LIGHTWEIGHT SMALL MAMMAL GPS TRACKER

By

INA ANNESHA KUNDU

A Thesis Submitted to The Honors College

In Partial Fulfillment of the Bachelors degree
With Honors in

Mechanical Engineering

THE UNIVERSITY OF ARIZONA

MAY 2013

Approved by:

____

Michael Marcellin
Department of Electrical and Computer Engineering

The University of Arizona Electronic Theses and Dissertations Reproduction and Distribution Rights Form

The UA Campus Repository supports the dissemination and preservation of scholarship produced by University of Arizona faculty, researchers, and students. The University Library, in collaboration with the Honors College, has established a collection in the UA Campus Repository to share, archive, and preserve undergraduate Honors theses.

Theses that are submitted to the UA Campus Repository are available for public view. Submission of your thesis to the Repository provides an opportunity for you to showcase your work to graduate schools and future employers. It also allows for your work to be accessed by others in your discipline, enabling you to contribute to the knowledge base in your field. Your signature on this consent form will determine whether your thesis is included in the repository.

Name (Last, First, Middle)

KUNDU, INA, ANNESHA

Degree title (eg BA, BS, BSE, BSB, BFA):

B.S

Honors area (eg Molecular and Cellular Biology, English, Studio Art):

MECHANICAL ENGINEERING

Date thesis submitted to Honors College:

MAY 01, 2013

Title of Honors thesis:

LIGHTWEIGHT SMALL MAMMAL GPS TRACKER

The University of Arizona Library Release Agreement

I hereby grant to the University of Arizona Library the nonexclusive worldwide right to reproduce and distribute my dissertation or thesis and abstract (herein, the "licensed materials"), in whole or in part, in any and all media of distribution and in any format in existence now or developed in the future. I represent and warrant to the University of Arizona that the licensed materials are my original work, that I am the sole owner of all rights in and to the licensed materials, and that none of the licensed materials infringe or violate the rights of others. I further represent that I have obtained all necessary rights to permit the University of Arizona Library to reproduce and distribute any nonpublic third party software necessary to access, display, run or print my dissertation or thesis. I acknowledge that University of Arizona Library may elect not to distribute my dissertation or thesis in digital format if, in its reasonable judgment, it believes all such rights have not been secured.

[X] Yes, make my thesis available in the UA Campus Repository!

Student signature: Ina Kundu Date: 5/1/13

Thesis advisor signature: [signature] Date: 5/1/13

[ ] No, do not release my thesis to the UA Campus Repository.

Student signature: ________________ Date: ________________

Last updated: 04/01/13

UNIVERSITY OF ARIZONA

Executive Summary

A position beaconing system for tracking small mammals, such as the Golden Lion Tamarin, was developed and tested. GPS acquires location of the animal. The system utilizes a VHF radio transmitter tuned to 144.390 MHz, which is located in the amateur radio band. APRS was selected as the protocol for position, transmission, and recovery. This allows users to benefit from any existing APRS enabled devices. The beacon was designed by attempting to optimize operational longevity and minimize size. Consequently, the system is implemented on a single board and enclosed for protection. As the system must be comfortable for the mammal, it was manufactured from lightweight components and enclosed in plastic housing. To attach the case to the mammal, it is connected to a flexible, zig-zag, wearable antenna, which functions as a collar.

Contents

List of Figures

List of Tables

Chapter 1

Introduction

Massive scale global deforestation is threatening the lives of countless species. The hunt for natural resources places biodiversity in jeopardy. Maintaining the populations of endangered species is a problem which in part can be solved through engineering design. Animal conservation reseachers can make use of information about the location of animals to ensure they are safe and thriving, whether they are indigenous or have been reintroduced to the wild.

One such animal which garners a significant conservational effort are the Golden Lion Tamarin (GLT) Monkeys. These primates are native to the Brazillian Rainforest near Rio de Janeiro[1]. With a population of only 1500 roaming southeastern Brazil and 490 captive in zoos, there is a need to study and preserve the species. Reddish-orange in color, the GLT monkeys are the largest of the callitrichines, averaging 10.3 inches (261 mm) in length and weighing 1.4 lb (620 g). To escape predators, the primates constantly move their sleeping nests and are active for up to 12 hours a day. They primarily rest 11-15 m (36-49 ft) above the forest floor and travel in groups of 2-8[1]. Thus, by installing a tracking device on one tamarin, the movement of one group can be monitored, which is the ultimate goal of the project.

1.1 Problem Statement

To track the GLT, a collar will be placed around the neck of the tamarin, providing GPS coordinates to animal researchers. The small size and weight of the GLT are the impetus for this project. Animal researchers need a small, lightweight, long lasting, affordable means to track Golden Lion Tamarins. Current products on the market do not meet the demands of these researchers as they are too large, too expensive, or do not have the correct functionalities. Thus, conservationist need an accurate device for small mammals. The size of the Tamarins and their environment demands a specifically engineered solution. Coordinates of the animals need to be found and stored, they must be transmitted to researchers, the systems must use minimal power, and the system must be as small as possible.

1.2 Background

According to animal researchers, a reasonable load for a small animal to withstand is 5% of its total weight. This requirement poses the greatest challenge of the project as the tracking device would have to weigh around 30 grams. Currently, there are limited tracking devices available for small mammals. The few existing options are often prohibitively expensive for the animal researchers, thus new solutions must be explored. Dr. Kathleen Melde and Dr. Michael Marcellin of the University of Arizona Electrical and Computer Engineering Department have started to seek viable solutions since 2011 by sponsoring projects carried out by senior engineering students. During the academic year 2011-2012, a team of six engineering students designed an antenna to fit around the neck of the tamarin. The antenna was designed to work with the Garmin DC40 collar and Astro 320 handheld device. The turnkey system they implemented with their antenna is designed for use with hunting dogs and is not ideal for tracking smaller mammals, such as the GLT. Location of the dogs are updated every 5, 10, 30, or 120 seconds, providing a battery life of 17-48 hours for the DC40 collar (Garmin). Such transmission frequencies require large batteries and are excessive for tracking GLTs. The existing Garmin product has other additional, unnecessary features, which can be modified to successfully complete the project. The system only needs to store data 2-4 times a day and potentially transmit the data on a weekly basis. Consequently, the goal for this year (AY 2012-2013) is to reduce the size of the transmitter while utilizing the previously designed antenna.

1.3 Objectives

The product is expected to receive GPS signal and send coordinates to animal researchers as frequently as desired. The system will be configurable to turn on a few times a day, log GPS coordinates, and beacon the collected data once a week.

The primary customers for the proposed low cost, lightweight tracking device are the animal researchers studying the endangered Golden Lion Tamarins. As mentioned previously, existing products are too expensive for animal researchers to utilize, so an alternate, low cost solution must be designed. To easily employ the device, the final product should be user-friendly, one of the considerations during the design stage. The device could also potentially be used for tracking different animals as well as other applications requiring remotely obtaining GPS coordinates of an object.

Chapter 2

Design Solution

With guidance from the sponsors, the chosen solution was to track the Tamarin monkeys with a GPS collar. This requires a GPS receiver as the means of aquiring the animal location, a radio transmitter to send the information to researchers, low power components, and an overall small system. The components chosen and their interactions with eachother can be seen in figure 2.1 below.

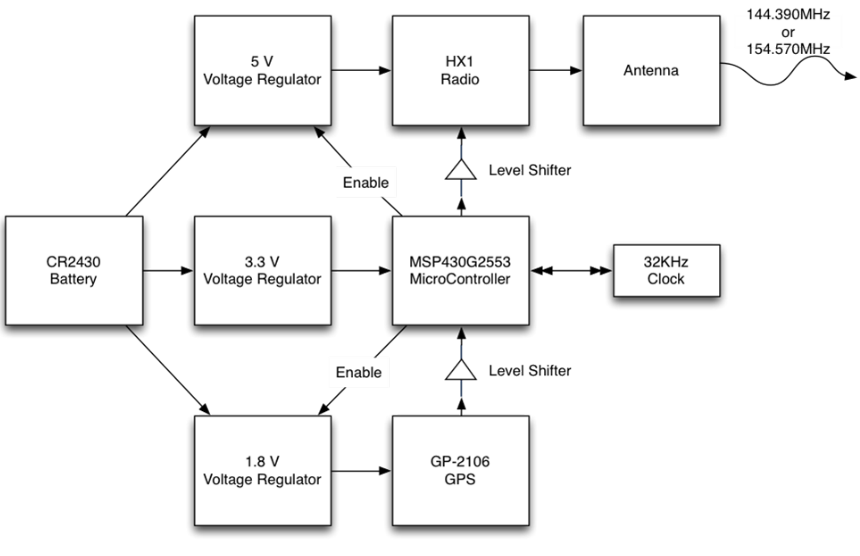


Figure 2.1: Transmitter Design Overview

The two CR2450 batteries are placed in series to provide 6V and be higher than the operating voltage required for the HX1 radio which was selected. The batteries connect directly to three voltage regulators, two switching and one linear, in order to power the circuit with 5V, 3.3V, and 1.8V. The microcontroller powered by 3.3V then interfaces with the radio and GPS module in order to communicate and send and recieve data. This requires logic level shifting so the components have the correct operating logic levels. The microcontroller also has an external 32kHz crystal connected for low power operation. Not shown in the diagram is a resistor ladder which enables the sinusoidal signal generation. Then the radio connects to the collar antenna which transmitts the information.

The operation of the system in software is also importnat to consider. Figure 2.2 shows a general overview of what the system does, although the voltage regulators are not enabled and disabled.

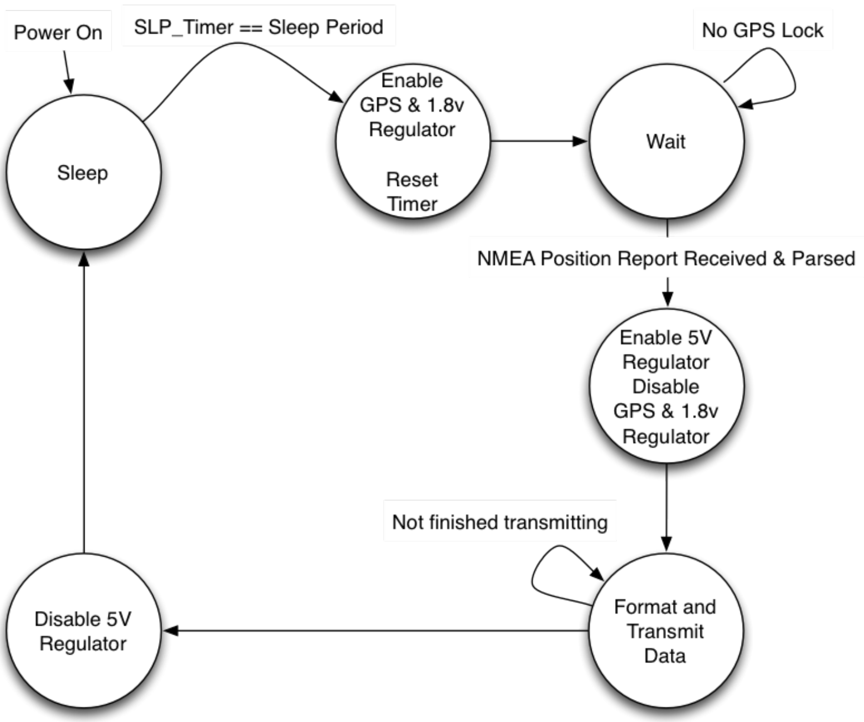


FIGURE 2.2: High Level Overview of System Operation

The system is enabled with a switch at which point it immediately goes into a low power sleep mode. A counter is enabled and counts until a user specified time is up. At this point, the GPS is enabled and begins to search for a location lock. Once a lock is obtained, the GPS is stream out data about the location of the beacon. This data is parsed by the microcontroller and stored in memory. With the NMEA0183 data stored, it can be immediately transmitted via the radio, or saved to transmitt later. When ready to transmitt, the software modem is enabled. The outputs of the microcontroller go to the resistor ladder which is able to encode the data. At the same time, the radio is enabled so the signal at the output of the resistor ladder can be transmitted on the 144.390 MHz carrier frequency.

2.1 Location Aquisition

The main objective of this project is to reduce the size and weight from the existing tracking system, so these two factors become the major concerns when selecting the GPS module. There were several options considered for the GPS the LS20031, Venus638FLPx, the GP-2106. The advantage of the first module is it has an input voltage of 3.3V which is the same input voltage as microcontroller and we can use the same voltage regulator providing the input voltage for it, however, it is slightly larger than the GP-2106 option measuring at $30 * 30 * 8\ mm^3$ [2]. The Venus638FLPx is even smaller measuring only $10 * 10 * 1.3\ mm^3$ [3], but the disadvantage is that it does not have an integrated antenna. Designing an extra antenna for GPS would be difficult and the size advantage will be lost.

The GP-2106 GPS receiver is only $21 * 6 * 6\ mm^3$ in size and 3.1 grams in weight, making it is less than half size and weight of most other modules [4]. In the rainforest, the GPS signal will potentially be weak because of the dense foliage and heavy rainfall. These factors necessitate that the system have a module with high sensitivity. The GP-2106 is powered by SiRF Star IV and it can receive signals as low as -163dBm, which is more sensitive than most of other modules we found (mostly are -159dBm and -161dBm). In addition, the GP-2106 has an integrated ceramic antenna. Not requiring separate antenna component for the GPS reduces the size and weight of the system. The component is ready to use off the shelf. It may not be as receptive as a receiver with a large external antenna, but this is a necessary trade-off. Also, the orientation of the module on the board must be considered. The patch antenna will have the best signal reception when oriented towards the sky. The major disadvantage of GP-2106 is its input voltage is 1.8V, which differs from the input voltage of the microcontroller and radio (3V and 5V)[5][4]. For this reason, the system needs another voltage regulator to lower the input voltage from the battery to 1.8V. Also the logic levels must be adjusted. Unfortunately this increases the volume in the package required for the and the complexity of the system. Fortunately though, there is a breakout board available for testing the component which does the necessary shifts down to 1.8V. The GP-2106 will use two pins , 1_V8 and GND will receive power from voltage regulator and connect to ground respectively. The other three ,ON/OFF, RXD, TXD pins will communicate with MSP430 microcontroller[4]. ON/OFF pin will receive a pulse input from the microcontroller to turn on the system and switch it to full-power mode or hibernate mode. RXD pin is the main receiver channel to receive command from the microcontroller and TXD pin is the main transmitting channel to output the measurement data to the microcontroller.

The GPS unit in the system will capture the signal automatically and transmit the data to microcontroller through UART. The GP-2013 GPS unit use a baud rate of 9600 for UART [4] . Since the internal clock in the system is 8MHz, and the register is set to

$8MHz/9600 = 833.33$. The system use GSPPA strings from a massive GPS data, and it include the longitude and latitude. In the string of GPGGA, a fixed bit will indicate if the GPS got accurate data. In the program, it will search for this pin, and if the bit set to 1 and the microcontroller will record the updated string of data.

2.2 Signal Transmission

A major requirement of this project was that we employ the zig-zag antenna design presented by last years University of Arizona small mammal tracker team [6]. Because of this, the frequency was constrained to somewhere in the 144MHz area. Any lower frequencies lead to less efficient collar antennas being produced. So first, selection of a desirable means of signal transmission was carried out.

2.2.1 Protocol

The Automatic Packet Reporting System (APRS) can be used for much more than position reporting (announcements, alerts, weather, and much more) however it seemed to fit perfectly with what was to be accomplished. The reader of this paper is encouraged to read more about APRS at www.aprs.org. The APRS exists at a frequency which design for a collar antenna could be designed (144.390MHz). A downside to using the APRS is that it exists, and was created for, the amateur radio bands. This means that during development a member of team was required to obtain a technician's license from the FCC. Further, testing was done in a basement and signals transmitted into a dummy load. The amateur bands are recognized by Brazil's spectrum regulatory organization ANATEL. This means that researchers will be required to either acquire some version of a technician's license provided by the FCC or change the frequency to somewhere else near that frequency that is unlicensed by ANATEL. These challenges were discussed with the sponsors of this project and it was decided that the APRS, which is a specific implementation of the AX.25 protocol was sufficient.

2.2.2 Packet Formation

An APRS packet is built off of the AX.25 layer-link protocol with several fields in the frame fixed. Implementation of the protocol was specified in [7, AX25]. Essentially several seconds of specific bit patterns, known as flag bytes are transmitted to get the receiver ready to demodulate the signal. Next the destination address, APRS in our case was transmitted. It is required that the number of bytes in that destination frame equal 7.

There are some fun caveats in the destination and source address fields as it the ascii characters are bit rotated in order for more than one source callsign to be recognized. Further reading on this can be found in the [8, APRS Protocl Reference]

The AX.25 Frame All APRS transmissions use AX.25 UI-frames, with 9 fields of data:

AX.25 UI-FRAME FORMAT									
	Flag	Destination Address	Source Address	Digipeater Addresses (0-8)	Control Field (UI)	Protocol ID	INFORMATION FIELD	FCS	Flag
Bytes:	1	7	7	0–56	1	1	1–256	2	1

Table 2.1: AX25 UI Packet

[7]

AX.25 UI-FRAME FORMAT									
	Flag	Destination Address	Source Address	Digipeater Addresses (0-8)	Control Field (UI)	Protocol ID	INFORMATION FIELD	FCS	Flag
Bytes:	1	7	7	0–56	1	1	1–256	2	2

Table 2.2: APRS UI Packet

[7]

2.2.3 Waveform Formation

Once the signal has been framed it will be encoded into either a 1200Hz tone for a one or a 2200Hz tone for a zero in a manner known as AFSK at 12000 baud. It is important that when the tone is switched that the phase be contiguous. This can be done effectively by implementing a numerically controlled oscillator (NCO).

$$FSK\ Signal = Amplitude * cos[t * 2 * \pi * f_{carrier} + (-f_{\Delta})]$$
$$\Delta = \frac{f_{desired}}{f_{sampling}} * 65536$$

This is done by first constructing a lookup table (LUT) that samples the first quadrant of a cosine wave in 128 equal steps of 0.7 degrees each. Some variable named phaser stores the current phase of the signal being generated. Delta increments the phasor on each sample and determines the frequency of the generated signal. In other words, phaser is incremented by Delta at every interrupt. If the next bit is a zero then delta will be changed to produce a different tone then was just transmitted. In this fashion, the transmission of a zero is communicated by changing the frequency from what it was. t The selected MSP430, the MSP430G2553 does not have an onboard digital to analog converter. Instead of implementing PWM to generate the audio signal, a resistor simple four bit resistor ladder was implemented. This reduced the amount of required code by allowing the LUT value that was already calculated to be written to he ppin register directly. This method also reduces the amount of calculations that have to occur between writing the next LUT value. The implemented four bit resistor ladder can be seen in Figure 2.3.

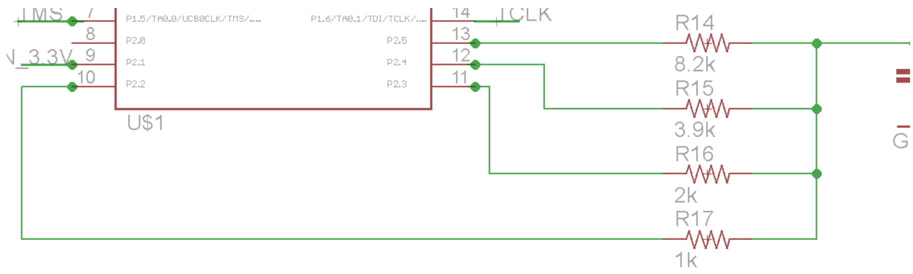


FIGURE 2.3: Implemented 4-bit Resistor Ladder

2.2.4 Radio

A Radiometrix HX1 was selected as the sole radio component for this project for a plethora of reasons. The HX1 is can be used for FM modulation at a specified frequency upon purchase. This means that it can be fed either digital high-low signals for modulation as fast as 3kbps or, as was decided, an analog signal that fits this bandwidth constraint. In addition, the HX1 comes in an very small package for a 2 meter radio solution. This package can transmit as much as 300mW of power without any additional amplifiers. It was decided that should more power be required for better signal propagation an additional amplifier would be added. Of course the HX1 isn't exactly suited for our application. The device requires a 5 volt power supply, logic level converters from the MSP430 to control the enable pin, as well as the relatively large current draw when transmitting (140mA). Despite these setbacks, no radio solution at the given frequency was more suitable to the small mammal tracker.

2.2.5 Antenna

The golden lion tamarin requires a small circumference collar-like antenna for its small neck, which is normally 11cm. The previous team designed four branches of a regular zigzag pattern of two wire layer as showed in the HFSS design on Figure 2.4; this wire design was imbedded into a collar so the tamarin could wear it around its neck and also to prevent interference with the tamarins natural behavior.

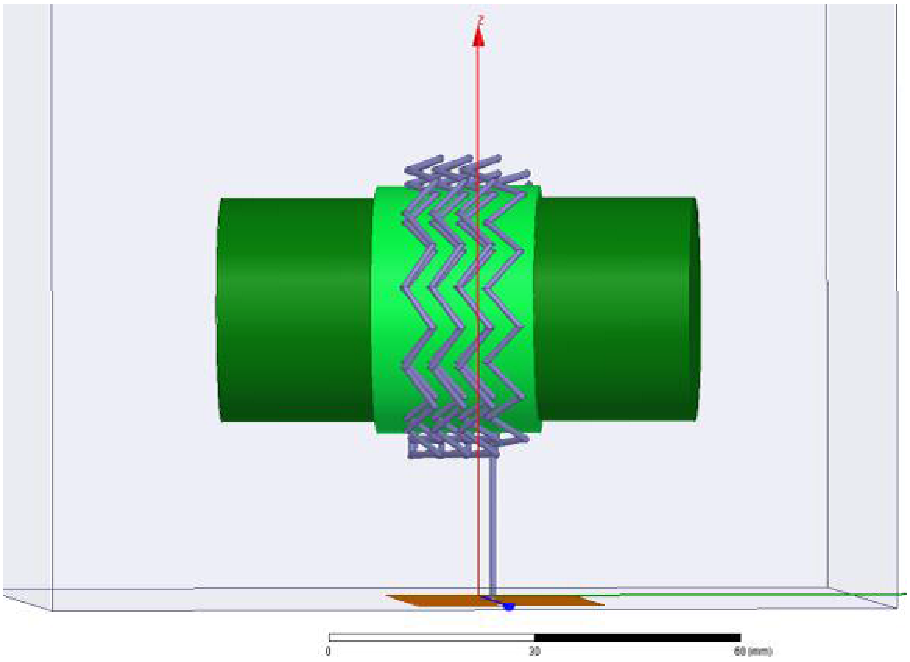


FIGURE 2.4: Simulation of zig-zag antenna using HFSS [6]

The zigzag antenna was designed to be used with Garmin Astro 320 GPS tracker and DC-40 collar turnkey system via an unlicensed frequency band in the VHF range, known was MURS band that lies between the 151.82MHz and 154.60MHz. The previous team achieved a resonant frequency of 152MHz as seen on the HFSS analysis on Figure 2.5.

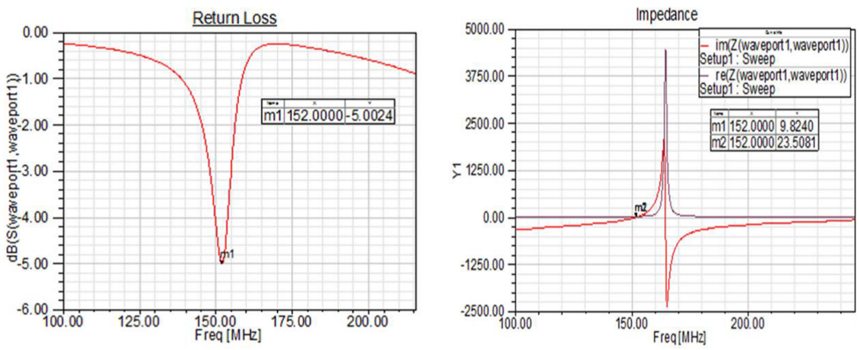


FIGURE 2.5: Original Zig-Zag Antenna Characteristics [6]

During the 2012-2013 year the team decided to use a radio with frequency of 144MHz for the transmission box design, therefore the antennas from the previous years did not meet the requirements of the present design; therefore, a new antenna had to be made using the same design as last year, but with a frequency of 144MHz. This year a 26 gauge solid core insulated copper wire was used as in the previous year, the mentioned thickness was chosen for the easiness to manipulate the wire while maintaining the desired shape once created, and the thickness of the insulation also works as a protective barrier to avoid shorts on the antenna. The zigzag bends on the antenna lower the resonant frequency, but in order to decrease it from 153 MHz to 144MHz more wire had to be added in length, so instead of four branches, the new antenna had five branches of 105mm in length of double wire as seen on Figure 2.6.

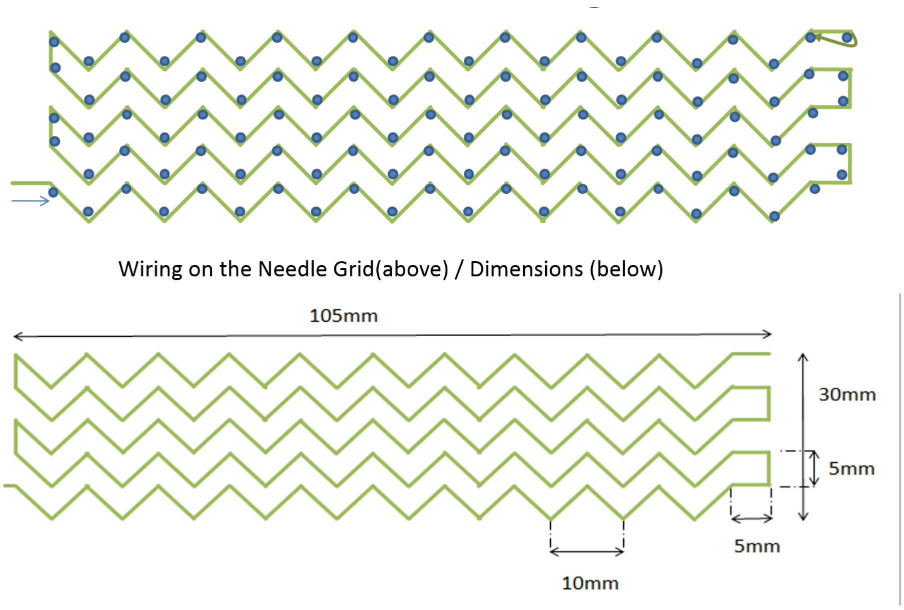


FIGURE 2.6: Zig-Zag Design

When the double wire was finished with 5 branches in double wire, the result was a resonant frequency of 180MHz, consequently to decrease the frequency, wire had to be eliminated, so 3.5 branches had to be cut down, the final result was 5 entire wired branches, and of out of those 5 only 1.5 branches were doubled wired. On figure 2.7 the final antenna prototype can be appreciated.

FIGURE 2.7: Antenna Stitching [6]

Figure 2.8: Antenna Mid-fabrication

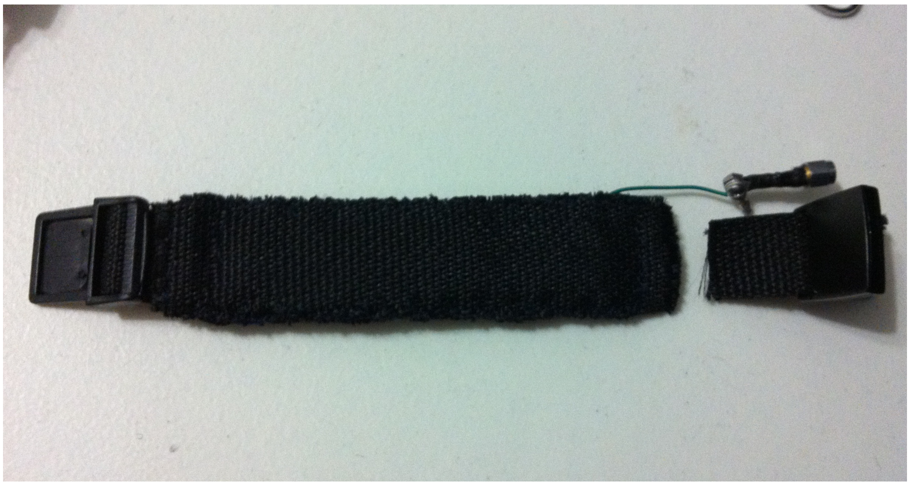


Figure 2.9: Antenna Fabrication

2.3 Low Power

One of the most imporant requirements for the project was operational longevity. The system must be able to continue operating for days to weeks in order for it to provide useful information for researchers. They need to see the long term behavior of the animals with minimal invasiveness. This was achieved through a number of design decisions. Each necessary component was selected with power consumption greatly in consideration. This resulted in the negative side effect of multiple operating frequencies. Microcontroller selection was paramount because the system is intended to be in the field for a period of time on the order of days. A microcontroller with extremely low power consumption when not directly in use in the field was important. Also the primary power source was carefully selected to be affordable, small, able to be changed for reuse, and to last a long time.

2.3.1 Low Power Microcontroller

In order to save the power consumption and battery life of the device, the microcontroller will stay in low power mode when it is not receiving or transmitting data. The Texas Instrument MSP430G2553 microcontroller provide three different modes[5] active mode, low power mode 0 and low power mode 3. The current usages in each mode are 300uA, 85uA and 1uA respectively. For minimum power usage objection, the system will go into low power mode 3 for the majority time. In low power mode 3, the only working clock is the external 32k crystal[5], but for radio transmitting, we need to use 8MHz internal clock to generate the waveform. For this reason, we need to switch clock between these two modes.

The commend for enter into and exit from low power mode 3 are _BIS_SR(LPM3_bits) and _BIC_SR(LPM3_EXIT)[5]. Since in the active mode, the system use internal 8MHz clock, and when it is ready for going into the low power mode, the system will switch to external clock by setting the 12.5pF capacitor and ACLK[5] and switch back to the 8MHz internal clock when it awake. In the low power mode, the system use CCR0 up mode interrupt for timing. The external crystal frequency is 32768Hz and it divided by 8 twice in the program, so the actual frequency is 512Hz. For this reason, the CCR0 up mode interrupt is set count up from 0 to 511, so the interrupt will occur in exact 1 second.

Since the system is designed to log the data twice a day, it will stay in low power mode for nearly 12 hours and the length of numbers will not enough for it. Also, for enter into and exit from the low power mode will use two interrupts, which makes the system more complicated. In order to solve this issue, the program uses a quite unique design in the interrupt. In the interrupt, a variable named sleep_counter will determine if the system is enter into or exit from low power mode. When is sleep_counter equal to 0, it enter into the sleep mode and then increase the value of it. Since the CCR0 interrupt is always working, the sleep_counter will keep increase. The interrupt will occur every second, so the sleep_mode will increase 1 each second. So the sleep_mode works like a clock and it can be sat at a desired value and that value is how many seconds the system need in low power mode. In that interrupt, the program will set the clock system back to the internal clock which need for UART and radio and then exit from low power mode. For example, the current design is sat the system in low power mode for 12 hours, and it equals 43200 seconds. Therefore, sleep_counter equals 43199 in the system and it will stay in low power mode for exact 12 hours and then exit.

2.3.2 Batteries

With the operating voltages of the major electrical components established, it is necessary to have a battery with provides greater than 5V. However, there are numerous types of batteries which can be considered to achieve this goal. The ideal battery would be rechargeable while in operation. With this in mind, research into solar and kinetic recharging batteries was conducted. Solar charging could be quickly eliminated as a viable option because of how deep beneath the trees the tamarins are (Golden Lion Tamarin). Shakable recharging batteries would be valuable, but the technology does not seem advanced enough to easily be used in this system. In the future when these batteries are more available and elective this system may be retrofitted.

Consequently lithium ion polymer batteries emerged as the optimal class of battery. Based on the dimensions of the other components and the first approximation of the PCB layout, coin cells were selected for the shape of the batteries. The voltages of these batteries are on the order of 3V. As a result, in order to power the radio at 5V two such batteries would need to be connected in series. Many options remained for LiPo batteries though. At the beginning, two good option were considered in greater detail for the powering the components in the design. Firstly, the Sony's CR2430 (Weight: around 4.1g Size: 24(d) x 3.0(h) mm Voltage: 3V Capacity: 285mAh) (CR2430 Sony). The advantage of this battery is that its capacity is high and the size is relatively small. Secondly was the LIR2450 (Weight: 5.5g Size: 24.5(d) x 5(h) mm Voltage: 3.7V Charges up to 4.2 Capacity: 160mAh) (Rechargeable Li- Ion Button Battery). Using these batteries in the series connection would result in a higher voltage. This would require a larger and less efficient step down. At the same time these have a lower capacity and are larger. These negative factors could potentially offset by the fact that the LIR2450s are rechargeable. However, non-rechargeable LiPo batteries are inexpensive. Therefore it would be as easy for the user of the tracking collar to replace them as it would be to recharge batteries. This caused the CR2430 to emerge as the battery of choice.

However, in the testing, the CR2430 cannot afford the enough capacity to the device. Hence, here is the third option, CR2450 (Weight: around 6.3g Size: 24(d) x 5(h) mm Voltage: 3V Capacity: 620mAh) (CR2450 Panasonic). It is non-rechargeable battery. The advantage of this battery is that its capacity is much higher than CR2430. Although the size and weight is the negative factor of CR2450, considering the battery life, CR2450 is better choice than CR2430.

2.4 Size and Weight

Since the goal of the project is to track the small Golden Lion Tamarin Monkeys, minimizing size while maintaing system operation was the primary focus. With an established set of necessary components, the ways to reduce the size of the system was to create a circuit board with components strategically and densly placed. Also, the entire case and housing of the board had to be considered. It had to be robust enough for the environment it will be placed in. More importantly, it needed to be as small and lightweight as possible. The packaging of the entire system also includes the antenna itself, which is integrated into the collar.

2.4.1 Board

With a set of components to be used, the printed circuit board layout was the primary determining factor for the size of the overall system. Significant consideration was put into the organizational scheme for the board. Components with related roles in the subsystem operation were placed close to one another. A considerable portion of the circuitry is devoted to power. The positioning of the power circuitry was largely guided by the placement established in the power breakout board in Figure 2.10, which will be discussed further in the analysis and results section.

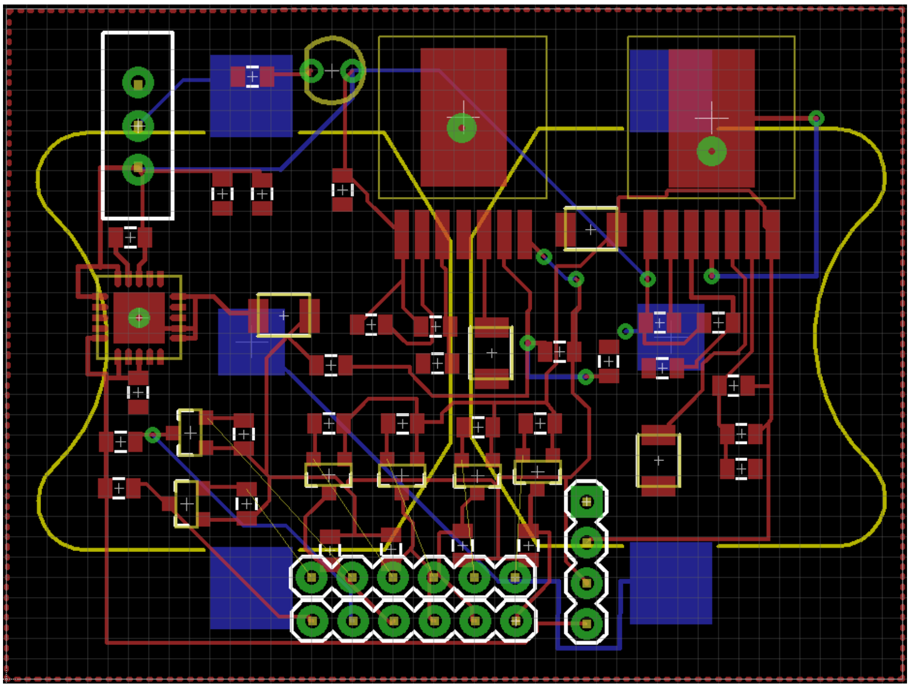


FIGURE 2.10: Power Breakout Board for Prototyping

The three voltage regulators are located on the left of the board and the logic level shifting is along the top as can be seen in Figure 2.11, the board schematic. It was important to ensure the components were compact, but at the same time there was enough space for traces. One challenge was determining which footprints should be placed on wich side of the board. It was determined that all of the electrical components should be on the front of the board with only the battery cell retainers on the back. This facilitated the assembly. Also, this allowed there to be limited issues with through hole components and pin interference. Holes could not have pins poking through to the batteries and it was importnat that pins did not block the ability to change batteries. The radio was positioned in an attempt to isolate other parts of the circuits from RF effects. The only traces which pass under the radio are few and are on the other side of the board. The microcontroller, because of its central role in the operation, is placed in the middle of the board. Pins are broken out for programming and limited debugging, 3.3V, GND, TEST, and RST. There is also a pin at the input voltage to verify that the batteries are still supplying the 6V required.

The outputs of the board are are placed along the perimeter: the SMA connector to connect to the antenna and the GPS ribbon connector. There is a small portion of space in front of the ribbon connector to give the ribbon space to fold over, having the GPS sitting on top of the other components. Finally two drill holes were necessary to have the board sit in the case securely. These are placed on opposite corners of the board so when fastened the degrees of freedom are sufficiently limited. All of these results of the design can be seen in Figure 2.11. The final dimension for the board was $2.5in \times 1.6in$, and a final rendered 3D image of the board can be seen in Figure ??

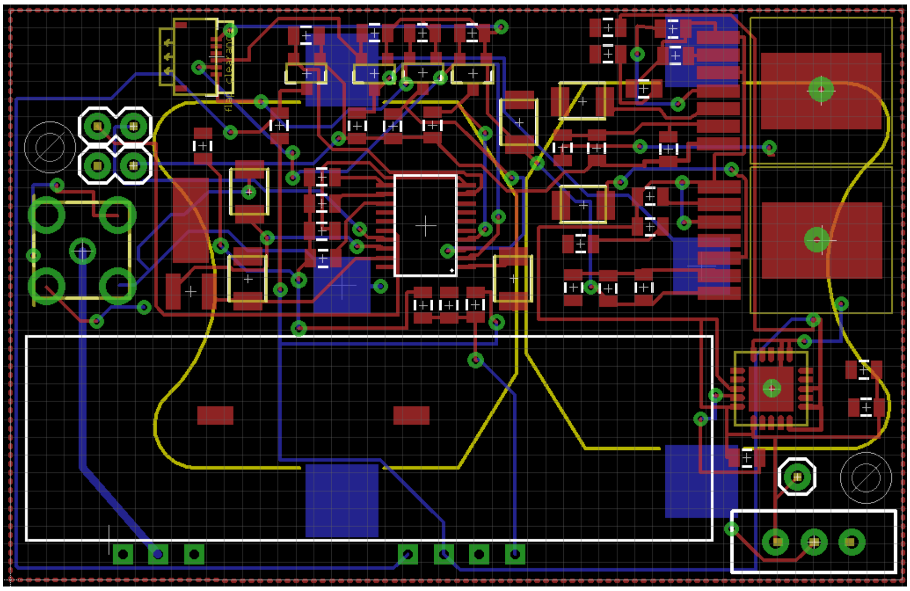


FIGURE 2.11: Board Layout and Routing

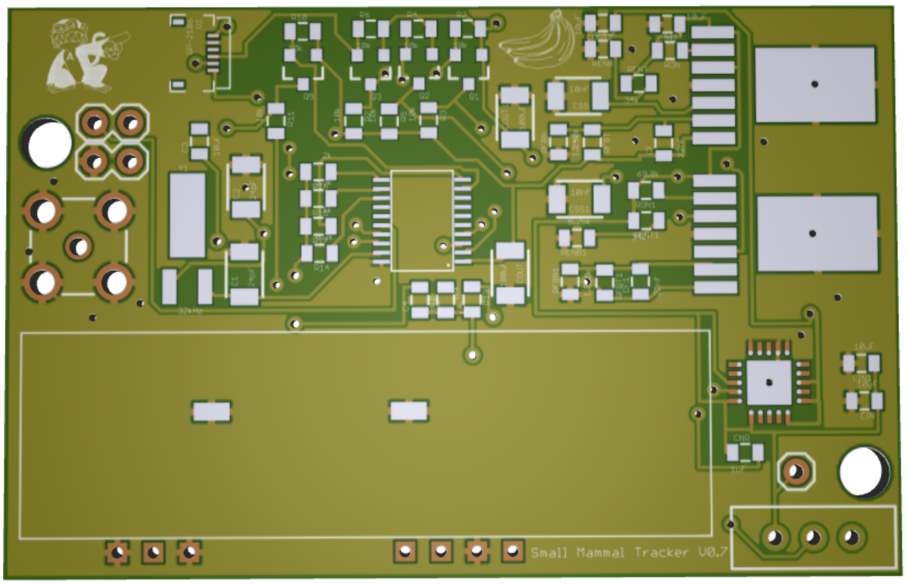


FIGURE 2.12: Rendered front view board

2.4.2 Package

To enclose the new miniature board layout, the next challenge lay in designing a case. This aspect would contribute to the weight and size of the overall system. A material that was electrically transparent, lightweight, and could be manufactured with a short lead time were just a few of the considerations. For a board as small as the one designed, it made little practical sense to machine a board out of aluminum, which is lightweight, or of steel, which is durable, yet would rust in the wet terrain of the Amazon Rainforest. Thus, ABS plastic was selected as the material of choice.

ABS plastic is both durable and lightweight. It is extensively utilized for electrical enclosures. With 0.25 mm thick strands, ABS plastic can be 3D printed with fine resolution, making the plastic a desirable material for such applications.

To continue with the case design, all major components had to be modeled by some 3D software, such as Solidworks, which would later be transformed to an STL file to be sent to the 3D printer. The case dimensions were limited by the thickness of the thickest component (in this design, the GPS) and length of the longest component (in this case, the radio). As described, a PCB was designed large enough to fit the two batteries (with holders), the radio, GPS, and microcontroller among other smaller components.

Final case dimensions required the finalized dimensions of the PCB. A work in progress, the PCB dimensions and layout were constantly changing in order to accurately place all components and electrical traces. Furthermore, to secure the board in the case, the board would be bolted, with the ends capped with nuts. Thus, the placement of holes reduced the available trace area of the PCB. 28 holes with a diameter of 0.1405 were selected on the top right and bottom left corners of the board. If well-designed, the bolts would not induce a torque on the board, which could destroy the components. Thus, the case dimensions had to be precise.

There were five case designs, four of which were printed, before a final design was selected. These designs are included in "Alternate Designs" found in the appendix. Holes to secure the board were selected as the optimal method compared to extrusions in the top and bottom of the case to hold the board in place.

As the link between the antenna and the circuit board, another critical consideration was how the antenna would be connected to the PCB. This was done with an SMA connector which would come out the side and connect to the wire of the antenna. To connect the antenna to the case, an extrusion needed to be created on the model that would be wide enough to hold the antenna but thin enough to cover only a fraction of the mammal's neck. Thus, a thickness of one third the mammal's neck was utilized.

The final consideration in creating the case is how this system will be placed on the Golden Lion Tamarin monkey's neck. Utilizing last year's antenna as the collar, the case will be connected to the antenna. If the box rests on the front of the neck, the primate's natural movement will be hindered, not satisfying one of the requirements. With the box at the back of the neck, the weight of the case will shift the center of mass of the animal, pulling it backwards off the tree (an undesirable effect). Thus, the best option is to place the box on the side, which will be most comfortable for the GLT while also providing for GPS signal.

Chapter 3

Analysis and Results

The operation of the system was tested to confirm the design meets project goals. The ability to obtain GPS coordinates was confirmed along with the amount of time it takes for the GPS receiver to obtain a lock. The generated waveform was recorded and analyzed, though further modification is required for demodulation. The antenna was tested to find the loss of power at different frequencies. Lastly, the overall system range and lifetime was tested.

3.1 GPS

The outdoor tests indicate the GPS uses approximately 43 seconds to capture the signal and find the fixed data. Since the system will be used in the rainforest, which may not have enough strong signal, an indoor test also performed. Although the GPS will have slightly more time to capture signal, which depend on the actual condition, the system still acquired fixed data which means the system will highly possible to work in the rainforest. The accuracy of the GPS data is within 2.5 meters given by the datasheet[4]. Since lacking of a good method to measure the actual distance in error, it is hard to have a number compare with the datasheet, but it is in a reasonable region (10 meters) and good enough to tracking animals. Overall, the GPS acquisition and accuracy satisfy the researchers requirement and it will working properly in the rainforest environment.

3.2 Waveform & Radio

The generated waveform matched what was expected for the AX25 protocol. However, it was noticed that bitrate fluctuated quite dramatically with temperature. This is because when the device is in the 8MHz mode it is operating off of the MSP430's internal oscillator. Any change in the bitrate will reduce the likelihood of a packet being decoded. It is believed that this is the reason why the APRS packets were not decoded by either the Byonics Tiny Trak 4 or the KPC3+. Figure 3.2 shows the waterfall of two different signals. The top signal is a sample APRS packet that decodes. The bottom half of the spectra plot shows the MSP430's generated APRS signal. What can be seen here is the slight difference. The MSP430 generates, in the initial flag transmission portion, a peak very close to 2200Hz. Also, the sidelobes are shifted accordingly.

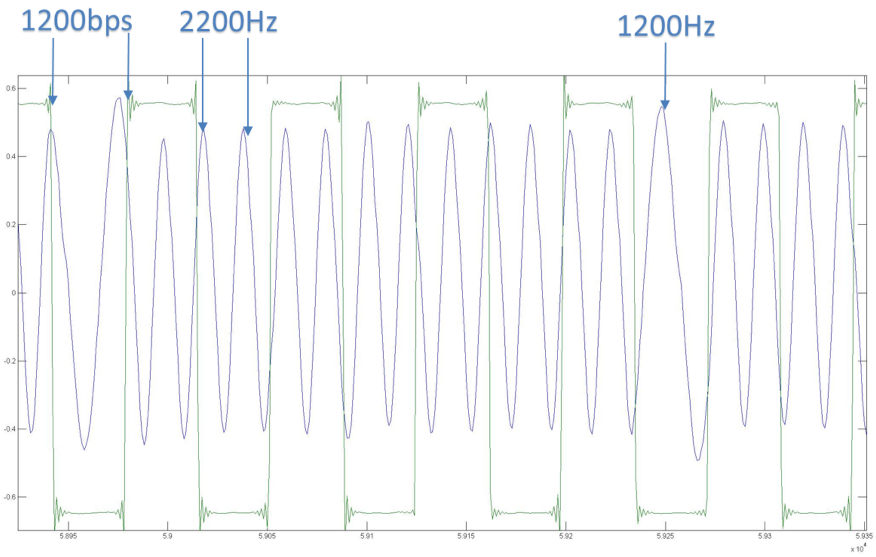


FIGURE 3.1: Generated Flag in blue, Baud in green

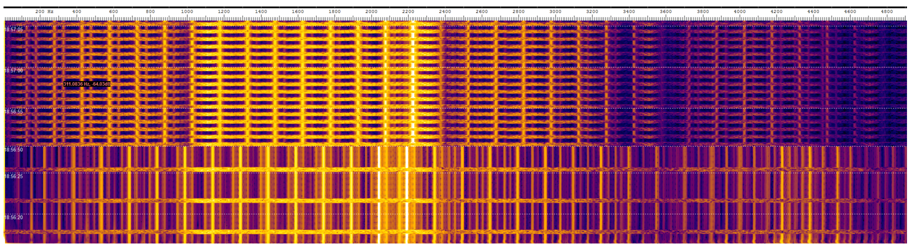


FIGURE 3.2: Spectra: Top half (Sample Packet) $\|Bottomhalf(GeneratedSignal)$

Next the waveform of several flags was captured after transmission through the HX1 radio and antenna using a soundcard at a sampling frequency of 44.1kHz. This waveform can be seen in Fig 3.3. Analysis of the flag byte showed that the lower frequency portion shown is indeed 1200Hz and the high portion of the flag is 2200Hz. However, the expected length of the byte did not match for all of the flags.

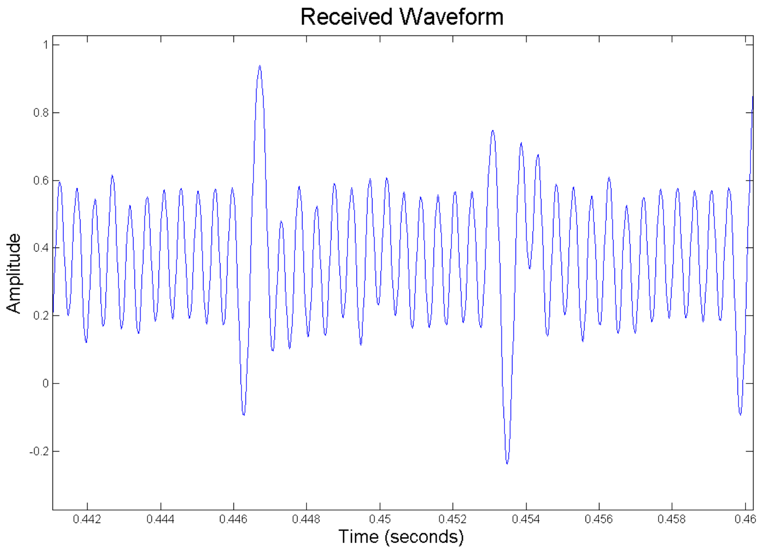


FIGURE 3.3: Captured Signal after TX via collar antenna

3.3 Antenna

After the antenna was covered with epoxy and nylon, it was tested again as usual with the network analyzer and it was placed around a small bottle of saline water to mimic the tamarin body which is 90% water, after testing it, it was observed that the resonant frequency went down to 135MHz, therefore the antenna had to be unwrapped from the nylon again and 2 zigzags of wire had to be cut down, the best frequency obtained after cutting down more wire was 141.5 MHz at -12dB, the location of 143.75MHz was located at -11.25dB, which was pretty close to the desired frequency. The final antenna was tested with the radio and it worked well with the 144MHz radio.

The most important achievement of the antenna portion on this years project was to be able to modify last years design and obtain an antenna with a frequency close to 144MHz which is at the same time small and lightweight.

FIGURE 3.4: Antenna on Case Cover

3.4 Final Package

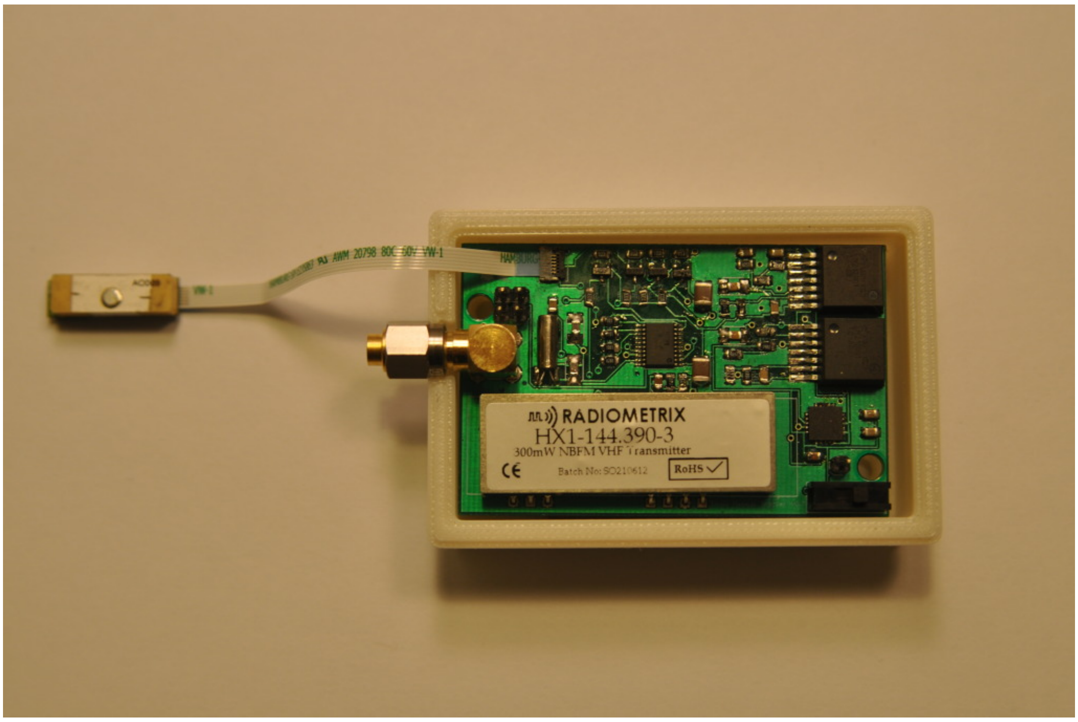


FIGURE 3.5: Final tracker board in case

3.4.1 Prototype Systems

To ensure that the power supply systems, which comprise a majority of the final board, worked as planned, a power breakout baord was designed. This board has headers for each of the 1.8, 3.3, and 5 volt supplies. Further, for functions requiring logic level changes, i.e. from the msp430 to gps enable pin, the mosfets were included. This allowed most of the system to be built on a breadboard and then wired to the breakoutboard as a seperate power supply.

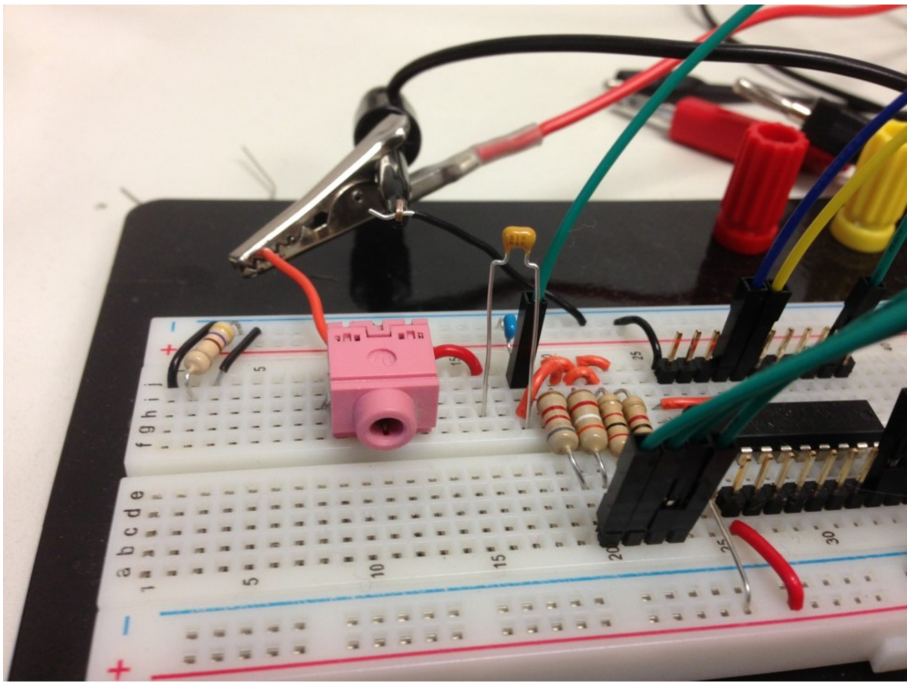


FIGURE 3.6: Radio Testing Breadboard

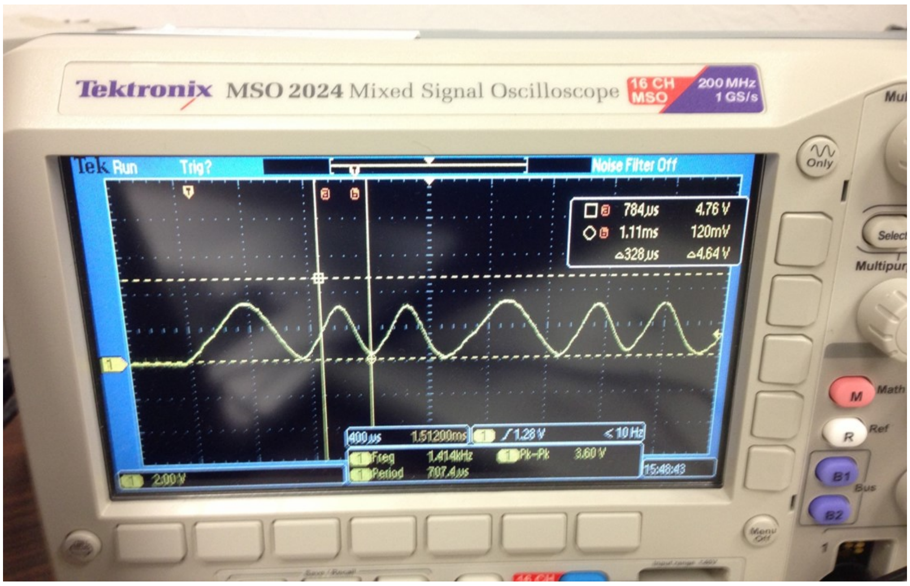


FIGURE 3.7: Initial Waveform

Next the entire radio subsystem was built on a breadboard. This includes the resistor ladder, a 5 volt power supply and a .1 μF capacitor for some filtering of the signal. Once the radio system was completed a final breadboard containing all non-surface mount components was built and tested. For the gps to interact with this system a Sparkfun Electronics GP-2016 breakout board was used. Fortunately the logic level design was the same.

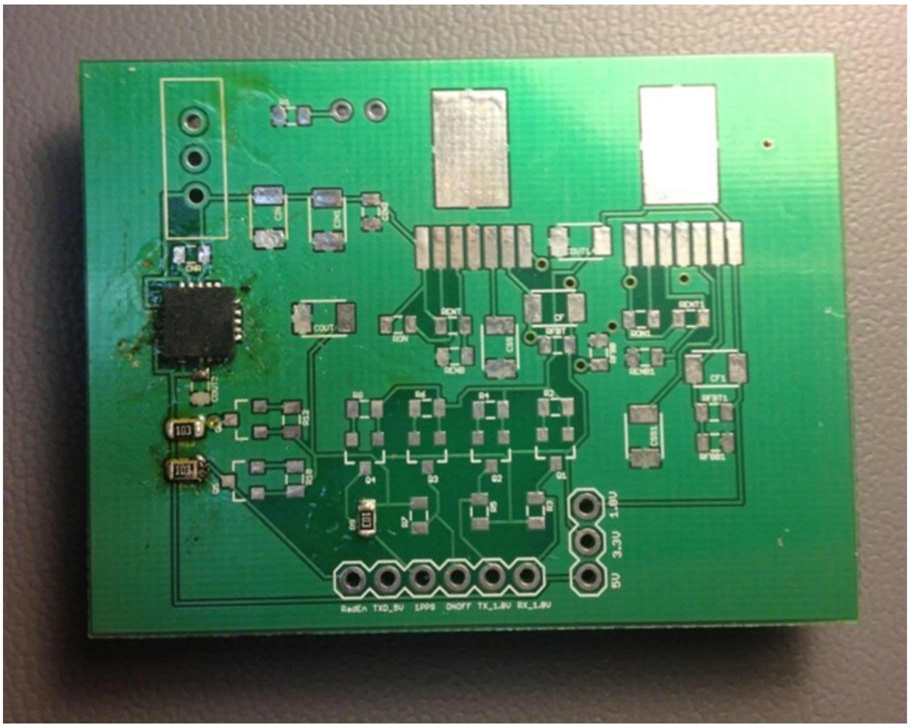


Figure 3.8: Power Breakout Board

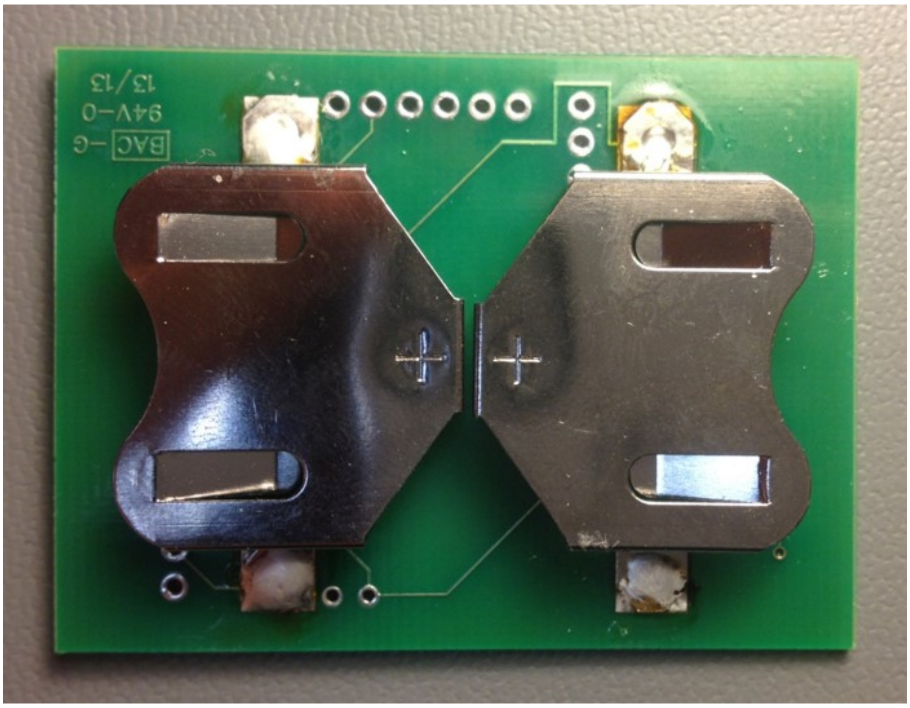


FIGURE 3.9: Power Breakout Board

It was useful for radio debugging to connect from the output of the resistor ladder digital analog converter to a computer soundcard. This is because many free utilities exist for the decoding of APRS signals via soundcard. This setup can be seen in Figure **??**.

3.4.2 Case

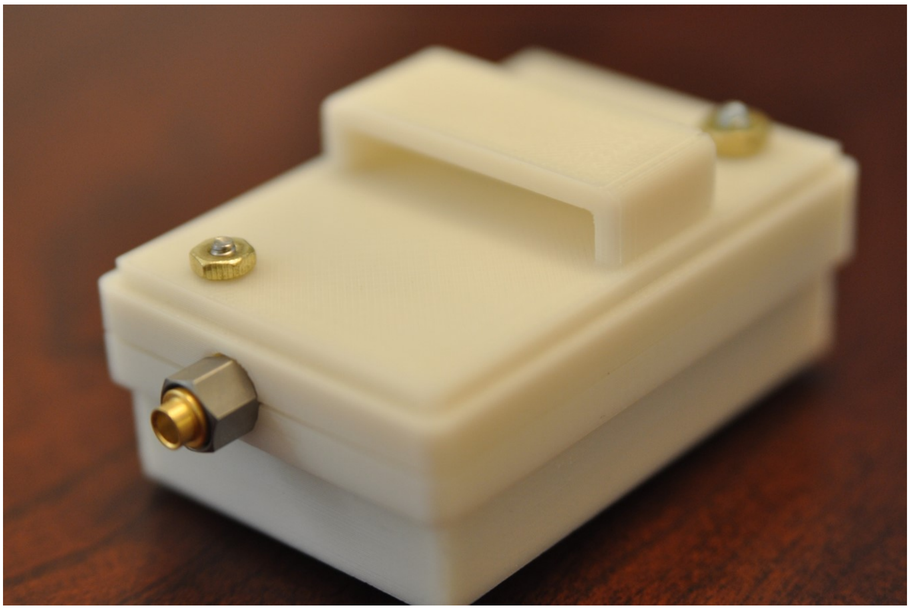


FIGURE 3.10: Final Closed Case Without Antenna

Taking care to minimize size and weight of the overall system, the dimensions and thicknesses of the case had to be very precise. To make the case as small as possible and as thin as possible, the walls were designed to be 1.5 mm thick at the shaved parts and 3 mm thick for connections with the top and bottom. The top and bottom required a thickness of 3 mm due to the low resolution of the available 3D printer, making it impossible to create thinner walls unless professionally made, which would be more expensive and provide a greater lead time. This allowed for a much tighter fit of the top and bottom. The final design is depicted in Fig 3.11 below.

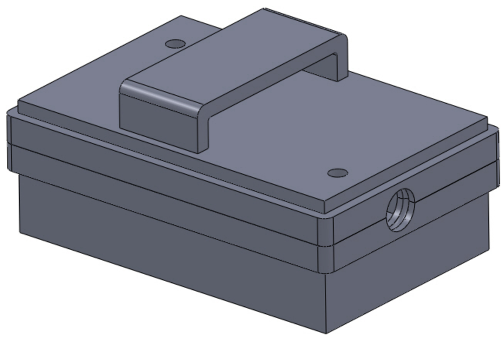


FIGURE 3.11: Isometric View of Final Case

While the tight fit and the O-Ring groove connection on the SMA connector aid in waterproofing the case, a necessity in the Amazon Rainforest, other modifications to the design would better the waterproofing capabilities. One modification would be to incorporate an O-Ring groove around the connection for the top to the bottom. Coating the case with waterproof paint, such as those used on the outside of homes, would be another modification. This would require modifying the surface texture of the plastic to ensure the paint sticks to the case.

Utilizing a light colored paint would prevent the internal heating of components. With a low thermal conductivity of 0.026 W/mK, ABS Plus plastic does not conduct much heat [9]. Additionally, since the electrical components will only be on for short periods of time, there will not be much heat generated inside the box, rendering heat transfer calculations unnecessary.

As the system will be placed on the Golden Lion Tamarin, it is expected the case will experience some stress with the movement of the GLT. Unlike steel and aluminum, which withstand much larger stress at low strain, ABS plastic experiences large stress at low strain (Fig 3.12). However, the tamarin will likely induce less strain on the case than that required to reach ultimate stress, so breaking the case due to tamarin induced stress is not a concern.

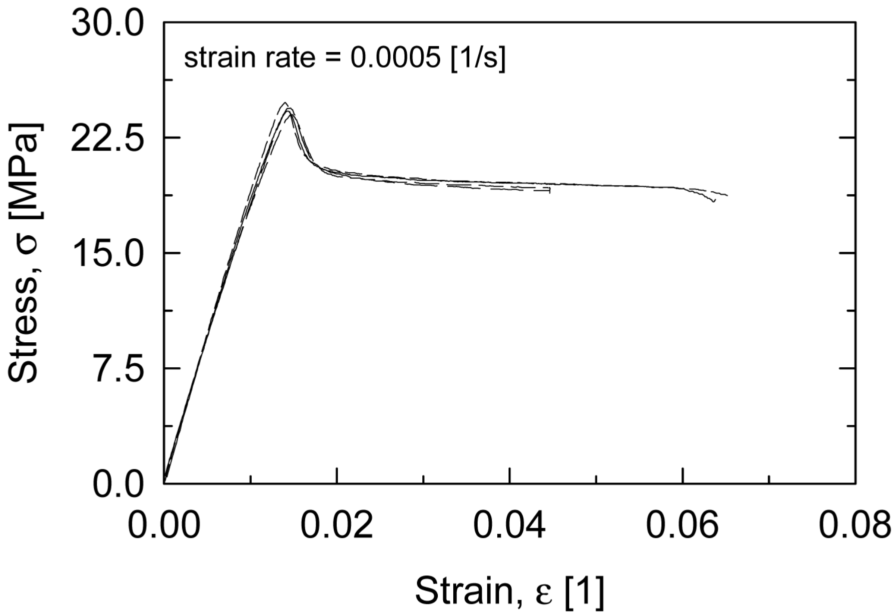


FIGURE 3.12: ABS Plastic Stress Strain Curve[10]

The final package loosely satisfied the project requirements. With a system mass of 105.3 grams (slightly larger than the required weight), the developed system weighs less than half of the existing device. Furthermore, where the system is limited in read-range accuracy, it makes up in lifetime. By incorporating a low-power mode in the code, the proposed system is predicted to last multiple days, whereas the current system lasts only few hours. Finally, the dimensions of the designed case are significantly smaller than the existing Garmin DC 40. At 2.7 x 4.9 x 7.3 cm, the case is smaller than the Garmin device, which measures in at 3.5 x 2.97 x 8.4 cm.

3.5 Power

Theoretically since the on current is between 100mA to 150mA and assuming there is no current in sleep state, 620mAh (total capacity) divided by 150mA is 4.13 hours. Assume the device will work twice a day and 45 seconds for each on time, that means the device can work for a maximum of 165 days. However, the real results are much different. Firstly, because the radio in the device needs at least 5V to work, the tracker will stop working when the battery cannot provide 5V. Secondly, the high current will hurt the battery so that leads to a massive voltage drop. In the test, testing one battery with 500Ω resister, the current is 6mA at the beginning then it drops slowly. Another same battery test with 100Ω, the current is 30mA at the beginning then it drops very fast. The internal resistance is 40Ω. That result shows that if the resistor in circuit is close to the 40Ω or the current is high, the voltage of the battery will decrease very fast. In the 100Ω testing, the battery voltage goes below 2.5V just takes almost an hour. But if turn off or break the circuit for a while then test it again, the voltage of the battery will go back to 3V. For save time, just use the battery continually until even let it free for a while the voltage can no go above 2.5V. According the result, there are 350mAh can be used. Because in the real working, the system will work twice a day, the battery has enough time to rest. Thats mean it could work for longer time than the testing. Comparing Garmins device (DC40), its datasheet shows that it can work 48 hours for every 2min mode. But, in the continually working test, it works for 38 hours. That proves that the continually working will kill the battery life. Hence, the small mammal tracker could roughly count work day around 90 days.

Continuous beaconing of the APRS flag (ASCII char' ') can be maintained for approximately 50 seconds before the switching power supplies shut off and the MSP430 is powered down. From this point the batteries need to be turned off such that they can recover some voltage. In order to increase the range as much as possible it was required to have the system turn on and aquire gps coordinates, thus drawing 100mA and then go to sleep for several minutes. The radio is then turned on and transmission can continue. If this process is not done then the device will not only be drawing 140mA from the batteries during packet transmission but also 100mA for the optimal 40 seconds it takes to aquire the GPS coordinates.

When the system is set to beacon at regular intervals rather than continuously, the lifetime is significantly improved. When beaconning approximately every 76-77 seconds the beacon lasted just under 46 minutes. This resulted in 36 beacons. The recovery time of 1:16 is much shorter than the system would actually operate and is insufficient for allowing the batteries to recover from the radio current draw. A small order of time in between beacons was necessary to test in a reasonable time frame. The potential of the beacon is evident. If the beacons are spread out to be daily or more, the batteries would recover and the system would be able to operate for days.

The longer the device is in sleep, the less damage is done to each of the batteries and the device will last longer.

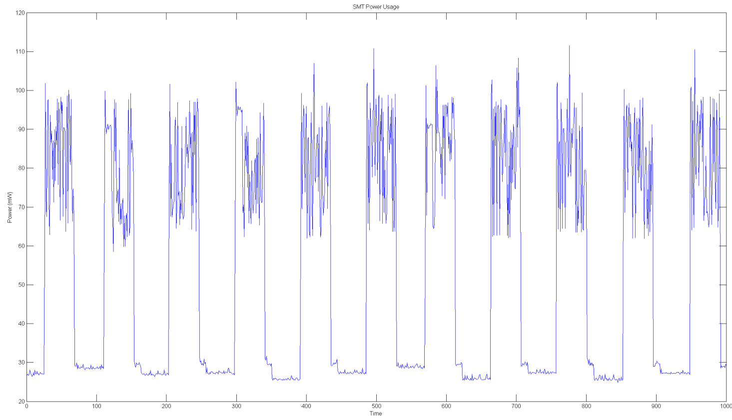


FIGURE 3.13: Power Usage on TI Launchpad & GP-2106

Power usage drops significantly when the device is in sleep mode as can be seen from the data taken from a USB current and voltage monitor [11, USB Tester]. Figure 3.13 shows the power usage when the gps is turned off and on when connected to the Texas Instruments MSP430 launchpad. The GPS is turned on, told to aquire, shutoff, then the system is placed into sleepmode.

3.6 Range

On April 28, 2013, a read range test was conducted. The maximum range for the zig zag collar antenna was determined and compared to that of an off the shelf 2M antenna.

Antenna	Range (m)	Percieved Signal Strength
2M off shelf	850	clear
2M off shelf	1000	clear
2M off shelf	1100	clear
2M off shelf	1300	faint
2M off shelf	1400	none
Collar Antenna	500	clear
Collar Antenna	1200	weak
Collar Antenna	1300	none

TABLE 3.1: Read Range Data (4/28/2013)

Chapter 4

Conclusion

The final system was electrically functional and operated as an effective small mammal tracker in several metrics. Unfortunately, the modulation of the signal was not exactly such that demodulation could occur and remotely provide a user with location data. There are certain metrics in which the final system outperforms existing products such as the Garmin DC40. In particular, the operational longevity, weight, and cost of the proposed design outperforms the existing Garmin device.

The components selected, along with the ability to vary the beacon frequency, allow the system to operate for extended periods of time on the order of days. If the beaconing is too frequent, the batteries do not have time to recover from the excessive current being drawn by the radio. However, the goal of the product is to beacon no more than a couple times a day. The system is modular and can be reprogrammed as well.

The size and weight minimalization goal was consistently the most difficult to acheive. Unfortunately the target weight is a fraction of the weight of the final system. It became clear that this is an inherent limitation to a system involving these components and enclosure. The weight of the system is however appreciably less than that of the Garmin DC40, weighing in at only 105.3 grams compared to the 227.5 grams of the Garmin device [12].

A benefit of this system is that it is entirely open source. This means anyone who is motivated and enthusiastic about the project can make improvements to the design. Thus, this allows the system to be an inexpensive solution for researchers. Bought on an individual basis, the system would only cost approximately $150 (See Bill of Material B.0.8). At such inexpensive prices, the final design is not only a viable solution to the problem of tracking small mammals, but it is much more affordable compared to existing products which are less suitable for this application such as the Garmin Astro 320 which costs more than $500[12].

Unfortunately, the system came short on several requirements. The maximum range of signal transmission was only slighlty more than 0.7 miles compared to the existing 7 miles of the Garmin device.

Other metrics, such as further reduction in size and range of operation, could be improved with redeisgns. This is only a first operating version of the product and as such, numerous improvements could be made.

4.0.1 Future Recommendations

There are many other ways to track a small mammal. One such viable method would be to place a small radio beacon on the monkey that transmits a single pulse every few hours. This pulse would then be recorded at several known positions throughout the forest. Position acquisition can then take place by either looking at the received signal strength of each beacon or via such digital signal processing methods as calculating the difference of the time of arrival. Such systems allow the tracker to be smaller and last much longer by offloading a significant portion of the tracking equipment and software from the monkey to a researcher's laptop.

The range of the tracker could be increased by adding an additional amplifier stage to the radio subsystem. However, such an addition will cause an increase in weight/size and decrease in total system lifetime.

If the tracker system outlined in this paper is to be implemented in the Brazilian rainforest, decoding of the transmitted signal using off the shelf equipment is required. This means that more time should be spent debugging the AX.25 protocol sections of the code. Additionally, the problem of varying bitrates needs to be further investigated. Use of the MSP430's internal digitally controlled oscillator is not recommended for actual signal generation in conditions with such widely varying temperatures.

Once decoding of the packet is completed, then being able to track the monkeys using the widely established APRS infrastructure such as online tracking (see www.APRS.fi) is possible. This opens up a plethora of possible sources of convservation revenue projects. A website like APRS.fi can be used so that fans and donors to conservation efforts can watch where their adoppted monkey is in the forest.

Another change that may be implemented in the future is the selection of components that have a common operating voltage. This will not only reduce the cost of the system but the footprint and waisted power as well. Finding a 3.3v 2-meter radio that has this specification may prove to be a difficult but worthwhile endeavor.

Appendix A

Code

A.0.2 main.c

```
#include <msp430G2553.h>
#include <string.h>
#include <stdint.h>
#include "global.h"
#include "gps.h"
#include "sleep.h"
#include "ax25.h"

bool sleep;

uint8_t main ( void ){
  char *gpgga;
  aprs_header header;
  header.CALL_D = "APRS  ";
  header.CALL_D_SSID = 0xE0;
  header.CALL_S = "KF7IYK";
  header.CALL_S_SSID = 0x47;
  header.Control = 0xC0;
  header.PID = 0x0F;

  //P2REN |= BIT1;
  P2DIR |= BIT1;
  P2OUT &= ~BIT1;
  P2OUT = 0x00;
  while(1){
    //GPGGA will contain the entire GPGGA string
    //that is received from the gps.
    do{
      GPS_setup();
      gpgga = GPS_aquire();
      ax_timer_setup();

    }while(!send_packet( header, gpgga ));
    P2OUT = 0x00;
    Sleep();
```

```
    Sleep();
    Sleep();

  }
}
```

LISTING A.1: Code/main.c

A.0.3 ax25.h

```
/*
 * ax25.h
 *
 *  Implements the transmission of AFSK data through a MSP430
 *
 *  Created on: Feb 1, 2013
 *      Author: kevinklug
 */

#ifndef AX25_H_
#define AX25_H_

#include "global.h"
#include <stdint.h>
#include <msp430.h>

#define send_flag send_byte('~')

//Initalizes MSP430 registers for transmission of APRS packets
void ax_timer_setup( void );

//Enables TimerA interrupts
void begin_tx ( void );

//Disables TimerA interrupts
void stop_tx ( void );

//update_crc will update the global 16 bit checksum with the byte to be sent
// according to the CRC-CCITT standard. [With inital crc = 0xFFFF]
inline void update_crc ( bool bit ){
        //This algorithm was taken from
        //trackuino EA5HAV Javi project
        crc ^= bit;
        if (crc & 1)
                crc = (crc >>1) ^ 0x8408;
        else
                crc = crc >>1;
}

//flip_crc changes the order of the FCS to be LSB first
void finalize_crc ( void );

//This function will set the timerA registers to the appropriate frequency.
```

```
//  It will then wait until one bit is sent.
//NOTE: This function will already NRZI encode the bits. That is, a series of
//  ones will be a continuous frequency and a zero will be encoded as a change
//  in frequency.
inline void send_bit ( bool bit ){
  begin_tx();

  //  Bell 202 Uses NRZI encoding which means a 0 is a change in tone
  //  and a 1 is a continuous tone.
  if (!bit){
    if (prev_freq == FREQ1){
      prev_freq = FREQ2;
    }else{
      prev_freq = FREQ1;
    }
  }
  TA1CCR0 = prev_freq;
  //Toggles led to logic state
  //P1OUT = !(P1OUT & BIT6) ? BIT6 : 0x00;
  //Wait for the bit to be sent
  while(!bit_sent){};
  bit_sent = false;
  stop_tx();
}

inline void send_byte ( char byte ){
  uint8_t byte_index = 0;
  uint8_t stuffer = 0;
  bool bit;
  bool Flag_flag = false;

  //Check if the byte being sent is the Flag 01111110
  //otherwise update the CRC
  if (byte == 0x7E){
    Flag_flag = true;
  }

  //Send bits in least significant bit first
  for ( byte_index = 0; byte_index < 8; byte_index++)
  {
    bit = (byte & (1<<byte_index)) != 0;
    stuffer += bit ? 1 : 0;
    send_bit ( bit );
    if (!Flag_flag) update_crc( bit );
    if (stuffer == 5 && !Flag_flag){
      send_bit( false );
      stuffer = 0;
    }
  }
}

inline void send_string (char* string ){
  uint8_t string_index = 0;
  for ( string_index = 0; string_index < strlen(string); string_index++){
    send_byte (string[string_index]);
```

```
  }
}

bool send_packet (aprs_header my_header, char* gpgga_string);

#endif /* AX25_H_ */
```

Listing A.2: Code/ax25.h

A.0.4 ax25.c

```
/*
 * ax25.c
 *
 *  Created on: Feb 1, 2013
 *      Author: kevinklug
 */
#include <msp430.h>
#include <string.h>
#include "ax25.h"

uint8_t Phase_Delta = 0;
uint8_t sent_periods = 0;
bool bit_sent = false;
uint8_t cycles = 0;
uint16_t crc = 0xFFFF;

void ax_timer_setup (void){
  WDTCTL = WDTPW + WDTHOLD;        // Stop watchdog timer

  BCSCTL1 = CALBC1_8MHZ;           // Set range
  BCSCTL2 = 0x00;                  // Change SMCLK divider to 1
  DCOCTL = CALDCO_8MHZ;            // Set DCO step and modulation

  P2DIR = 0xFF;                    // Set Resistor Ladder output pins

  //P1DIR |= BIT0;                   // Set P1.0 to output direction
  //P1OUT &= ~BIT0;                  // Set the red LED off

  //P1DIR |= BIT6;                   // Set P1.6 to output direction
  //P1OUT &= ~BIT6;                  // Set the green LED off

  TA0CCR0 = FREQ1;                 // Count limit (16 bit)
  TA0CTL = TASSEL_2 + MC_1;        // Timer A0 with SMCLK, count UP

  TA1CCR0 = FREQ2;                 // Count limit (16 bit)
  TA1CTL = TASSEL_2 + MC_1;        // Timer A1 with SMCLK, count UP

  IE2 &= ~UCA0RXIE;

  _BIS_SR( GIE );                  // General interrupts enabled

  crc = 0xFFFF;
```

```
}

void begin_tx ( void ){
  TA0CCR0 = FREQ1 +10;                  // Count limit (16 bit)
  TA1CCR0 = FREQ1;                  // Count limit (16 bit)
  TA0CCTL0 = CCIE;                  // Enable Timer A0 interrupts, bit 4=1
  TA1CCTL0 = CCIE;                  // Enable Timer A1 interrupts, bit 4=1
  prev_freq = FREQ1;
}

void stop_tx ( void ){
  TA0CCTL0 &= ~CCIE;                // Disable Timer A0 interrupts, bit 4=1
  TA1CCTL0 &= ~CCIE;                // Disable Timer A1 interrupts, bit 4=1
}


void finalize_crc( void ){
        //This was taken from Trackduino 2/21/2013 send_footer function
        // Save the crc so that it can be treated it atomically
        uint16_t final_crc = crc;
  // Send the CRC
        send_byte(~(final_crc & 0xff));
        final_crc >>= 8;
        send_byte(~(final_crc & 0xff));
}

bool send_packet (aprs_header my_header, char* gpgga_string){

  //Check if gpgga_string is valid
  if (*gpgga_string != '$') return false;

  //Transmit several flags to prepare the receiver
  uint8_t num_flag = 0;
  for( num_flag = 0; num_flag < TX_DELAY; num_flag++ ){
    send_flag;
  }

  //Transmit the aprs_header
  send_string( my_header.CALL_D );
  send_byte( my_header.CALL_D_SSID );
  send_string( my_header.CALL_S );
  send_byte( my_header.CALL_S_SSID );
  send_byte( my_header.Control );
  send_byte( my_header.PID );

  //Potential problem with this code. If gpgga_string
  // is not \0 terminated! Check
  send_string( gpgga_string );

  //Send FCS
  finalize_crc();

  //End APRS-UI Frame
  send_flag;
  send_flag;
```

```
  send_flag;

  return true;
}
```

Listing A.3: Code/ax25.c

A.0.5 gps.h

```
/*
 * gps.h
 *
 *  Created on: April 4, 2013
 *      Author: hao c & kevin klug
 */

#ifndef GPS_H_
#define GPS_H_

//Changes MSP430 clock to internal at 8MHz
//TODO: Implement ON/OFF switch
void GPS_setup( void );

//Checks GPS string for valid GPS Position fix
bool GPS_fix( char* gpgga_string);

//Waits for a valid GPS signal
char* GPS_aquire( void );

//Toggles the gps ON/OFF pin
void GPS_toggle( void );

#endif /* GPS_H_ */
```

Listing A.4: Code/gps.h

A.0.6 sleep.c

```
#include <msp430.h>
#include "sleep.h"
#include "global.h"

volatile uint8_t sleep_counter = 0;
volatile bool sleep_on;

void Sleep( void ){
  WDTCTL = WDTPW + WDTHOLD; // Stop WDT

  BCSCTL1 = CALBC1_8MHZ;
  DCOCTL = CALDCO_8MHZ;
```

```
  TA0CCR0 = 511; //?
  TA0CTL = TASSEL_2 +MC_1;
  TA0CCTL0 = CCIE;
  sleep_on = true;
  __enable_interrupt();
  //Stay here while sleeping
  while(sleep_on);

  //DEBUGGGING!!
  //P1OUT =0x01; //LED on

  BCSCTL1 = CALBC1_8MHZ;
  DCOCTL = CALDCO_8MHZ;
  TA0CCR0 = 2;
  TA0CTL = TASSEL_2 +MC_1;  //Switch to DCO
  TA0CCTL0 &= ~CCIE;  //Disable TimerA Interrupt
}

//Timer A0 interrupt service routine
//Sleep Interrupt & AX25 Baudrate timer
#pragma vector=TIMER0_A0_VECTOR
__interrupt void Timer_A (void)
{
  //Using TimerA for deep sleep timer
  if (sleep_on){
    if (sleep_counter==0){ // 11428 10min
      sleep_counter++;
      BCSCTL1 |= DIVA_3; // ACLK/8
      BCSCTL3 |= XCAP_3; //12.5pF cap- setting for 32768Hz crystal

      TA0CCR0 = 511;
      TACTL = TASSEL_1 + ID_3+ MC_1;       // ACLK, /8, upmode
      TA0CCTL0 = CCIE;

      //DEBUGGING
      //P1OUT = 0x00; // P1.0 turn off
      _BIS_SR(LPM3_bits+ GIE); // Enter LPM3 w/interrupt
    }else if (sleep_counter==10) //set time stay in LPM
    {
      sleep_counter=0;
      sleep_on = false;
      _BIC_SR(LPM3_EXIT); //exit LPM
        }else{
          sleep_counter++;
        }
  }else{
    //This should contain the AX25 interrupt code.
    if(cycles > 15){
      bit_sent = true;
      cycles = 0;
    }
    cycles++;
  }
}
#pragma vector=TIMER1_A0_VECTOR    // Timer0 A0 interrupt service routine
```

```
__interrupt void Timer0_A0 (void) {
  P2OUT = lut[Phase_Delta]<<2 | BIT1;
  Phase_Delta++;
  if (Phase_Delta > 15){
    Phase_Delta = 0;
  }
}
```

Listing A.5: Code/sleep.c

A.0.7 global.h

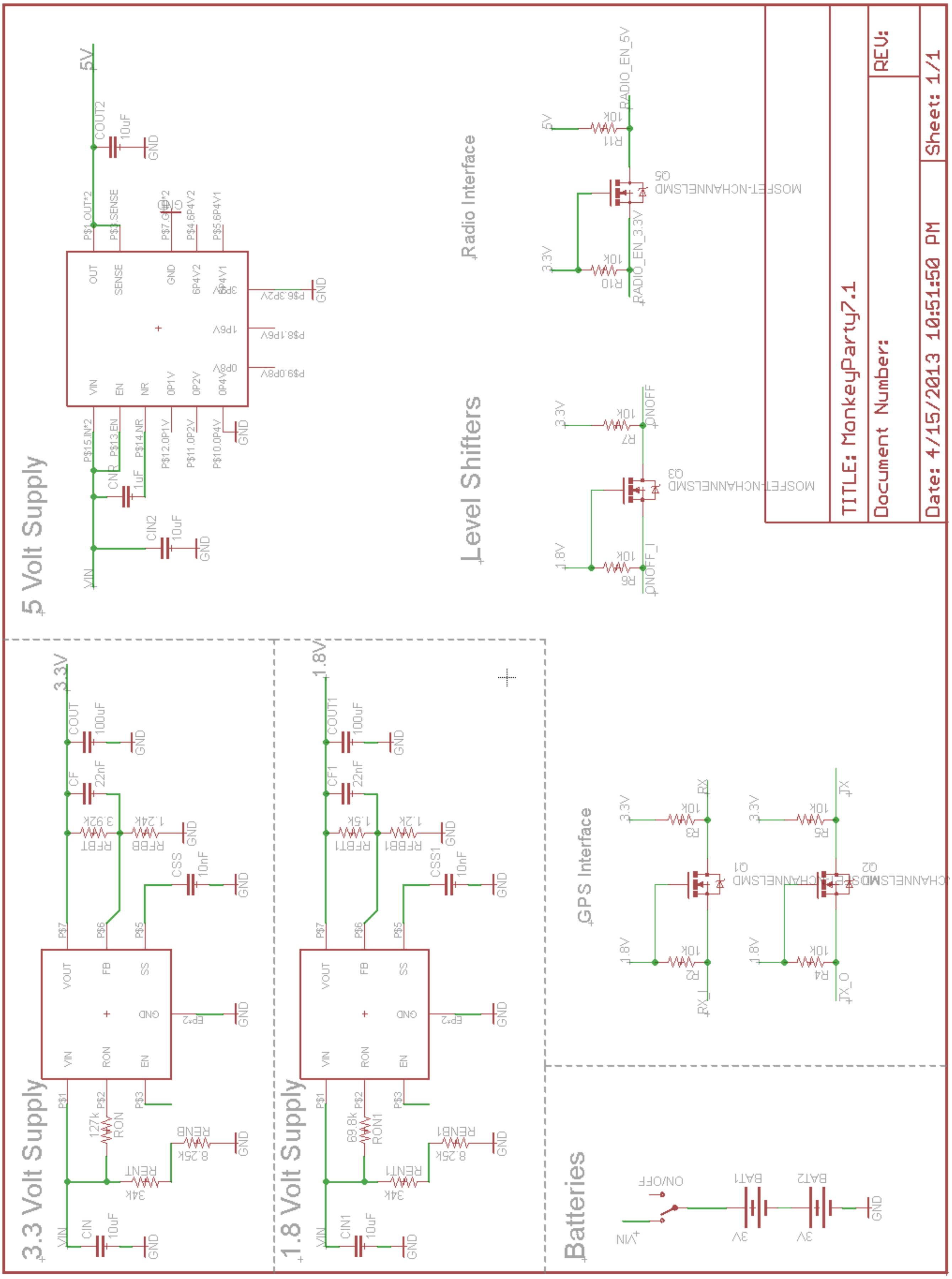
```
/*
 * global.h
 *
 *  Created on: Feb 1, 2013
 *      Author: kevinklug
 */

#ifndef GLOBAL_H_
#define GLOBAL_H_

#include <stdint.h>

typedef unsigned char bool;

#define true 1
#define false 0
#define STOP_BITS 2
#define RST_TA_R (TAR = 0x00)

#define TX_DELAY 200

//  Toggle rate = 8e6/(2* CCR0 - 1) = 4e6Hz
//  Generated sine = 4e6 / 16
//at CCR0 = 400 1.255kHz
#define FREQ1 410

//at CCR0 = 227 2.442kHz
#define FREQ2 230

//Sine wave look up table for afsk generation
//static const short lut[16] = {0,  2,  4,  7, 8, 11, 13, 15,
//                              15, 14, 12,  9, 6,  3,  1,  0};
//};
//This is half a period.
//static const short lut[16] = {0, 3, 6, 9, 11, 13, 14, 15, 15,
//                                                 14, 13, 11, 9, 6, 3, 0};
//This is resistors in backwards position
//static const short lut[16] = {7, 11, 13, 15, 15, 14, 12, 9, 6,
//                                                   3, 1, 0, 0, 2, 4, 7};
static const short lut[16] = {14, 13, 11, 15, 15, 7, 3, 9, 6,
                                                   12, 8, 0, 0, 4, 2, 14};
```

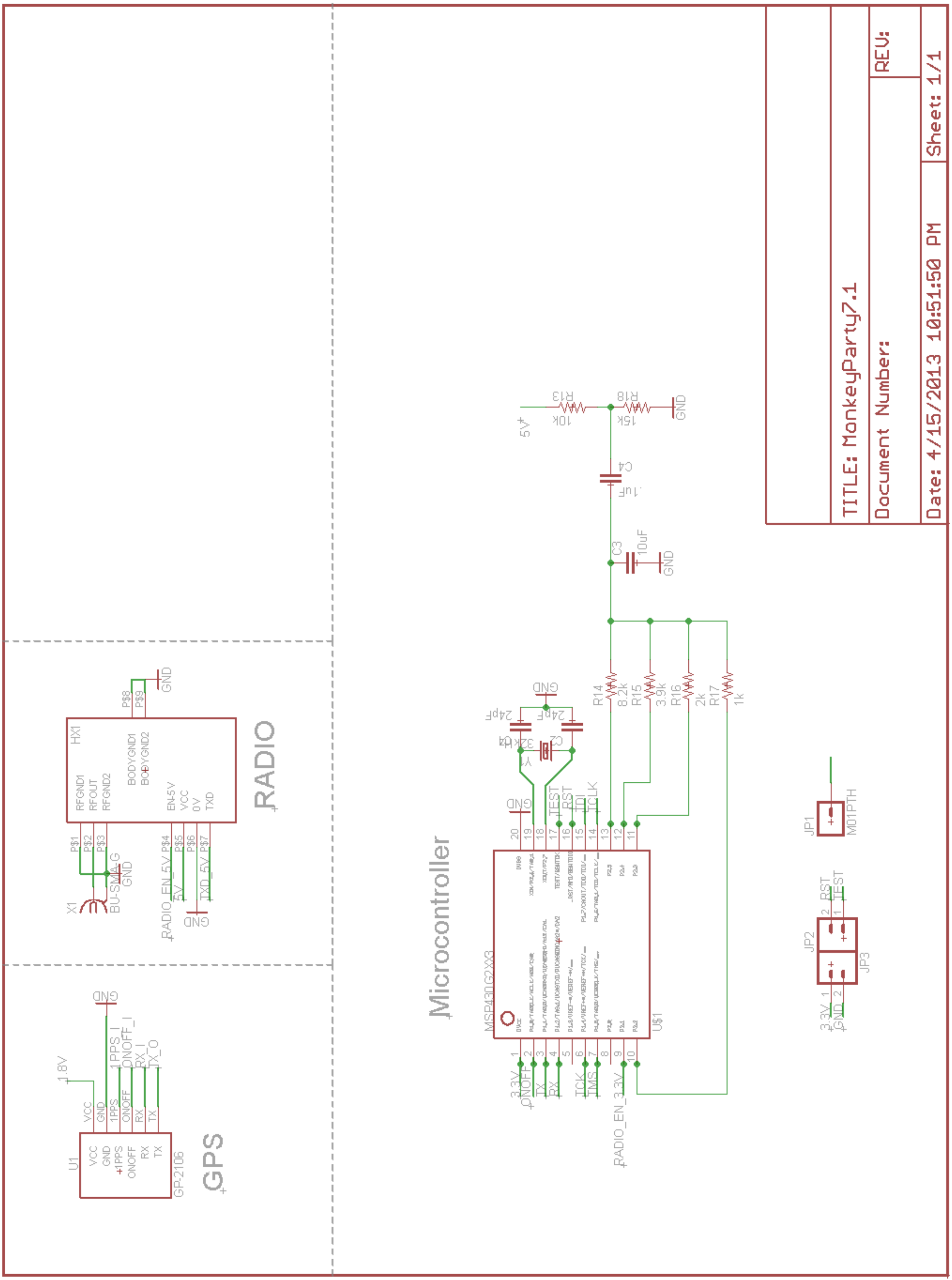
```
//FCS value
extern uint16_t crc;

//Phase Delta for generating sine wave
extern uint8_t Phase_Delta;

//Variables that control AFSK generation
extern uint8_t sent_periods;
extern bool bit_sent;
extern uint8_t cycles;
static uint16_t prev_freq = FREQ1;


typedef struct {
// AX.25 UI-Frame Format
// *********************
// Destination Address
  char *CALL_D;
  uint8_t  CALL_D_SSID;
// Source Address
  char *CALL_S;
  uint8_t CALL_S_SSID;
// Digipeater Address
// Control Field
  uint8_t Control;
// Protocol ID
  uint8_t PID;
// Frame Check Sequence
} aprs_header;

extern volatile bool sleep_on;

#endif /* GLOBAL_H_ */
```

Listing A.6: Code/global.h

Appendix B

Schematics


5 Volt Supply
3.3 Volt Supply
1.8 Volt Supply
Radio Interface
Level Shifters
GPS Interface
Batteries
TITLE: MonkeyParty7.1
Document Number:
REV:
Date: 4/15/2013 10:51:50 PM
Sheet: 1/1


TITLE: MonkeyParty7.1
Document Number:
REV:
Date: 4/15/2013 10:51:50 PM
Sheet: 1/1
GPS
RADIO
Microcontroller
MSP430G2XX3
GP-2106

B.0.8 Bill of Materials

Qty	Value	Device	Package	Parts	Description
2		M02PTH	1X02	JP2, JP3	Header 2
1		SWITCH-SPSTKIT	SWITCH-SPDT_KIT	ON/OFF	SPST Switch
1	.1uF	CAP0805	0805	C4	Capacitor
1	1.24k	RESISTOR0805-RES	0805	RFBB	Resistor
1	1.2k	RESISTOR0805-RES	0805	RFBB1	Resistor
1	1.5k	RESISTOR0805-RES	0805	RFBT1	Resistor
2	100uF	CAP1210	1210	COUT, COUT1	Capacitor
9	10k	RESISTOR0805-RES	0805	R2, R3, R4, R5, R6, R7, R10, R11, R13	Resistor
2	10nF	CAP1210	1210	CSS, CSS1	Capacitor
5	10uF	CAP0805	0805	C3, CIN, CIN1, CIN2, COUT2	Capacitor
1	127k	RESISTOR0805-RES	0805	RON	Resistor
1	15k	RESISTOR0805-RES	0805	R18	Resistor
1	1k	RESISTOR0805-RES	0805	R17	Resistor
1	1uF	CAP0805	0805	CNR	Capacitor
2	22nF	CAP0805	0805	CF, CF1	Capacitor
2	24pF	CAP1210	1210	C1, C2	Capacitor
1	2k	RESISTOR0805-RES	0805	R16	Resistor
1	3.92k	RESISTOR0805-RES	0805	RFBT	Resistor
1	3.9k	RESISTOR0805-RES	0805	R15	Resistor
1	32kHz	CRYSTAL32-SMD	CRYSTAL-32KHZ-SMD	Y1	Crystals
2	34k	RESISTOR0805-RES	0805	RENT, RENT1	Resistor
2	3V	BATTERY245MM	BATTCON_245MM	BAT1, BAT2	Battery Holders
1	69.8k	RESISTOR0805-RES	0805	RON1	Resistor
2	8.25k	RESISTOR0805-RES	0805	RENB, RENB1	Resistor
1	8.2k	RESISTOR0805-RES	0805	R14	Resistor
1	BU-SMA-G	BU-SMA-G	BU-SMA-G	X1	FEMALE SMA CONNECTOR
1	G2XX3---PW20	G2XX3---PW20	PW20	U$1	MSP430G2XX1
1	GP-2106	GP-2106	GP-2106	U1	GP-2106 GPS SiRF IV
1	HX1	HX1	HX1	U$2	Radiometrix HX1
2	LMZ12001	LMZ12001	TO-PMOD7PIN	1.8VREG, 3.3VREG	
1	M01PTH	M01PTH	1X01	JP1	Header 1

```
4    MOSFET-NCHANNELSMD MOSFET-NCHANNELSMD SOT23-3          Q1, Q2, Q3, Q5
1    TPS7A4700          TPS7A4700          S-PVQFN-N20      5VREG
```

Listing B.1: Appendices/BOM.txt

Appendix C

Alternate Designs

The first design had a square output, which would not make the case watertight as desired. This is illustrated in Fig C.1.

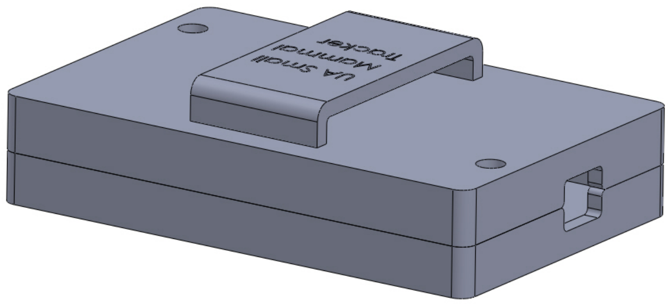


FIGURE C.1: First Attempt at Designing Case

To rectify this situation, a circular extrusion with an O-Ring groove was inserted, as shown in Fig C.2.

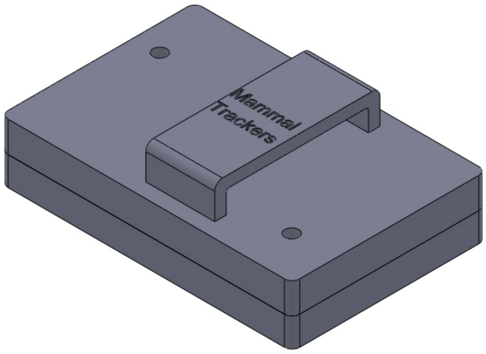


FIGURE C.2: Second Attempt at Designing Case–With O-Ring Groove

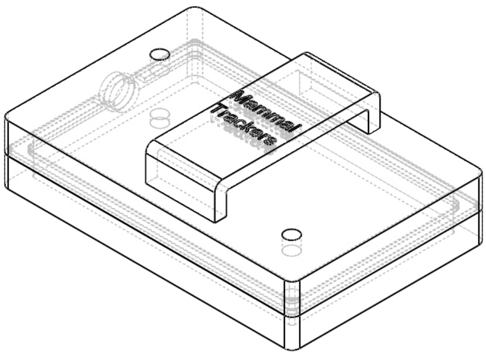


FIGURE C.3: Second Attempt at Designing Case–With O-Ring Groove

The low resolution of the 3D printer was apparent after the second iteration of the board, so alternate solutions were sought. In this iteration, the holes were removed, replaced instead by support material (Fig C.4).

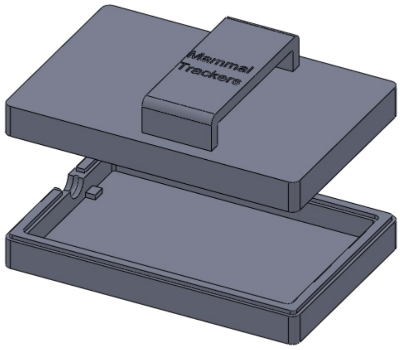


FIGURE C.4: Third Attempt at Designing Case with Supports

After getting the final board, it was realized the board was not deep enough to fit the SMA connector. Thus, in the next iteration, the bottom was created much deeper (Fig C.5).

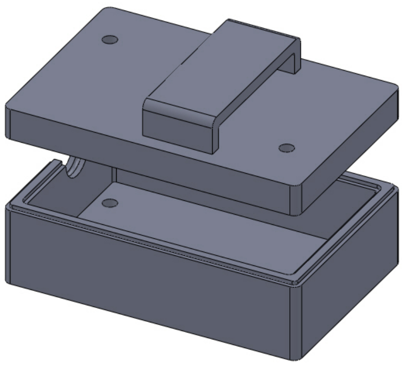


FIGURE C.5: Fourth Attempt at Designing Case-Thicker Case

The last iteration proved to be the final design with the holes correctly aligned and a shorter inner distance, as illustrated in Fig C.6.

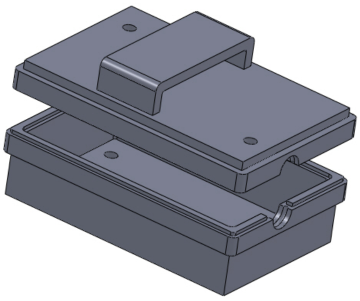


FIGURE C.6: Final Case Design

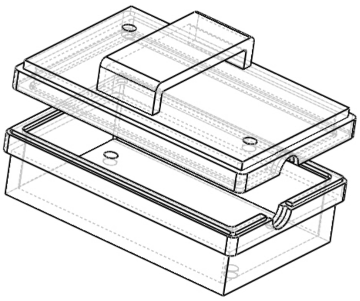


FIGURE C.7: Interior of Final Case Design

Appendix D

Roles and Responsibilities

Sean Rice: Electrical design, board layout, component placement (soldering), purchasing lead, testing, Report compilation, formating, editing
Kevin Klug: Vision, Electrical design, Software lead, APRS signal modulation, prototyping, Report compilation, formating, editing
Ina Kundu: Project lead, Mechanical Lead, Designed and printed case, wrote case and final packaging sections, editing
Hao Chen: Low power mode programming, wrote low power microcontroller and UART sections
Elizabeth Marquez: Modified zig zag antenna to close to 144.390MHz resonant frequency, Engineering Notebook
Yizhou Zhong: Wrote battery sections

Bibliography

[1] Golden lion tamarin. Wikipedia. Wikimedia Foundation, December 2012. URL http://en.wikipedia.org/wiki/Golden_lion_tamarin.

[2] "rtl-09891." 66 channel ls20031 gps 5hz receiver retail. n.p., n.d. web. 06 dec. 2012. URL https://www.sparkfun.com/products/9891.

[3] "gps-11058." venus gps with sma connector. n.p., n.d. web. 06 dec. 2012. URL https://www.sparkfun.com/products/11058.

[4] "adh technology gp-2106 sirf star iv gps module with antenna." 2010. ms.adh technology co. ltd. web. 29 nov. 2012.

[5] Msp430g2x53. documentation. n.p.: Texas instruments, 2011. print.

[6] Fowler, jared r., jon m. austin, kathy t. estrada, martin velazquez, robyn a. mohr, and ruben sanchez. small mammal gps tracker. rep. n.p.: n.p., n.d. print.

[7] Ax.25 link access protocol for amateur packet radio tech. no. 2.2. 2.2nd ed. tucson: Tucson amateur packet radio, 1998. print.

[8] Aprs protocol reference, August 2000. URL ftp://ftp.tapr.org/aprssig/aprsspec/spec/aprs101/APRS101.pdf.

[9] George Fischer. Refrigeration systems in wineries. 2010.

[10] John E. Renaud Jos F. Rodrguez, James P. Thomas. Mechanical behavior of acrylonitrile butadiene styrene (abs) fused deposition materials. experimental investigation. *Rapid Prototyping Journal*, 7:148–158, 1995. URL http://www.emeraldinsight.com/journals.htm?articleid=877416&show=html.

[11] Oled power sensor. URL http://friedcircuits.us/docs/usb-tester-oled-backpack-desc.

[12] Garmin astro 320 gps tracker for sporting dogs (bundle, us).