;    //Enable global high priority interrupts

            RCSTA2bits.CREN = 1;    //enables continous recieve mode
*/

            //These settings are used for syncrounous transmission

            TRISCbits.TRISC7 = 1;   //Set CLK pin as input
            TRISCbits.TRISC6 = 1;   //Set RX pin as input

            INTCONbits.GIE = 1;           //enable global intrrupts
            INTCONbits.PEIE = 0;    //disables perpheral interrupts

            INTCON2bits.INTEDG1 = 1;      //INT 1, rising edge
            INTCON2bits.INTEDG2 = 1;      //INT 2, rising edge

            INTCON3bits.INT1IP = 1;       //INT 1, High prioity
            INTCON3bits.INT2IP = 1;       //INT 2, High prioity

            INTCON3bits.INT1IF = 0;       //INT 1, Flag clear
            INTCON3bits.INT2IF = 0;       //INT 2, Flag clear

            INTCON3bits.INT1IE = 1;       //INT 1, Enable
            INTCON3bits.INT2IE = 0;       //INT 2, Disables, This gets
enabled when SYNC word is detected

            //initizlies global variables from handler.c
            global_var_init();

      }
      return;
}


//----->this function sets the required oscillator registers<-----//
void osc_init(void)
{
```

```
      OSCCONbits.IRCF2 = 1;   //these three bits control osc freq (see
datasheet)
      OSCCONbits.IRCF1 = 1;   //bits 111 equate to an 8MHz osc freq
      OSCCONbits.IRCF0 = 0;   //bits 110 equate to an 4MHz osc freq

      return;
}

//----->this function sets the required input/output registers<-----//
void io_init(void)
{
      TRISBbits.TRISB0 = 1;   //VHF Read Line
      TRISBbits.TRISB1 = 0;   //VHFW Line
      TRISBbits.TRISB2 = 0;   //VHF_SLE Line
      TRISBbits.TRISB3 = 0;   //VHF_CE Line
      TRISCbits.TRISC0 = 1;   //VHF_MUXOUT Line, input
      TRISCbits.TRISC5 = 0;   //5V Shutdown Line
      TRISDbits.TRISD2 = 0;   //3.3V Shutdown Line
      TRISDbits.TRISD6 = 1;   //VHF_SWD_INT Line
      TRISDbits.TRISD7 = 0;   //VHF_SCLK Line
      TRISEbits.TRISE0 = 0;   //ANT_CTL0 Line
      TRISEbits.TRISE1 = 0;   //ANT_CTL1 Line

      ANCON1bits.PCFG12 = 1;  //makes RB0 a digital port and not an analog
port

      LATCbits.LATC0 = 0;
      LATCbits.LATC5 = 0;
      LATBbits.LATB1 = 0;
      LATBbits.LATB2 = 0;
      LATBbits.LATB3 = 0;
      LATDbits.LATD2 = 0;
      LATDbits.LATD6 = 0;
      LATDbits.LATD7 = 0;
      LATEbits.LATE0 = 0;
      LATEbits.LATE1 = 0;
      return;
}

//This procedure configures the transciever in eithr TX or RX mode
//by writing to the appropriate registers as defined in the Final Document
void vhf_init(byte mode)
{
      byte txrx_mode = mode;

      //These register values are used for asyncrounous transmission
/*    long reg_1 = 0x21A1091;//0x21B9011;CP high current //0x21A1091;(clock)
//0x21A1011;(no clock)
      long reg_3 = 0x28A34883;
      long reg_0_TX = 0x11AEA140;//0x11AFFFF0;//0x11AEA140; //195 MHz
      long reg_2 = 0x22749BC2;//0x2277FBC2; //max power //0x22749BC2; //0 dBM

      long reg_6 = 0x3661E3F6;
      long reg_5 = 0xA35;
      long reg_0_RX = 0x59AEA140; //digital_lock_ready //0x99AEA140;
      long reg_4 =0x8010CA14;//k=10, dis_BW=50 // 0x8011AA94; //k=21
```

```
      long reg_10 = 0x4B97043A;//0x3C97043A;//30 kHZ // 0x3297043A;  // MAX-
AFC at 25kHZ //0x4B97043A; //AFC at 37.5kHz
//    long reg_15 = 0x4000F; //for testing purposes only
*/

      //These register values are used for Syncrounous transmssion
      //See Final Document for Details in the values

      //These registers are used for both TX and RX
      long reg_1 = 0x21A1091;//0x21B9011;CP high current //0x21A1091;(clock)
//0x21A1011;(no clock)
      long reg_3 = 0x28A34883;

      //these register are used for TX only
      long reg_0_TX = 0x1AEA140;//regulator ready on mux out//0x11AEA140;
//195 MHz //0x1B00000; //no factional N value //
      long reg_2 = 0x43A5B82;//not inverted,fdev 8.30kHz, 18
power//0x22725B82; //inverted power 18 //0x22749B82; //inverted 36
power//0x22749B92; //36 power Guassian //0x22749BD2;//inverted, raised Cosine
// 0x225C9B92; //inverted Guassian with FX devivation 0.25*300 =
75//0x22749B82;

      //These Registers of used for RX only
      long reg_6 = 0x3661E3F6;
      long reg_5 = 0xA35;
      long reg_11 = 0x5DAB5B; //not inverted sync word 1 error//0x5DAB9B;
//bad5 not inverted 2 errors//0xA2549B; //2 errors allowed,BAD5 inverted
//0xA2545B; //1 errors allowed
      long reg_12 = 0x13AC; //packet length of 19 //0x5AC; //packet length of
5
      long reg_0_RX = 0x49AEA140;//Syncronice MoDE// //digital_lock_ready
//0x99AEA140;  //0x9B00000;//no fractional N value;
      long reg_4 = 0x8010F014; //k=12,fdev=8.30k //0x8011AA94; //k=21
IFBW=25k//0x4011AA94;//k=21 IFbW =18.5k //0x11AA94; //k=21, IFBW =
12.5kHz//0x10CA14; //k=10,IFBW=12.5k //0x8010CA14; //k=10, dis_BW=50
      long reg_10 = 0x897043A; //4kHz
//0x4697043A;//AFC=35k//0x1897043A;//12kHz 0x1497043A;//10kHz //0x1097043A;
//AFC at 8k range //0x3297043A; //AFC at 25 kHz range// 0x2097043A; //AFC
16kHz//0x4B97043A; //AFC at 37.5kHz //0x3C97043A;//30 kHZ // 0x3297043A;  //
MAX-AFC at 25kHZ

      int k;

      if(txrx_mode == 1){
            //Do TX mode configuration here
            send_gpio(reg_1);
            for(k = 0; k < 37; k++); //delay 0.840 ms
            send_gpio(reg_3);
            send_gpio(reg_0_TX);
            for(k = 0; k < 2; k++); //delay for ~80 us
            send_gpio(reg_2);
            for(k = 0; k < 170; k++); //delay for ~3.6 ms
      }
      if(txrx_mode == 2){
            //Do RX mode configuration here
            send_gpio(reg_1);
            for(k = 0; k < 37; k++); //delay 0.840 ms
```

```
            send_gpio(reg_3);
            send_gpio(reg_6);
            send_gpio(reg_5);
            for(k = 0; k < 340; k++); //delay for ~6.2 ms
            send_gpio(reg_11);
            send_gpio(reg_12);
            send_gpio(reg_0_RX);
            for(k = 0; k < 2; k++); //delay for ~80 us
            send_gpio(reg_4);
            send_gpio(reg_10);
            for(k = 0; k < 340; k++); //delay for ~6.2 ms
      }
      return;
}

/*************************************************************************
/* OLD FUNCTIONS Not Used at the moment
/*************************************************************************

//----->this function sets up all regesters required for eusart1 transmission
and reception<-----//
void eusart1_init(void)
{
      SPBRG1 = 207;                 //Baud rate (207 = 300 baud) - (Use
SYNC=0,BRGH=0,BRG16=0 to determine SPBRG1)
      TXSTA1bits.SYNC = 0;    //Required for TX/RX setup
      RCSTA1bits.SPEN = 1;    //Required for TX/RX setup

      PIE1bits.TX1IE = 0;           //No transmission interrupts
      PIE1bits.RC1IE = 1;           //Set receive interrupts
      INTCONbits.GIEL = 1;    //Enable global low priority interrupts
      INTCONbits.GIEH = 1;    //Enable global high priority interrupts

      RCSTA1bits.CREN = 1;    //RX setup

      TRISCbits.TRISC7 = 1;   //Set RX pin as input
      TRISCbits.TRISC6 = 0;   //Set TX pin as output
      return;
}


//----->this function remaps the eusart2 pins to RP17(RX) and RP18(TX) for
asyncrounous<-----//
void eusart2VHF_remap(void)
{
      //*************************************
      // Unlock Registers
      //*************************************
      _asm
      MOVLB 0x0E
      MOVLW 0x55
      MOVWF EECON2, 0
      MOVLW 0xAA
      MOVWF EECON2, 0
      BCF PPSCON, 0, BANKED
      _endasm
      //**************************
```

```
        // Configure Input Functions
        // (See Table 9-13)
        //**************************
        //**************************
        // Assign RX2 To Pin RP17
        //**************************
        _asm
        MOVLW 0x11
        MOVWF RPINR16, BANKED
        _endasm
        //**************************
        // Configure Output Functions
        // (See Table 9-14)
        //**************************
        //**************************
        // Assign TX2 To Pin RP18
        //**************************
        _asm
        MOVLW 0x05
        MOVWF RPOR18, BANKED
        _endasm
        //************************************
        // Lock Registers
        //************************************
        _asm
        MOVLW 0x55
        MOVWF EECON2, 0
        MOVLW 0xAA
        MOVWF EECON2, 0
        BSF PPSCON, 0, BANKED
        _endasm

        return;
}
*/
```

Appendix 13: PIC Code – init.h

```
//Define variables
#define VHFREGLEN 32
#include "datatypes.h"

//Define prototypes

void eusart2_init(byte mode);
void eusart2USB_remap(void);
void syc_eusart2VHF_remap(byte mode);
void syc_eusart2_init(byte mode);
void osc_init(void);
void io_init(void);
void vhf_init(byte mode);
extern void send_gpio(long reg_val);



/*************************************
/* Old Functions currently not in use
/*************************************
void eusart1_init(void);
void eusart2VHF_remap(void);


*/
```

Appendix 14: PIC Code – datatypes.h

```
#ifndef _DATATYPES_H_
#define _DATATYPES_H_
typedef unsigned char byte;
#endif
```

```
//====================data_handler.c================================//
//    file: datahandler.c                                          //
//    author: John Pritchard                                 //
//    project: Bear Tracker Project                          //
//    date: Spring 2010                                            //
//                                                                 //
// functions:                                                      //
//                                                                 //
//    Desc: This file contains all functions that handle    data    //
//                                                                 //
//=================================================================//
#include "p18cxxx.h"
#include "dpslp.h"
#include "handler.h"
#include "datatypes.h"
#include "encoding.h"
#include "init.h"
#include "ublox_read.h"
#include "gps_i2c.h"

#define ON 1
#define OFF 0
#define TX 1
#define RX 2
#define VHF 0
#define USB 1

void reset_buff2(void);
#define BUFFSIZE 50

//Global variables
int count1, count2;

//These global variables are used in receiving the VHF data
int VHF_bit_count=0, VHF_byte_count=0;          //keeps track of how many VHF
RX bits and bytes stored
static byte VHF_buff[VHF_BUFFSIZE];             //Contains the RX data
//byte *VHF_buff_end = VHF_buff+VHF_BUFFSIZE;
byte *VHF_rx = VHF_buff;                              //pointer to the array
unsigned char VHF_data_ready = 1;                     //polling variable to
determine if valid data is in the VHF_Buff Array

//These global variables contain the most valid decoded RX data
signed long lat=0, lon =0;    //latitude and longitude
unsigned long time = 0;       //Time in ms of week
unsigned char status=0, ID=0; //Status byte and ID of unit

extern byte *rx2;
extern byte eusart2_buff[BUFFSIZE];

//Global structures used in deep sleep library
SRC ptr;
CONTEXT read_state;

/*-----------Deep Sleep Handler-----------------------------------/
*     functions: (none declared)                                  *
```

```
*                                                                     *
*     desc: This function handles deep sleep functionality. If the    *
*     PIC has woken from a deep sleep, then a counter is incremented. *
*     Once the counter has completed, decisions are made on when to   *
*     activate the unit.                                              *
*                                                                     *
/---------------------------------------------------------------------*/
//void ds_handler(void)
int ds_handler(void){
      int dpslpevent = 0;           //this variable determines what the
source of deep sleep wakeup is

      //Check if the device is waking up from deep sleep, else, it must be a
normal power on reset
      if(IsResetFromDeepSleep()==0xFF){                          //if this
is the reset after the deep_sleep wakup...then do this
            dpslpevent = dpslp_chk();
      //determine the wakeup source
            if(dpslpevent == 1){                                       //if
wakeup source is from watchdog timer, do this...
                  if(DSGPR1==SCALAR2 && DSGPR0==SCALAR1){        //once the
count registers hit a desired point, do something
                        Write_DSGPR(0x00,0x00);
      //reset the counter data
                        return(3);
                  }
                  else
                        return(2);
            }
            if(dpslpevent == 2){
      //if wakeup source is from deep sleep fault, do this...
                  Nop();
            }
      //FAULT RECOVERY LOGIC NEEDED!!! (change this...)
            else
                  Nop();
      }
      else
            return(1);
}

/*-----------Deep Sleep Source Checke-------------------------------/
*     functions: dpslp_chk(),                                         *
*                                                                     *
*     desc: This function is called after a decision is made about    *
*     the type of wakeup (either normal POR or from deep sleep). It   *
*     then determines the wakeup source. It is supposed to be woken   *
*     up by the watchdog timer. Anything else would be because of a   *
*     fault or special case.                                          *
*                                                                     *
/---------------------------------------------------------------------*/

int dpslp_chk(void)
{
      extern int count1, count2;
      ReadDSGPR(&read_state);             //Read the deep sleep GPR
```

```
      DeepSleepWakeUpSource(&ptr);  //Check the deep sleep wakup soruce (if
required)
      ReleaseDeepSleep();                        //Release the Deep sleep (IO
configuration)
      TRISBbits.TRISB1 = 0;               //configure the IO [TRIS and LAT
register] to output ssignal for LED

      if( (read_state.Reg0!=count1) || (read_state.Reg1!=count2) )
      //count1 and count2 represents the state of device before going to deep
sleep
      {
            while(1)
                  Nop();            //this indicates an error has occurred
while in deep sleep
      }
      if(ptr.WK_SRC.DS_WDT==TRUE)
            return 1;   //deep sleep wakeup source is DSWDT
      if(ptr.WK_SRC.DS_FLT==TRUE)
            return 2;   //deep sleep wakeup source is Falut in deep sleep
configuration
      else
            return 0;
}

/*-----------Go to Sleep-------------------------------------------/
*     function: go_to_sleep()                                      *
*                                                                  *
*     desc: This function is called after a decision is made about *
*     the type of wakeup (either normal POR or from deep sleep).   *
*     Within this function is a sleep counter that allows a versatile  *
*     sleeping period. The postscalars for the watchdog timer have *
*     only a certain set of sleep periods, so the sleep counter    *
*     increments those periods.                                  *
*                                                                  *
/-----------------------------------------------------------------*/
void go_to_sleep(void)
{
      unsigned int config=0;
      sleep_count();    //This function increments the sleep counter
                              //e.g. 5 seconds can be acheived with
about 151 increments of a 33ms sleep time
      while(1)
      {
            Write_DSGPR(count1,count2);         //Save the counter data
before deep sleep
            config = (DPSLP_ULPWU_DISABLE | DPSLP_RTCC_WAKEUP_DISABLE);
      //configure deep sleep wake up sources
            GotoDeepSleep(config);        //This function puts the device
into deep sleep
      }
      return;
}

/*-----------Miscellaneous Functions-------------------------------/
*     functions: blink_led(), sleep_count(), gps_parser(),         *
*     send_eusart(), send_gpio(), batt_chk()               *
*                                                                  *
```

```
*                                                                     *
*     desc: This function is called after a decision is made about    *
*     the type of wakeup (either normal POR or from deep sleep).      *
*     Within this function is a sleep counter that allows a versatile *
*     sleeping period. The postscalars for the watchdog timer have    *
*     only a certain set of sleep periods, so the sleep counter       *
*     increments those periods.                                     *
*                                                                     *
/---------------------------------------------------------------------*/

//----->This function sends eusart1 data<-----//
void send_eusart1(int datatx)
{
      int send_val;
      send_val = datatx;
      TXSTA1bits.TXEN = 1;    //enable transmission
      TXREG1 = send_val;            //Send byte
      return;
}

//----->This function sends eusart2 data<-----//
void send_eusart2(int datatx)
{
      int send_val;
      send_val = datatx;
      while(!PIR3bits.TX2IF);       //makes sure shift register is empty
before sending new infomation

      TXREG2 = send_val;            //Send byte

      return;
}

//this procedure writes to the VHF register
void send_gpio(long reg_val)
{
      int i, j, k, b;
      long send_val = reg_val;

      //Define bits
      byte bits[ARRAYLEN];

      for(b=0;b<32;b++)
      {
            bits[b] = send_val & 0x01;
            send_val = send_val >> 1;
      }

      //Set enable pin
      LATBbits.LATB2 = 0;

      //Send bits to i/o
      LATBbits.LATB1 = bits[31];for(j = 0; j < 2; j++){LATDbits.LATD7 =
j;for(k = 0; k < 37; k++);}   //Data Bit
      LATBbits.LATB1 = bits[30];for(j = 0; j < 2; j++){LATDbits.LATD7 =
j;for(k = 0; k < 37; k++);}   //Data Bit
```

```
      LATBbits.LATB1 = bits[29];for(j = 0; j < 2; j++){LATDbits.LATD7 =
j;for(k = 0; k < 37; k++);}   //Data Bit
      LATBbits.LATB1 = bits[28];for(j = 0; j < 2; j++){LATDbits.LATD7 =
j;for(k = 0; k < 37; k++);}   //Data Bit
      LATBbits.LATB1 = bits[27];for(j = 0; j < 2; j++){LATDbits.LATD7 =
j;for(k = 0; k < 37; k++);}   //Data Bit
      LATBbits.LATB1 = bits[26];for(j = 0; j < 2; j++){LATDbits.LATD7 =
j;for(k = 0; k < 37; k++);}   //Data Bit
      LATBbits.LATB1 = bits[25];for(j = 0; j < 2; j++){LATDbits.LATD7 =
j;for(k = 0; k < 37; k++);}   //Data Bit
      LATBbits.LATB1 = bits[24];for(j = 0; j < 2; j++){LATDbits.LATD7 =
j;for(k = 0; k < 37; k++);}   //Data Bit
      LATBbits.LATB1 = bits[23];for(j = 0; j < 2; j++){LATDbits.LATD7 =
j;for(k = 0; k < 37; k++);}   //Data Bit
      LATBbits.LATB1 = bits[22];for(j = 0; j < 2; j++){LATDbits.LATD7 =
j;for(k = 0; k < 37; k++);}   //Data Bit
      LATBbits.LATB1 = bits[21];for(j = 0; j < 2; j++){LATDbits.LATD7 =
j;for(k = 0; k < 37; k++);}   //Data Bit
      LATBbits.LATB1 = bits[20];for(j = 0; j < 2; j++){LATDbits.LATD7 =
j;for(k = 0; k < 37; k++);}   //Data Bit
      LATBbits.LATB1 = bits[19];for(j = 0; j < 2; j++){LATDbits.LATD7 =
j;for(k = 0; k < 37; k++);}   //Data Bit
      LATBbits.LATB1 = bits[18];for(j = 0; j < 2; j++){LATDbits.LATD7 =
j;for(k = 0; k < 37; k++);}   //Data Bit
      LATBbits.LATB1 = bits[17];for(j = 0; j < 2; j++){LATDbits.LATD7 =
j;for(k = 0; k < 37; k++);}   //Data Bit
      LATBbits.LATB1 = bits[16];for(j = 0; j < 2; j++){LATDbits.LATD7 =
j;for(k = 0; k < 37; k++);}   //Data Bit
      LATBbits.LATB1 = bits[15];for(j = 0; j < 2; j++){LATDbits.LATD7 =
j;for(k = 0; k < 37; k++);}   //Data Bit
      LATBbits.LATB1 = bits[14];for(j = 0; j < 2; j++){LATDbits.LATD7 =
j;for(k = 0; k < 37; k++);}   //Data Bit
      LATBbits.LATB1 = bits[13];for(j = 0; j < 2; j++){LATDbits.LATD7 =
j;for(k = 0; k < 37; k++);}   //Data Bit
      LATBbits.LATB1 = bits[12];for(j = 0; j < 2; j++){LATDbits.LATD7 =
j;for(k = 0; k < 37; k++);}   //Data Bit
      LATBbits.LATB1 = bits[11];for(j = 0; j < 2; j++){LATDbits.LATD7 =
j;for(k = 0; k < 37; k++);}   //Data Bit
      LATBbits.LATB1 = bits[10];for(j = 0; j < 2; j++){LATDbits.LATD7 =
j;for(k = 0; k < 37; k++);}   //Data Bit
      LATBbits.LATB1 = bits[9];for(j = 0; j < 2; j++){LATDbits.LATD7 =
j;for(k = 0; k < 37; k++);}   //Data Bit
      LATBbits.LATB1 = bits[8];for(j = 0; j < 2; j++){LATDbits.LATD7 =
j;for(k = 0; k < 37; k++);}   //Data Bit
      LATBbits.LATB1 = bits[7];for(j = 0; j < 2; j++){LATDbits.LATD7 =
j;for(k = 0; k < 37; k++);}   //Data Bit
      LATBbits.LATB1 = bits[6];for(j = 0; j < 2; j++){LATDbits.LATD7 =
j;for(k = 0; k < 37; k++);}   //Data Bit
      LATBbits.LATB1 = bits[5];for(j = 0; j < 2; j++){LATDbits.LATD7 =
j;for(k = 0; k < 37; k++);}   //Data Bit
      LATBbits.LATB1 = bits[4];for(j = 0; j < 2; j++){LATDbits.LATD7 =
j;for(k = 0; k < 37; k++);}   //Data Bit
      LATBbits.LATB1 = bits[3];for(j = 0; j < 2; j++){LATDbits.LATD7 =
j;for(k = 0; k < 37; k++);}   //Data Bit
      LATBbits.LATB1 = bits[2];for(j = 0; j < 2; j++){LATDbits.LATD7 =
j;for(k = 0; k < 37; k++);}   //Data Bit
```

```
	LATBbits.LATB1 = bits[1];for(j = 0; j < 2; j++){LATDbits.LATD7 =
j;for(k = 0; k < 37; k++);}   //Data Bit
	LATBbits.LATB1 = bits[0];for(j = 0; j < 2; j++){LATDbits.LATD7 =
j;for(k = 0; k < 37; k++);}   //Data Bit

	//release enable pin
	LATBbits.LATB2 = 1;
	for(k = 0; k < 37; k++);
	LATBbits.LATB2 = 0;

	//Turn off data and clock pins
	LATBbits.LATB1 = 0;
	LATDbits.LATD7 = 0;

	return;
}


/*------>Send and Receive 0x00 - 0x03<------*/
void eusart_test(void)
{
	int send_val;
	for(send_val = 0x00; send_val <= 0x03; send_val++)
		{
			send_eusart1(send_val); //Send send_val over EUSART
		}
	return;
}

/*------>Sleep Count Incrementer<------*/
void sleep_count(void)
{
	extern int count1, count2;

	//extract counter data from deep sleep save registers
	count1 = DSGPR0;  //"Low" count register
	count2 = DSGPR1;  //"High" count register

	//The two count registers will make a 16 bit counter in the following
code
	//increment the counters
	if(count1 < 0xFF)
		count1++;
	if(count1 >= 0xFF){
		count2++;
		count1 = 0x00;
	}
	return;
}

/*------>Turn on/off 3.3V Power<------*/
void power_33(byte x)
{
	int on_off = x;
	LATDbits.LATD2 = on_off;
	return;
}
```

```
/*------>Turn on/off 5V Power<------*/
void power_5(byte x)
{
      int on_off = x;
      LATCbits.LATC5 = on_off;
      return;
}

/*------>Turn on/off VHF transceiver<------*/
void vhf_trx(byte x)
{
      int on_off = x;
      LATBbits.LATB3 = on_off;
      return;
}

/*------>Set RF switch to TX mode<------*/
void switch_ctrl(byte x)
{
      byte ctrl_chk = x;

      if(ctrl_chk == 0) //If turned off...
      {
            LATEbits.LATE0 = 0;
            LATEbits.LATE1 = 0;
            return;
      }
      if(ctrl_chk == 1) //If put in tx mode...
      {
            LATEbits.LATE0 = 1;
            LATEbits.LATE1 = 0;
            return;
      }
      if(ctrl_chk == 2) //If put in rx mode...
      {
            LATEbits.LATE0 = 0;
            LATEbits.LATE1 = 1;
            return;
      }
      else
            return;
}

//This procedure is called when a Sync word has been detected by
//the rising edge of the VHF_SYNC_INT. Once a sync word has been detected
//the pic will retrive the data on the rising edge of the VHF data clock
void swd(void){

      INTCON3bits.INT1IE = 0; //disables interrupt 1, SWD
      INTCON3bits.INT2IF = 0; //clears interrupt flag 2
      INTCON3bits.INT2IE = 1; //enables int 2, VHF RX CLK

      INTCON3bits.INT1IF = 0; //clears int 1 flag

      return;
}
```

```
//Configures the board to be in VHF recieve mode and waits until a valid
//packet is retrived. It then checks to see if there are any errors in the
//recieved packet and if not, decodes the data and assigns the data to the
//corrisponding global varibles. When new valid data is available, the
//function returns a 1.
unsigned char VHF_RX_Mode(void){
      unsigned char k, success=0;
      int i=0;
      unsigned int decode_chk_sum = 0, calc_chk_sum = 0;
      float Avg = 100000;
/*
      //Configures the PIC for transciver RX mode
      syc_eusart2VHF_remap(RX);
      syc_eusart2_init(RX);

      //Turns on the 3.3 line and makes sure the 5V line is OFF
      power_33(ON);
      power_5(OFF);

      //turns on the transceiver and switches the RF switch to RX mode
      vhf_trx(ON);
      switch_ctrl(RX);

      //Delay to allow the transciever to power up
      for(k = 0; k < 90; k++); //delay for ~3.6 ms

      //Configures the receiver to RX mode
      vhf_init(RX);
*/
      //Waits until the VHF_data is ready
      while(VHF_data_ready){
/*          if(i==100){
                i=0;
            }

            Avg = (Avg + VHF_AFC_RB())/2;
            i++;
            for(k=0;k<3000;k++);
*/
      }

      //Decodes the packets check sum and recalculates the check sum
      decode_chk_sum = rx_decode_check_sum(VHF_rx);
      calc_chk_sum = check_sum(VHF_rx,17);

      //Checks for bit errors
      if(decode_chk_sum == calc_chk_sum){
            success = 1;

            //decodes the message and assigns to the corrisponding global
variables
            lat = rx_decode_lat(VHF_rx);
            lon = rx_decode_lon(VHF_rx);
            time = rx_decode_time(VHF_rx);
            status = rx_decode_status(VHF_rx);
            ID = rx_decode_ID(VHF_rx);
```

```
	}

	//Resets the VHF_Buff and the RX counters and the flag when VHF data is
ready
	global_var_init();
	VHF_data_ready = 1;

	//powers down the transciever
//	vhf_trx(OFF);
//	power_33(OFF);

	return success;
}

//Returns the current latitude from the RX data
signed long get_lat(void){
	return lat;
}

//Returns the current longitude from the RX data
signed long get_lon(void){
	return lon;
}

//Returns the current time from the RX data
unsigned long get_time(void){
	return time;
}

//Returns the current Status byte from the RX data
unsigned char get_status(void){
	return status;
}

//Returns the current ID from the RX data
unsigned char get_ID(void){
	return ID;
}

//This procedure retrives GPS data, formats the data, and sends it wirelessly
//via the transciever
void VHF_TX_Mode(void){
	int k;

	unsigned char gpsdata[36]; //Will store the UBX NAV-POSLLH message
	unsigned char packet_array[19];	//will contain the encoded packet
to send
	unsigned char *packet = packet_array; //pointer to packet_array

//	signed long longitude;
//	signed long latitude;
//	unsigned long msTOW; //Store the milisecond Time of Week

	//Gets the GPS data to send
//	get_gps_data(gpsdata, 20000); //will receive a GPS data with accuracy
of 20 m
```

```
//    longitude = ubx_navpllh_get_longitude(gpsdata);
//    latitude = ubx_navpllh_get_latitude(gpsdata);
//    msTOW = ubx_navpllh_get_msTOW(gpsdata);

      //Encodes the GPS data into a packet
      format_packet(packet, 0x190CD848, 0x37CF0F1C, 0x240C8400, 0x0F,0x01);
//    format_packet(packet, latitude, longitude, msTOW, 0x0F,0x01);

      //Sets up the Ports on the PIC for VHF Transmission
      syc_eusart2VHF_remap(TX);
      syc_eusart2_init(TX);

      //Power on the 3.3V and 5V rail
      power_33(ON);
      power_5(ON);

      //Turn on the transciever and turn the RF switch to TX mode
      vhf_trx(ON);
      switch_ctrl(TX);

      //Delay to allow the transciever to warm up
      for(k = 0; k < 90; k++); //delay for ~3.6 ms

      //configure the transciever's registers to TX mode
      vhf_init(TX);

      //Delay to allow transciever to finish configuring before sending data
      for(k = 0; k < 20; k++); //delay 0.840 ms

      //Sends the packet to the transciever using Eusart 2
      VHF_send_packet(packet);

      //Makes sure that the last byte has been sent to the transciever
      while(!TXSTA2bits.TRMT);

      //gives time for the transciever to modulate the last packet
      //before powering down
      for(k = 0; k < 8000; k++); //delay 0.840 ms

      //Powers down the 5 volt line and the transciever
      power_5(OFF);
      vhf_trx(OFF);

      return;
}
//Thus procedure sends the formatted packet through the VHF transciever
void VHF_send_packet(unsigned char *packet){
      int i;

      //Sends the preamble
      for(i=0; i<11;i++){
            send_eusart2(0xAA);
      }

      //send Start Word 0xBAD5
      send_eusart2(0xBA);
      send_eusart2(0xD5);
```

```
	//Send the packet
	for(i=0;i<19;i++){
		send_eusart2(*(packet+i));
	}

	return;
}

//This procedures gets the VHF data from the I/O pin
//It runs for the length of the packet and is initiated
//by the interrupt of the rising edge of the VHF data clock
void VHF_data_rx(void){

	unsigned char data=0;
	char i;

	data = PORTCbits.RC6;   //reads the data pin
	data = data << VHF_bit_count; //shifts the bit to the approprate bit
position
	VHF_bit_count++;

	//Adds the bit to the data
	VHF_buff[VHF_byte_count] = VHF_buff[VHF_byte_count] | data;

	//checks to see if the length of the packet has been captured
	if(VHF_bit_count == 8 && VHF_byte_count == (VHF_BUFFSIZE-1)){
		INTCON3bits.INT1IF = 0; //clears interrupt 1 flag
		INTCON3bits.INT2IE = 0; //disables int 2, VHF RX CLK
		INTCON3bits.INT1IE = 1; //enables int 1 to look for sync word

		//Signals the there is VHF data ready in VHF_Buff
		VHF_data_ready = 0;
	}

	//checks to see if the byte is complete and needs to move to the next
byte
	if(VHF_bit_count == 8){
		VHF_bit_count = 0;
		VHF_byte_count++;
	}

	INTCON3bits.INT2IF = 0; //clears int 2 flag

	return;
}

//Initilizes the VHF global VHF received data and the bit and byte counters
void global_var_init(void){
	int i;

	VHF_bit_count = 0;
	VHF_byte_count = 0;

	for(i=0;i<VHF_BUFFSIZE;i++)
		VHF_buff[i] = 0x00;
}
```

```
//This procedures writes to the read back register of the tranciever
//and then reads the output of the read register
signed long VHF_read_back(long reg_val){

      int i, j, k, b;
      long send_val = reg_val;
      int data=0, data_bit=0;

      //Define bits
      byte bits[ARRAYLEN];

      //Assigns the individual bit to the array bits
      for(b=0;b<32;b++)
      {
            bits[b] = send_val & 0x01;
            send_val = send_val >> 1;
      }

      //Set enable pin
      LATBbits.LATB2 = 0;

      //Writes to the register by setting the write port and the generating
the clock
      LATBbits.LATB1 = bits[31];for(j = 0; j < 2; j++){LATDbits.LATD7 =
j;for(k = 0; k < 37; k++);}   //Data Bit
      LATBbits.LATB1 = bits[30];for(j = 0; j < 2; j++){LATDbits.LATD7 =
j;for(k = 0; k < 37; k++);}   //Data Bit
      LATBbits.LATB1 = bits[29];for(j = 0; j < 2; j++){LATDbits.LATD7 =
j;for(k = 0; k < 37; k++);}   //Data Bit
      LATBbits.LATB1 = bits[28];for(j = 0; j < 2; j++){LATDbits.LATD7 =
j;for(k = 0; k < 37; k++);}   //Data Bit
      LATBbits.LATB1 = bits[27];for(j = 0; j < 2; j++){LATDbits.LATD7 =
j;for(k = 0; k < 37; k++);}   //Data Bit
      LATBbits.LATB1 = bits[26];for(j = 0; j < 2; j++){LATDbits.LATD7 =
j;for(k = 0; k < 37; k++);}   //Data Bit
      LATBbits.LATB1 = bits[25];for(j = 0; j < 2; j++){LATDbits.LATD7 =
j;for(k = 0; k < 37; k++);}   //Data Bit
      LATBbits.LATB1 = bits[24];for(j = 0; j < 2; j++){LATDbits.LATD7 =
j;for(k = 0; k < 37; k++);}   //Data Bit
      LATBbits.LATB1 = bits[23];for(j = 0; j < 2; j++){LATDbits.LATD7 =
j;for(k = 0; k < 37; k++);}   //Data Bit
      LATBbits.LATB1 = bits[22];for(j = 0; j < 2; j++){LATDbits.LATD7 =
j;for(k = 0; k < 37; k++);}   //Data Bit
      LATBbits.LATB1 = bits[21];for(j = 0; j < 2; j++){LATDbits.LATD7 =
j;for(k = 0; k < 37; k++);}   //Data Bit
      LATBbits.LATB1 = bits[20];for(j = 0; j < 2; j++){LATDbits.LATD7 =
j;for(k = 0; k < 37; k++);}   //Data Bit
      LATBbits.LATB1 = bits[19];for(j = 0; j < 2; j++){LATDbits.LATD7 =
j;for(k = 0; k < 37; k++);}   //Data Bit
      LATBbits.LATB1 = bits[18];for(j = 0; j < 2; j++){LATDbits.LATD7 =
j;for(k = 0; k < 37; k++);}   //Data Bit
      LATBbits.LATB1 = bits[17];for(j = 0; j < 2; j++){LATDbits.LATD7 =
j;for(k = 0; k < 37; k++);}   //Data Bit
      LATBbits.LATB1 = bits[16];for(j = 0; j < 2; j++){LATDbits.LATD7 =
j;for(k = 0; k < 37; k++);}   //Data Bit
```

```
      LATBbits.LATB1 = bits[15];for(j = 0; j < 2; j++){LATDbits.LATD7 =
j;for(k = 0; k < 37; k++);}   //Data Bit
      LATBbits.LATB1 = bits[14];for(j = 0; j < 2; j++){LATDbits.LATD7 =
j;for(k = 0; k < 37; k++);}   //Data Bit
      LATBbits.LATB1 = bits[13];for(j = 0; j < 2; j++){LATDbits.LATD7 =
j;for(k = 0; k < 37; k++);}   //Data Bit
      LATBbits.LATB1 = bits[12];for(j = 0; j < 2; j++){LATDbits.LATD7 =
j;for(k = 0; k < 37; k++);}   //Data Bit
      LATBbits.LATB1 = bits[11];for(j = 0; j < 2; j++){LATDbits.LATD7 =
j;for(k = 0; k < 37; k++);}   //Data Bit
      LATBbits.LATB1 = bits[10];for(j = 0; j < 2; j++){LATDbits.LATD7 =
j;for(k = 0; k < 37; k++);}   //Data Bit
      LATBbits.LATB1 = bits[9];for(j = 0; j < 2; j++){LATDbits.LATD7 =
j;for(k = 0; k < 37; k++);}   //Data Bit
      LATBbits.LATB1 = bits[8];for(j = 0; j < 2; j++){LATDbits.LATD7 =
j;for(k = 0; k < 37; k++);}   //Data Bit
      LATBbits.LATB1 = bits[7];for(j = 0; j < 2; j++){LATDbits.LATD7 =
j;for(k = 0; k < 37; k++);}   //Data Bit
      LATBbits.LATB1 = bits[6];for(j = 0; j < 2; j++){LATDbits.LATD7 =
j;for(k = 0; k < 37; k++);}   //Data Bit
      LATBbits.LATB1 = bits[5];for(j = 0; j < 2; j++){LATDbits.LATD7 =
j;for(k = 0; k < 37; k++);}   //Data Bit
      LATBbits.LATB1 = bits[4];for(j = 0; j < 2; j++){LATDbits.LATD7 =
j;for(k = 0; k < 37; k++);}   //Data Bit
      LATBbits.LATB1 = bits[3];for(j = 0; j < 2; j++){LATDbits.LATD7 =
j;for(k = 0; k < 37; k++);}   //Data Bit
      LATBbits.LATB1 = bits[2];for(j = 0; j < 2; j++){LATDbits.LATD7 =
j;for(k = 0; k < 37; k++);}   //Data Bit
      LATBbits.LATB1 = bits[1];for(j = 0; j < 2; j++){LATDbits.LATD7 =
j;for(k = 0; k < 37; k++);}   //Data Bit
      LATBbits.LATB1 = bits[0];for(j = 0; j < 2; j++){LATDbits.LATD7 =
j;for(k = 0; k < 37; k++);}   //Data Bit

      //release enable pin
      LATBbits.LATB2 = 1;
      for(k = 0; k < 37; k++);                        //delay

      //procedure for reading back the data
      //Data is outputed on the raising edge of the clock
      //Data is read on the lower edge of the clock
      //The first bit outputted must be ignored
      for(i = 0;i<18;i++){
            for(j = 0; j < 2; j++){
                  LATDbits.LATD7 = j;
                  if(j==0 && i>1){                    //samples on lower edge
and skips the first two iteration
                        data_bit = PORTBbits.RB0;
                        data = data | (data_bit<<17-i);
                  }
                  for(k = 0; k < 37; k++);
            }
      }

      //lowers the SLE and performs one more clock cycle to allow the
      //transciever to turn off the readback
      LATBbits.LATB2 = 0;
      for(j = 0; j < 2; j++){
```

```
            LATDbits.LATD7 = j;
            for(k = 0; k < 37; k++);
      }

      //Turn off data and clock pins
      LATBbits.LATB1 = 0;
      LATDbits.LATD7 = 0;

      return data;

}

//Reads back the AFC values from the tranciever
//Only valid during reception of FSK signals
//The Freq_RB in Hz is given by the following: Freq_RB =
AFC_Readback*Demod_Clk/2^18
//In the absence of frequency error, Freq_RB = 100kHz
//Note for a valid result, the down converted input signal must not fall
//outside the BW of the analog IF filter
float VHF_AFC_RB(void){
      long reg_val = 0x107;
      signed long RB_Value= 0;
      float constant = 7.69043;                 //demodulation CLK/2^18 where
demodulation CLK = 2.016 MHz

      RB_Value = VHF_read_back(reg_val);

      return RB_Value*constant;
}

//Reads back the Silicon Revision of the transciever
long VHF_Silicon_Rev_RB(void){
      long reg_val = 0x1C7;

      return VHF_read_back(reg_val);
}

//Reads back the RSSI of the transciever
signed float VHF_RSSI_RB(void){
      long reg_val = 0x147;
      long data = 0;
      char RSSI=0,I_gain=0,LNA_gain=0 ;
      char gain_correction;
      data = VHF_read_back(reg_val);

      RSSI = 0x7F & data;                 //masks the RSSI readback to only
retreive the RSSI-level information
      I_gain = (data>>7) & 0x03;          //gets the Current Filter Gain from
the data
      LNA_gain = (data>>9) & 0x03;  //gets the LNA gain from data

      //Gets the Gain Mode Correction based on the LNA Gain and I_Gain
(Filter Gain)
      //The data is from the tranciever datasheet on page 32
      if(LNA_gain == 0x02 && I_gain ==0x02)
            gain_correction = 0;
      else if (LNA_gain == 0x01 && I_gain ==0x02)
```

```
            gain_correction = 24;
      else if (LNA_gain == 0x01 && I_gain ==0x01)
            gain_correction = 38;
      else if (LNA_gain == 0x01 && I_gain ==0x00)
            gain_correction = 58;
      else if (LNA_gain == 0x00 && I_gain ==0x00)
            gain_correction = 86;

      //RSSI Formula in dBm is -130 + (Readback RSSI + Gain Correction)*0.5
      return (-130 + (gain_correction + RSSI)*0.5);
}

//Reads back the Filter Calibration of the transciever
//This is used for manual filter adjust
//IF_Filter_Adjust = FILTER_CAL_READBACK - 128
//IF_Filter_Adjust can be read to R5_DB[14:19]
long VHF_Filter_Cal_RB(void){
      long reg_val = 0x187;
      long data = 0;

      data = data & 0xFF;           //masks the data so only first eight bits
are used

      return (data-128);
}

//Reads back the Battery Voltage which is read from VDD4
float VHF_Battery_RB(void){
      long reg_val = 0x157;
      long data = 0;

      send_gpio(0x17D8);            //enables ADC
      data = VHF_read_back(reg_val);
      data = data & 0x7F;           //masks the data so only first seven bits
are used
      send_gpio(0x16D8);            //Disables ADC

      //Voltage of the battery = Battery_Voltage_Readback/21.1
      return (data/21.1);
}

//Reads back the Temperature which is in degrees Celecius
float VHF_Temperture_RB(void){
      long reg_val = 0x167;
      long data = 0;

      send_gpio(0x17D8);            //enables ADC
      data = VHF_read_back(reg_val);
      data = data & 0x7F;           //masks the data so only first seven bits
are used
      send_gpio(0x16D8);            //Disables ADC

      return (-40 + (68.4-data)*9.32);
}
```

Appendix 16: PIC Code – handler.h

```
#define SCALAR1 100     //(SCALAR1*255+SCALAR2)*(postscalar time) = approx.
sleep period in milisec
#define SCALAR2 0       //SEE TDMA_MAIN.H FOR POSTSCALAR VALUE (DSPER needs
to stay in tdma_main.h)
#define ARRAYLEN 32
#define VHF_BUFFSIZE 19
#include "datatypes.h"

//Define prototypes
void send_eusart1(int datatx);
int dpslp_chk(void);
void sleep_count(void);
void eusart_test(void);
int ds_handler(void);
void wake_to_sleep(void);

void power_33(byte x);
void power_5(byte x);

void send_gpio(long reg_val);
void vhf_trx(byte x);
void switch_ctrl(byte x);
void send_eusart2(int datatx);

unsigned char VHF_RX_Mode(void);
signed long get_lat(void);
signed long get_lon(void);
unsigned long get_time(void);
unsigned char get_status(void);
unsigned char get_ID(void);

void VHF_TX_Mode(void);
void VHF_send_packet(unsigned char *packet);

void swd(void);
void VHF_data_rx(void);
void global_var_init(void);

signed long VHF_read_back(long reg_val);
float VHF_AFC_RB(void);
long VHF_Silicon_Rev_RB(void);
signed float VHF_RSSI_RB(void);
long VHF_Filter_Cal_RB(void);
float VHF_Battery_RB(void);
float VHF_Temperture_RB(void);

extern void activate_unit(void);
extern void go_to_sleep(void);
```

Appendix 17: PIC Code – interrupts.c

```
//====================tdma_interrupts.c============================//
//    file: tdma_interrupts.c
            //
//    author: John Pritchard
            //
//    project: Bear Tracker Project
      //
//    date: Spring 2010
            //
//
                        //
// functions: high_vector_table(), low_vector_table(),
      //
//    eusart_rx_int(), high_vector(), low_vector()
      //
//
                        //
//    Desc: This function handles all interrupts
      //
//
                        //
//=================================================================//
#include "p18cxxx.h"
#include "interrupts.h"
#include "datatypes.h"
#include "handler.h"

//Define Global variables
static byte eusart_buff[BUFFSIZE];
byte *buff_end = eusart_buff+BUFFSIZE;
byte *rx = eusart_buff;
//int trans,error;

byte eusart2_buff[BUFFSIZE];
byte *buff_end2 = eusart2_buff+BUFFSIZE;
byte *rx2 = eusart2_buff;

/*-------------------------------------------------------
            Function: high_vector_table
            Params: void
            Returns: void
            Description: Vector table for high interrupts. All high
                        interrupts come here to find out what to do
                        next.
      -------------------------------------------------------*/

#pragma interrupt high_vector_table
void high_vector_table() {

/*    if(PIR1 & 0x20)   {
            eusart1_rx_int();
      }
*/

      if(INTCON3bits.INT1F == 1){
            swd();
```

```
	}
	if(INTCON3bits.INT2F == 1){
		VHF_data_rx();
	}
	if(PIR3 & 0x20){
		eusart2_rx_int();
	}
	else
		Nop();
}

	/*-------------------------------------------------------------
		Function: low_vector_table
		Params: void
		Returns: void
		Description: Vector table for low interrupts. All low
				interrupts come here to find out what to do
				next.
	-------------------------------------------------------------*/

#pragma interrupt low_vector_table
void low_vector_table() {
	Nop();	//Do nothing. No low-priority interrupts have been set up
at this time
}

	/*-------------------------------------------------------------
		Function: interrupt_euart
		Params: void
		Returns: void
		Description: Interrupt point when rx data is received.
				Loads rx data into a buffer and checks for
				any ids that were received.
	-------------------------------------------------------------*/

void eusart2_rx_int(void) {
	//TXSTA1bits.TXEN = 0;  //clear TX enable (this clears TX int flag)
	//TXSTA2bits.TXEN = 0;
	*rx2 = RCREG2;
	rx2++;
	if(rx2 > buff_end2)
	{
		rx2 = eusart2_buff;
	}
	return;
}



	/*-------------------------------------------------------------
		Function: high_vector
		Params: void
		Returns: void
		Description: interrupt point for high interrupts
	-------------------------------------------------------------*/

#pragma code high_vector_section=0x08
```

```
void high_vector(void)
{
	_asm GOTO high_vector_table _endasm
}

	/*-------------------------------------------------------------
		Function: low_vector
		Params: void
		Returns: void
		Description: interrupt point for low interrupts
	-------------------------------------------------------------*/

#pragma code low_vector_section=0x18
void low_vector(void)
{
	_asm GOTO low_vector_table _endasm
}


/*****************************************************
********************OLD FUNCTIONS

void eusart1_rx_int(void) {
	//TXSTA1bits.TXEN = 0;  //clear TX enable (this clears TX int flag)
	//TXSTA2bits.TXEN = 0;
	*rx = RCREG1;
	rx++;
	if(rx > buff_end)
	{
		rx = eusart_buff;
	}
	return;
}

//used for Asycronous RX with VHF transciever
void eusartVHF_rx_int(void) {
	//TXSTA1bits.TXEN = 0;  //clear TX enable (this clears TX int flag)
	//TXSTA2bits.TXEN = 0;
	int gohere;

	*rx = RCREG2;

	rx++;

	if(rx > buff_end)
	{
		rx = eusart_buff;
	}

	return;
}

void Find_RX_Data(void)
{
	byte *i;
	int j;
	int current_data;
```

```
	char start,VHF_Count;
	byte VHF_RX[6];
	byte VHF_Correct[6];

	VHF_Correct[0] = 0xAB;
	VHF_Correct[1] = 0xAC;
	VHF_Correct[2] = 0xAD;
	VHF_Correct[3] = 0xAE;
	VHF_Correct[4] = 0xAF;
	VHF_Correct[5] = 0x55;

	start = 0;
	VHF_Count = 0;

	for(i=eusart_buff;i<rx;i++)
	{
		current_data = *i;
		if(current_data == 0xAB && start ==0){
			start = 1;
		}
		if(start == 1){
			if(VHF_Count == 6){
				rx = eusart_buff;
				trans++;
				for(j=0;j<6;j++){
					if(VHF_RX[j] !=VHF_Correct[j]){
						error++;
						return;
					}
				}
				return;
			}
			else{
				VHF_RX[VHF_Count] = current_data;
				VHF_Count++;
			}
		}
	}

}
*/
```

Appendix 18: PIC Code – interrupts.h

```
#include "datatypes.h"

//Define prototypes
void eusart2_rx_int(void);
void high_vector(void);
void low_vector(void);
void Find_RX_Data(void);

//Define constants
#define BUFFSIZE 50
```

Appendix 19: PIC Code – projconfig.h

```
//Set configuration bits (see datasheet for details)
#if defined(__18F26J11) || defined(__18F46J11)
#pragma config WDTEN = OFF, XINST = OFF, OSC = INTOSC
#pragma config T1DIG = ON, LPT1OSC = OFF, DSWDTOSC = INTOSCREF
#pragma config RTCOSC = INTOSCREF, DSBOREN = ON, DSWDTEN = ON
#pragma config DSWDTPS = DSPER, FCMEN = OFF, IESO = OFF
#endif
```

Appendix 20: PIC Code – encoding.c

```
#include <stdio.h>
#include <stdlib.h>
#include <math.h>
#include "encoding.h"

//This procedure takes in a four bit message and encodes it into 4b/5b
encoding
long encode_message(long message)
{
	long encoded_message = 0;
	switch (message)
	{
		case 0b0000:
			encoded_message = 0b11110;
			break;
		case 0b0001:
			encoded_message = 0b01001;
			break;
		case 0b0010:
			encoded_message = 0b10100;
			break;
		case 0b0011:
			encoded_message = 0b10101;
			break;
		case 0b0100:
			encoded_message = 0b01010;
			break;
		case 0b0101:
			encoded_message = 0b01011;
			break;
		case 0b0110:
			encoded_message = 0b01110;
			break;
		case 0b0111:
			encoded_message = 0b01111;
			break;
		case 0b1000:
			encoded_message = 0b10010;
			break;
		case 0b1001:
			encoded_message = 0b10011;
			break;
		case 0b1010:
			encoded_message = 0b10110;
			break;
		case 0b1011:
			encoded_message = 0b10111;
			break;
		case 0b1100:
			encoded_message = 0b11010;
			break;
		case 0b1101:
			encoded_message = 0b11011;
			break;
		case 0b1110:
			encoded_message = 0b11100;
```

```
                break;
          case 0b1111:
                encoded_message = 0b11101;
                break;
          default:
                encoded_message = 0b00100;
    }

    return encoded_message;

}

//The procedure takes in the 4b/5b encoded message and decodes it
//back to its true 4 bit message
long decode_message(long encoded_message){
    long decoded_message = 0;

    switch (encoded_message)
    {
          case 0b11110:
                decoded_message = 0b0000;
                break;
          case 0b01001:
                decoded_message = 0b0001;
                break;
          case 0b10100:
                decoded_message = 0b0010;
                break;
          case 0b10101:
                decoded_message = 0b0011;
                break;
          case 0b01010:
                decoded_message = 0b0100;
                break;
          case 0b01011:
                decoded_message = 0b0101;
                break;
          case 0b01110:
                decoded_message = 0b0110;
                break;
          case 0b01111:
                decoded_message = 0b0111;
                break;
          case 0b10010:
                decoded_message = 0b1000;
                break;
          case 0b10011:
                decoded_message = 0b1001;
                break;
          case 0b10110:
                decoded_message = 0b1010;
                break;
          case 0b10111:
                decoded_message = 0b1011;
                break;
          case 0b11010:
                decoded_message = 0b1100;
```

```
                break;
        case 0b11011:
                decoded_message = 0b1101;
                break;
        case 0b11100:
                decoded_message = 0b1110;
                break;
        case 0b11101:
                decoded_message = 0b1111;
                break;
        default:
                decoded_message = 0b0000;
    }

    return decoded_message;

}

//The procedure takes in the latitude, longitude, time, status, and ID and
//formats it into 4b/5b. Once in 4b/5b, the procedure compresses the data
//to reduce the number of bytes send. The compression takes into advantage of
the
//fact that each encoded 4b/5b message has three empty bits. Thus data in the
//next byte can be shifted into these three empty bits
void format_packet(unsigned char *packet, signed long latitude, signed long
longitude, unsigned long time, unsigned char status, unsigned char ID)
{
    int i;
    char message_array[32];
    unsigned char *message=message_array;
    int counter=0;

    //splits up the latitude, longitude, and time in 4b/5b encoding
    //into 8 bits and encodes them into 4b/5b
    for (i=0;i<PACKET_OCT/4;i++)
    {
        *(message+i) = encode_message(latitude>>(i*4) & 0x0000000F);
        *(message+i+8) = encode_message(longitude>>(i*4) & 0x0000000F);
        *(message+i+16) = encode_message(time>>(i*4) & 0x0000000F);
    }

    //encodes the status and ID into 4b/5b
    *(message+24) = encode_message(status & 0x0F);
    *(message+25) = encode_message((status>>4) & 0x0F);
    *(message+26) = encode_message(ID & 0x0F);
    *(message+27) = encode_message((ID>>4) & 0x0F);

    //Compresses the encoded data since each byte in message
    //only contains 5 bits. The compressions moves bits from
    //the next message into the prevouis byte
    tx_packet_shift(message, packet);

    //performs the check sum on the shifted message
    counter = check_sum(packet, 17);

    //encodes the check sum and puts it in the message
    *(message+28) = encode_message(counter & 0x0F);
```

```
	*(message+29) = encode_message(((counter)>>4) & 0x0F);
	*(message+30) = ((counter>>8) & 0x03);

	*(packet+17) = *(packet+17) | (*(message+28)<<4);
	*(packet+18) = (*(message+28)>>4) | (*(message+29)<<1) |
(*(message+30)<<6);
	return;

}


//Performs the compression of the data to be sent. It takes advantage of the
//fact that encoded 4b/5b data has 3 unused bits and thus shifts the next
//encoded 4b/5b data into the previous 3 unused bits
void tx_packet_shift(unsigned char *message, unsigned char *packet)
{
	int i=0;
	int j=0;

	//Shifts the data in the encoded 4b/5b data to prevent
	//wasting bits that are not used in the 4b/5b scheme
	for (i=0; i < 24; i=i+8)
	{
		*(packet+j) = (*(message+i)) | (*(message+i+1)<<5);
		j++;
		*(packet+j) = (*(message+i+1)>>3) | (*(message+i+2)<<2) |
(*(message+i+3)<<7);
		j++;
		*(packet+j) = (*(message+i+3)>>1) | (*(message+i+4)<<4);
		j++;
		*(packet+j) = (*(message+i+4)>>4) | (*(message+i+5)<<1) |
(*(message+i+6)<<6);
		j++;
		*(packet+j) = (*(message+i+6)>>2) | (*(message+i+7)<<3);
		j++;
	}

	//Encodes the status and ID and adds to packet
		*(packet+j) = (*(message+i)) | (*(message+i+1)<<5);
		j++;
		*(packet+j) = (*(message+i+1)>>3) | (*(message+i+2)<<2) |
(*(message+i+3)<<7);
		j++;
		*(packet+j) = (*(message+i+3)>>1);
	return;
}

//Performs a check sum on the encoded packet for TX mode
unsigned int check_sum(unsigned char *packet, int length){  //Check Sum
Fields

	unsigned int CK_A = 0;
	int i = 0;

	//sums up all the decimal values of the shifted packet except
	//for the last data value because it only has 4 bits in it
	//so it needs masks
```

```
      for(i = 0; i < length; i++)
      {
            CK_A = CK_A + *(packet + i);
    }

      //masks the last byte to get only the last four digits
      CK_A = CK_A + (*(packet+i)& 0x0F);

      //Only use 10 bits in the check sum
      CK_A = CK_A & 0x3FF;

      return CK_A;
}

//Decodes the latitude data from the encoded-shifted packet
signed long rx_decode_lat(unsigned char *RX){
      long lat1, lat2, lat3, lat4, lat5, lat6, lat7, lat8,lat=0;

      lat1 =      (decode_message(*RX & 0x1F));
      lat2 =      (decode_message(((*RX >>5)|(*(RX+1)<<3))&0x1F)<<4) ;
      lat3 =      (decode_message((*(RX+1)>>2)& 0x1F)<<8) ;
      lat4 =      (decode_message(((*(RX+1)>>7)|(*(RX+2)<<1))&0x1F)<<12) ;
      lat5 =      (decode_message(((*(RX+2)>>4)|(*(RX+3)<<4))&0x1F)<<16) ;
      lat6 =      (decode_message(((*(RX+3)>>1))&0x1F)<<20) ;
      lat7 =      (decode_message(((*(RX+3)>>6)|(*(RX+4)<<2))&0x1F)<<24);
      lat8 =      (decode_message(((*(RX+4)>>3))&0x1F)<<28);

      lat = lat1|lat2|lat3|lat4|lat5|lat6|lat7|lat8;

      return lat;
}

//Decodes the longitude data from the encoded-shifted packet
signed long rx_decode_lon(unsigned char *RX){
      long lat1, lat2, lat3, lat4, lat5, lat6, lat7, lat8,lat=0;

      lat1 =      (decode_message(*(RX+5) & 0x1F));
      lat2 =      (decode_message(((*(RX+5) >>5)|(*(RX+6)<<3))&0x1F)<<4) ;
      lat3 =      (decode_message((*(RX+6)>>2)& 0x1F)<<8) ;
      lat4 =      (decode_message(((*(RX+6)>>7)|(*(RX+7)<<1))&0x1F)<<12) ;
      lat5 =      (decode_message(((*(RX+7)>>4)|(*(RX+8)<<4))&0x1F)<<16) ;
      lat6 =      (decode_message(((*(RX+8)>>1))&0x1F)<<20) ;
      lat7 =      (decode_message(((*(RX+8)>>6)|(*(RX+9)<<2))&0x1F)<<24);
      lat8 =      (decode_message(((*(RX+9)>>3))&0x1F)<<28);

      lat = lat1|lat2|lat3|lat4|lat5|lat6|lat7|lat8;

      return lat;
}

//Decodes the time from the encoded-shifted packet
unsigned long rx_decode_time(unsigned char *RX){
      long lat1, lat2, lat3, lat4, lat5, lat6, lat7, lat8,lat=0;

      lat1 =      (decode_message(*(RX+10) & 0x1F));
      lat2 =      (decode_message(((*(RX+10) >>5)|(*(RX+11)<<3))&0x1F)<<4) ;
      lat3 =      (decode_message((*(RX+11)>>2)& 0x1F)<<8) ;
```

```
	lat4 =	(decode_message(((*(RX+11)>>7)|(*(RX+12)<<1))&0x1F)<<12) ;
	lat5 =	(decode_message(((*(RX+12)>>4)|(*(RX+13)<<4))&0x1F)<<16) ;
	lat6 =	(decode_message(((*(RX+13)>>1))&0x1F)<<20) ;
	lat7 =	(decode_message(((*(RX+13)>>6)|(*(RX+14)<<2))&0x1F)<<24);
	lat8 =	(decode_message(((*(RX+14)>>3))&0x1F)<<28);

	lat = lat1|lat2|lat3|lat4|lat5|lat6|lat7|lat8;

	return lat;
}

//Decodes the status data from the encoded-shifted packet
unsigned char rx_decode_status(unsigned char *RX){
	char status1, status2, status=0;

	status1 = (decode_message(*(RX+15) & 0x1F));
	status2 = (decode_message((*(RX+15)>>5 | *(RX+16)<<3) & 0x1F)<<4);


	status = status1 | status2;

	return status;
}

//Decodes the ID data from the encoded-shifted packet
unsigned char rx_decode_ID(unsigned char *RX){
	char ID1,ID2,ID=0;

	ID1 = (decode_message((*(RX+16)>>2) & 0x1F));
	ID2 = (decode_message(((*(RX+16)>>7)|(*(RX+17)<<1)) & 0x1F)<<4);

	ID = ID1|ID2;

	return ID;
}

//Takes in the recieved packet and decodes the check sum of the packet
unsigned int rx_decode_check_sum(unsigned char *RX){
	unsigned int check1, check2, check3;
	unsigned int check = 0;

	//decodes the check sum which is located at the end of the packet
	//The decoding requires shifting because the 5 bit encoded data
	//was compressed
	check1 = (decode_message(((*(RX+17)>>4)|(*(RX+18)<<4)) & 0x1F));
	check2 = (decode_message((*(RX+18)>>1) & 0x1F)<<4);
	check3 = (*(RX+18)& 0xC0);
	check3 = check3<<2;

	check = check1|check2|check3;

	return check;

}

/*OLD FUNCTIONS NOT USED
```

```
int check_sum(unsigned char *packet){     //sums all the 1's in the entire
packet then appends that to an additional byte in the packet
      int i=0;
      int j=0;
      int counter=0;

      for (i=0;i < 25; i++)
      {
            for (j=0;j<8;j++)
            {
                  counter += ((*(packet+i)>>j) & 0x01);
            }
      }

      return counter;
}

int send_message(double message_to_send)
{
      int encoded_message_to_send = encode_message(message_to_send);
      TXSTA1bits.TXEN = 1;                //enable transmission

      TXREG1 = encoded_message_to_send;   //sends encoded message

      return encoded_message_to_send;           //returns encoded message to
ensure correct encoding was sent

}

struct coordinates
{
      long latitude;          //latitude signed long variable, 4 bytes, 1E-7
to convert to coordinate system
      long longitude;         //longitude, signed long variable, 4 bytes, 1E-
7 to convert to coordinate system
      unsigned long time;     //time, unsigned long variable, 4 bytes, ms
since beginning of week
      short int status; //status variable, 2 bytes, can use as needed to send
flags to receiver
}

struct packet
{
      int message[28];
}

int send_preamble(void)
{
      TXSTA1bits.TXEN = 1;    //enable transmission
      for(int i=0;i<6;i++)    //send 48 bits of alternating 1's and 0's
      {
            TXREG1 = 0XAA;    //10101010
      }

      return 1;   //return 1 for completed preamble
}
```

```
long check_sum_encode(unsigned int counter){
      long encoded = 0;

      encoded = (encode_message(counter &
0x0F))|(encode_message((counter>>4)& 0x0F)<<5);

      return encoded;
}
*/
```

Appendix 21: PIC Code – encoding.h

```
//Number of bytes in packet not including preamble
#define PACKET_SIZE 28

//Next largest mulitple of 8 of packet_size
#define PACKET_OCT 32

void format_packet(unsigned char *packet, signed long latitude, signed long
longitude, unsigned long time, unsigned char status, unsigned char ID);
      //Forms an array of 5 encoded bits which can then be sent to the VHF
transciever with a for loop
void tx_packet_shift(unsigned char *message, unsigned char *packet);
signed long rx_decode_lat(unsigned char *RX);
signed long rx_decode_lon(unsigned char *RX);
unsigned long rx_decode_time(unsigned char *RX);
unsigned char rx_decode_status(unsigned char *RX);
unsigned int check_sum(unsigned char *packet, int length);
unsigned char rx_decode_ID(unsigned char *RX);
long check_sum_encode(unsigned int counter);
unsigned int rx_decode_check_sum(unsigned char *RX);
```

Appendix 22: PIC Code – eeprom_i2c.c

```
/*-------------------------------------------------------------
/
/ File: eeprom_i2c.c
/ Contains i2c funtionaility for the EEPROM
/
-------------------------------------------------------------*/


#include <p18f46j11.h> //The PIC used in final design
#include <i2c.h>
#include "eeprom_i2c.h"

#define I2C_V6

      /*-------------------------------------------------------------
            Function: eeprom_i2c_init
            Params:     void
            Returns: void
            Description: intialize the I2C for the EEPROM chip
      -------------------------------------------------------------*/

void eeprom_i2c_init(void)
{

      TRISDbits.TRISD0 = 1;   //Set pin 38 as input for I2C to function
      TRISDbits.TRISD1 = 1;   //Set pin 39 as input for I2C to function

      //Set MSSPEnable Bit <5> for i2c instead of SPI
      SSP2CON1bits.SSPEN = 1;

      //1011 = I2C Firmware Controlled Master mode (slave Idle)
      //1000 = I2C Master mode, clock = FOSC/(4 * (SSPxADD + 1))
      SSP2CON1bits.SSPM3 = 1;
      SSP2CON1bits.SSPM2 = 0;
      SSP2CON1bits.SSPM1 = 0;
      SSP2CON1bits.SSPM0 = 0;


      //  4/8/10: no clock appear until the clock was changed to 200 KHz
      //Set I2C clock to 100 KHz (ADD = 0x09)
      SSP2ADD = 0x09;

      return;
}

      /*-------------------------------------------------------------
            Function: eeprom_write_byte
            Params:     byte = byte to write to EEPROM
                        address_block = either 1 or 0 for the page of the
memory
                        address = the address of the memory
            Returns: void
            Description: write a byte to the EEPROM at the defined address
      -------------------------------------------------------------*/
void eeprom_write_byte( unsigned char byte,
                              unsigned char address_block,
```

```
                                    unsigned int address)
{
      unsigned char eeprom_control, high_address, low_address;

      IdleI2C2();// ensure module is idle
      StartI2C2();// initiate START condition
      while ( SSP2CON2bits.SEN );// wait until start condition is over

      //load EEPROM control byte in buffer
      //<7:4> = 1010
      //<3> = address block, shown as input to function
      //<2:1> = hardware defined address, 00 in this case
      //<0> = 0 for write
      eeprom_control = 0xA0 | (((address_block & 0x01) << 3) & 0x08);
      WriteI2C2( eeprom_control );// write 1 byte - R/W bit should be 0
      IdleI2C2();// ensure module is idle

      //load high byte of address into buffer
      high_address = (address >> 8) & 0x00FF;
      WriteI2C2( high_address );// write address byte to EEPROM
      IdleI2C2();// ensure module is idle

      //load low byte of address into buffer
      low_address = (address) & 0x00FF;
      WriteI2C2( low_address ); // write address byte to EEPROM
      IdleI2C2();// ensure module is idle

      WriteI2C2( byte );// Write data byte to EEPROM
      IdleI2C2();// ensure module is idle

      StopI2C2();// send STOP condition

      while ( SSP2CON2bits.PEN );// wait until stop condition is over
      eeprom_ack_polling();//Wait for write cycle to complete

      return; // return

}


/*-------------------------------------------------------------
            Function: eeprom_ack_polling
            Params:     void
            Returns: void
            Description: poll the EEPROM chip to see if it is busy
                              for a page write
-------------------------------------------------------------*/

void eeprom_ack_polling(void)
{
      unsigned char eeprom_control, ack_bit;
      eeprom_control = 0xA0;
      ack_bit = 1;

      while(ack_bit == 1)
      {
            IdleI2C2();// ensure module is idle
```

```
            StartI2C2();// initiate START condition
            while ( SSP2CON2bits.SEN );// wait until start condition is over

            //load EEPROM control byte in buffer
            //<7:4> = 1010
            //<3> = address block = 0
            //<2:1> = hardware defined address, 00 in this case
            //<0> = 0 for write
            WriteI2C2( eeprom_control );// write 1 byte - R/W bit should be 0
            IdleI2C2();// ensure module is idle

            ack_bit = SSP2CON2bits.ACKSTAT;
      }

      return;

}

      /*-------------------------------------------------------------
            Function: eeprom_read
            Params:     address_block = either 1 or 0 for the page of the
memory
                        address = the address of the memory
                        *rdptr = Character type pointer to PICmicro MCU RAM
                                          for storage of data read from I2C
device
                        length = Number of bytes to read from I2C device.
            Returns: none
            Description: read from the EEPROM
      -------------------------------------------------------------*/
void eeprom_read(unsigned char address_block,
                         unsigned int address,
                         unsigned char *rdptr,
                         unsigned char length)
{
      unsigned char eeprom_control, high_address, low_address, data;

      IdleI2C2();                       // ensure module is idle
      StartI2C2();                      // initiate START condition
      while ( SSP2CON2bits.SEN );       // wait until start condition is over

      //load EEPROM control byte in buffer
      //<7:4> = 1010
      //<3> = address block, shown as input to function
      //<2:1> = hardware defined address, 00 in this case
      //<0> = 0 for write
      eeprom_control = 0xA0 | (((address_block & 0x01) << 3) & 0x08);
      WriteI2C2( eeprom_control );        // write 1 byte
      IdleI2C2();                       // ensure module is idle

      //load high byte of address into buffer
      high_address = (address >> 8) & 0x00FF;
      WriteI2C2( high_address );            // WRITE word address to EEPROM
      IdleI2C2();                       // ensure module is idle

      //load low byte of address into buffer
      low_address = (address) & 0x00FF;
```

```
      WriteI2C2( low_address );              // write HighAdd byte to EEPROM
      IdleI2C2();                       // ensure module is idle

      StartI2C2();                      // initiate START condition
      while ( SSP2CON2bits.SEN );       // wait until start condition is over

      WriteI2C2( eeprom_control | 0x01 ); // WRITE 1 byte - R/W bit should be
1 for read
      IdleI2C2();                          // ensure module is idle

      getsI2C2( rdptr, length );        // read in multiple bytes

      NotAckI2C2();                     // send not ACK condition
      while ( SSP2CON2bits.ACKEN );     // wait until ACK sequence is over

      StopI2C2();                       // send STOP condition
      while ( SSP2CON2bits.PEN );       // wait until stop condition is over

      return;

}



      /*-------------------------------------------------------------
            Function: eeprom_write
            Params:     address_block = either 1 or 0 for the page of the
memory
                        address = the address of the memory to write
                        *dataptr = Character type pointer to data to write
                        length = Number of bytes to write to I2C device.
            Returns: void
            Description: write a byte to the EEPROM at the defined address
      -------------------------------------------------------------*/
void eeprom_write(      unsigned char address_block,
                              unsigned int address,
                              unsigned char *dataptr,
                              unsigned char length)
{
      unsigned char eeprom_control, high_address, low_address, k, byte;

      IdleI2C2();// ensure module is idle
      StartI2C2();// initiate START condition
      while ( SSP2CON2bits.SEN );// wait until start condition is over

      //load EEPROM control byte in buffer
      //<7:4> = 1010
      //<3> = address block, shown as input to function
      //<2:1> = hardware defined address, 00 in this case
      //<0> = 0 for write
      eeprom_control = 0xA0 | (((address_block & 0x01) << 3) & 0x08);
      WriteI2C2( eeprom_control );// write 1 byte - R/W bit should be 0
      IdleI2C2();// ensure module is idle

      //load high byte of address into buffer
      high_address = (address >> 8) & 0x00FF;
      WriteI2C2( high_address );// write address byte to EEPROM
```

```
	IdleI2C2();// ensure module is idle

	//load low byte of address into buffer
	low_address = (address) & 0x00FF;
	WriteI2C2( low_address ); // write address byte to EEPROM
	IdleI2C2();// ensure module is idle

	for(k = 0; k < length; k++)
	{
		byte = *dataptr++;
		WriteI2C2( byte );// Write data byte to EEPROM
		IdleI2C2();// ensure module is idle
	}

	StopI2C2();// send STOP condition

	while ( SSP2CON2bits.PEN );// wait until stop condition is over
	eeprom_ack_polling();//Wait for write cycle to complete

	return; // return

}
```

Appendix 23: PIC Code – eeprom_i2c.h

```
#ifndef _EEPROM_I2C_H_
#define _EEPROM_I2C_H_

      /*-------------------------------------------------------------
            Function: eeprom_i2c_init
            Params:     void
            Returns: void
            Description: intialize the I2C for the EEPROM chip
      -------------------------------------------------------------*/

void eeprom_i2c_init(void);


      /*-------------------------------------------------------------
            Function: eeprom_write_byte
            Params:     byte = byte to write to EEPROM
                        address_block = either 1 or 0 for the page of the
memory
                        address = the address of the memory
            Returns: void
            Description: write a byte to the EEPROM at the defined address
      -------------------------------------------------------------*/

void eeprom_write_byte( unsigned char byte,
                                    unsigned char address_block,
                                    unsigned int address);

      /*-------------------------------------------------------------
            Function: eeprom_read
            Params:     address_block = either 1 or 0 for the page of the
memory
                        address = the address of the memory
                        *rdptr = Character type pointer to PICmicro MCU RAM
                                        for storage of data read from I2C
device
                        length = Number of bytes to read from I2C device.
            Returns: none
            Description: read from the EEPROM
      -------------------------------------------------------------*/
void eeprom_read(unsigned char address_block,
                         unsigned int address,
                         unsigned char *rdptr,
                         unsigned char length);



/*-------------------------------------------------------------
            Function: eeprom_ack_polling
            Params:     void
            Returns: void
            Description: poll the EEPROM chip to see if it is busy
                              for a page write
-------------------------------------------------------------*/
void eeprom_ack_polling(void);
```

```
/*-------------------------------------------------------------
            Function: eeprom_write
            Params:     address_block = either 1 or 0 for the page of the
memory
                        address = the address of the memory to write
                        *dataptr = Character type pointer to data to write
                        length = Number of bytes to write to I2C device.
            Returns: void
            Description: write a byte to the EEPROM at the defined address
-------------------------------------------------------------*/
void eeprom_write(      unsigned char address_block,
                              unsigned int address,
                              unsigned char *dataptr,
                              unsigned char length);


#endif
```

Appendix 24: PIC Code – gps_i2c.c

```
/*-------------------------------------------------------------
/
/   File: gps_i2c.c
/   Contains i2c funtionaility for the NEo-5 GPS
/
-------------------------------------------------------------*/

#include "gps_i2c.h"
#include "eeprom_i2c.h"
#include "ublox_cfg.h"
#include "ublox_read.h"
#include <i2c.h>
#include <delays.h>


      /*-------------------------------------------------------
            Function: gps_i2c_init
            Params:     void
            Returns: void
            Description: intialize the I2C for the NEo-5 GPS chip
      -------------------------------------------------------*/

void gps_i2c_init(void)
{
      LATDbits.LATD2 = 1; //Power 3.3V selectable Line
      Delay10KTCYx (30);
      //this is about a 300 ms delay
      //After the 3.3V line is on for 300 ms the GPS will look for the eeprom
      //Need to wait this 250 ms for the GPS to be in slave mode
      //If the 3.3V line gets turned off, this will need to be waited again

      TRISCbits.TRISC3 = 1;   //Set pin 37 as input for I2C to function
      TRISCbits.TRISC4 = 1;   //Set pin 42 as input for I2C to function

      //Set MSSPEnable Bit <5> for i2c instead of SPI
      SSP1CON1bits.SSPEN = 1;

      //1000 = I2C Master mode, clock = FOSC/(4 * (SSPxADD + 1))
      SSP1CON1bits.SSPM3 = 1;
      SSP1CON1bits.SSPM2 = 0;
      SSP1CON1bits.SSPM1 = 0;
      SSP1CON1bits.SSPM0 = 0;

      //Set I2C clock to 100 KHz (ADD = 0x09)
      //Set I2C clock to 31.25 KHz (ADD = 0x1F)
      SSP1ADD = 0x1F;

      SSP1STATbits.SMP = 1; //Slew Rate control, Must be 1!
      //At a value of zero, the clock edges have a higher slew rate
      //and the UBLOX has difficulty processing them

      //Turn off various NMEA strings
      ubx_cfg_msg_off(0xF0, 0x03);//Turn off GSV
      ubx_cfg_msg_off(0xF0, 0x04);//Turn off RMC
      ubx_cfg_msg_off(0xF0, 0x02);//Turn off GSA
      ubx_cfg_msg_off(0xF0, 0x00);//Turn off GGA
```

```
	ubx_cfg_msg_off(0xF0, 0x01);//Turn off GLL
	ubx_cfg_msg_off(0xF0, 0x05);//Turn off VTG
	ubx_cfg_msg_off(0xF0, 0x41);//Turn off TXT

	//Turn on NAV-POSLLH message all the time!
	ubx_cfg_msg_on(0x01, 0x02);

	//Turn off all info messages
	ubx_cfg_inf_off();

	//Need to delay in order for the PIC I2c buffer to clear out
	Delay10KTCYx (120);




	return;
}

	/*-------------------------------------------------------------
		Function: gps_read
		Params:	*rdptr = Character type pointer to PICmicro MCU RAM
					for storage of data read from I2C
device
			length = Number of bytes to read from I2C device.
		Returns: unsigned int number of bytes read
		Description: reads all buffered information from the GPS
	-------------------------------------------------------------*/
unsigned char gps_read(unsigned char *rdptr)
{
	unsigned char length_of_string[2];
	unsigned char length_high, length_low, length;

	gps_write_loop();
	//will continue to address the GPS until ack
	//and then will address the for Write

	//load address of the bytes available: 0xFD
	WriteI2C1( 0xFD );		// WRITE address to GPS
	IdleI2C1();			// ensure module is idle

	gps_read_loop();
	//will continue to address the GPS until ack
	//and then will address the for Read

	getsI2C1(length_of_string, 2);
	// read in string of the length of the string in memory

	NotAckI2C1();			// send not ACK condition
	while ( SSP1CON2bits.ACKEN );	// wait until ACK sequence is over

	StopI2C1();			// send STOP condition
	while ( SSP1CON2bits.PEN );	// wait until stop condition is over

	length_high = length_of_string[0];
	length_low = length_of_string[1];
	if (length_high > 1)
```

```
	{
		length = 0xFF;
	}
	else
	{
		length = length_low;
	}

	gps_read_loop();
	//will continue to address the GPS until ack
	//and then will address the for Read

	getsI2C1( rdptr, length ); // read in multiple bytes

	NotAckI2C1();			// send not ACK condition
	while ( SSP1CON2bits.ACKEN );	// wait until ACK sequence is over

	StopI2C1();			// send STOP condition
	while ( SSP1CON2bits.PEN );	// wait until stop condition is over

	return length;

}

	/*-------------------------------------------------------------
		Function: gps_write
		Params:	*dataptr = Character type pointer to data to write
			length = Number of bytes to write to I2C device.
		Returns: void
		Description: write a CFG message to the UBLOX
	-------------------------------------------------------------*/
void gps_write(	unsigned char message[],
			unsigned char length)
{
	unsigned char k, byte;

	gps_write_loop();
	//will continue to address the GPS until ack
	//and then will address the for Write

	for(k = 0; k < length; k++)
	{
		byte = message[k];
		WriteI2C1( byte );// Write data byte to UBLOX
		IdleI2C1();// ensure module is idle
	}

	StopI2C1();// send STOP condition
	while ( SSP1CON2bits.PEN );// wait until stop condition is over

	return; // return

}

/*-------------------------------------------------------------
		Function: gps_write_loop
		Params:	void
```

```
            Returns: void
            Description: poll the gps chip to see if it is busy
                                 and then send a write message
------------------------------------------------------------*/

void gps_write_loop(void)
{
      unsigned char ack_bit = 1;

      while(ack_bit == 1)
      {
            IdleI2C1();// ensure module is idle
            StartI2C1();// initiate START condition
            while ( SSP1CON2bits.SEN );// wait until start condition is over

            //Address the UBLOX for a write: 0x84
            //<7:1> are default 0x42
            //<0> is 0 for a write
            WriteI2C1( 0x84 );        //Address the UBLOX
            IdleI2C1();               // ensure module is idle

            ack_bit = SSP1CON2bits.ACKSTAT;
      }

      return;

}

/*------------------------------------------------------------
            Function: gps_read_loop
            Params:     void
            Returns: void
            Description: poll the gps chip to see if it is busy
                                 and then send a read message
------------------------------------------------------------*/

void gps_read_loop(void)
{
      unsigned char ack_bit = 1;

      while(ack_bit == 1)
      {
            IdleI2C1();// ensure module is idle
            StartI2C1();// initiate START condition
            while ( SSP1CON2bits.SEN );// wait until start condition is over

            //Address the UBLOX for a write: 0x84
            //<7:1> are default 0x42
            //<0> is 1 for a read
            WriteI2C1( 0x85 );        //Address the UBLOX
            IdleI2C1();               // ensure module is idle

            ack_bit = SSP1CON2bits.ACKSTAT;
      }

      return;
```

```
}


      /*-------------------------------------------------------------
            Function: get_gps_data
            Params:     gpsdata[] = Array of UBX-NAV-PLLH message
            Returns: 1 if message contains valid data at correct accuracy
                        0 if message timed out and contains no data
            Description: Loops a read to the UBLOX GPS so that the PIC buffer
                                    does not fill and waits for a valid UBX-
NAV-PLLH message
                                Also waits to message at correct accuracy and
outputs a valid bit
      -------------------------------------------------------------*/
unsigned char get_gps_data(unsigned char gpsdata[], unsigned long accuracy)
{
      unsigned char valid = 0;
      //Have the function time out if no valid data is found for about 2
minutes
      unsigned char time_out = 0;

      unsigned char class;
      unsigned char id;
      signed long longitude;
      unsigned long accuracy_msg;
      unsigned char valid_msg;

      //Continue to loop until a valid GPS message was received
      while( (valid == 0) && (time_out < 250) )
      {
            //Read the buffer from the UBLOX
            gps_read(gpsdata);

            //Delay so that the PIC I2C buffer does not overload
            Delay10KTCYx (120);

            //Tests to make sure message received has a UBX header
            valid_msg = valid_ubx_msg(gpsdata);

            if(valid_msg == 1)
            {
                  //Check the class and header to make sure the message is
                  //a NAV-POSLLH message
                  class = ubx_msg_class(gpsdata);
                  id = ubx_msg_id(gpsdata);

                  if((class == 0x01) && (id == 0x02))
                  {
                        //Checks the longitude of the message to make sure it
is
                        // and thus valid for the United States, also make
sure the
                        //accuracy of the message is acceptable
                        longitude = ubx_navpllh_get_longitude(gpsdata);
                        accuracy_msg =  ubx_navpllh_get_accuracy(gpsdata);

                        if((longitude < -1) && (accuracy_msg < accuracy))
```

```
                        {
                              valid = 1;
                        }
                  }
            }

            //Only allows to increment to 250 which is about 2 to 3 minutes
            time_out++;
      }

      return valid;
}
```

Appendix 25: PIC Code – gps_i2c.h

```
#ifndef _GPS_I2C_H_
#define _GPS_I2C_H_

      /*-------------------------------------------------------
            Function: gps_i2c_init
            Params:     void
            Returns: void
            Description: intialize the I2C for the EEPROM chip
      -------------------------------------------------------*/

void gps_i2c_init(void);

      /*-------------------------------------------------------
            Function: gps_read
            Params:     *rdptr = Character type pointer to PICmicro MCU RAM
                                 for storage of data read from I2C
device
                        length = Number of bytes to read from I2C device.
            Returns: none
            Description: reads all buffered information from the GPS
      -------------------------------------------------------*/
unsigned char gps_read(unsigned char *rdptr);

      /*-------------------------------------------------------
            Function: gps_write
            Params:     *dataptr = Character type pointer to data to write
                        length = Number of bytes to write to I2C device.
            Returns: void
            Description: write a CFG message to the UBLOX
      -------------------------------------------------------*/
void gps_write(   unsigned char *message,
                        unsigned char length);

/*-------------------------------------------------------
            Function: gps_read_loop
            Params:     void
            Returns: void
            Description: poll the gps chip to see if it is busy
                              and then send a read message
-------------------------------------------------------*/

void gps_read_loop(void);

/*-------------------------------------------------------
            Function: gps_write_loop
            Params:     void
            Returns: void
            Description: poll the gps chip to see if it is busy
                              and then send a write message
-------------------------------------------------------*/

void gps_write_loop(void);


      /*-------------------------------------------------------
            Function: get_gps_data
```

```
            Params:     gpsdata[] = Array of UBX-NAV-PLLH message
            Returns: 1 if message contains valid data at correct accuracy
                     0 if message timed out and contains no data
            Description: Loops a read to the UBLOX GPS so that the PIC buffer
                                 does not fill and waits for a valid UBX-
NAV-PLLH message
                               Also waits to message at correct accuracy and
outputs a valid bit
      ------------------------------------------------------------*/
unsigned char get_gps_data(unsigned char gpsdata[], unsigned long accuracy);

#endif
```

Appendix 26: PIC Code – ublox_cfg.c

```
/*-------------------------------------------------------------
/
/   File: ublox_CFG.c
/   Contains the Configuration messages for the NEO-5 GPS
/
-------------------------------------------------------------*/


#include <p18f46j11.h> //The PIC used in final design
#include <i2c.h>
#include "gps_i2c.h"
#include "eeprom_i2c.h"
#include "main.h"
#include "ublox_cfg.h"


/*-------------------------------------------------------------
      Function: ubx_cfg_msg_off()
      Params:     void
      Returns: void
      Description: Set the rate that a message is polled to 0
-------------------------------------------------------------*/

void ubx_cfg_msg_off(unsigned char class, unsigned char id)
{
      //See page 83 of the Protocol Specification Document
      char CK_A, CK_B;
      int Inc;
      unsigned char length = 11; //payload + 8
      unsigned char message[11];

      //UBX message headers
      message[0] = 0xB5;
      message[1] = 0x62;

      message[2] = 0x06; //Class ID
      message[3] = 0x01; //Message ID

      //Payload Length - Little Endian
      message[4] = 0x03;
      message[5] = 0x00;

      //Class and ID of message to turn off
      message[6] = class;
      message[7] = id;

      message[8] = 0x00; //set rate to zero to cancel message

      //Check Sum Fields
      CK_A = 0;
      CK_B = 0;
      for(Inc = 2; Inc < (length - 2); Inc++)
      {
            CK_A = CK_A + message[Inc];
            CK_B = CK_B + CK_A;
      }
```

```
	message[length-2] = CK_A;
	message[length-1] = CK_B;

	gps_write(message, length);

	return;
}

/*-----------------------------------------------------------
	Function: ubx_cfg_msg_on()
	Params:     void
	Returns: void
	Description: Set the rate that a message is polled to high as possible
-----------------------------------------------------------*/

void ubx_cfg_msg_on(unsigned char class, unsigned char id)
{
	//See page 83 of the Protocol Specification Document
	char CK_A, CK_B;
	int Inc;
	unsigned char length = 11; //payload + 8
	unsigned char message[11];

	//UBX message headers
	message[0] = 0xB5;
	message[1] = 0x62;

	message[2] = 0x06; //Class ID
	message[3] = 0x01; //Message ID

	//Payload Length - Little Endian
	message[4] = 0x03;
	message[5] = 0x00;

	//Class and ID of message to turn on
	message[6] = class;
	message[7] = id;

	message[8] = 0x01; //set rate to one to send message everytime
					//the message is available

	//Check Sum Fields
	CK_A = 0;
	CK_B = 0;
	for(Inc = 2; Inc < (length - 2); Inc++)
	{
		CK_A = CK_A + message[Inc];
		CK_B = CK_B + CK_A;
	}
	message[length-2] = CK_A;
	message[length-1] = CK_B;

	gps_write(message, length);

	return;
}
```

```
/*-------------------------------------------------------------
      Function: ubx_cfg_inf_off()
      Params:     void
      Returns: void
      Description: Disable all warning and INFormation messages
-------------------------------------------------------------*/

void ubx_cfg_inf_off(void)
{
      //See page 93 of the Protocol Specification Document
      char CK_A, CK_B;
      int Inc;
      unsigned char length = 24; //payload + 8
      unsigned char message[24];

      //UBX message headers
      message[0] = 0xB5;
      message[1] = 0x62;

      message[2] = 0x06; //Class ID
      message[3] = 0x02; //Message ID

      //Payload Length - Little Endian
      message[4] = 0x10;
      message[5] = 0x00;

      message[6] = 0x00; //Configure UBX Messages

      message[10] = 0x00; //Disable all messages
      message[11] = 0x00;
      message[12] = 0x00;
      message[13] = 0x00;

      message[14] = 0x01; //Configure NMEA Messages

      message[18] = 0x00; //Disable all messages
      message[19] = 0x00;
      message[20] = 0x00;
      message[21] = 0x00;

      //Check Sum Fields
      CK_A = 0;
      CK_B = 0;
      for(Inc = 2; Inc < (length - 2); Inc++)
      {
            CK_A = CK_A + message[Inc];
            CK_B = CK_B + CK_A;
      }
      message[length-2] = CK_A;
      message[length-1] = CK_B;

      gps_write(message, length);

      return;
}
```

Appendix 27: PIC Code – ublox_cfg.h

```
#ifndef _UBLOX_CFG_H_
#define _UBLOX_CFG_H_

//Page 91 - CFG-MSG
//Sets how often a message is sent to the GPS Module Settings
//For example, how often do we need to send a GPS message?
/*-------------------------------------------------------------
      Function: ubx_cfg_msg_off()
      Params:     void
      Returns: void
      Description: Set the rate that a message is polled to 0
-------------------------------------------------------------*/

void ubx_cfg_msg_off(unsigned char class, unsigned char id);

/*-------------------------------------------------------------
      Function: ubx_cfg_msg_on()
      Params:     void
      Returns: void
      Description: Set the rate that a message is polled to high as possible
-------------------------------------------------------------*/

void ubx_cfg_msg_on(unsigned char class, unsigned char id);

//Page 92 - CFG-INF
//Sets which error messages are sent to the I2C lines
//For example, Test, Debug, Notice, Warning, Error messages?
/*-------------------------------------------------------------
      Function: ubx_cfg_inf_off()
      Params:     void
      Returns: void
      Description: Disable all warning and INFormation messages
-------------------------------------------------------------*/

void ubx_cfg_inf_off(void);

//Page 94 - CFG-RST
//Can run a complete cold start, or control reset the UBLOX chip

//Page 95 - CFG-DAT
//Set the datum, seems more complicated than necessary

//Page 97 - CFG-TP
//Set the configuration for the timepulse output
//Will not need a timepulse because we can get exact ms times

//Page 98 - CFG-RATE
//How often is the GPS calculating a new location?

//Page 99 - CFG-CFG
//Can save the configuration settings, but there is no battery backup
//or flash or EEPROM memory

//Page 101 - CFG-RXM
//Set the unit into Eco Mode, no Poll available
//This must be set after other settings
```

```
//Page 101 - CFG-ANT
//Antenna control settings, not sure which settings we need

//Page 102 - CFG-SBAS
//What extra tracking to use, WAAS, etc.

//CFG-NMEA: sets the NMEA version, not needed
//CFG-USB: not needed, dont use as USB
//CFG-TMODE: Used when fixed location and used for precise time

//Page 108 - CFG-NAVX5
//Used to set min, max number of satellites for navigation
//Very specific settings

//Page 108 - CFG-NAV5
//Used to make different settings for Navigation, probably necessary




#endif
```

Appendix 28: PIC Code – ublox_read.c

```
/*-------------------------------------------------------------
/
/   File: ublox_read.c
/   Contains the functionality to read strings from the NEo-5 GPS
/
-------------------------------------------------------------*/


#include <p18f46j11.h> //The PIC used in final design
#include <i2c.h>
#include "gps_i2c.h"
#include "main.h"
#include "ublox_read.h"


/*-------------------------------------------------------------
      Function: valid_ubx_msg
      Params:     message = Character type array
                            of the UBX message read from the NEO-5
      Returns: 1 = Message is a valid UBX Message
               0 = Message is not a valid UBX Message
      Description: Read the first two bytes and confirm UBX Message
-------------------------------------------------------------*/

unsigned char valid_ubx_msg(unsigned char message[])
{
      unsigned char valid;

      if( (message[0] == 0xB5)&&(message[1] == 0x62) )
      {
            valid = 1;
      }
      else
      {
            valid = 0;
      }

      return valid;
}

/*-------------------------------------------------------------
      Function: ubx_msg_length
      Params:     message = Character type array
                            of the UBX message read from the NEO-5
      Returns: Unsigned int
      Description: return the length of the message including the header and
checksum fields
-------------------------------------------------------------*/

unsigned int ubx_msg_length(unsigned char message[])
{
      unsigned int length;

      length = (0x00FF & message[4])|(0xFF00 & ((message[5])<<8));

      length = length + 8;
```

```
	return length;
}

/*------------------------------------------------------------
	Function: ubx_msg_class
	Params:		message = Character type array
				of the UBX message read from the NEO-5
	Returns: Unsigned char of Class
	Description: Returns the class of the message
------------------------------------------------------------*/

unsigned char ubx_msg_class(unsigned char message[])
{
	unsigned char class;

	class = message[2];

	return class;
}

/*------------------------------------------------------------
	Function: ubx_msg_id
	Params:		message = Character type array
				of the UBX message read from the NEO-5
	Returns: Unsigned char of ID
	Description: Returns the ID of the message
------------------------------------------------------------*/

unsigned char ubx_msg_id(unsigned char message[])
{
	unsigned char msg_id;

	msg_id = message[3];

	return msg_id;
}

/*------------------------------------------------------------
	Function: ubx_navpllh_get_latitude
	Params:		message = Character type array UBX-NAV-PLLH message
	Returns: Signed Long of lattitude
	Description: Returns lattitude of the message lowest seven
			digits are decimal. Returns in 1e-7.
------------------------------------------------------------*/

signed long ubx_navpllh_get_latitude(unsigned char message[])
{
	signed long latitude;

	latitude = (0x0000FF & message[17]);
	latitude = latitude << 8;
	latitude = latitude | (0x0000FF & message[16]);
	latitude = latitude << 8;
	latitude = latitude | (0x0000FF & message[15]);
	latitude = latitude << 8;
	latitude = latitude | (0x0000FF & message[14]);
```

```
	return latitude;
}

/*------------------------------------------------------------
	Function: ubx_navpllh_get_longitude
	Params:		message = Character type array UBX-NAV-PLLH message
	Returns: Signed Long of longitude
	Description: Returns longitude of the message lowest seven
			digits are decimal. Returns in 1e-7.
------------------------------------------------------------*/

signed long ubx_navpllh_get_longitude(unsigned char message[])
{
	signed long longitude;

	longitude = (0x0000FF & message[13]);
	longitude = longitude << 8;
	longitude = longitude | (0x0000FF & message[12]);
	longitude = longitude << 8;
	longitude = longitude | (0x0000FF & message[11]);
	longitude = longitude << 8;
	longitude = longitude | (0x0000FF & message[10]);

	return longitude;
}


/*------------------------------------------------------------
	Function: ubx_navpllh_get_msTOW
	Params:		message = Character type array UBX-NAV-PLLH message
	Returns: unsigned Long of ms time of week
	Description: Returns the unsigned long of ms so far in the week
------------------------------------------------------------*/

unsigned long ubx_navpllh_get_msTOW(unsigned char message[])
{
	unsigned long msTOW;

	msTOW = (0x0000FF & message[9]);
	msTOW = msTOW << 8;
	msTOW = msTOW | (0x0000FF & message[8]);
	msTOW = msTOW << 8;
	msTOW = msTOW | (0x0000FF & message[7]);
	msTOW = msTOW << 8;
	msTOW = msTOW | (0x0000FF & message[6]);

	return msTOW;
}

/*------------------------------------------------------------
	Function: ubx_navpllh_get_accuracy
	Params:		message = Character type array UBX-NAV-PLLH message
	Returns: unsigned Long accuracy measurement in mm
	Description: Returns the unsigned long of estimated accuracy
			measurement in  milimeters
------------------------------------------------------------*/
```

```
unsigned long ubx_navpllh_get_accuracy(unsigned char message[])
{
	unsigned long accuracy;

	accuracy = (0x0000FF & message[29]);
	accuracy = accuracy << 8;
	accuracy = accuracy | (0x0000FF & message[28]);
	accuracy = accuracy << 8;
	accuracy = accuracy | (0x0000FF & message[27]);
	accuracy = accuracy << 8;
	accuracy = accuracy | (0x0000FF & message[26]);

	return accuracy;
}
```

Appendix 29: PIC Code – ublox_read.h

```
#ifndef _UBLOX_READ_H_
#define _UBLOX_READ_H_

/*-------------------------------------------------------------
      Function: valid_ubx_msg
      Params:     message = Character type array
                            of the UBX message read from the NEO-5
      Returns: 1 = Message is a valid UBX Message
               0 = Message is not a valid UBX Message
      Description: Read the first two bytes and confirm UBX Message
-------------------------------------------------------------*/

unsigned char valid_ubx_msg(unsigned char message[]);

/*-------------------------------------------------------------
      Function: ubx_msg_length
      Params:     message = Character type array
                            of the UBX message read from the NEO-5
      Returns: Unsigned int
      Description: return the length of the message including the header and
checksum fields
-------------------------------------------------------------*/

unsigned int ubx_msg_length(unsigned char message[]);

/*-------------------------------------------------------------
      Function: ubx_msg_class
      Params:           message = Character type array
                            of the UBX message read from the NEO-5
      Returns: Unsigned char of Class
      Description: Returns the class of the message
-------------------------------------------------------------*/

unsigned char ubx_msg_class(unsigned char message[]);

/*-------------------------------------------------------------
      Function: ubx_msg_id
      Params:           message = Character type array
                            of the UBX message read from the NEO-5
      Returns: Unsigned char of ID
      Description: Returns the ID of the message
-------------------------------------------------------------*/

unsigned char ubx_msg_id(unsigned char message[]);

/*-------------------------------------------------------------
      Function: ubx_navpllh_get_latitude
      Params:           message = Character type array UBX-NAV-PLLH message
      Returns: Signed Long of lattitude
      Description: Returns lattitude of the message lowest seven
                        digits are decimal. Returns in 1e-7.
-------------------------------------------------------------*/

signed long ubx_navpllh_get_latitude(unsigned char message[]);

/*-------------------------------------------------------------
```

```
      Function: ubx_navpllh_get_longitude
      Params:           message = Character type array UBX-NAV-PLLH message
      Returns: Signed Long of longitude
      Description: Returns longitude of the message lowest seven
                          digits are decimal. Returns in 1e-7.
-------------------------------------------------------------*/

signed long ubx_navpllh_get_longitude(unsigned char message[]);


/*-------------------------------------------------------------
      Function: ubx_navpllh_get_msTOW
      Params:           message = Character type array UBX-NAV-PLLH message
      Returns: unsigned Long of ms time of week
      Description: Returns the unsigned long of ms so far in the week
-------------------------------------------------------------*/

unsigned long ubx_navpllh_get_msTOW(unsigned char message[]);

/*-------------------------------------------------------------
      Function: ubx_navpllh_get_accuracy
      Params:           message = Character type array UBX-NAV-PLLH message
      Returns: unsigned Long accuracy measurement in mm
      Description: Returns the unsigned long of estimated accuracy
                          measurement in  milimeters
-------------------------------------------------------------*/

unsigned long ubx_navpllh_get_accuracy(unsigned char message[]);


#endif
```