Wireless Bear Tracking System

Design Document

Clients
Digi, International
Wildlife Research Institute

Faculty Advisor
Dr. Ahmed Kamal

Team Members
Zach Bruce
Blane Chesnut
Chris Donnelly
John Pritchard
Adam Rasmussen

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Definitions

Term	Description
VHF	Very High Frequency, the radio frequency range from 30 MHz to 300 MHz
UHF	Ultra High Frequency, the radio frequency range from 300 MHz to 3 GHz
GPS	Global Positioning System
TX	Transmit
RX	Receive
RF	Radio Frequency
LEO	Low Earth Orbiting, used in describing satellite orbits
SPOT	Commercially available personal tracking unit, which uses satellites for communication
Sync	Synchronize
bps	Bits per second
UART	Universal asynchronous receiver/transmitter
I/O	Input and Output
ISM	Industrial, Scientific, and Medical Equipment
FCC	Federal Communications Commission
dBm	Decibel referenced to milliwatts
PIC	Programmable Integrated Circuit
PC	Personal Computer
ADC	Analog to digital conversion
AFC	Automatic frequency control
RSSI	Received signal strength indication
ASK	Amplitude-shift Keying

FSK	Frequency-shift Keying
MSK	Minimum-shift keying
FM	Frequency Modulation
CSMA/CA	Carrier sense multiple access with collision avoidance
TDMA	Time Division Multiple Access
TDM	Time Division Multiplexing
PA	Power Amplifier
ESR	Effective Series Resistance
ACK	Acknowledgement
MAC	Media Access Control
CRC	Cyclical Redundancy Check
BER	Bit Error Rate

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 $280. 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 ISU Faculty including, Dr. Ahmed Kamal, Dr. Nathan Neihart, Dr. Jiming Song, Dr. Mani Mina, 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.

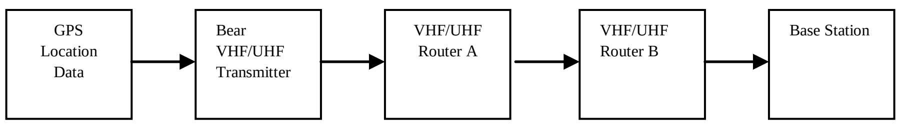


Figure 1: VHF/UHF Solution

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

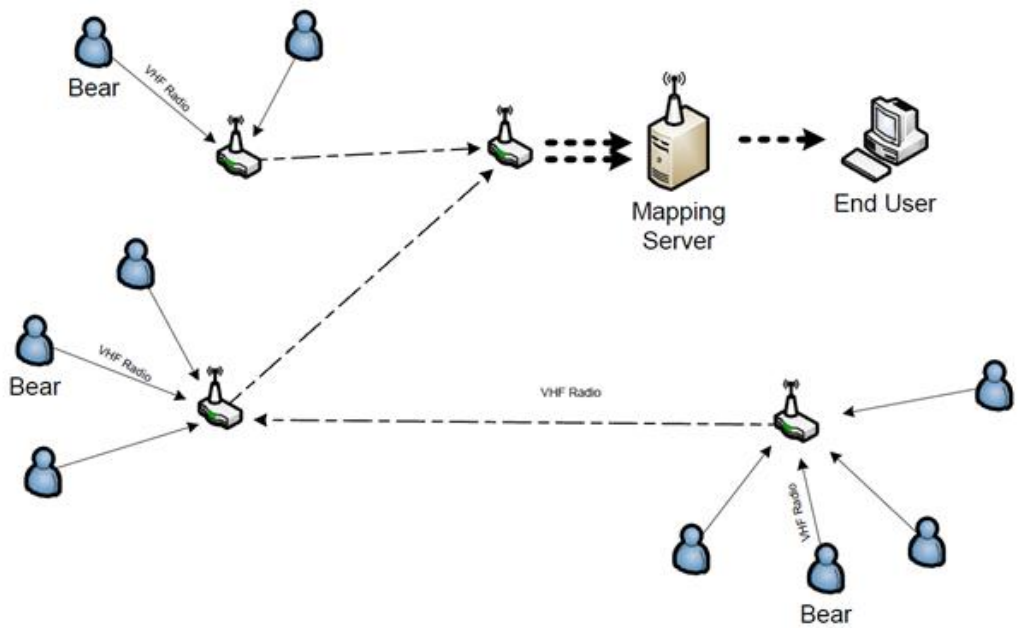
DigiMesh 900MHz Collar Mounted Solution

- 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.

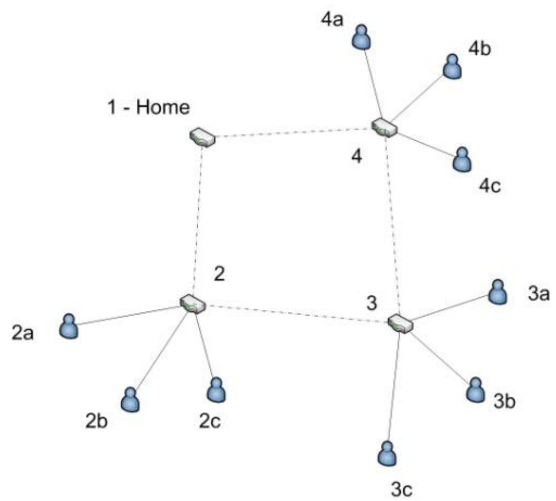


Figure 2. Network Example

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.

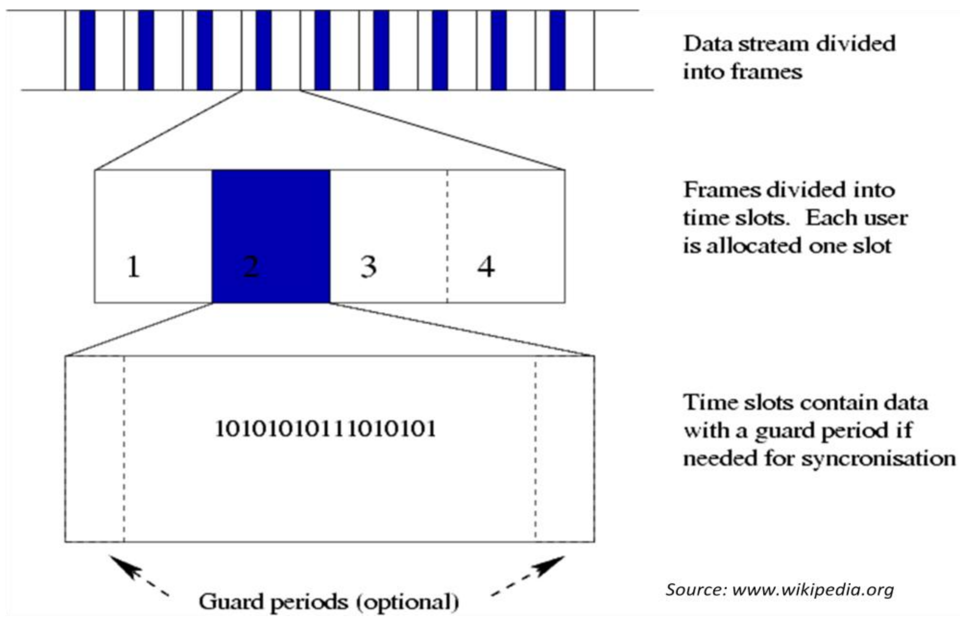


Figure 3. TDM General Diagram

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.

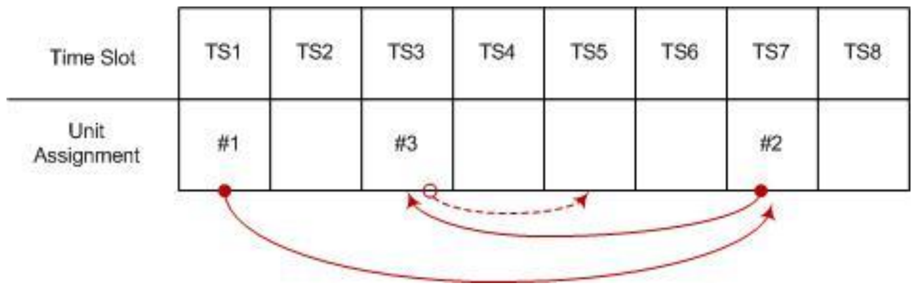


Figure 4. Time Slot Assignment

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. 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

Schematic in Appendix 1the final design for the VHF communication. 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**.**

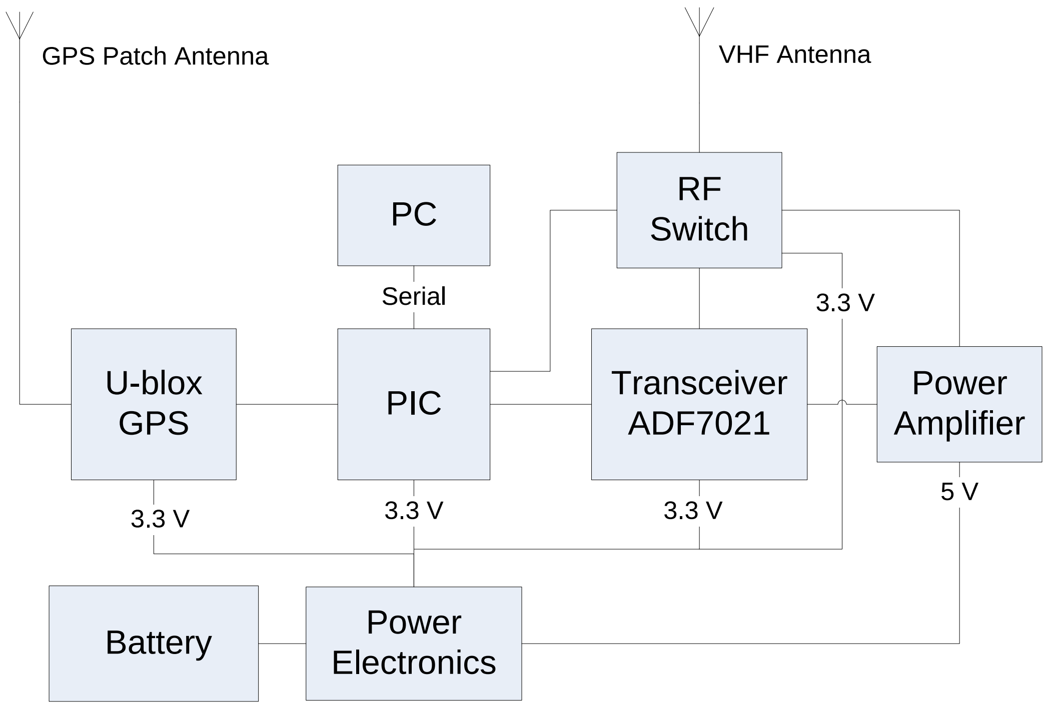


Figure 5. System Block Diagram

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.

3.3.3.2.1. 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.

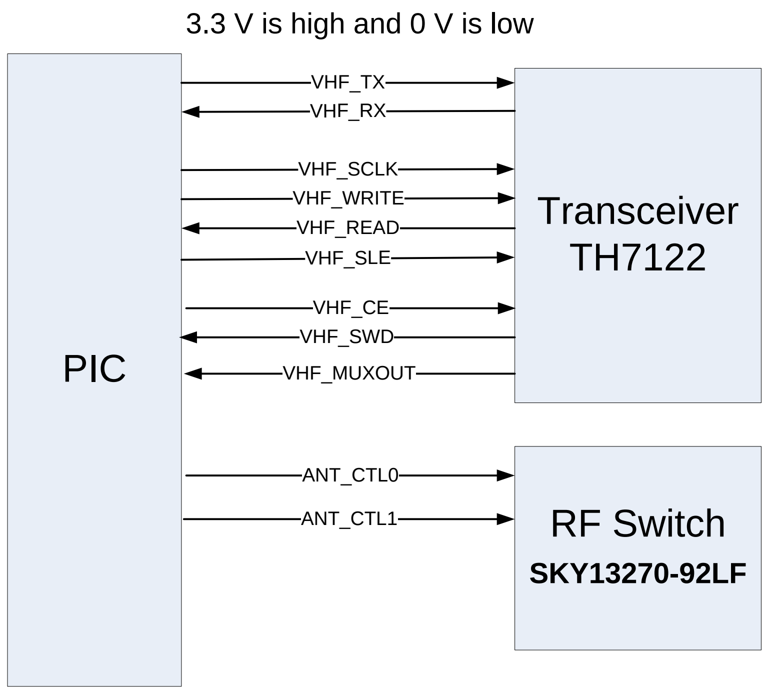


Figure 6. Interface of Transceiver and RF Switch to Microcontroller

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)

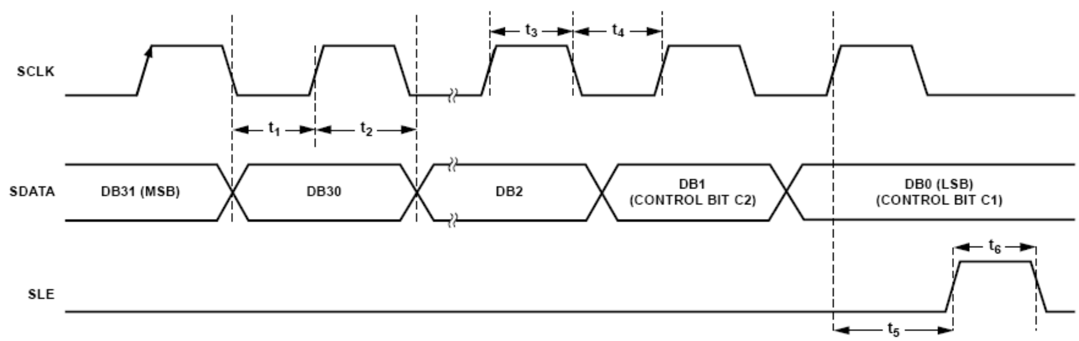


Figure 7. Timing Diagram for Writing to ADF7021 Registers (Analog Devices)

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.

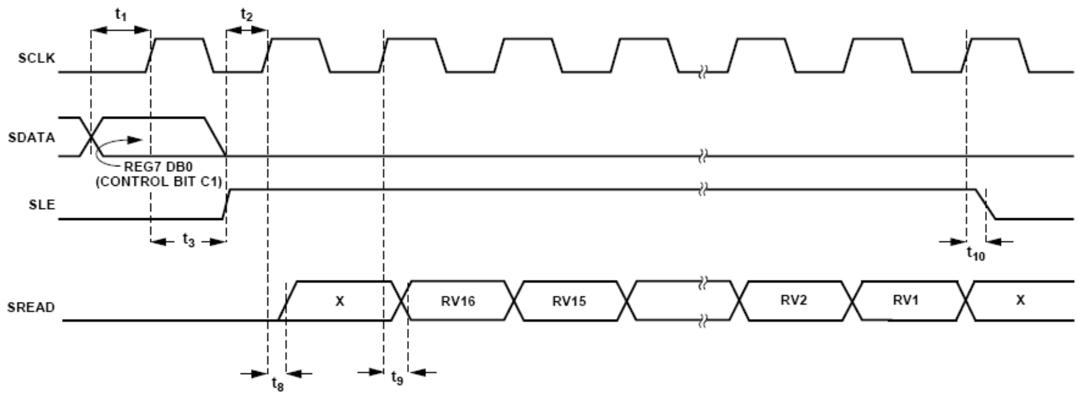


Figure 8. Timing Diagram for Readback (Analog Devices)

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.

3.3.3.2.2. 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.

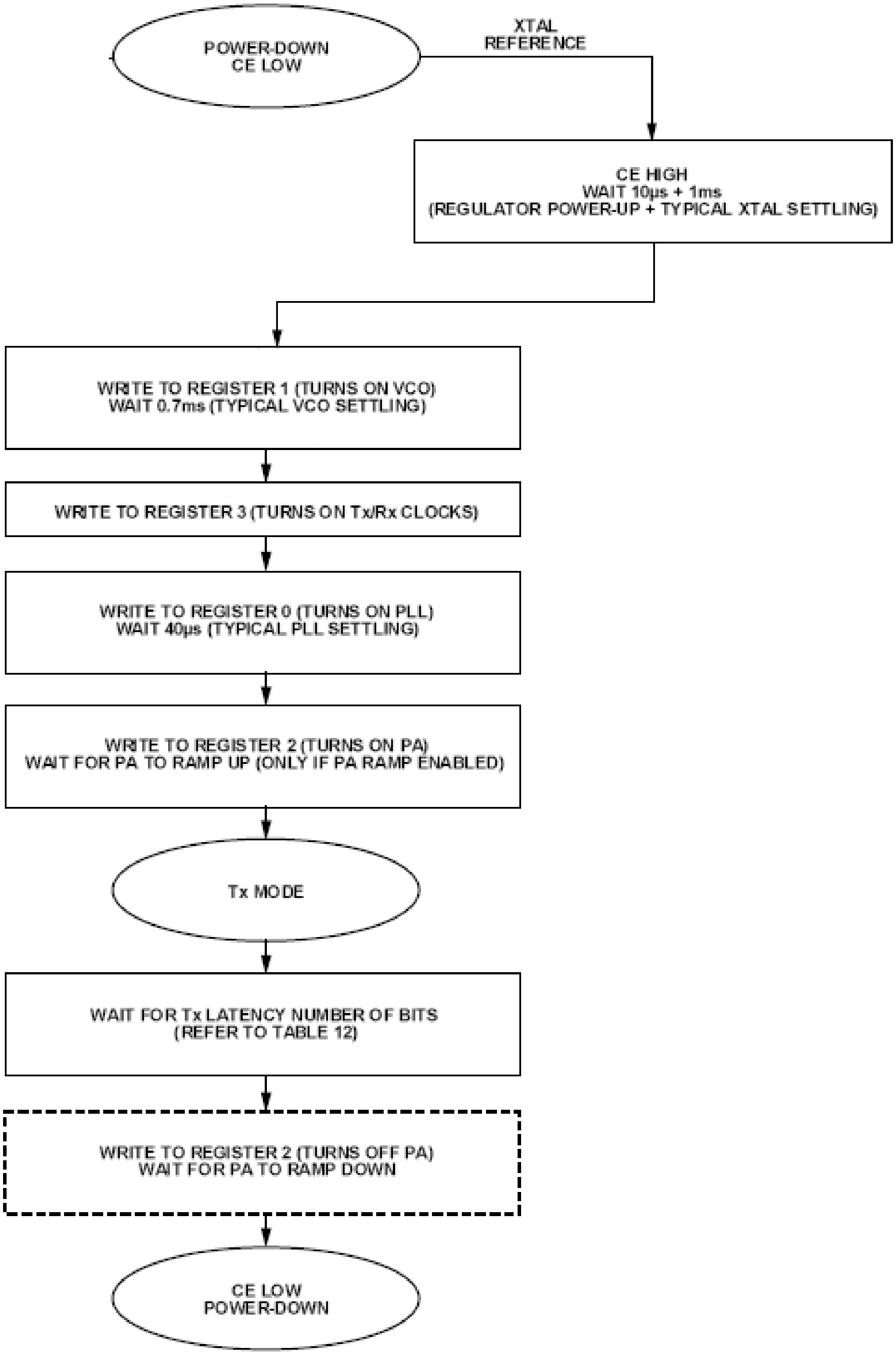


Figure 9. Transmit sequence after power up (Analog Devices, 2009)

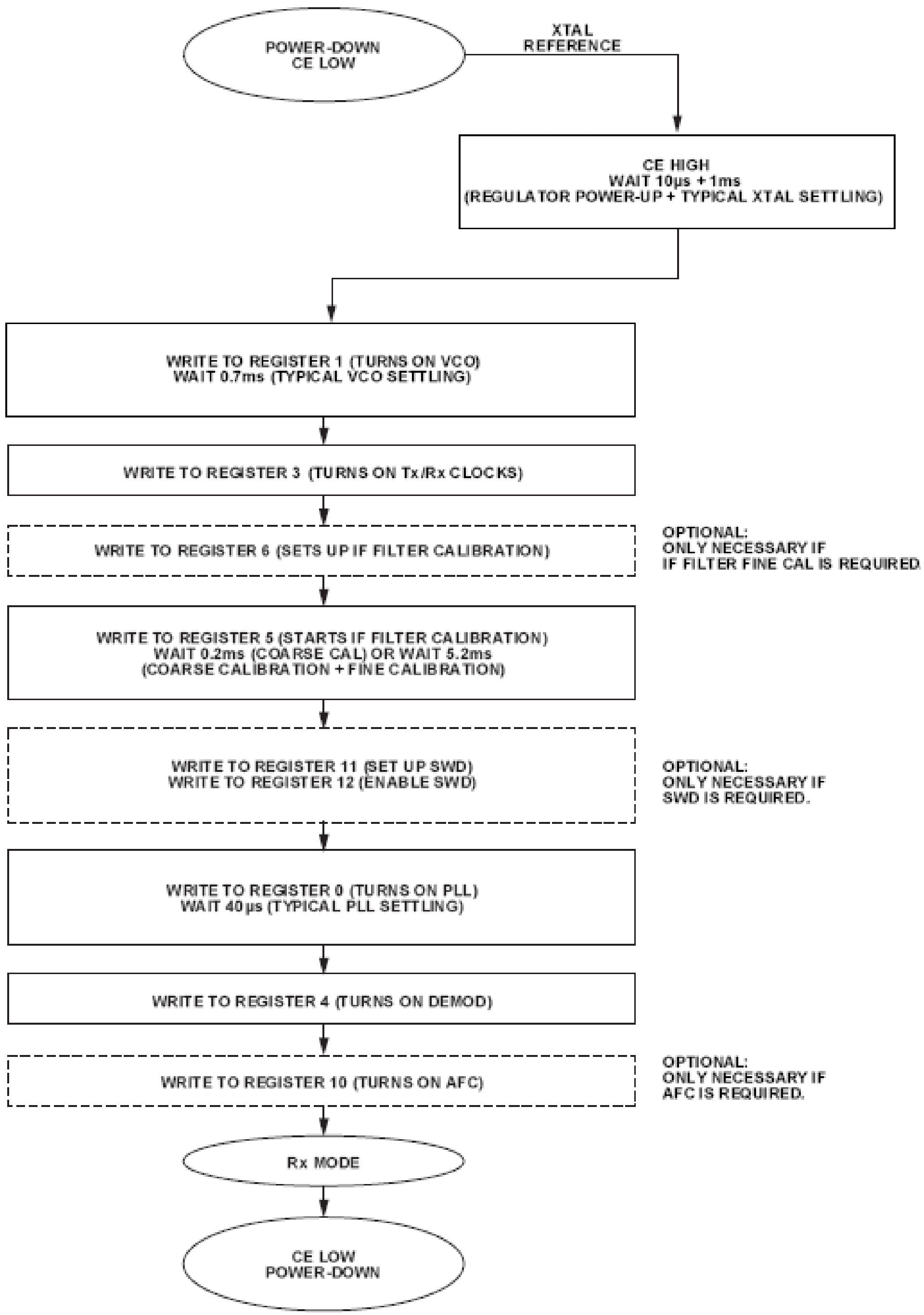


Figure 10. Receive sequence after power up (Analog Devices, 2009)

3.3.3.2.3. 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.

3.3.3.2.4. 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.

3.3.3.2.5. 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.

3.3.3.2.6. 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.

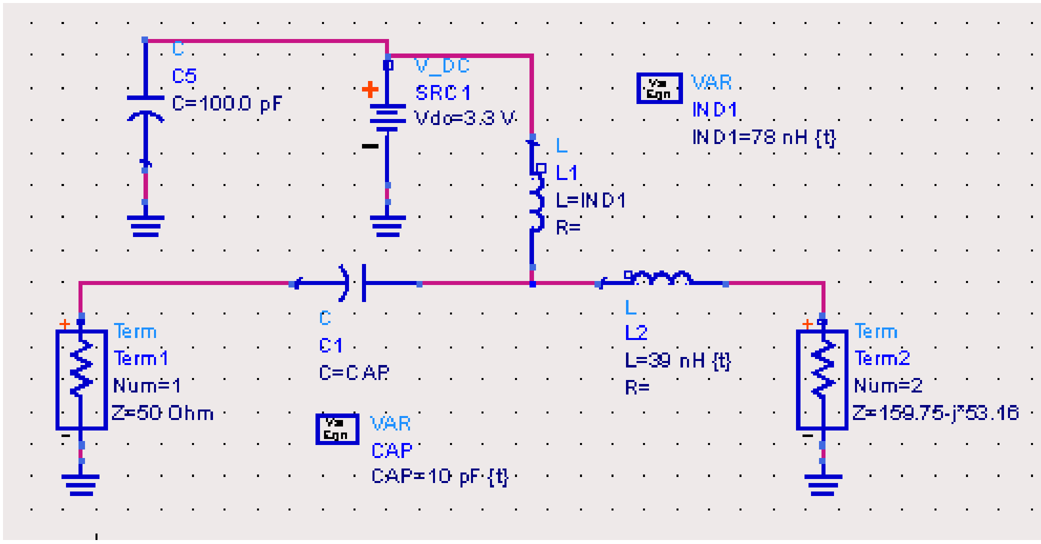


Figure 11. RF Output Matching Network

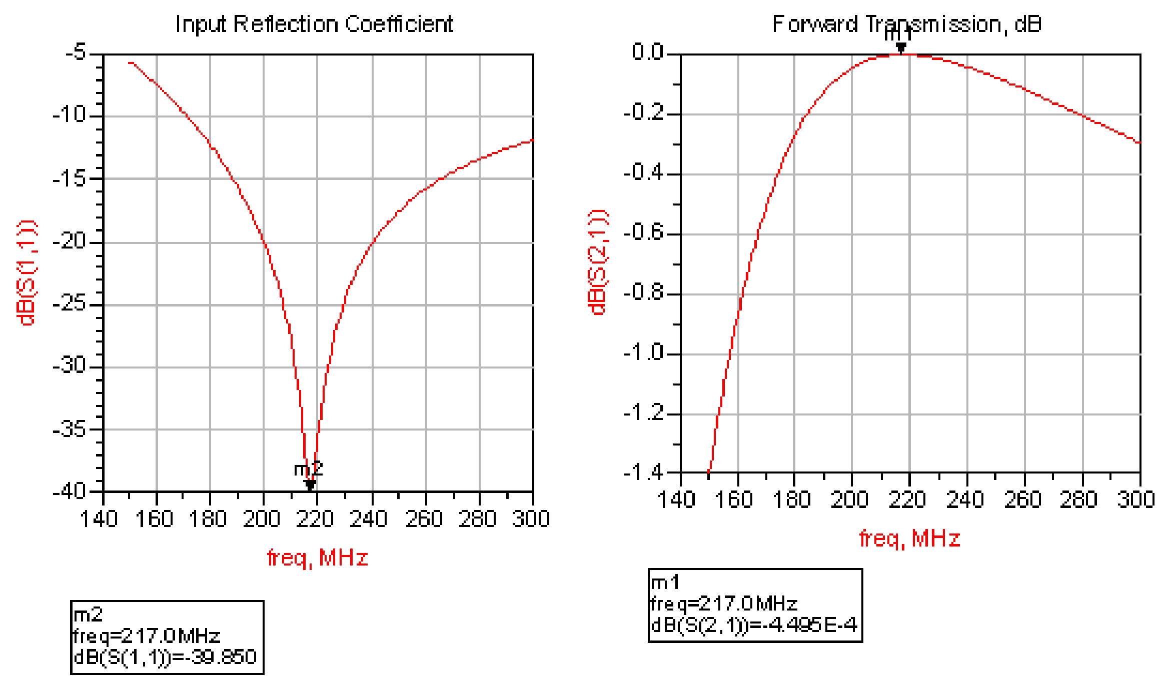


Figure 12. RF Output Matching Network Simulation

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.

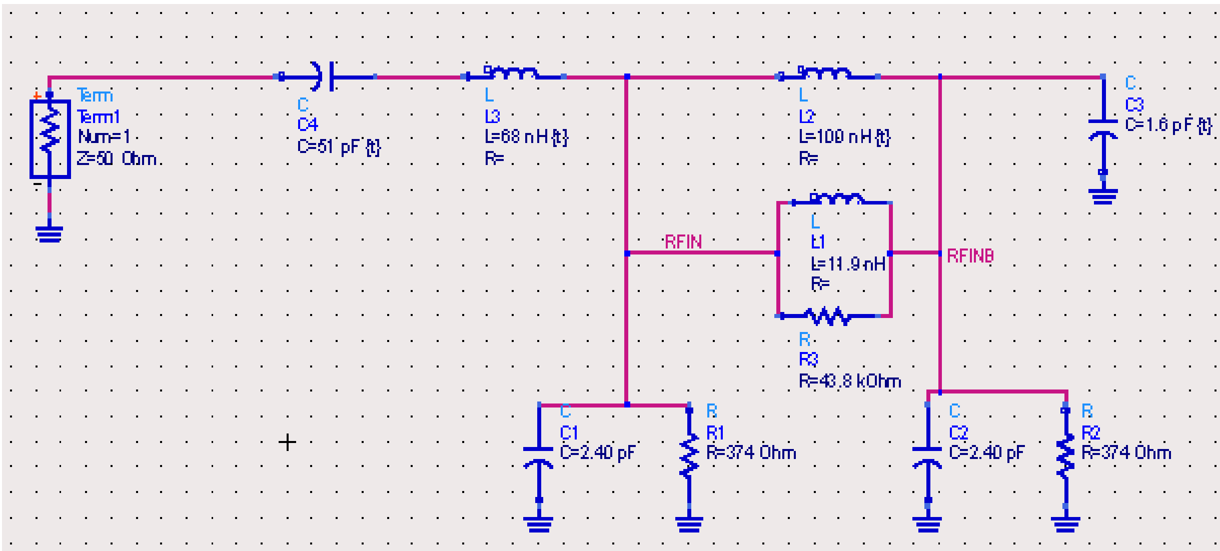


Figure 13. RF Input Matching Network

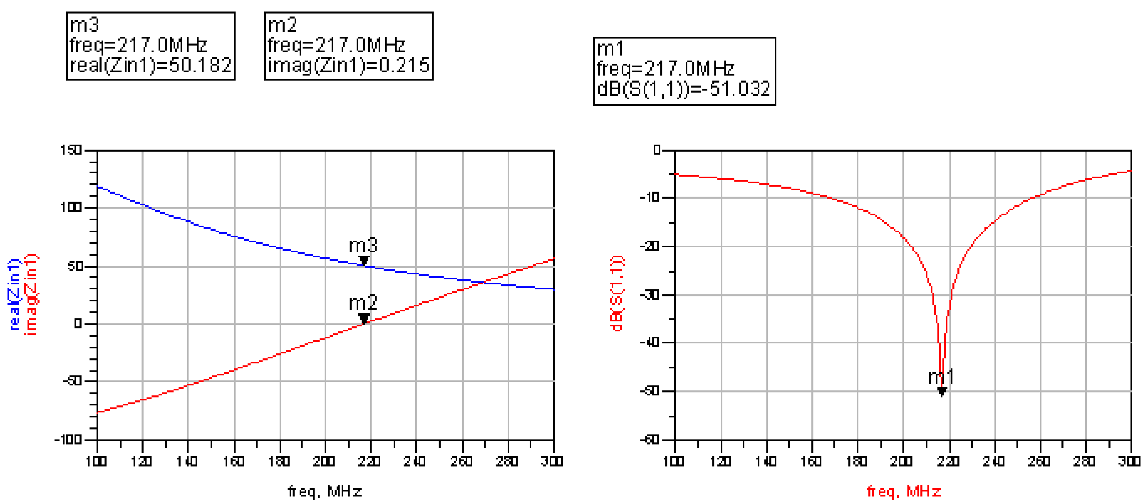


Figure 14. RF Input Matching Network Simulation

3.3.3.2.7. 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.

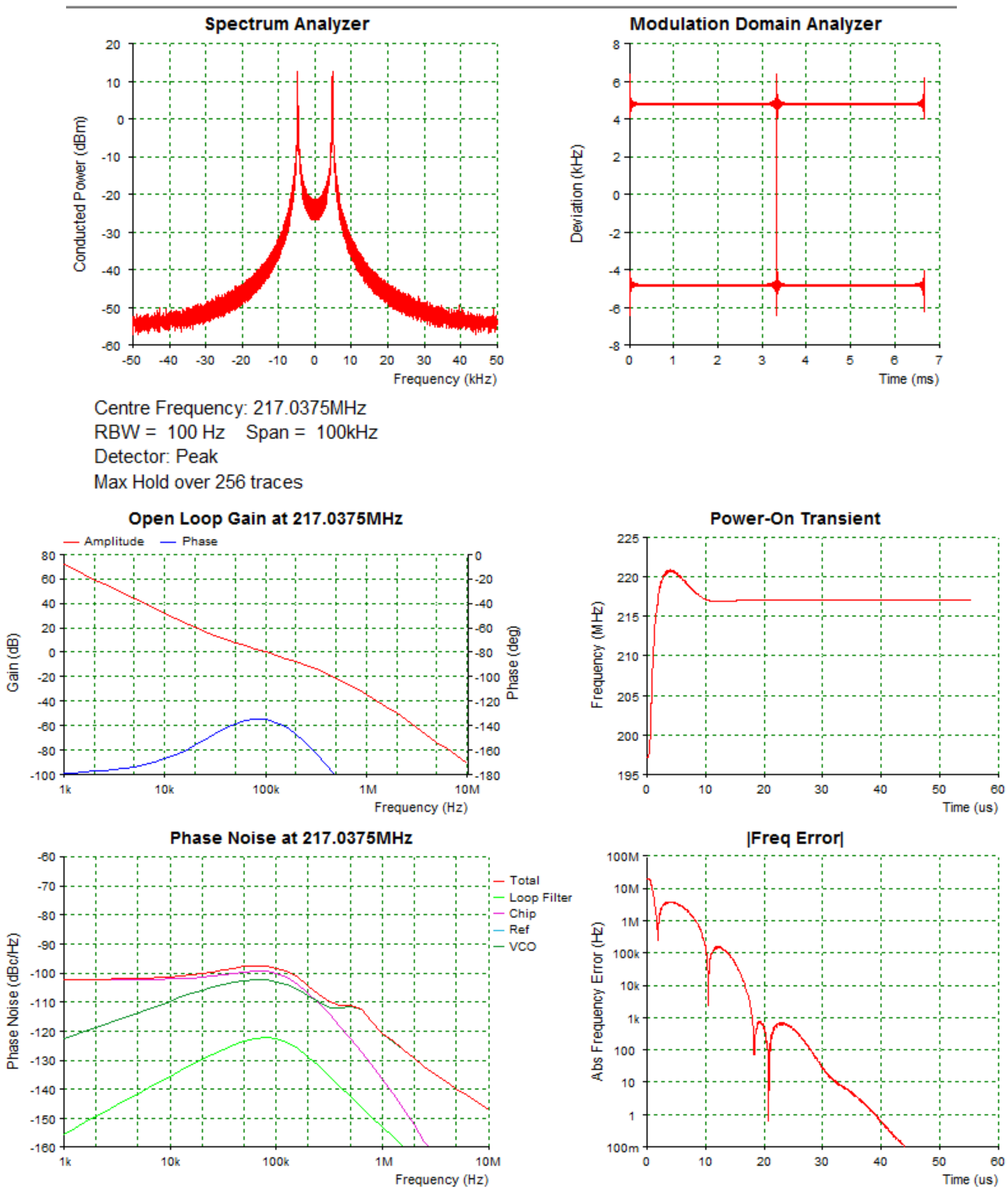


Figure 15. ADF7021 Simulations

3.3.3.3. 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.

3.3.3.4. External Power Amplifier

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	0	1
Receive	1	0

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.

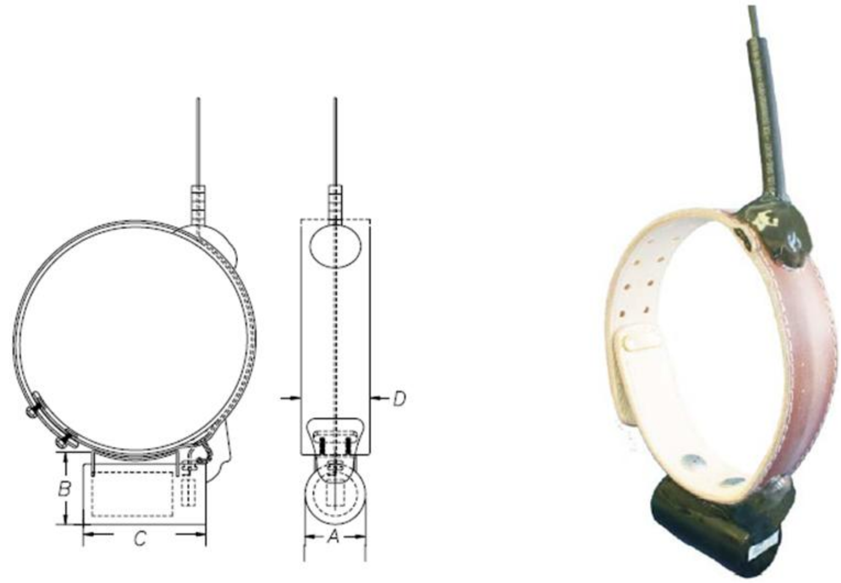


Figure 16. Example Whip Collar Antenna(Advanced Telemetry Systems)

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.

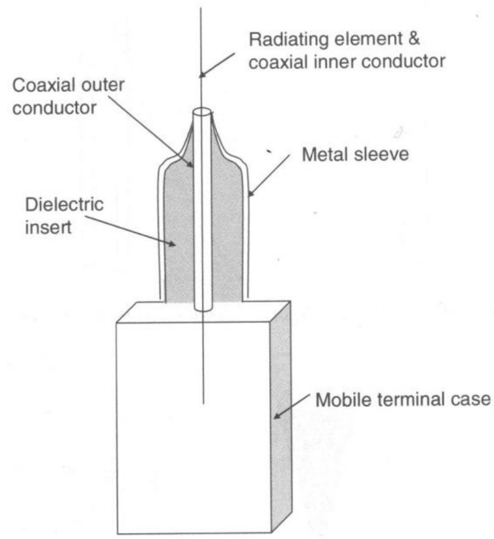


Figure 17. Sleeve Dipole Antenna(Saunders and Aragon-Zavala)

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.

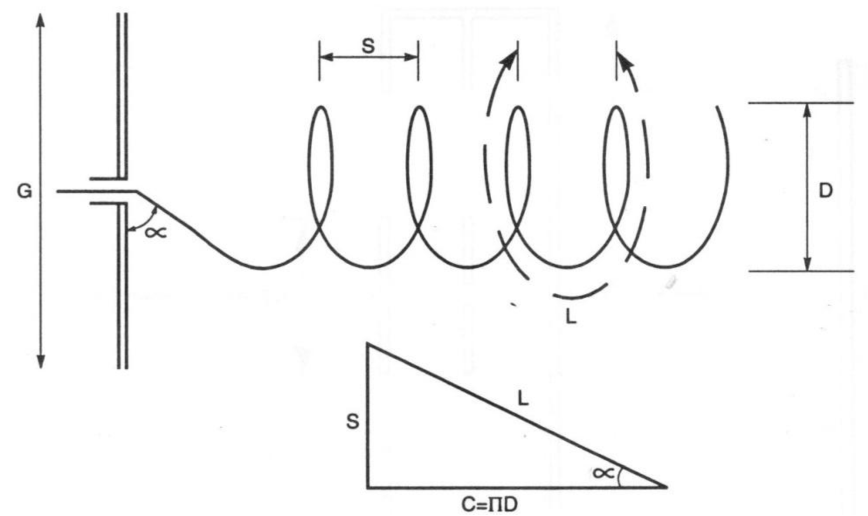


Figure 18. Helical Antenna (Burberry)

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.

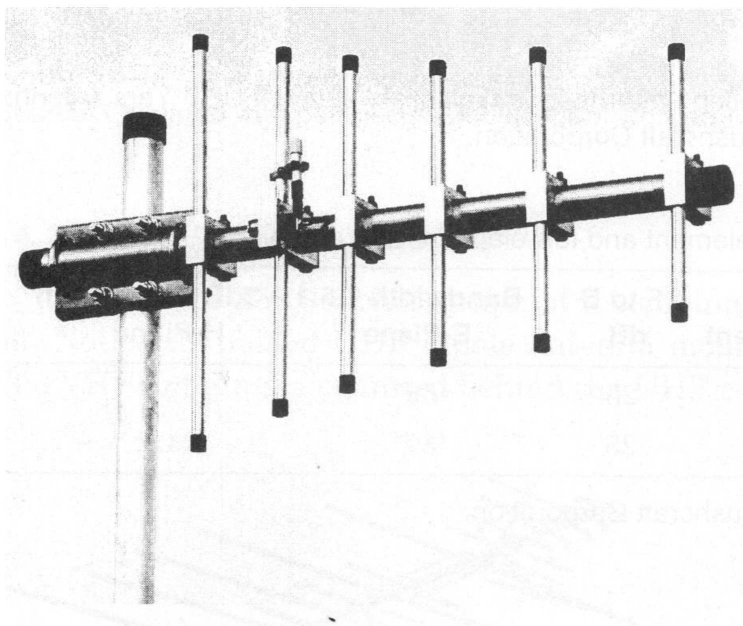


Figure 19. Six Element Yagi Antenna(Setian)

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.

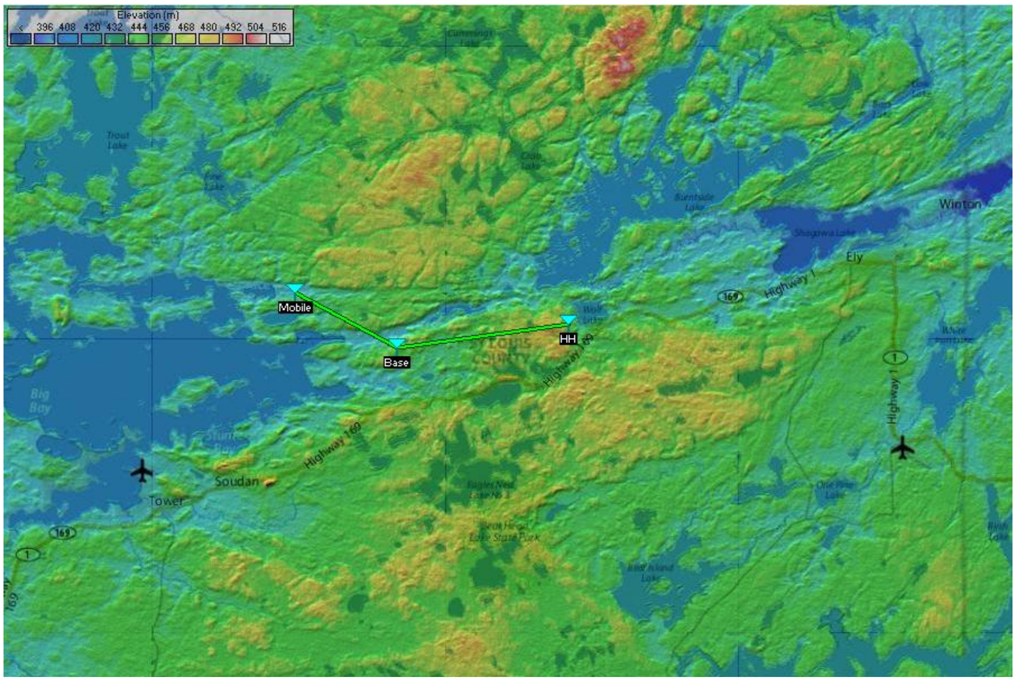


Figure 20. Radio Mobile Area of Concern

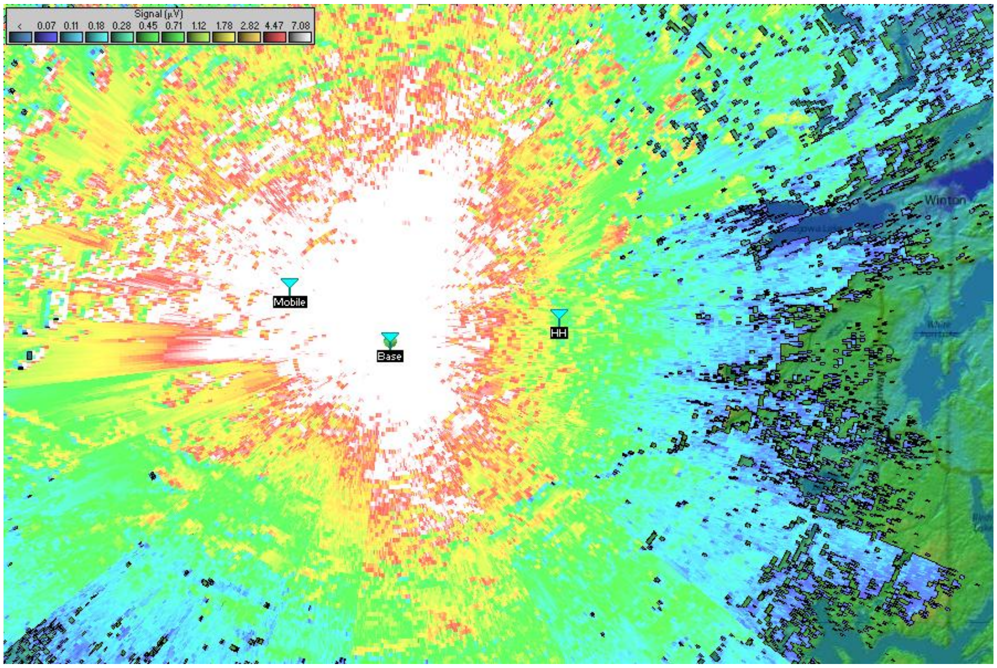


Figure 21. Radio Mobile Router Station Propagation

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.

Schematic detail and design of GPS module is attached in Appendix 4: Power Supply.

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.

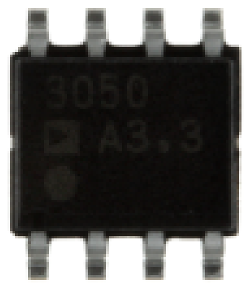


Figure 25. ADP3050

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.

3.9.3.1.1. 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.

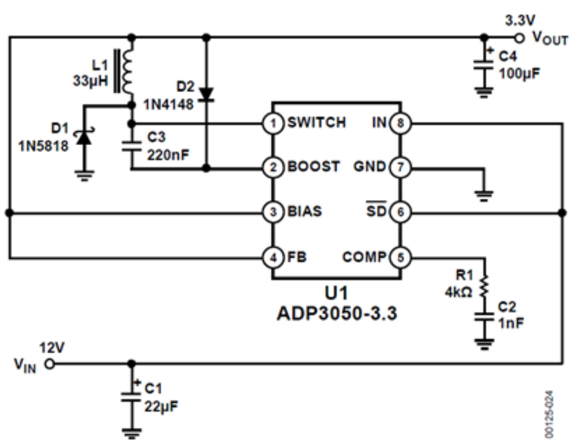


Figure 26. ADP3050 General Circuit

3.9.3.1.2. Switching Inductor and Output Capacitor Choice for GPS Unit

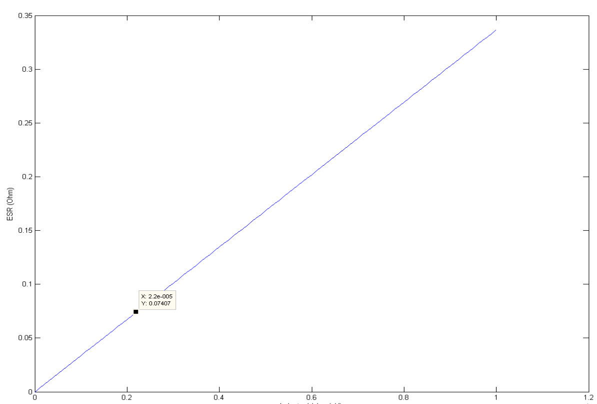
The GPS unit requires an input of 3.3V with a maximum ripple voltage of 50mVPP. Thus, the switching regulator must be designed to meet these conditions. To be safe, the regulator was designed such that the output ripple voltage is 25mVPP. For the ADP3050, the output Vripple depends on the inductor value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

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

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

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.

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

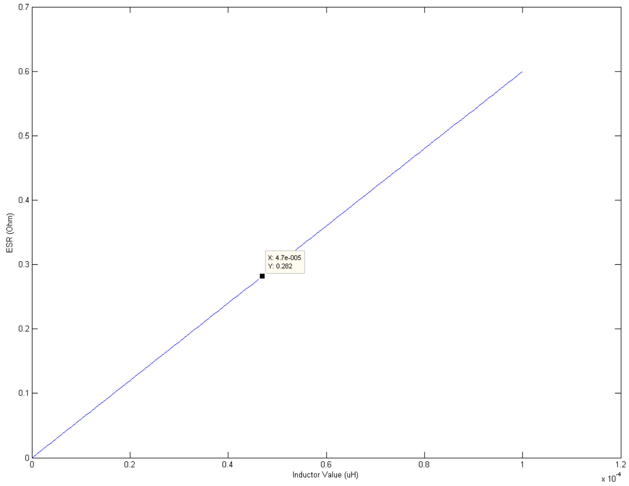
$$1.20 \times \text{Isw(pk)} = 1.20 \times 0.28875 = 0.3465\text{A}$$

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.

3.9.3.1.3. 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.

3.9.3.1.4. 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.

The final power supply schematic can be seen in Appendix 4.

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. 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.

4.1. 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.

4.1. 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.

4.2. 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.

4.3. 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.

4.4. 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.

4.5. 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.

4.6. 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.

4.7. 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.

5. Recommendation for Project Continuation

Our team has decided to continue with the project; however, we have made some modifications. Originally we were asked to produce at least 5 functioning units, but after discussions with our advisor, we have been told to make our initial system as simple as possible with only three collars and two router units.

This is a very extensive project that requires a large time commitment. Because of this, we believe that it would easily be feasible to make this a multiyear project. Since the basic functionality is crucial, our team does not believe that we will have the opportunity and time to make it as efficient and effective as possible. Below are various suggestions for continual project opportunities.

- Since both the collars and router units contain the same hardware it would be easy to incorporate the collars into the routing scheme as well. Essentially, a continuation of the project could ask the team to make the collars act as routers as well in terms of data relay.

- Create a more dynamic system that allows for addition and removal of units without having to manually alter the routing protocol.

6. Statement of Work

The project will be broken down into seven tasks (Table 6) and every member of the team will contribute to complete these tasks.

Table 6: 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

6.1. 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.

6.1.1. 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.

6.1.2. 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.

6.1.3. 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.

6.2. 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.

6.2.1. 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.

6.2.2. 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.

6.2.3. 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.

6.2.4. 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.

6.2.5. 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.

6.2.6. 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.

6.2.7. 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.

6.3. 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.

6.3.1. 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.

6.3.2. 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.

6.3.3. 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.

6.3.4. 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.

6.4. 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.

6.4.1. 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.

6.4.2. 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.

6.5. 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.

6.5.1. 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.

6.5.2. 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.

6.5.3. 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.

6.6. 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.

6.6.1. 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.

6.6.2. 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.

6.6.3. 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.

6.6.4. 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.

6.7. 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.

6.7.1. 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.

6.7.2. 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.

6.7.3. 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.

6.7.4. 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.

6.7.5. 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.

7. Estimated Resources and Schedule

In Section 4.1, we estimate the single unit material cost to be $280 and development labor cost to be $20,500. With an estimated build of five units, the estimated total cost of the project is $21,900. The development labor costs are being donated by the team, and the material costs are being covered by the client.

Section 4.2 outlines the schedule of the entire project. The schedule consists of all the tasks and subtasks from Section 3.2. The schedule was produced to ensure an on-time completion of the project.

7.1. Estimated Resources

Based on initial research and our conceptual diagram, we estimated the unit material cost to be $280 (see Table 7). 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 7: Single Unit Estimated Cost

Item	Estimate Cost
VHF Communication	$20.00
RF Antenna	$20.00
GPS	$100.00
GPS Antenna	$15.00
Battery	$15.00
Microcontroller	$18.00
Connectors	$25.00
Printing Wiring Board	$40.00
Chassis	$17.00
Power Electronics	$10.00
Total	$280.00

The estimated development labor hours required to complete the project was estimated at 1025 hours (see Table 7). The hours were based on the number of days allocated to each task (see 7.2 - Schedule) and an average work effort per member of the team of 8 hours a week which includes individual contributions along with any team meetings. With an hourly rate of $20 per hour, the estimated development labor cost for the project is $20,500. However, for this project, our team will donate the development labor cost.

Table 8: Estimated Development Labor Costs

Task	Estimated Hours	Estimated Cost @ $20/hrs
Task 1 - Problem Definition	75	$1,500
Task 2 - Technology Research and Selection	60	$1,200
Task 3 - End-Product Design	200	$4,000
Task 4 - End-Product Prototype Implementation	200	$4,000
Task 5 - End-Product Testing	300	$6,000
Task 6 - Presentations	90	$1,800
Task 7 - Product Documentation	100	$2,000
Totals	1025	$20,500

The total estimated cost for the project is $21,900. The total estimated cost includes building five prototypes (see Table 9).

Table 9: Estimated Project Costs

Description	Estimated Unit Cost	Estimated Qty	Extended Cost
Prototypes	$280.00	5	$1,400
Development Labor Costs	$20.00	1025	$20,500
Total			$21,900

7.2. 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 29 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

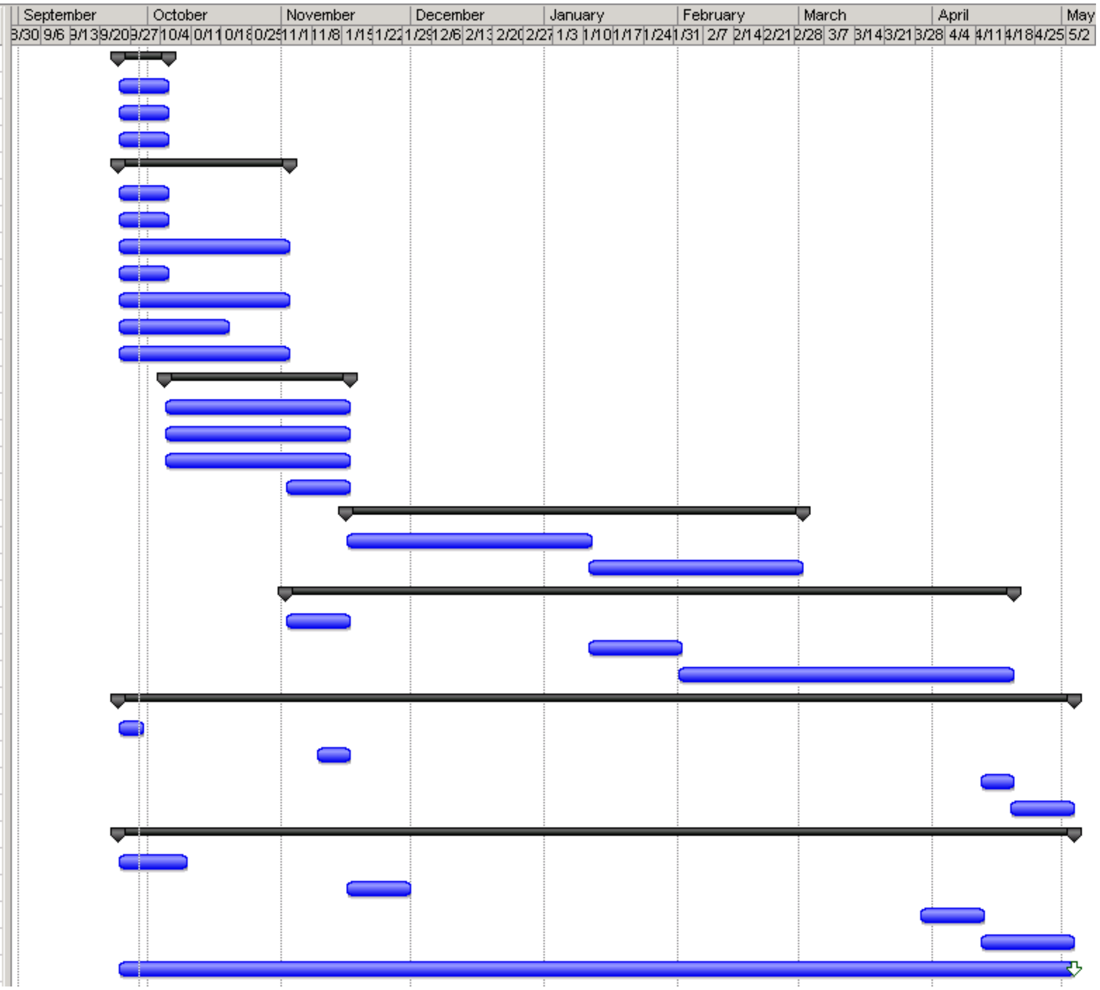


Figure 29: Schedule for Project

8. 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.

8.1. Project Contact Information

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

8.1.1. Client Information

Digi International
Mark Tekippe, Jim Stroner, and Jordan Husney
11001 Bren Road East
Minnetonka, MN 55343
Phone: 1-877-912-3444
Email: digisd@iastate.edu

8.1.2. Faculty Advisor Information

Dr. Ahmed Kamal
319 Durham Hall
Ames, IA 50011
Phone: 515-294-3580
Email: kamal@iastate.edu

8.1.3. Student Team Information

Zach Bruce
225 N. Hyland APT 6
Ames, IA 50014
Phone: 515-975-7836
Email: zbruce@iastate.edu

Blane Chesnut
Webmaster
4335 Frederickson CT
Ames, IA 50010
Phone: 515-572-7820
Email: bchesnut@iastate.edu

Chris Donnelly
4335 Frederickson CT
Ames, IA 50010
Phone: 515-572-7820
Email: cdonns87@iastate.edu

John Pritchard
Communication Liaison
4700 Mortensen RD Unit 201
Ames, IA 50014
Phone: 712-389-0381
Email: johnp@iastate.edu

Adam Rasmussen
Team Leader
3055 190TH ST
Goldfield, IA 50542
Phone: 515-824-3456
Email: adamras@iastate.edu

8.2. 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 an estimated unit material cost of $280 and development labor costs of $20,500, we have develop a initial solution for Digi International that meets their requirements for the project.

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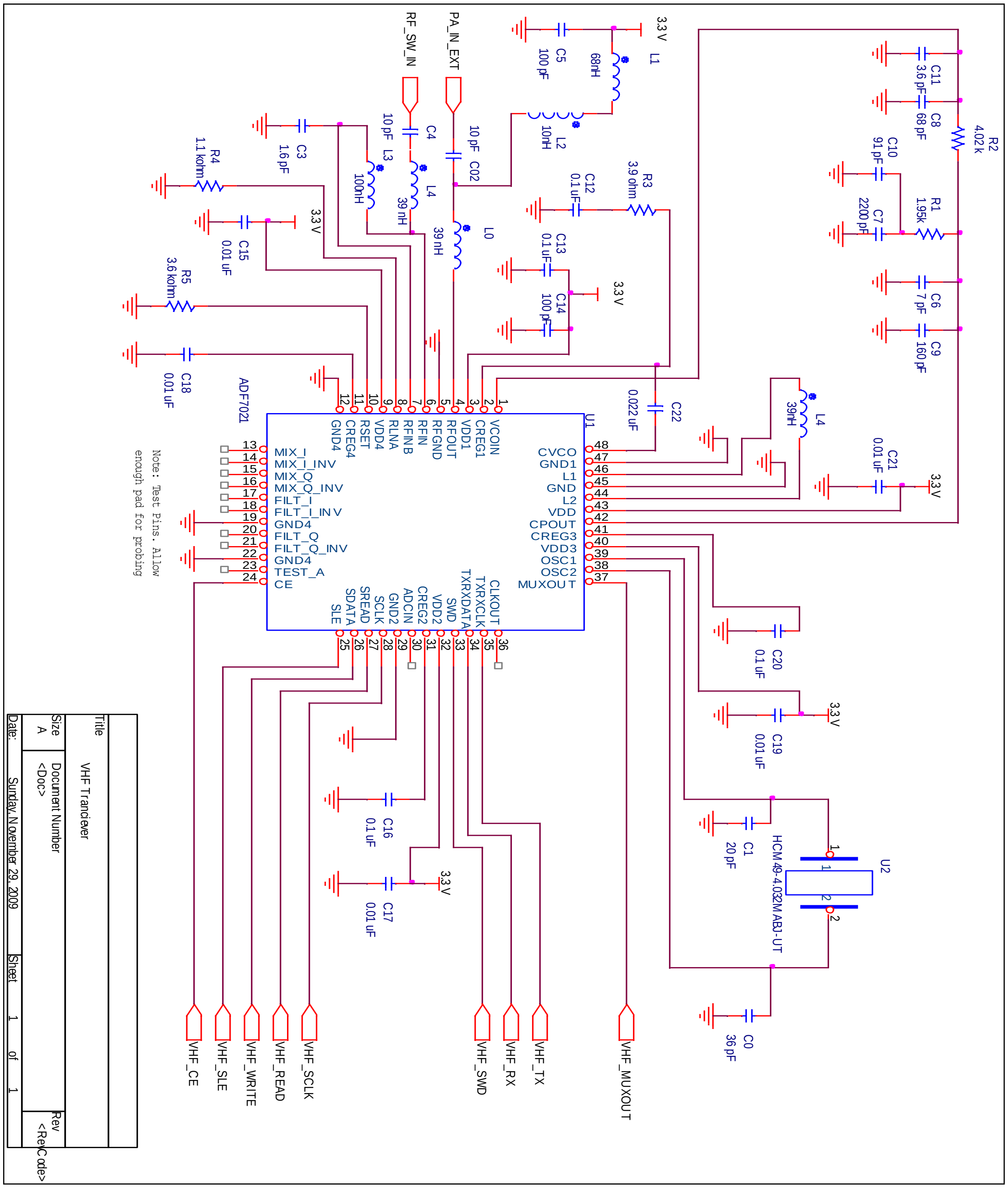
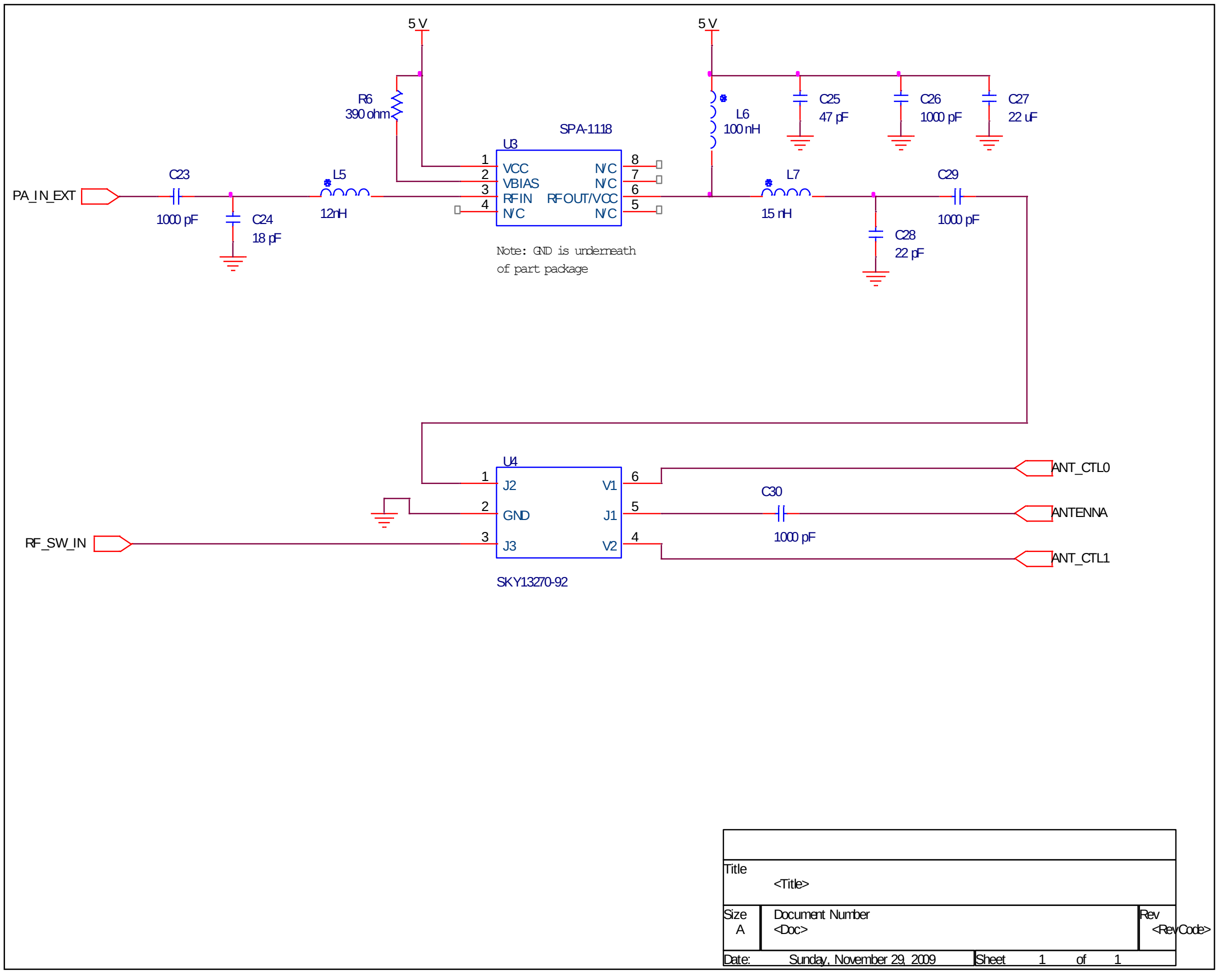
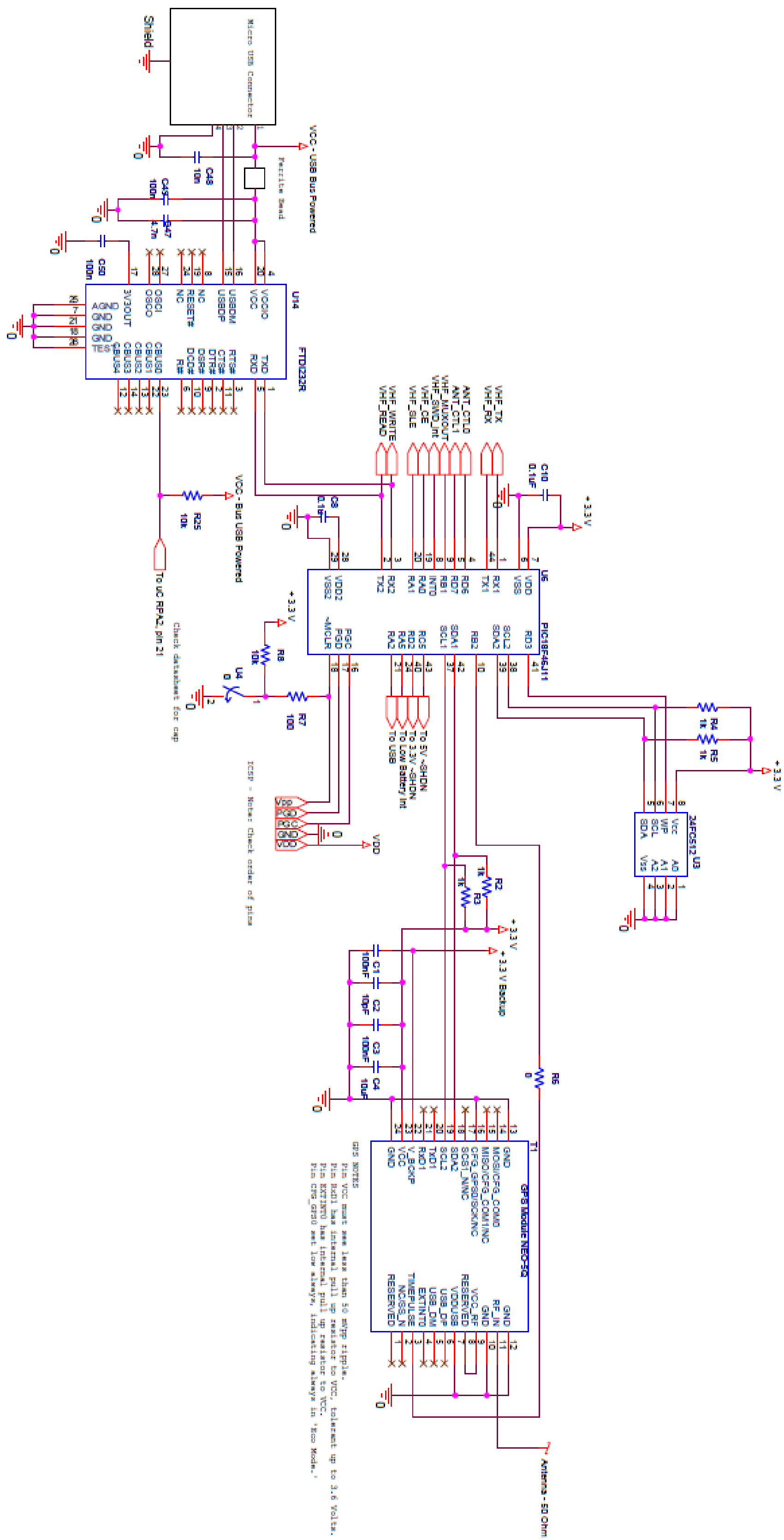
Appendix 1: VHF Transceiver



Appendix 2: Power Amplifier



Appendix 3: GPS, Microcontroller



Appendix 4: Power Supply