Design Review
Version 2.0

IROTS

Illinois River Otter GPS Tracking System

UIUC ECE 445 – Senior Design
Spring 2013 – Team #33

Developers

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Date

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Contents

INTRODUCTION

The Illinois River otter tracking system is a project that will massively improve the tools researchers have to perform studies that involve animal tracking. The Illinois River otters are amazing creatures, extremely active, curious and playful. Working on a device that will improve our understanding of such enjoyable animals is in itself enough motivation. The project is also attractive for the challenges we will face on the road to creating a viable product. We will have to accommodate stringent size restrictions, power availability, product life and data accuracy requirements.

Objectives

The goal of the project is to create a device to track the Illinois River otter movement patterns. The device will need to be sub-cutaneous so as to minimize risk of injury to the otter, while ensuring the device is secured to the otter. This device will periodically acquire and store its GPS (global positioning system) coordinate. When the otter is within the download range of the base station, the implant will automatically relay the information to the base station. The base station will have a USB interface for easy data retrieval by the researchers.

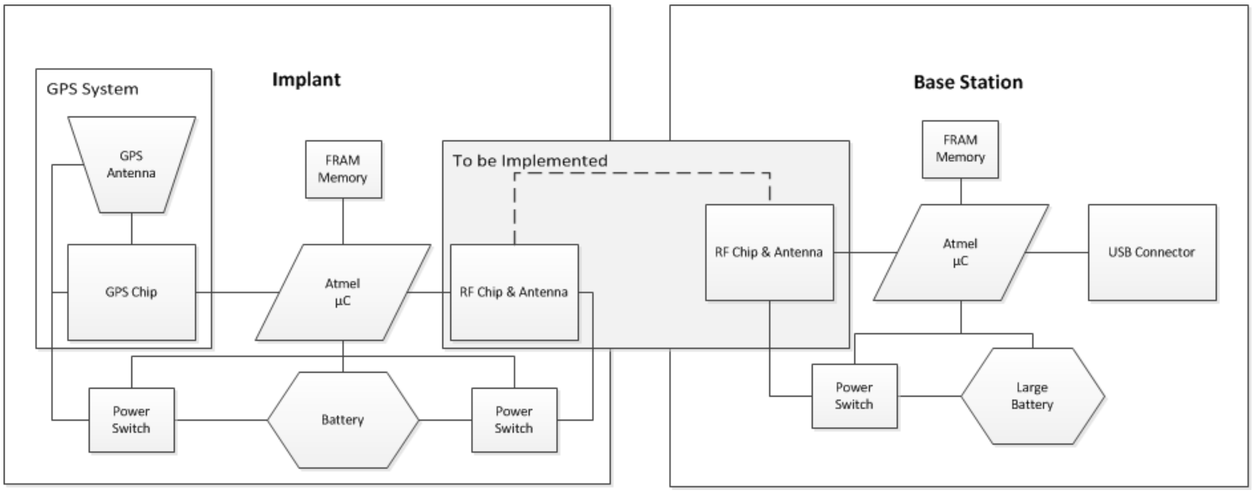
Benefits

- Alternative tracking system(for animals where collars or vests are impractical)
- Ease of use for researcher
  - No need to re-capture otter for data download
  - Data easily downloaded from base station in Excel (.csv) format
  - Easily readable data present/full indicator (turned on only if USB activity present so as to not scare otters away)
- Reduced risk to the animals
- High mapping definition with data points every five hours to ten hours
- Base station uses easily replaceable and/or rechargeable battery packs

Features

- Micro-power and small size
- Base station operational for 1-2 weeks before battery change
- Stores latitude, longitude, altitude, and time stamp information
- Implantable within the animal
- Automatic data transfer to base station
- Antenna is non-directional

BLOCK DIAGRAM



Note: µC⇒ Microcontroller;   Note: RF⇒ Radio Frequency

Block Description

IMPLANT

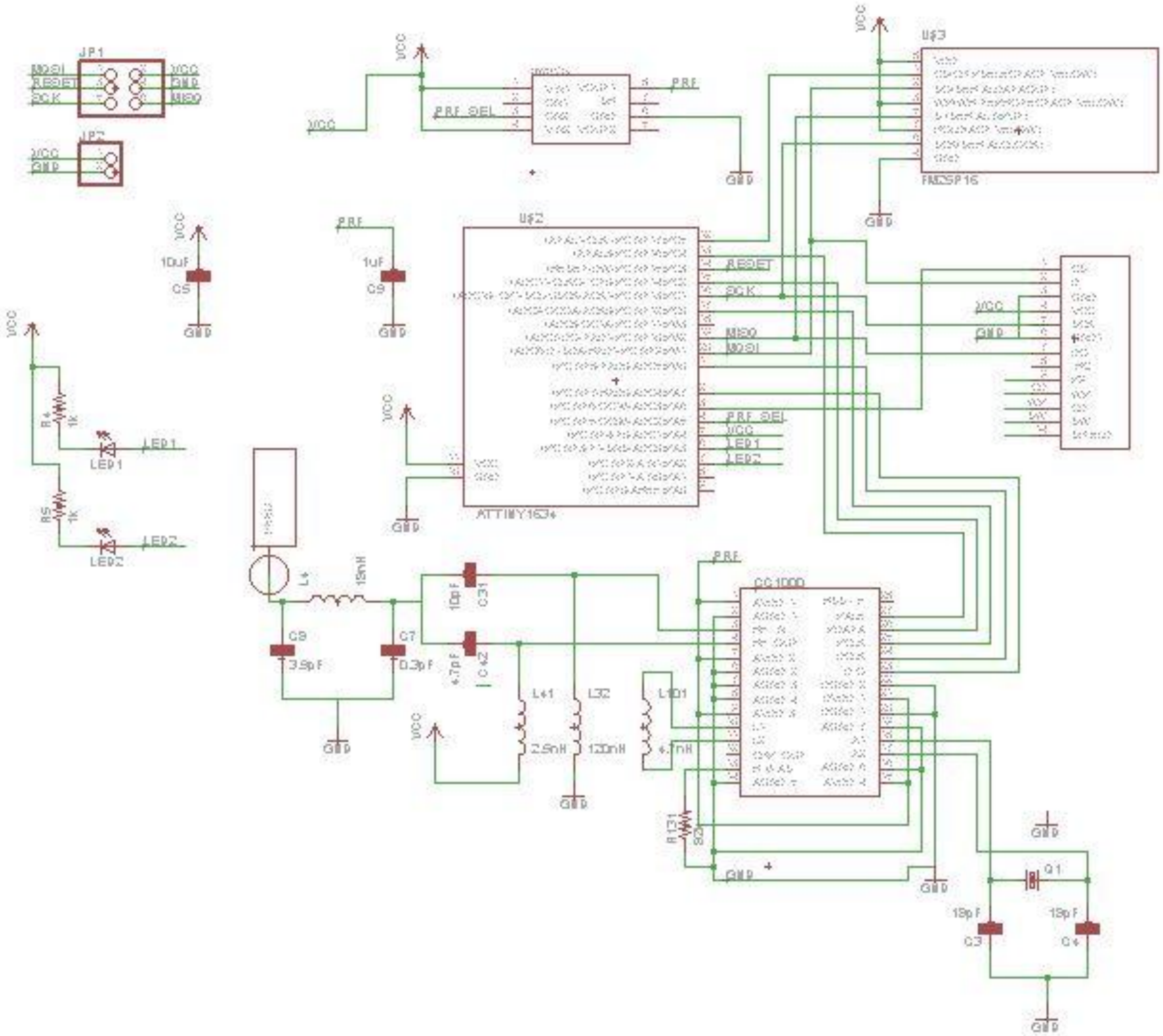
GPS System: This system acquires the GPS location data from the satellites. This data includes the time stamp, Longitude, and Latitude. The altitude is acquired but not stored.
Implant µC: This is the processing center of the implants. It controls power consumption and data storage. It receives the data from the GPS system and stores it. It receives battery level information from the Battery and uses this information, along with its internal clock, to control the RF chip and GPS system.
FRAM Memory: This is the low power memory storage chip which we will be using to store the location data in the implant.
Battery: This block contains the battery being used by that system. It sends information about the battery power level to the µC. It also powers all components of the implant.
RF Chip & Antenna: This relays the stored data from the µC to the base station. It receives its power from the battery.

BASE STATION

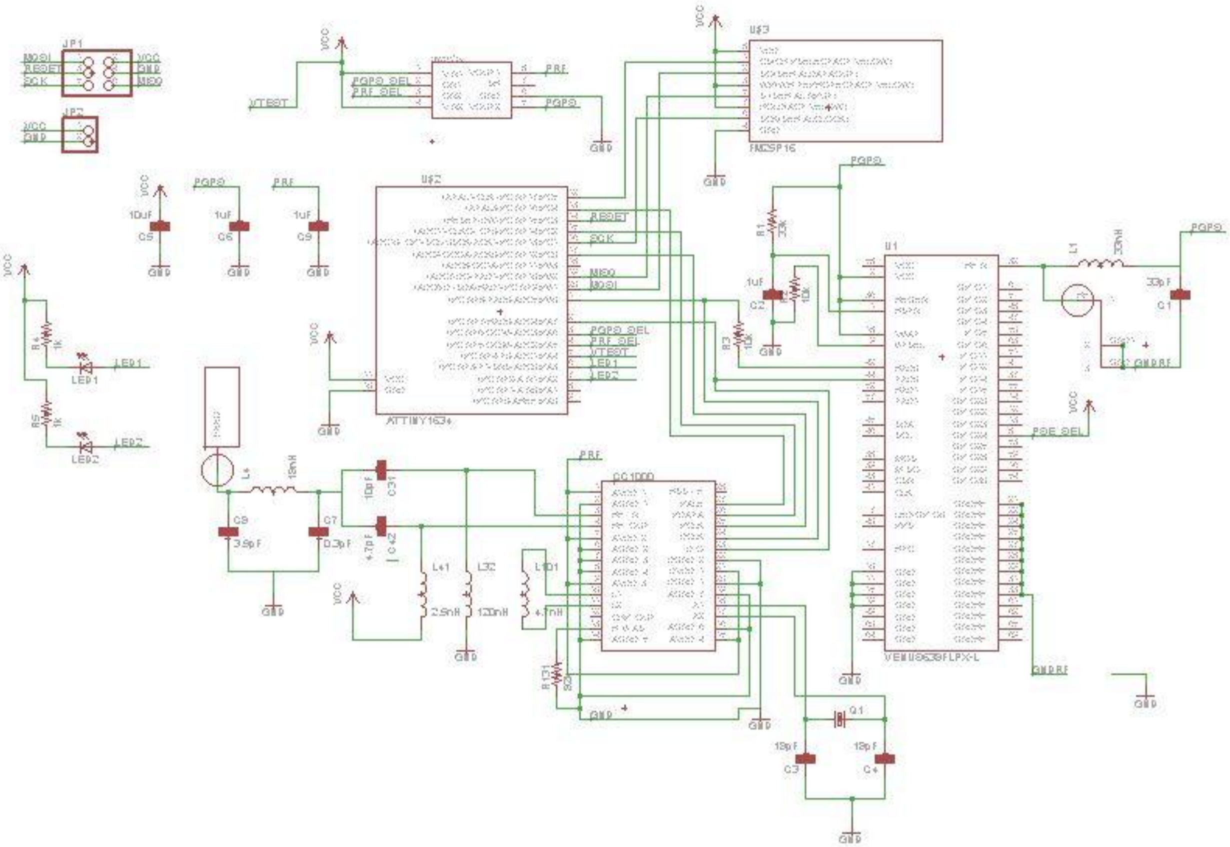
Large Battery: This battery will supply power to the other components of the base station. It will be rechargeable and easily changeable.
RF Chip: This receives the relayed data from the implant and sends it to the µC on the base station. It receives its power from the battery in the large battery.
Base Station µC: This is the processing center of the base station. It controls power consumption and data storage. It receives the data from the RF chip and stores it. It receives power from the large battery.
FRAM Memory: This is the low power memory storage chip which we will be using to store the location data in the base station.
USB Connector: This is used to transfer the stored data to a computer when the data is being retrieved by the researcher. It gets its data from the µC.

SCHEMATICS

<u>Base Station Schematic</u>



<u>Implant Schematic</u>



Schematic Description

IMPLANT

GPS System: [1] This system consists of the GPS antenna and the GPS chip. The Antenna signal goes through a small filter network [1] and goes into the RF_{in} of the GPS chip. The other two pins on the antenna are connected to ground. The GPS chip has communication pins RXD0 and TXD0 that are connected to the TX and RX pins of the microcontroller respectively. Power has to be supplied to the GPS chip to the VCC and VBAT pins which is done using the signal called GPS_BAT so that the microcontroller can completely shut off the GPS chip to conserve power.

Implant µC: [2] Other than the connections mentioned above the microcontroller is connected to the RF chip and the Rechargeable Battery and Charging System. The RF chip connections are discussed in the RF chip and Antenna section of the Schematic description. The signals BAT_RF_EN, BAT_GPS_EN are signals that enable power to the RF and GPS chips and antennas respectively. BAT_MIC is connected to VCC of the implant microcontroller and is the supply voltage out of the rechargeable Battery and Charging system. The BAT_RD_EN signal enables the BAT_RD signal to have a voltage that is a fraction of the battery voltage so that the µC can read the battery voltage and estimate the amount of power left.

FRAM Memory: This is connected to power and ground directly as it uses only trickle power. It is also connected via SPI to the microcontroller for data transfer.

Battery: BAT_GPS and BAT_RF are connected to the battery voltage when BAT_GPS_EN and BAT_RF_EN are high otherwise they are left unconnected (High Z). The output voltage is read using the VCC voltage using the internal reference provided by the µC.

RF Chip & Antenna: [3] The antenna filter network for the RF antenna is based off the design from the datasheet [3]. The external oscillator is to maintain the internal clocks so as to encode and decode RF signals. At the RF bias pin a high-precision resistor is connected for the band gap of the internal system. The inductor L1 is the high-precision inductor for the internal VCO circuit. The connections PALE, PDATA and PCLK are communication pins to set up the operating modes of the chip. They are connected to the microcontroller GPIO pins as the TI-CC1000 does not follow any standard communication protocol. Similarly the DCLK and DIO are the communication pins for data transfer and are connected to GPIO pins of the µC.

BASE STATION

Large Battery: This will have two terminals. The positive terminal will go into the 7805 to be regulated and the negative terminal will be considered as ground for the internal circuit.

RF Chip: This will be hooked up almost exactly the same as in the implant.

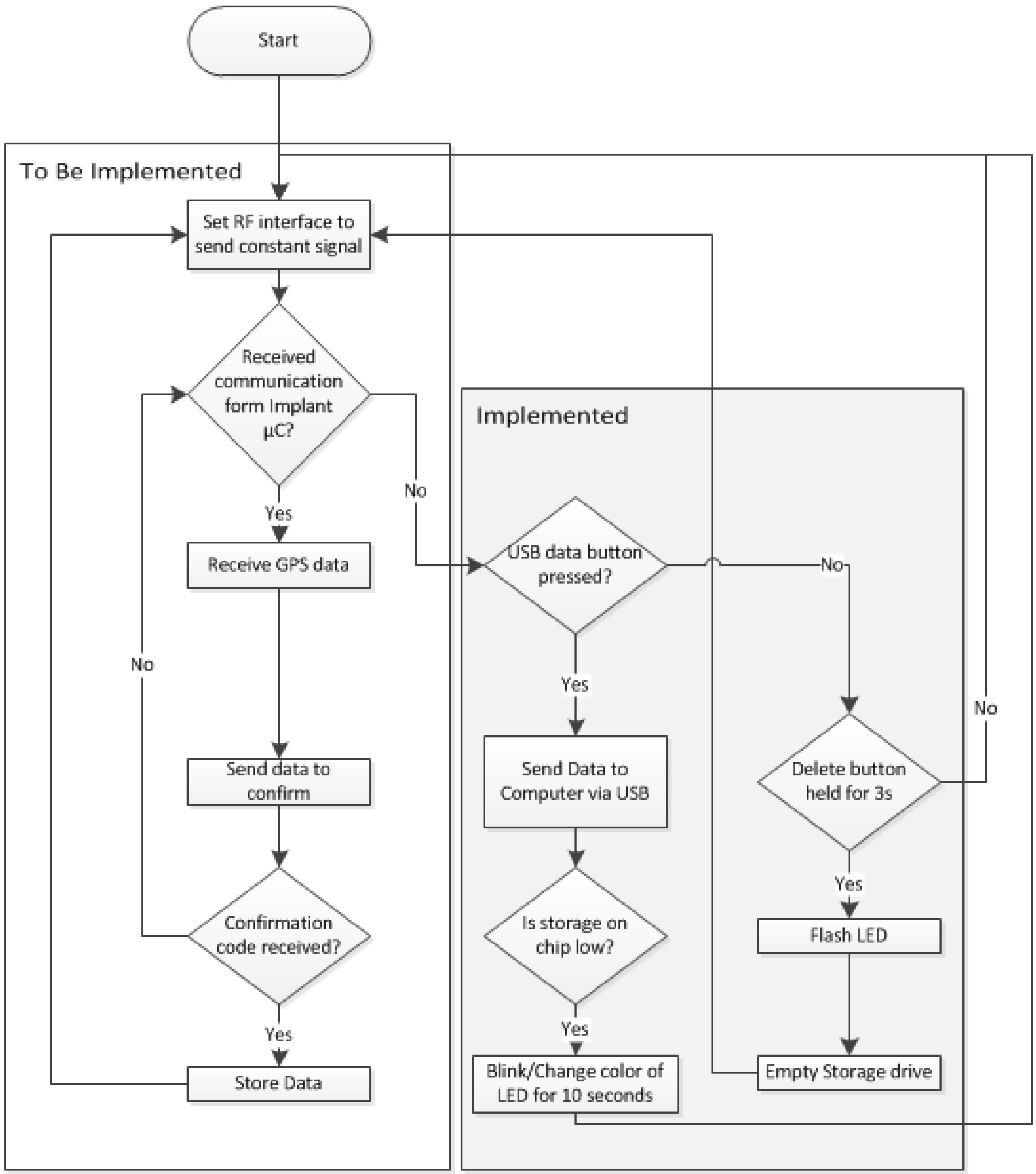
Base Station µC: The connections to the RF chip are exactly the same. VCC is connected to the output of the line regulator 7805. The USB connector is connected to the µC via GPIO pins so as to implement the FAT32/16 library to write files onto the USB device connected.

FRAM Memory: This is connected to power and ground directly as it uses only trickle power. It is also connected via SPI to the microcontroller for data transfer.

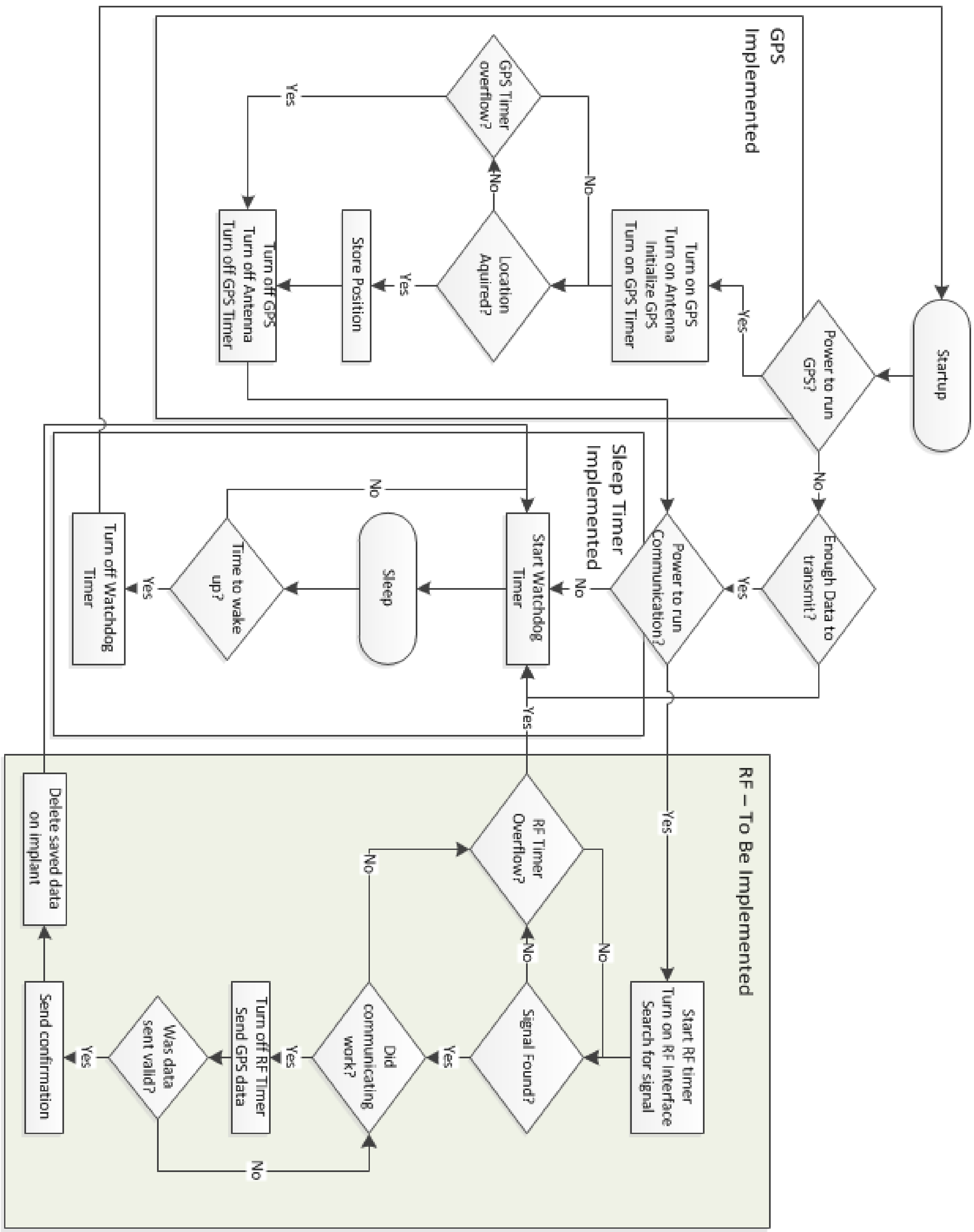
USB Connector: This is a female USB connector to enable easy connection of a portable USB stick to the solder pads of the Base Station µC

CODE BLOCK DIAGRAM

The code block diagrams are shown below. All of the code will be written in C and commented thoroughly. The compiler will be avr-gcc (from win-avr). We will be using an in-system-programmer (ISP) called USB-ASP.



Code Flowchart 1 – Base Station



Code Flowchart 2 – Implant

REQUIREMENTS AND TESTING

Requirements	Reasoning	Testing
I. GPS System 1. Valid location (Two or Three dimensional location and time stamp) acquisition within 10 minutes of power up	1. The GPS system needs to acquire a valid signal within 10 minutes of power up so the GPS Timer does not overflow. Chip needs to retrieve the Longitude, Latitude, time stamp and (optionally) Altitude for every properly stored GPS coordinate in designated time.	1. Power the GPS system by connecting 3.3V to pins 58 & 2 of the GPS chip and to the Vcc pin of the GPS antenna. Connect ground to pins 10 & 11 of the GPS chip and pins 1 & 3 of the antenna. Connect RX of a tested and ready µC to pin 44 and connect the antenna pin 2 to the GPS chip pin 32. Within 10 minutes of these connections, the µC should receive a $GPGGA (in ASCII) through the RX terminal followed by the location co-ordinates. Use the datasheet [2] to check if location is within 10m of actual location.
	1. a) Make sure the measurement environment has a signal by checking for GPS activity on a thoroughly tested device.	1. a) Look for a GPS signal using a smartphone with AGPS (Assisted Global Positioning System, i.e. turn off sensor abiding and WIFI) turned off.
	1 b) The GPS chip needs a signal of at least -148 dBm to acquire a location fix.	1. b) Use a spectrum analyzer to measure the amplitude of the antenna output at the RF out pin of the antenna. 1. c) Check amplitude from another antenna (rerun Test **I**.1.a with another antenna)
2. Non directional antenna	2. The antenna needs to be non-directional so as to receive the GPS satellite signal regardless of the orientation of the otter.	2. Check time to make GPS acquisitions in different antenna orientations using a stop watch. (Cold start every time, i.e. restart the GPS power before every test) 2.a) Check output amplitude from the antenna (Test **I**.1.a) using different orientations
	2.b) Varying current will result in varying acquisition times.	2. b) Ensure the power to GPS chip is not varying by using a current

		meter to measure the current into the chip at the VCC pins.
3. Low power consumption	3. To save power and ensure long product life, we need to make sure the GPS system does not consume excessive power.	3. Use current meter to measure current from the battery during GPS acquisition when antenna is used in active mode. Power consumed (measured current * 3.3V) should be less than 165mW. (Use connections as in **I**.2.b)
	3. a) Ensure that the power saver mode on the GPS chip works	3. a) Use current meter to measure the current from the battery in normal mode and in power saver mode. Power saver mode consumption should be less than 75% of normal mode consumption.
4. Send data in Skytraq Binary format via UART (Instead of NMEA)	4. In order to minimize the data being transmitted without reducing data quality we will be transmitting and storing data in binary format.	4. Use tested LCD-µC pair with same connections as in Test **I**.1 to receiving location data.
	4.a) Querying the software version is the simplest command that utilizes the TX and RX	4. a) Check the communication of GPS chip by querying the software version. Details of test given in GPS chip datasheet[3] 4.a.i) Check GPS chip power using a volt meter across its terminals
	4.b) To make sure there is no error in SkyTraq Binary conversion	4.b) Read data in NMEA using the µC
5. Greater than 10m accuracy	5. 10 m accuracy is reasonable for tracking animal movement patterns over long periods.	5. Use a USB serial convertor and connect the TX and RX terminals of the GPS chip to the RX and TX terminals of the serial convertor. Power the GPS chip and connect the grounds of the convertor and the GPS chip. Receive the co-ordinates using any standard serial reading program. Check received co-ordinate in Google Maps.
	5.a) Check that power saver mode is not the problem	5. a) Rerun Test **I**.3 when not in power saver mode.
	5.b) Check that antenna orientation is not the problem	5. b) Rerun Test **II**.4 with a different antenna orientation.

II. Implant µC 1. Store 170 GPS data points all in an external 16Kb FRAM. Using ~2KB. (Already tried and tested last semester)	1. µC should be able to store locations corresponding to ~60 days of activity. Each GPS location will include latitude (4 bytes), longitude (4 bytes), time stamp (Has to be reduced from 6 bytes to 3 bytes) and a fix mode and # of satellites information (1 byte). Also verify non-volatility of the FRAM. 1.a)Check if GPS system is sending data to storage.	1. Using a GPS chip we will generate several GPS locations and store them on the FRAM chip (connections as in Test **I**.1 and connect the SPI pins of the microcontroller to the FRAM chip.) Turn off power. Then export the data to Matlab on a computer from FRAM chip using different program. 1.a) Check GPS communication by rerunning Test **I**.1
2. UART interface should work at 4800 BAUD	2. The GPS chip communicates with the microcontroller at a minimum of 4800 baud using one of the UART interfaces.	2. Using a standard USB to serial convertor we will communicate with a computer to check that the UART works at 4800 BAUD. Connecting TX, RX and GND of the µC to the RX, TX and GND of the serial convertor respectively. 2.a) Check that the µC is powered using a voltmeter across its VCC and GND terminals.
3. Consumes 25% of run time power during sleep mode	3. The micro controller spends most of its time in sleep mode. This would help utilize as little power as necessary.	3. Using a current meter to measure current (into the VCC pin) test and make sure power in sleep mode is less than 25% of the power in active mode.
III. RF Chip 1. Communicate at a minimum distance of at least 10 meters	1. The otters are known to get within at least a 10 meter radius of a known location. Use two tested µCs to simulate the base station and implant, test the communication between two RF chips 10 meters apart. 1. a) Make sure the RF chips has power 1. b) Confirm that the RF chips are outputting data 1. c) Test RF Transmitter	1. Connect the two RF chips to two different µC's as described in the schematic, and send a test signal from the transmitter to the receiver. Received data should be identical to the sent data. 1.a) Check power to the RF chips using a voltage meter connected to its VCC and GND pins 1. b) Connect the RF_OUT pin out to a signal analyzer. Should be able to see modulated signal at the output. 1. c) Using a signal analyzer 10m away with a wire antenna, analyze the transmitted signal.

	1. d) Test RF Receiver	1. d) Connect the output pins of the test receiver RF chip to a data analyzer when transmitter is within range and transmitting a test signal. Output simulation should be same as test data being sent from the tested transmitter
2. Lower power consumption in receive mode	2. 10 mA is a reasonable low power receive for sub 1Ghz RF.	2. Use current meter to measure the current used by RF chip when in Receive mode. Measured value should be less than 10 mA.
3. Low power consumption in in transmit mode	3. This balances power consumption with communication distance and reliability without creating unreasonable expectations for a cheaper RF chip	3. Use current meter to measure the current used by RF chip when in Transmit mode. Measured value should be less than 17mA 3.a) Change Power output configuration till spec is met.
IV. Battery 1. There should have a minimum of 1.68Ah at 3.0-3.6V	1. 1.68Ah estimated maximum power usage for 60 days by the implant.	1. Using a resistor and voltmeter hooked up to the positive and negative terminals of the battery, we will run down the battery to test the energy rating of the battery.
2. Able to provide a current of 60 mA for ten minutes.	2. Battery must be able to supply 60 mA of current continuously during active mode, which has a timer of ten minutes.	2. Using a resistor, voltmeter and current meter (similar to Test IV.1 except the current meter measure the battery current) to consume 60mA. The battery should be able to provide the required current for at least 10 minutes.
V. Base Station Microcontroller 1. Minimum 3 kB non-volatile data storage.	1. The storage is for at least 4 month intervals of GPS data from 4 otters (3 kB)	1. Rerun Test **II**.1 to with the base station and turn off the power to the µC in between the data write and data read.
2. Including RF chip and Antenna should be consuming less than 30 mA	2. We need the base station to run without needing to recharge for at least a week.	2. Use a current meter test the current consumption.
VI. USB connector and interface	1. For ease of transfer of data.	1. Use the USB interface to write a sample GPS text file to a USB stick and check it on the computer.

1. Connect, power and write files to USB as required	1.a) To check if there errors in the USB format of the data being transferred.	1.a) Read the data directly from the µC to insure the data has actually been written
VII. Large Battery 1. Greater than 5 V output power for 2 weeks	1. Assuming data is retrieved once every 1-2 weeks, the battery must maintain power to the RF chip for this time frame.	1. Test the battery capacity by running it down using a large resistor while measuring the voltage and current using a voltmeter and current meter. Similar to set up in Test **IV**.2

Size/Weight Requirements

The weight will be less than 0.5lb
The size should be as small as possible. The size depends largely on the battery chosen.
The size will be less than: 20-25mm wide 14-15mm thick 50mm-60mm long

Casing Requirements

Casing must completely isolate the device from the otter and last at least 9 years. We are planning on using an epoxy covering to separate the electronics from the otter's body. The particular epoxy we are planning on using is EPO-TEK 302-3M as it was used in previous scientific studies in a similar application.

Full System Test

In order to test the functionality of the completed device, we will need to put it through conditions similar to what it will be facing while implanted in the otter. The signal quality is the main area that will be impacted by the field environment. The otter's skin and hair will attenuate the signal. To see how this impacts device functionality the implant will be wrapped in slightly wet fur. Otters spend a large portion of their time on the forest floor. It is possible to test this environmental factor directly by traveling to a forest and running the device underneath the canopy. The device will then be placed within 10 meters of a base station. Data will be offloaded onto a USB drive and taken to a generic laptop. The test files data will then be put into Google maps. The resulting maps will be compared to the actual locations the device was taken to complete the full system test.

Tolerance Analysis

The implants successful tracking and recording of the GPS locations are heavily dependent on the Microcontrollers both at the base station and on the implant. Since we are using microcontrollers that are 'Pico-power' the energy required to keep the chip running is very minimal. The microcontrollers should be functional even at voltages as low as 2.0 +/-

0.2 V and only require currents as low as 1 +/- .1 µA when in sleep mode. To test that the microcontroller can function at 2.0 +/- 0.2 V a 1.8 V signal from a power supply will be given to the Vcc pin on the microcontroller. We will then do a software version test on the GPS chip and read this onto an LCD screen. To test the sleep mode we will write test code that saves data into the ram and then goes onto sleep mode. Once in sleep mode, we will use a multi meter to test the current being drawn by the chip. Once the chip wakes up the program will output the ram to the LCD screen. These numbers will be tested against the numbers from the same test code without the sleep mode included. Passing both these tests gives the implant the ability to store data over a lengthy period of time when in power saver mode (not acquiring new GPS locations). At <3V we have used up ~75% of the power on the battery. If the battery drops below 3V then we will switch to power saver mode where the priority will be to get the data to the base-station.

CALCULATIONS

These calculations were used to make an approximate on the power generation requirements. These are all done on a day basis.

<u>GPS & Antenna power usage</u>

Assuming a worst case 10 minute, 3 times a day GPS search would give us

30 minutes of GPS searching a day will give us. Assuming a voltage supply of 3.3V

Time in hours * (GPS current + Antenna current)

(30/60) *(50mA + 5mA) = 27.5mAh

@ 3.3V => 27.5*3.3 = 90.75mAhV = 90.75*60*60mJ = 326.7J

<u>Micro Controller Power Usage</u>

Assuming the micro controller sleeps for the rest of the time.

Active time: 30/60*(0.4mA) = 0.2mAh

Sleep time: 1µA*24= 24µAh

Total = 0.224mAh

@3.3v => 0.224*3.3 = 0.7392mAhV = 0.7392*60*60mJ = 2.66112J

<u>RF Power Usage</u>

Assuming we run for 10 seconds 5 times a day gives us

Time in hours * Receiver Current usage

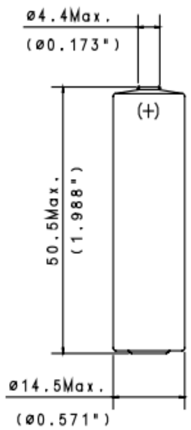
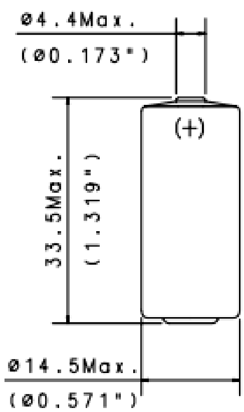
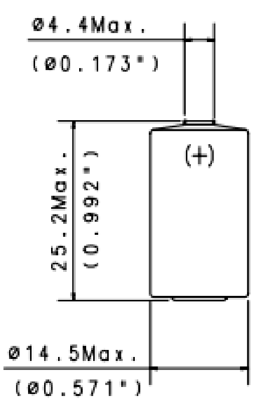
(10/60/60) *10mA = 0.027mAh

@3.3V =>0.027*3.3 = 0.09166mAhV = 0.09166*60*60mJ = 0.33J

<u>Total Power Usage per day</u> is ~= 340J or 28mAh

DESIGN QUESTIONS

Choosing a Battery

Image	Type	Capacity	Max recommended continuous current	Part Number	Cost
	AA	2.5Ah	100mA	TLH-5903	$8.98
	2/3AA	1.5Ah	75mA	TL-5955	$8.10
	1/2AA	1.2Ah	50mA	TL-5902	$7.24

Choosing package of Microcontroller

The decision is whether to switch from a 13x10.65mm SOIC package to a 4x4mm WFQFN package. This will significantly reduce the PCB footprint and give us the ability to move the RF transceiver to the top level of the board to reduce the overall size of the board. The issue with moving the QFN package is that we have not tested that particular package and testing and debugging QFNs is not easy.

Choosing GPS antenna

The decision is whether to switch from a geo-helical active antenna to a passive chip/surface mount antenna. While the chip antenna reduces the size considerably it doesn't have any gain and we might not get a 'loud' enough signal at the input of the GPS chip to get an accurate fix in certain situations.

TEST & SIMULATIONS

GPS Test Results

Using the test breakout board we were able to test a sample of the GPS chip which we will use. The antenna used was a patch antenna and was not under open sky. We started by testing communications with the chip. Using an LCD screen we were able to display the ASCII (NMEA) and the Hex (Skytraq Binary™) output. Since the NMEA output has a higher space requirement we decided to use the binary output as conversion would just add time/power requirements. Here are some readings we were able to obtain from the GPS chip.

Name of Value	Format	Scale	Hex Value read	Scaled value
Latitude*	SINT32	10^{-7} degrees	0x17e8d479 0x17e8d470	40.1134713°N 40.1134704°N
Longitude*	SINT32	10^{-7} degrees	0xcb6a26e4 0xcb6a20ee	88.2235676°W 88.2237202°W
Week number	UINT16	Counted up from 1/6/1980	0x06ac	1708 ⇨Week of 9/30/2012
Time of week	UINT32	10^{-2} seconds	0x13776b8	2041220.88 seconds ~9am Tuesday GMT

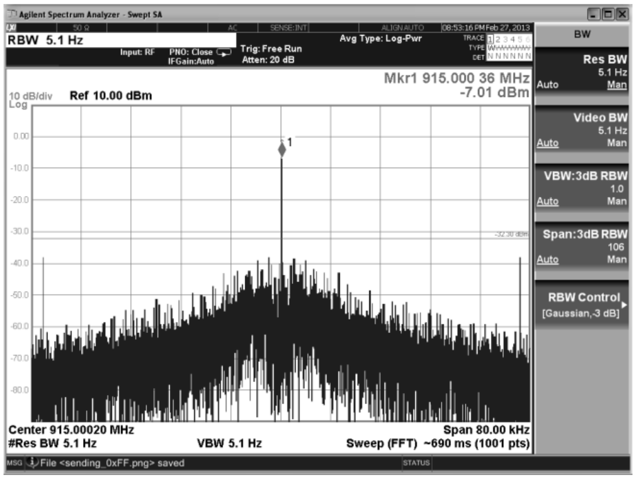
*From two different cold starts.

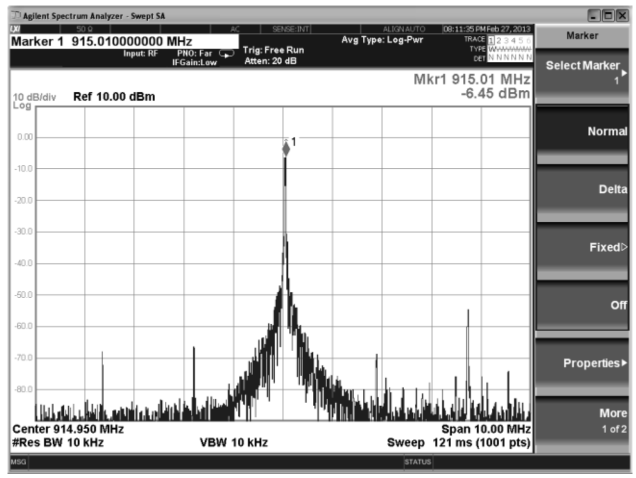
This is a Google Maps image of the locations acquired (two blue pins) and the actual position(approximately green pin).
The distance between the measurements and the actual location is very small compared to the required accuracy.

RF Test Results

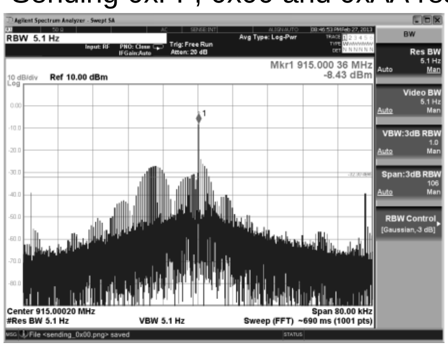
Below are the graphs obtained of the cc1000's RF out when programmed to transmit at 915MHz (which is an ISM band).

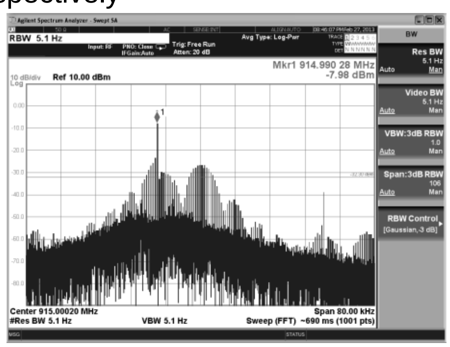
Only the Carrier.

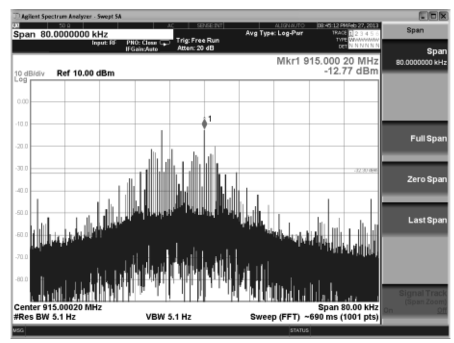




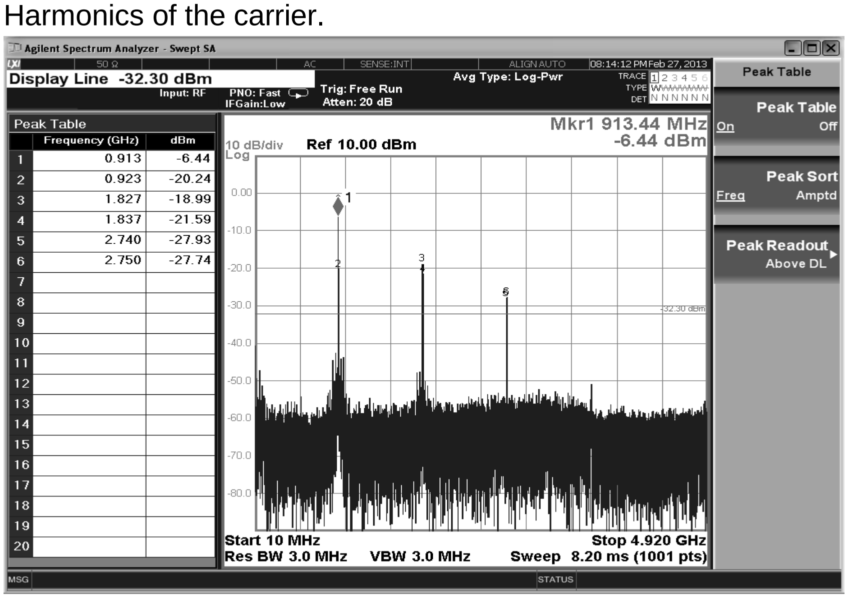
Sending 0xFF, 0x00 and 0xAA respectively







Harmonics of the carrier.



COST AND SCHEDULE

Cost Analysis

Parts	**Unit price ($)**	**Quantity (#)**	**Total cost ($)**
Attiny 1634 (Microcontroller)[1]	1.80	2	3.60
Venus638FLPx-L (GPS chip)[1]	39.95	1	39.95
GeoHelix GPS Antenna[4]	22.95	1	22.95
USB A female connector	0.71	1	0.71
Texas Instruments CC1000[3] RF transceiver	7.17	2	7.17
TLH593 2.5AH Battery	8.98	1	8.98
PCB main board (Design to be completed and sent)	200.00	1	200.00
Miscellaneous parts and antennas	100.00	-	100.00
TOTAL:			382.76

People	Hourly Rate	Hours per Week	Total
Bilal Gabula	$20*2.5	24	14400
Osayanmo Osarenkhoe	$20*2.5	24	14400

Project Total: $29182.76

SCHEDULE

Week	Deliverables	To get done	Assignments
~~2/18/2013~~		~~RF board done~~ ~~Microcontroller Breakout re-tested~~ ~~RF testing started~~	~~Bilal~~ ~~Bilal~~ ~~Osa~~
2/25/2013	Design Review	Finish RF testing GPS surface mount antenna test Test Batteries Ordered Start on Final Board	Osa Bilal Osa Bilal
3/4/2013		Batteries test Final Parts ordered Final Board sent to FAB	Osa Bilal Bilal
3/11/2013		Base station board finalized Base station board tested	Bilal Osa
3/18/2013		Spring Break	
3/25/2013	Mock Demo	Final Board setup and tested	Bilal/Osa
4/1/2013		Base station and Final board working together	Bilal/Osa
4/8/2013		Matlab functionality for easy offload	Bilal/Osa
4/15/2013		Testing on random things	Bilal/Osa
4/22/2013	Demo	Demo	Bilal/Osa
4/29/2013	Presentation ,Final Papers	Presentation	Bilal/Osa
5/6/2013		Cleanup and Graduate	

ETHICAL CONSIDERATIONS

We plan to follow all aspects of the IEEE code of ethics when designing and implementing this project. Since we are implanting the device into an animal there are extra issues that arise. We have to make sure the device does not bother or injure the otter. The area of greatest concern is the degradation of materials inside the otter. We should make the product so that it can last indefinitely inside the otter and use the epoxy casing that does not degrade in a subcutaneous environment.

REFERENCES

[1] SkyTraq Technology. Data sheet for Venus638FLPx GPS Receiver [Online]. Available : http://dlnmh9ip6v2uc.cloudfront.net/datasheets/Sensors/GPS/Venus638FLPx.pdf

[2] Atmel. Datasheet for Attiny 1634 an 8-bit microcontroller with 16K Bytes In-System Programmable Flash. [Online]. Available: http://www.atmel.com/Images/doc8303.pdf

[3] Texas Instruments. Data sheet for CC1000 a single chip very low power RF transceiver. [Online]. Available: http://www.ti.com/lit/ds/symlink/cc1000.pdf

[4] Sarantel. Data sheet for SL1024 (GeoHelix -M) a 2nd generation active helical GPS antenna. [Online]. Available: http://www.sparkfun.com/datasheets/GPS/SL1204%20Product%20Specification_v2_10_2009.pdf