A REPORT
on

ANIMAL TRACKING USING GPS AND GSM

by
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Contents

List of Figures

Chapter 1

Introduction

> *A true conservationist is a man who knows that the world is not given by his fathers but borrowed from his children.*
>
> – John James Audubon

Wildlife is neither a resource nor a gift to man. We have no right over it. Activities of man have led to drastic changes in the population of animals, their behaviour and affected ecology too. Serious concerns have been raised by ecologists and environmentalists about these changes. Study of animals is beautiful for a nature lover or an explorer and is useful for a researcher or an environmentalist. Man has been studying animals trying to understand its complexities through various techniques. Animal tracking is one of man's attempts to unfold mysteries of animal kingdom and also put his foot forward for the cause of wildlife conservation.

1.1 Motivation

During the study phase we had a talk with Dr. Sukumar from Ecology Department of IISc who has worked on collaring of elephants. During this interaction we understood that the requirement for an ecologist is to track the animal for 12 to 18 months to completely study its migration patterns. Most of the companies making GPS collars claim that the battery life of collar is 18 to 24 months. But these installed collars barely last for 6-8 months. The major design challenge for us is to make an extremely low power collar which lasts for 2years.

1.2 Use of animal collar

Study through animal tracking reveals some facts like:

- A deeper knowledge of critical habitats used by animals and their fundamental needs.
- Study of animals in their natural habitat to understand habitat usage, behavior, survival, migration and distribution patterns.
- More accurate delineation of animal corridors and crucial feeding and drinking locations.
- Better fence positioning to lessen animal-human conflict in high risk zones.
- Re-routing animals or humans to forestall a human-animal conflict.
- Faster detection and action response times against potential threats.
- Enhanced early warning systems to detect any changes in poaching levels.
- Better definitions of sites for potential reintroduction of animals.

Chapter 2

Overview of the System

This product is a remotely programmable, battery operated, wild animal tracking GPS collar with a lifetime of 18-24 months which can give fixes even under dense foliage and communicates to the base station using GSM/GPRS.

2.1 Block Diagram of the System

The components of a system shown in figure (2.1) are :

- Collar
- SMS Server
- Main Server
- Application Software(GUI)
- Website

The collar will be strapped to the animal. Depending upon the configurations of the collar, it will communicate to the server using SMS or GPRS periodically. The SMS server is separate from the main server. This was decided mainly to keep the SMS server local to the place where the collar is so that the collar need not send national or international SMSs. The SMSs can be local if the server is local to a group of collars in a region or state. There needs to be only one main server either in CEDT or in any ecology institute. Only this main server needs to have a public IP address so that it is accessible to all the collars over GPRS. The application software is having a GUI to configure the collar, view the fixes, see the battery status, view the locations on Google Earth and anlayse them by placing markers over a time period. The website will be useful for administration and viewing fixes

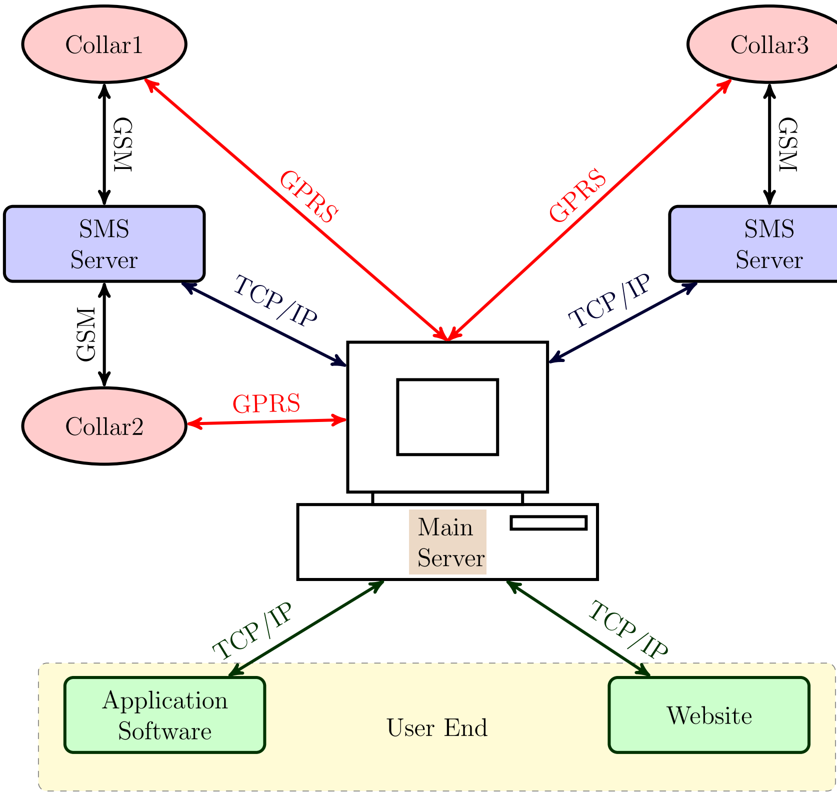


Figure 2.1: Block Diagram of the System

on Google maps. Thus with the help of website the ecologist can track the animal from any place.

Chapter 3

Survey Of Existing Solutions

Figure 3.1: Commercially available collars

Some of the commercially available GPS collars have been discussed below:

1. **Vectronic Aerospace** Vectronic Aerospace has GPS technology combined with a UHFVHF radio beacon and UHF or GSM download possibility. They provide 4 complete different options of data download:

    - UHF radio link on demand,
    - Data download via the mobile/cell phone system directly into the office
    - Argos satellite service directly into the office
    - Via satellite telephone communication directly into the office

2. **Sirtrack**

    - Sirtrack GPS data logging receivers can log up to 80, 000 compressed locations or 40, 000 uncompressed locations. The locations are stored in non-volatile flash memory.

- The GPS receiver has an accuracy of 6m R50 CEP. The means that 50% of the locations will be within a circle of 6m.
- Operational life with six hour interval between fixes is about 18 - 24 months.
- To aid in recovery GPS collars can also be fitted with VHF transmitters. These transmitters operate on separate cells and generally run much longer than the GPS receiver.
- A single download interface is required and comes complete with custom software and connection cables. This software enables the user to set time and distance filters.
- Can hold a temporary strain of 50kg.
- Lithium batteries are used.

3. **Televilt: GPS collars**
    - Recovery beacon - the GPS unit will send continuous double pulse VHF/UHF beacon to indicate time for recovery.
    - Mortality indicator:The GPS unit will send continuous VHF/UHF beacon to indicate mortality.
    - Large memory:Memory capacity is always larger than battery lifetime, eliminating risk of losing data
    - Temperature tested: All GPS collars and GPS backpacks are tested in temperatures ranging from -30 to +50 degrees Celsius before being approved and delivered.
    - Adjustable belting: Size can be changed +/- 10collars
    - Non-volatile memory: Data is safe in GPS unit even after battery is completely drained
    - Lithium batteries: The only reliable choice for GPS units in areas with changing and/or low (below zero degrees Celsius) temperatures
    - All GPS units allow defining the schedule of fixes and VHF/UHF beacon to fit tracking schedules.
    - A program to calculate operational life based upon selected schedule is available.

4. **CellTraX GPS Collar :(BlueSky Telemetry):**
    - CellTraX data can be received using a standard SMS text message on the user's mobile phone.

- GPS and GSM separately scheduled.
- Schedules, diagnostics and data can all be downloaded in next to real time.
- Collar has additional feature of tracking beacon.
- GPS data stored on board until animal comes within GSM coverage to download data.
- User replaceable batteries.
- Up to 65, 000 locations can be recorded at intervals ranging from one location every 4 seconds through to one location each day.
- Data records can be downloaded and schedules can be changed at user's convenience.

Remarks: The cost of most of these products has not been discussed as they are generally custom-made for the given animal. But on an average they range from anywhere from $2000 to $10000.

Chapter 4

Target Specifications

- Weight of the system:
  - Weight of electronics: < 100 gm.
  - Battery weight: < 2 kg.
- Life of the collar: 10 fixes per day - 2 years.
- Communication system:
  - SMS and GPRS communication with the base station.
  - Communication is tried a minumum of 2 times in a day.
- Remotely reprogrammable functions:
  - Time between periodic fixes. 15 minutes - 24 hours. Default: 4 hours.
  - Specific fixes: Times with a resolution of 15 minutes. Default: None.
  - If fix is not obtained after X number of attempts then the module switches off and tries after Y minutes. (X and Y can be programmed by the user.)
    1. Range of X: 2 to 5.
    2. Range of Y: 15 minutes to 2 hours in steps of 15 minutes.
  - Enabling real time tracking - Real time tracking will give animal location every 5 minutes.
  - communication option: SMS mode or GPRS mode
- Software: GUI software on the PC:

  - Interface for displaying the locations of fixes.
  - Remote command interface for reprogramming.
- Mechanical and ID specifications of collar:
  - Vibrations: 2 g.
  - Impulse: Drop test from 2 m.
  - Load: 100 kg.
  - Water and Dust: IP class 68 compliant.
- Thermal specifications: Ambient temperature range: 0°C to 50°C.

Chapter 5

Block Diagram of Embedded Hardware

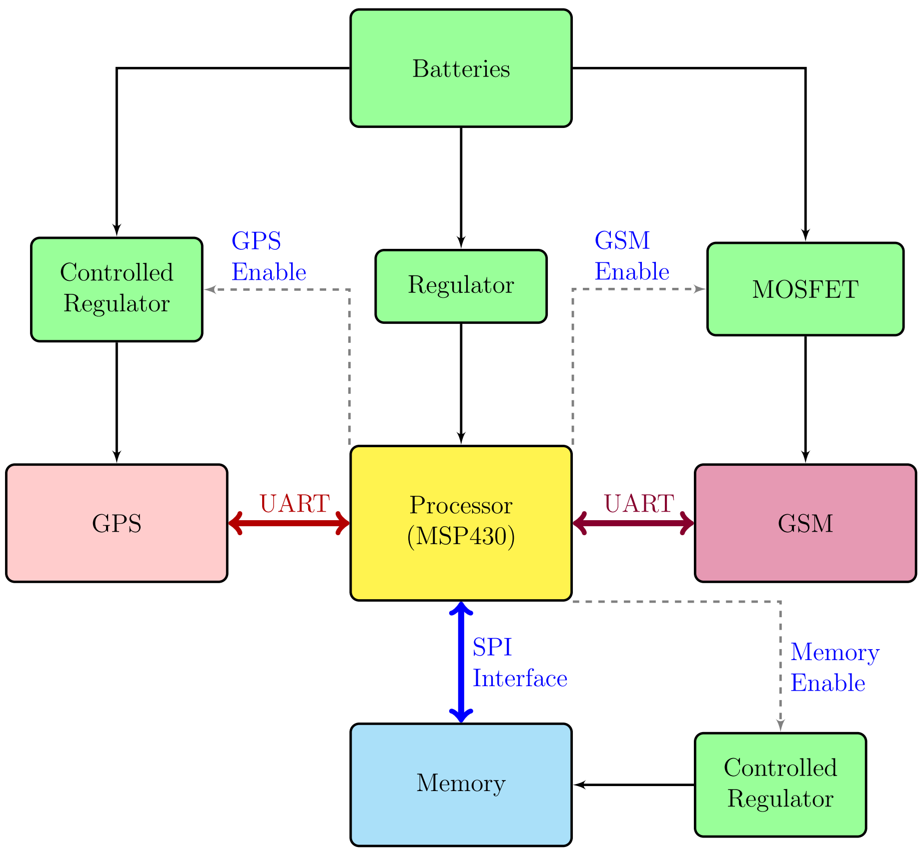


Figure 5.1: Block Diagram of the Collar

The GPS system gives the location information which is then stored in the external memory. This fix is transmitted using either the GSM or GPRS network to the base station.Very little processing is done on the collar which is battery operated.The block diagram of the collar system is given in figure (5.1). The major modules of the project are :

- **Controller**
- **GPS:** It gives the location information
- **GSM and GPRS:** It is the communication link between the collar and the server
- **Serial Flash Memory:** For storing the fixes.The memory talks to controller using SPI interface.
- **Regulators:** The basic requirement of all the linear regulators is that they should have extremely low dropout voltage and very low quiescent current. The regulator for the controller is always going to be on. The regulators for GPS and memory are controlled linear regulators. They are enabled and disabled by the controller. When these regulators are disabled they leak very less(1μA). A regulator was not used for GSM. The reason will be explained in the hardware design section. Instead a MOSFET having very low ON resistance is used. The MOSFET is enabled and disabled by the controller.

5.1 Major Components used and their part numbers

Type	**Part No.**	**Company**
GPS module	LEA-4T	UBLOX
GPRS module	TC-65	SIEMENS
Controller	MSP430F2418	TI
Memory	AT25DF321	ATMEL
Regulator for controller	TPS79730	TI
MOSFET for GPRS	IRF7410	IRF
Regulator for GPS	TPS73230	TI
Regulator for memory	TPS73230	TI

Chapter 6

Embedded Hardware Design

6.1 Prototype Board

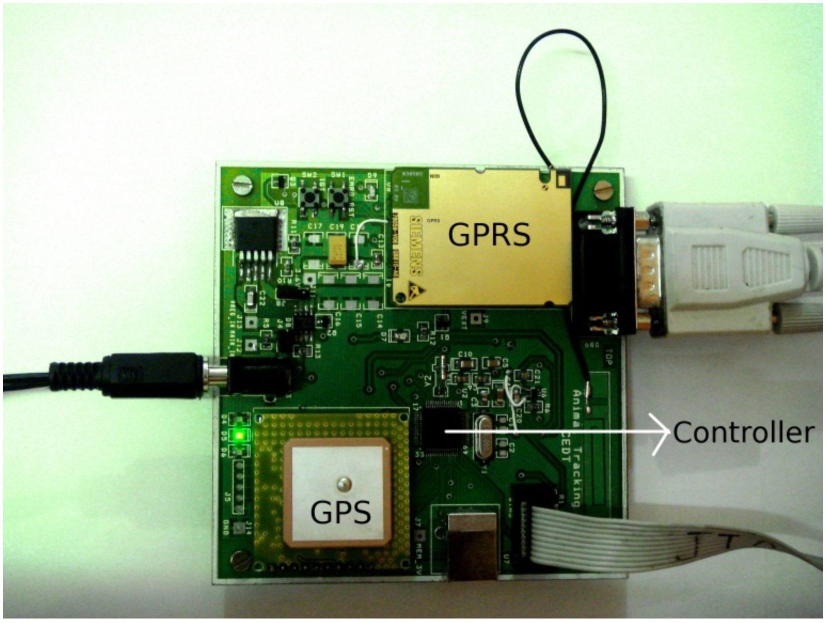


Figure 6.1: Prototype PCB

A prototype board was prepared with all test and debug interfaces. This was useful for developing the embedded software.The prototype was ready by Feb 1.The prototype board contained the readymade UBLOX Smart Antenna Module. GPS module was connected to the computer using USB for debugging.The GSM module's serial interface was connected to serial port of the computer for debugging.

6.2 Controller Hardware Design

The controller schematic is shown in figure(6.2).The selection of components and design is explained in the following sections.

6.2.1 Selection of processor

TI has released MSP430F24x series which consumes less power than the existing ones. Features are:

- Less power: LPM3 2μA
- During full operation: 3mA
- Supply Voltage supervisor
- It has 2 independent UARTs which are required for GPS and GPRS.
- The processor used is MSP430F2418.It has code flash 116KB and RAM of 8KB.

6.2.2 Selection of RTC

There were two options:

- **Using internal timer of the controller as RTC:** Timer A of the controller can be used to get a periodic interrupt every 1s to 16s(max) so that the count is accumulated to get the appropriate time interrupt.In between the MSP can be put to sleep mode which consumes $2\mu A$.Since RTC can be implemented through an internal timer there is no need of external RTC chip.

  Total mAh = $2\mu\text{A} \times 365 \times 2 \times 24 \times 1000 = 35\text{mAh}$.

  As the energy cost is very less we have decided to go with software implementation of RTC.Accuracy is not a great concern because the GPS is going to use its own internal RTC. Also the controller RTC will be caliberated with the GPS time so that accuracy is maintained.

6.2.3 Functions done by the controller

- 32.786kHz is the clock for the RTC.
- Controls the wake-up of other modules by enabling the respective regulators.

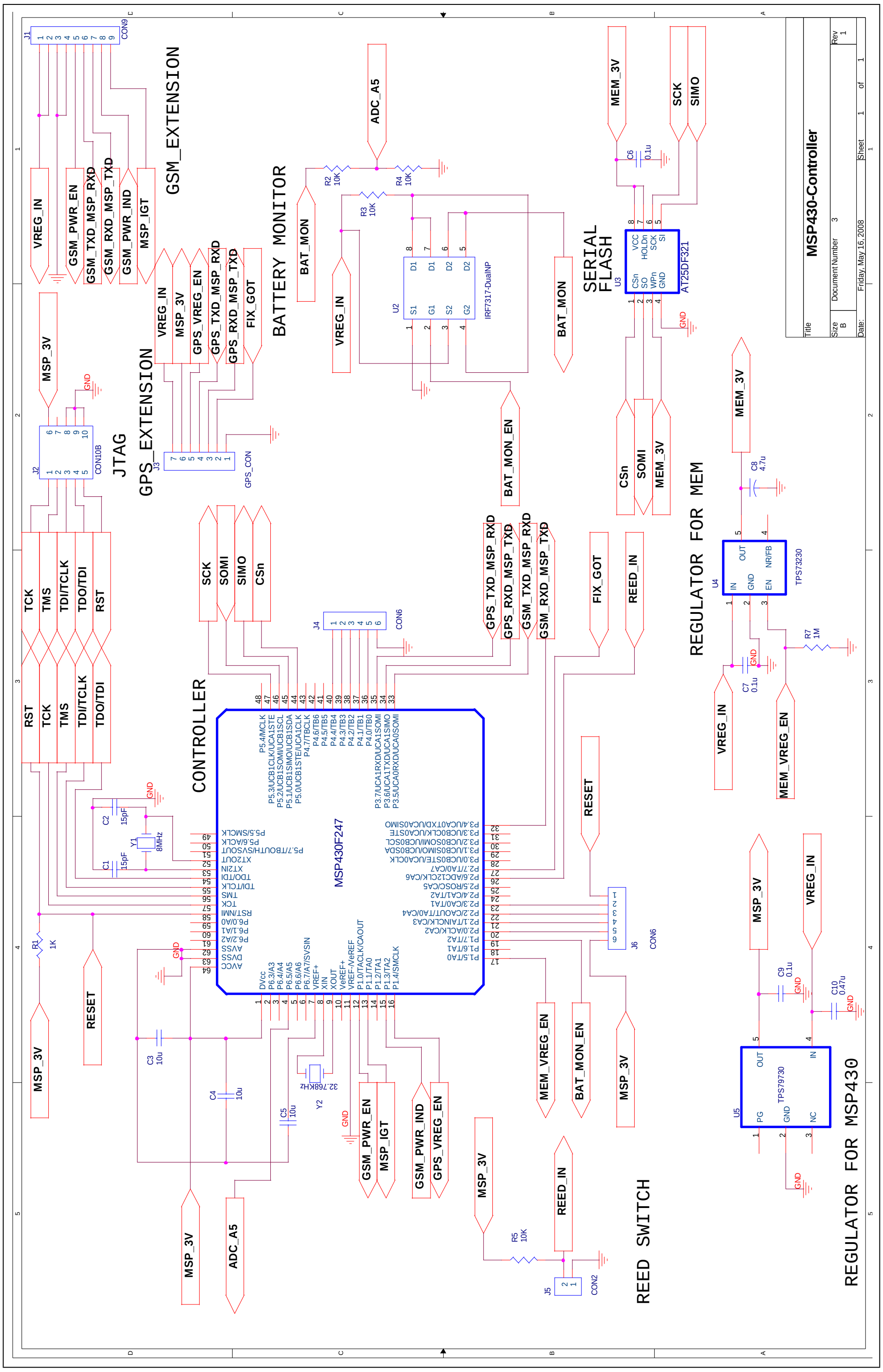


Figure 6.2: Schematic of the Controller

- Internal flash of the controller is going to store configuration details of the collar-Mobile number of the SMS server to which the collar has to transmit, when to take GPS fixes, when to transmit, etc.

6.2.4 Regulator for the controller

The regulator of the controller is going to be on always and hence needs to have very low quiescent current consumption.The characteristics of the regulator chosen for the controller are given in table (6.1).

Table 6.1: Controller Regulator-TPS79730

Dropout Voltage	**Quiescent Current @ full load**
100mV @ 10mA	1.2μA @ 10mA

6.2.5 Reed Switch for magnetic activation of the collar after sealing

The collar will be configured using an SMS.The configurations consists of default parameters like time between the GPS fixes, time between GSM transmissions, SMS server mobile number, etc.These configurations will get burnt into the internal flash of the controller.After configuring the collar with an external power supply, the lithium batteries will be connected and the collar will be completely sealed.The sytem starts functioning according to the configurations.Now, the collar has to be dispacted to the location.It might take quite some time before the collar is actually installed on the animal.This means that the battery will drain out substantially if the collar is installed after a long break.To avoid this a magnetic REED switch is put.The REED switch is connected to one of the port pin of the controller and that pin is configured for edge triggered interrupts.When there is no magnet placed on the box of the collar it will function normally.When a magnet is placed, the collar will get an interrupt and put the controller in deep sleep mode.The magnet is placed during transportation of the collar and should be removed before installtion.

6.3 Controller - Memory Hardware Interface Design

The schematic of the external memory circuit is shown in figure(6.2). The memory is interfaced to the controller via SPI.The size of memory according to calculations for storing GPS fixes is 3.2MB.Memory selected is 4MB serial flash.The controller enables the regulator for the memory when it wants to read/write to it.Otherwise the memory is OFF and the regulator is in standby.The TPS series of controlled regulators from TI has extremely low standby currents so they are used as switches to turn ON/OFF the supply to the memory.The memory and the controller's power supply voltage is 3V.The memory requires a maximum of 7mA during a write operation. Characteristics of the controlled regulator chosen for memory are given in table (6.2).

Table 6.2: Memory Regulator-TPS73230

Dropout Voltage	Standby current	Quiescent Current @ full load
40mV @ 250mA	1μA	400 μA

6.4 Controller - GSM Hardware Design

The schematic of the GSM board is shown in figure(6.3).The selection of components is discussed in the following sections.

6.4.1 Power Supply design of GPRS module

The highest power consuming element on the entire board is the GPRS module.

The constraints for the power supply design as specified in the datasheet are:

- Power supply input range to the module is 3.2V to 4.5V.
- Supply voltage should not drop below 3.2V even during transmit burst where current consumptions peaks to 2A.The module shuts off if the voltage goes below 3.2V.
- Any voltage drop that may occur in transmit burst should not exceed 400mV.

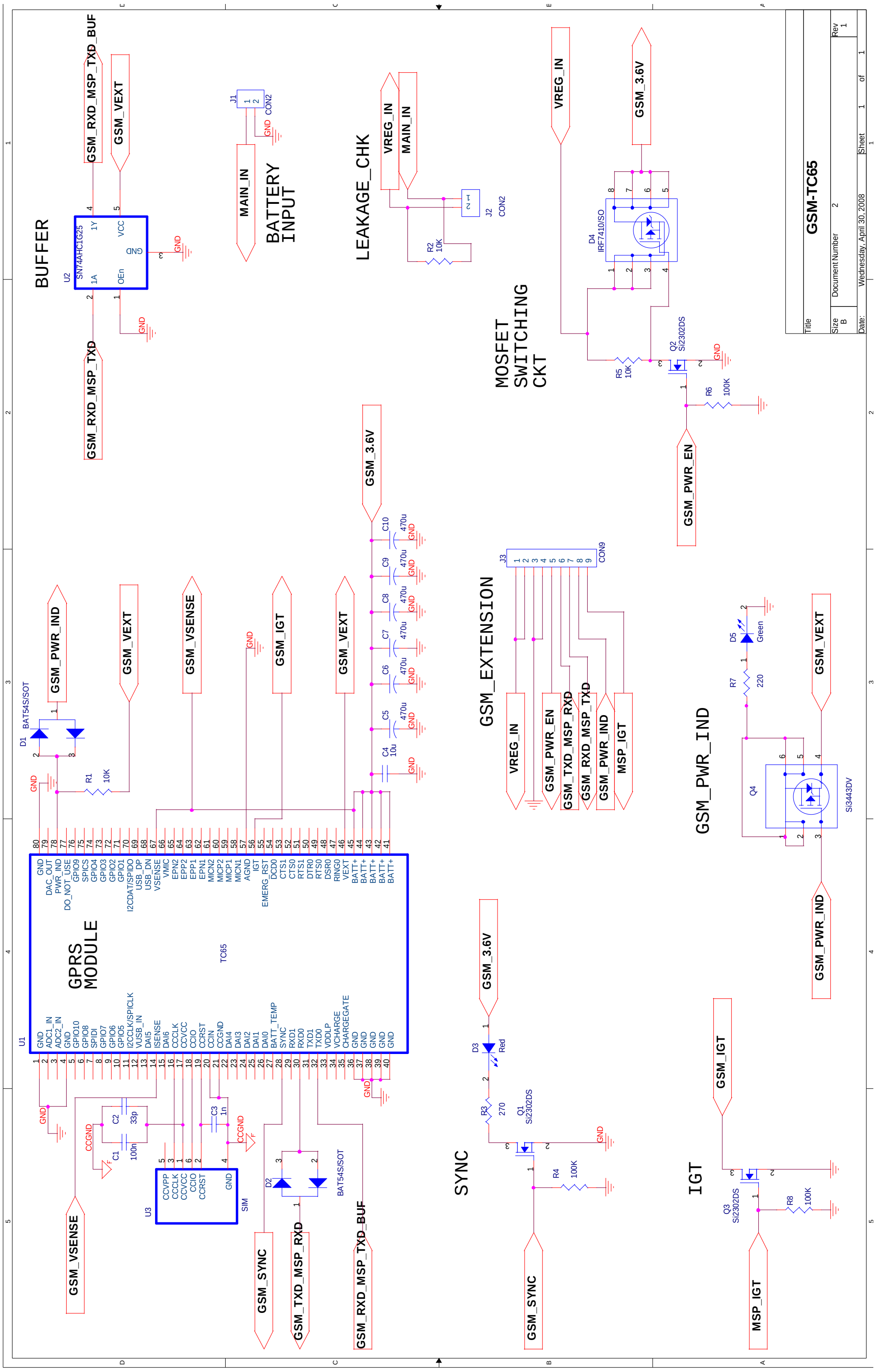


Figure 6.3: Schematic of GSM module

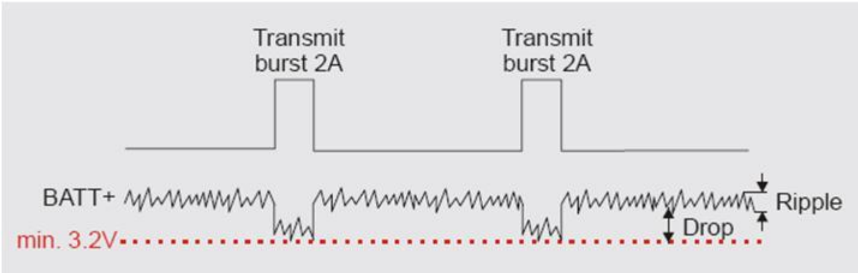


Figure 6.4: Current and Voltage requirement of GPRS module

- Average current consumption of the module is 540mA during transmission.

Various Designs proposed for power supply: Considering these constraints, the designs that were thought of are as follows:

- **Use of a 3.67 lithium battery and regulator :**The battery that is going to be used for the system is lithium thionyl chloride battery(selection of the battery will be discussed in later section) having Open Circuit Voltage=3.67V and Nominal Voltage = 3.5 to 3.6V.Hence considering the nominal voltage of 3.4V, there is only a margin of 0.2V left.The best regulator from TI had a dropout voltage of .15V @ current of 2A.Also ordinary lithium-thionyl batteries will drop heavily if we try to draw current bursts.The track resistance will also contribute to the voltage drop when current in burst of 2A is drawn. With this method the design will be very critical with absolutely no margin left. The battery chemistry puts a limitation of 3.6V.

- **Use of a secondary battery in parallel with primary battery** : Rechargeable batteries have the capability to supply high current pulses. The capacity of the battery should be small otherwise the leakage will increase heavily. This method has a serious disadvantage of leakage.

- **Use of a large capacitor in parallel with the regulator**:The problem with lithium battery is current surge. But if the capacitor connected after the regulator is sized such that it caters to all the peak current requirements and the regulator takes care of the average current, the battery will not be loaded with peaks. Example calculation: Let the regulator supply the average current of 500mA.

Remaining 1.5A is supplied by the capacitor and let the design be such that the voltage drops only by 0.1V.

$$I \times t = C \times \Delta V$$
$$C = \frac{I \times t}{\Delta V}$$
$$C = \frac{1.5A \times 577\mu s}{0.1V}$$
$$C = 8.6mF$$

Thus the capacitor is very large. We need a low ESR capacitor. Otherwise there will be a voltage drop across ESR during current burst. Also many small value capacitors can be connected in parallel so that the effective ESR is reduced. But there is one serious disadvantage-Every time the capacitor is charged, $\frac{1}{2} \times C \times V^2$ is wasted in charging it and another $\frac{1}{2} \times C \times V^2$ is wasted once it discharges after use.

- **Use a 4.5V battery linear regulator and a large capacitor**: The linear regulator supplies the average current and a low ESR value supercapacitor provides the current bursts. But this has a disadvantage–Entire system other than the GPRS works at 3.0V. Hence if we use 4.5V battery for the entire system the efficiency will be poor because the voltage at the linear regulator will have to drop from 4.5V to 3V.

- **Use two kind of batteries**:One for the GPRS circuit(4.5V) and one for other circuit (3.6V) so that the GPRS battery can be a customized battery which can specifically supply the high current pulses and the other battery can be chosen which has very low nominal current discharge. But this means that battery lifes have to be matched which is difficult.

- **SOLUTION IMPLEMENTED**:**POWER DELIVERY TO THE MODULE USING LOW $R_{DS(ON)}$ MOSFETS**:The advantage is that this method will have the least dropout voltage as compared to others. The $R_{DS(ON)}$ of the MOSFET(IRF7410) used is $9m\Omega$. The leakage current $I_{DSS(leakage)}$ is $25\mu A$ (absolute max). The voltage drop across the switch when a pulse of 2A is drawn is : $9m\Omega \times 2A = 18mV$. This is far less than any of the linear regulators. Hence using a MOSFET switch for delivery of power to the GPRS works out better as compared to a linear regulator. The batteries used for the system are TADIRAN PulsesPlus battery which are customized for the GSM/GPRS current requirements.

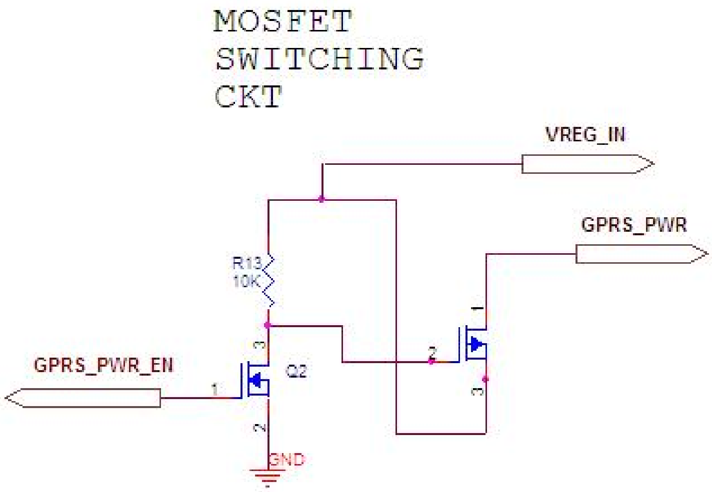


Figure 6.5: MOSFET Switching Circuit

6.4.2 Why are the Schottky diodes used ?

All those signals which are output from the GPRS and are input to the controller are not directly connected but are having Schottky diodes in the path. This is because the output voltage on the pin of GPRS can go upto a maximum of $3.05V$. The controller works @3V. The datasheet says that voltage on any pin of the controller should not exceed $(V_{CC} + 0.3V)$. This is specified in the absolute maximum rating. So as to not to stress the controller these diodes are put. When the GPRS pin drives, the diode D_F in the figure below conducts and drops the extra voltage so that controller sees 3V. When GPRS stops driving the capacitor at the controller pin has a discharge path through the diode D_R.

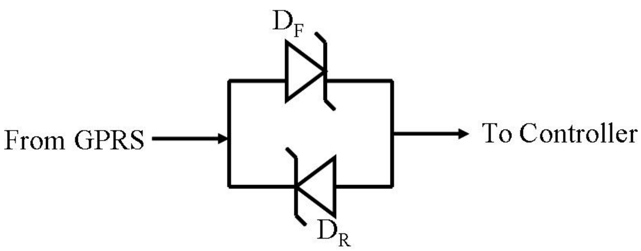


Figure 6.6: Schottky diodes

6.5 Controller - GPS Hardware Interface Design

6.5.1 Need for a custom GPS Board

A readymade GPS smart antenna module was purchased from UBLOX which was used in the development stage. But the readymade development module is having some components which are not necessary.

- For example, it has a USB controller chip for giving a USB connectivity to the computer.

- The regulator used by UBLOX is MIC5255. It is a controlled linear regulator. The dropout voltage of the regulator is 135mV to 250mV. This is not desirable as the margin of operation with a 3.6V battery reduces. We have used TPS73230 which has a dropout voltage of 40mV to 150mV. Also the enable pin of the regulator is not available on the Smart Antenna. It is directly shorted to the Vcc. Hence to control the regulator we would have required one more switch which is not at all efficient.

- For maintaining the RTC and GPS tracking related information, the module is having a small 5mA-h rechargeable lithium battery. It charges when the power is connected. When there is no power it maintains the backup. In our case the lithium battery will never get charged because we ON the GPS for very short time in a day and rest of the time it is OFF. Thus backup battery is not required and we can directly use the controller's power supply(which is always going to be ON) to maintain the backup. This will do away with charging of the battery which will further save power. Also the rechargeable lithium batteries have a considerable leakage which will add to the overall leakage of the system. But for testing and configuring the collar we have put two primary 1.55V watch batteries in series. These batteries will not go on the final product.

Figure 6.7: GPS Smart Antenna - Top -(Module purchased from UBLOX)

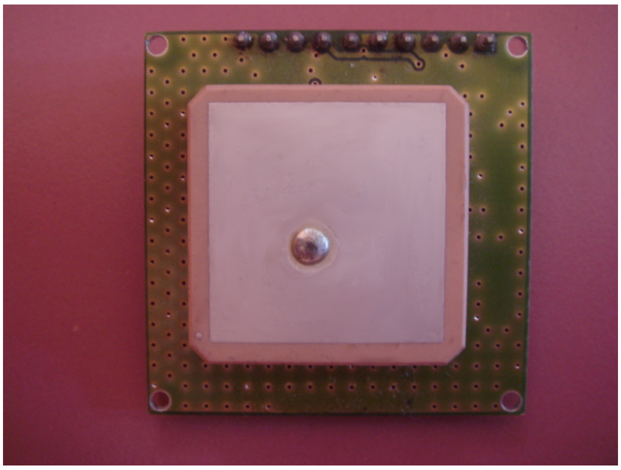


Figure 6.8: GPS Smart Antenna - Bottom

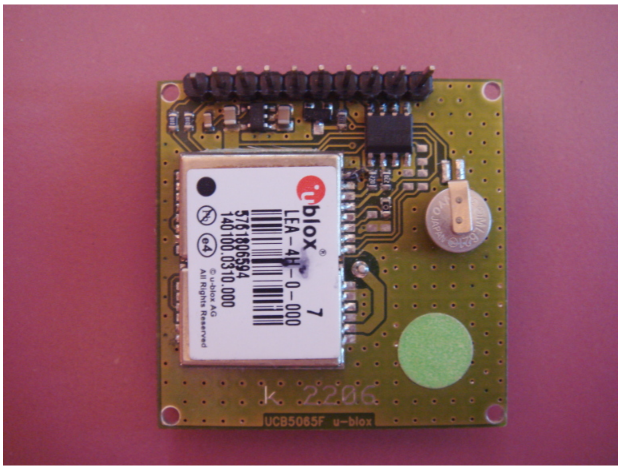


Figure 6.9: New GPS Board by us - Top

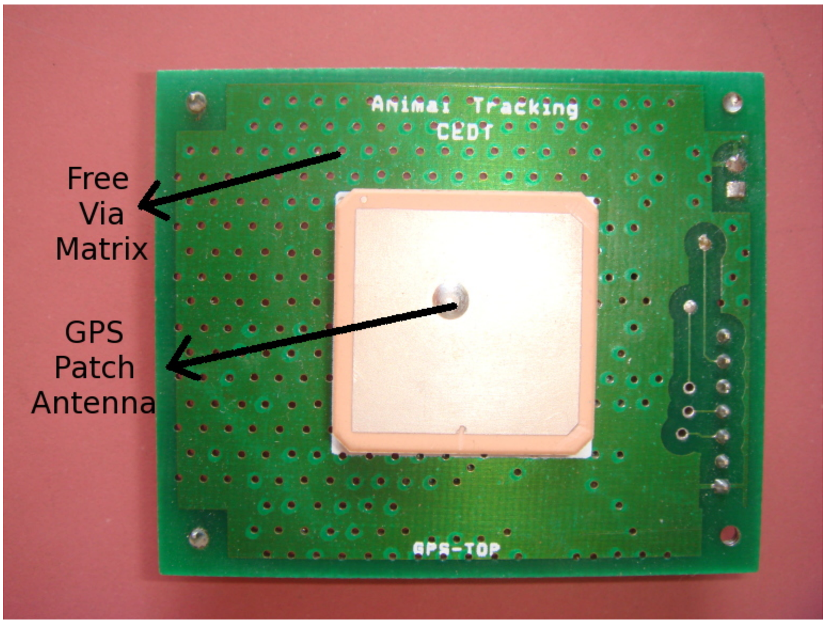
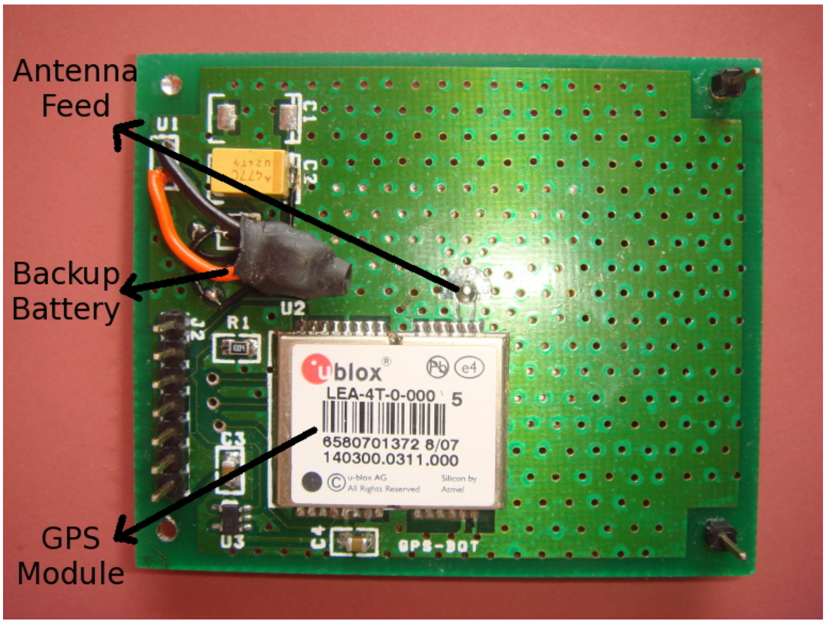


Figure 6.10: New GPS Board - Bottom



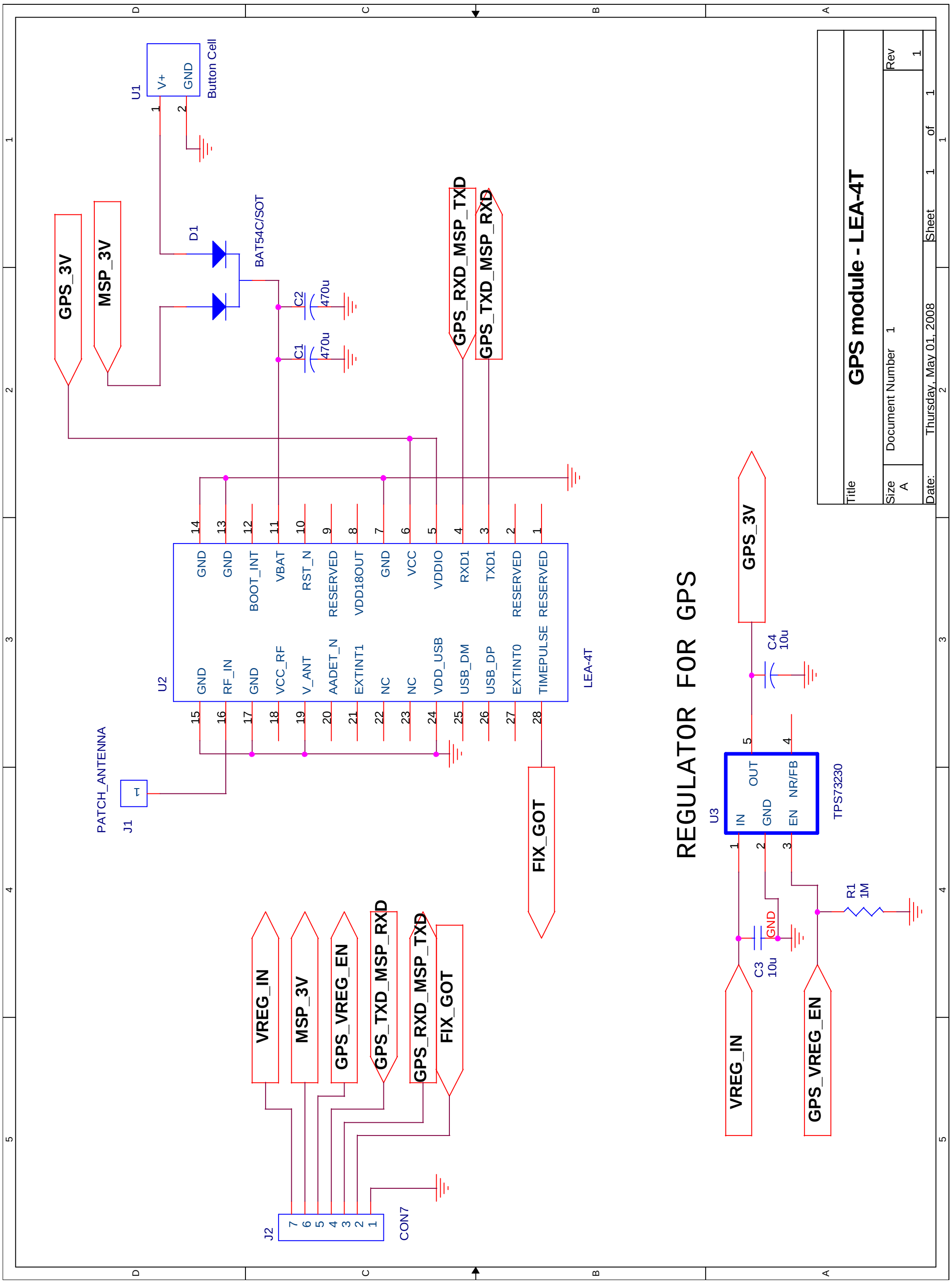


Figure 6.11: Schematic of GPS module

The schematic of the GPS board is shown in figure(6.11). The GPS module talks to the controller through UART. The UART of GPS module talks at 3V. Since the controller works at 3V there is no problem of voltage levels. The GPS takes a peak current of 70mA and consumes 40mA on an average. Characteristics of the controlled regulator chosen for GPS are:

Table 6.3: GPS Regulator-TPS73230

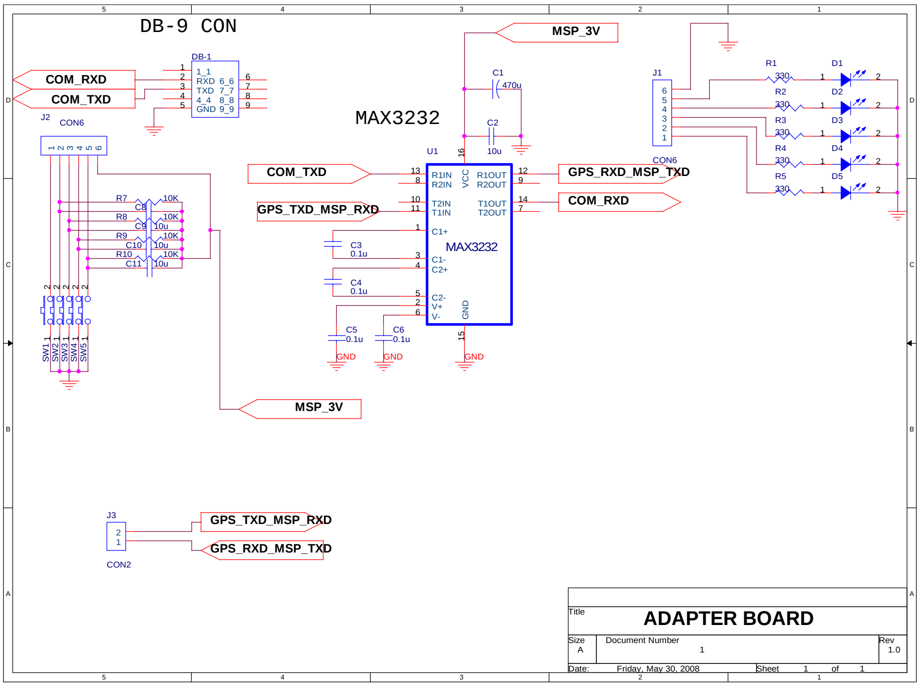
Dropout Voltage	**Standby current**	**Quiescent Current @ full load**
40mV @ 250mA	1μA	400 μA

A small backup power supply is required for the RTC and storing the tracking information of GPS.The VBAT pin of the GPS module is getting power from 2 places(as shown in figure(6.11) through a diode so that reverse current is not possible.One is from the regulator of the controller.Other is primary watch batteries(2 series connected batteries each of 1.55V).For testing and for configuring the collar before dispatch a backup battery is necessary. It can be removed before potting the system.

6.6 Need For Adapter Board

For configuring the collar before completely sealing it, some switches and LEDs were required.To save space, a separate adapter board for configurations was made whose schematic is shown in figure (6.12). It consists of 5 switches and 5 LEDs. It is not a part of the final product.

Figure 6.12: Schematic of Adapter Board



Chapter 7

Calculations For Embedded Hardware

7.1 Standby current calculations

The circuit elements which are going to contribute for the standby current are:

- Regulator for the controller,
- Regulator for Memory,
- Regulator for GPS,
- MOSFET switching circuit, and
- Backup battery current for GPS.
- Controller

Component	Conditions	Typ current(μA)	Max current (μA)
Regulator for the Controller	Ground pin current @ $I_{\text{out}} = 10mA$	1.3	2
Controller	Standby current @ $V_{\text{cc}} = 3V$ @f = 32.768KHz , 85 °C	3.9	4
Regulator for the Memory	Standby current	1	2
Regulator for the GPS	Standby current	0.2	1
Battery Backup for GPS	Backup current	5	15
MOSFET switching circuit for powering GPRS	Drain to Source leakage current (I_{DSS})@ V_{DS} = $9.6V$ $V_{\text{GS}} = 0V$	1@25 °C	25@70 °C
Total standby current		12.4	49

Table 7.1: Standby currents

Typical and maximum current ratings of various components are shown in the table (7.1) which suggests a typical standby current of 12.4μA. However, *actual measurements show the standby current to be only* $1\mu A$.

Measured standby current of the system is $1\mu A$.

7.2 Battery Capacity Calculations

- Size of the GPS fix data = 20 bytes.
- Memory is sized to take 100 fixes/day for 2 years (oversized).
- Memory size = 100 fixes/day × 20 bytes/fix × 365 × 2 = 1.4 MB
- Memory selected = 4 MB.

- But for all battery sizing calculations, 12 fixes/day and 2 years of lifetime will be taken into consideration (i.e. Time between fixes = 2 hrs)

7.2.1 Battery calculations for GPRS/GSM

GPRS offers a high data speed compared to GSM. GPRS supports 56kbps to 118kbps depending on network availability, channel coding and terminal capacity. Typically observed speeds for GPRS are between 3 - 5kbps. Our system intends to support communication via both GSM and GPRS. This was decided because in cases of low signal strength of the mobile network in the forests SMS transmission over GSM is effective.

Some facts about SMS transmission are as follows:

- If SMS over GPRS is used, a SMS transmission speed of about 30 SMS messages/minute can be achieved.
- SMS transmission speed over GSM is about 6 messages/minute.
- Size of SMS = 140 bytes for 8bit characters
- SMS transmission speed over GSM in bits/sec $= \frac{6 \times 140 \times 8}{60} = 112$ bits/sec.
- SMS transmission speed over GPRS in bits/sec $= \frac{30 \times 140 \times 8}{60} = 560$ bits/sec.

Hence for the worst case calculations we will consider the GSM network.

$$\begin{aligned}
\text{No of bytes/day to be transmitted for 12 fixes} &= 12 \times 20 \\
&= 240 \text{ bytes} \\
&= \text{Equal to 2 SMS} \\
\text{Therefore Energy cost per day} &= 240 \times \text{cost per byte using SMS} \\
+\text{SMS overhead} & \\
&= 3mA - h
\end{aligned}$$

The cost per byte using SMS and cost of SMS overhead are measured; please refer to Energy Measurements section.
Total Energy cost for 2 years= $2 \times 365 \times 3mA - h = 2.190Ah$

$\boxed{\textbf{Battery capacity for GPRS/GSM} = 2.2 \text{ Ah}}$

7.2.2 Battery calculations for GPS

- GPS receiver consumes 70mA peak and 40mA average current during acquisition of the fix.
- Time to obtain a fix in warmstart in open sky = 34 secs.

$$\begin{aligned}\text{Battery A - h} &= 12 \times 365 \times 2 \times \text{Cost to obtain 1 fix under canopy}\\ &= 5.2\ \text{Ah}\end{aligned}$$

The cost to obtain 1 fix under canopy is actually measured.Please refer to chapter on Energy Measurements.

$\boxed{\textbf{Battery capacity for GPS} = 5.2\ \text{Ah}}$

7.2.3 Battery calculations for Controller

- Controller active current at $V_{cc} = 3V$, $f = 8$MHz and $25 - 85\,^{\circ}$C with program executing from the flash = 3 mA.
- Time required for the controller to do all the housekeeping and controlling= 60 secs per day(assumption).

$$\begin{aligned}\text{Battery A-h} &= \frac{60}{3600} \times 365 \times 2 \times 0.003 \\ &= 0.0365 \text{ Ah}\end{aligned}$$

$\boxed{\textbf{Battery capacity for Controller} = 36.5 \text{ mAh}}$

7.2.4 Battery calculations for Memory

- Active current during Read operation@ $V_{cc} = 3.6V$ (@f = 20MHz) = 7 mA
- Active current during Write operation@ $V_{cc} = 3.6V$ (@f = 20MHz) = 12 mA

$$\begin{aligned}\text{Battery A-h} &= 7 \text{ mA} \times 12 \times 365 \times 2 \times 48 \times 6\mu\text{s} + 12 \text{ mA} \times 12 \times 365 \times 2 \times 48 \times 6\mu\text{s} \\ &= 0.05 \text{ A-h}\end{aligned}$$

$\boxed{\textbf{Battery capacity for Memory} = 50 \text{ mA-h}}$

7.2.5 Battery calculations for Leakages/Standby currents

$$\begin{aligned}\text{Battery A-h for leakages} &= 24 \times 365 \times 2 \times 49\mu A \\ &= 0.86 \text{ Ah}\end{aligned}$$

$\boxed{\textbf{Battery capacity for Leakages} = 0.86 \text{ Ah}}$

$\boxed{\therefore \textbf{Total Battery capacity} = \textbf{8.35 Ah}}$

Chapter 8

Selection Of The Battery

Figure 8.1: Tadiran Battery 8.5Ah

Parameters that affected battery selection:

- The system has conflicting demands. It has very low background currents combined with large peaks.This was an important point considered while selecting the battery.

- The only module which requires a very high peak current is the GPRS module(upto 2A). Hence, the power supply requirements of the GPRS module dictated the current ratings of battery.

- Passivation of lithium primary batteries was a big concern.

Lithium thionyl-chloride cells have the highest energy density of all lithium types. Hence they were chosen.

8.1 Some Facts about Lithium batteries

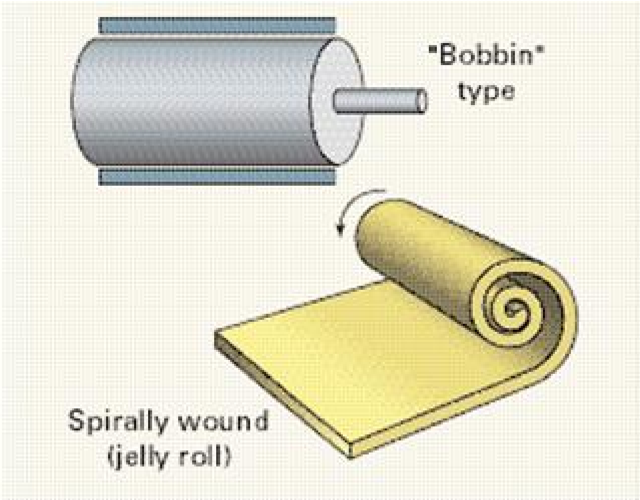


Figure 8.2: Bobbin and Spiral Lithium Batteries

- There are two types of lithium batteries:
  - **Spirally wound cells** deliver high current, but with less capacity and much **higher self-discharge** compared to bobbin-type cells.This is because spirally wound cells, also known as jelly rolls, have wound layers of lithium compared to bobbin-type which has only one layer. The larger the lithium area (anode), larger current can be drawn.Also the rate of self-discharge increases because of larger area.
  - **Bobbin-type cells** have ideal capacity and energy density, but suffer from two main drawbacks: **severe passivation** problems after storage and **low current** due to its design.
- Other serious limitation of lithium batteries is the maximum continuous current that can be drawn is very limited. Life of the battery decreases and the voltage drop increases as the amplitude of the maximum continuous current increases. This can be seen in the discharge characteristics graph of the battery shown in the figure (8.3).

To overcome these obstacles a design with a supercapacitor or a rechargeable battery in parallel with primary battery was considered. The rechargeable battery/supercapacitor can deliver high current pulses and the primary

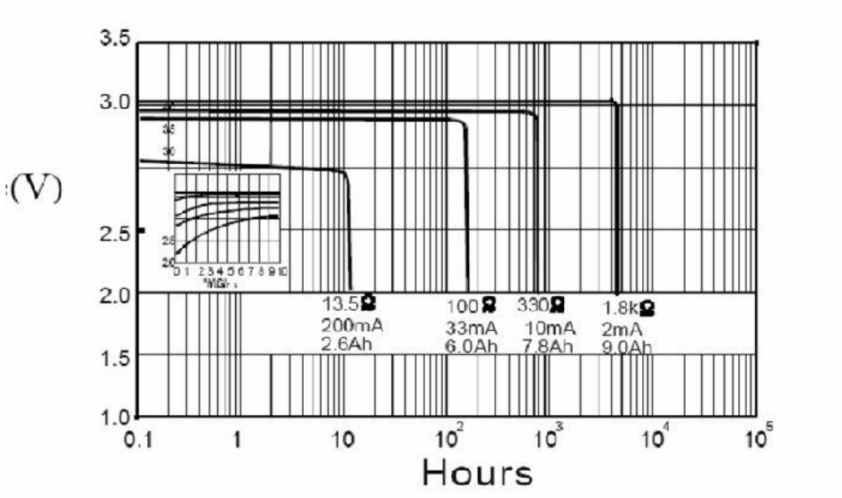
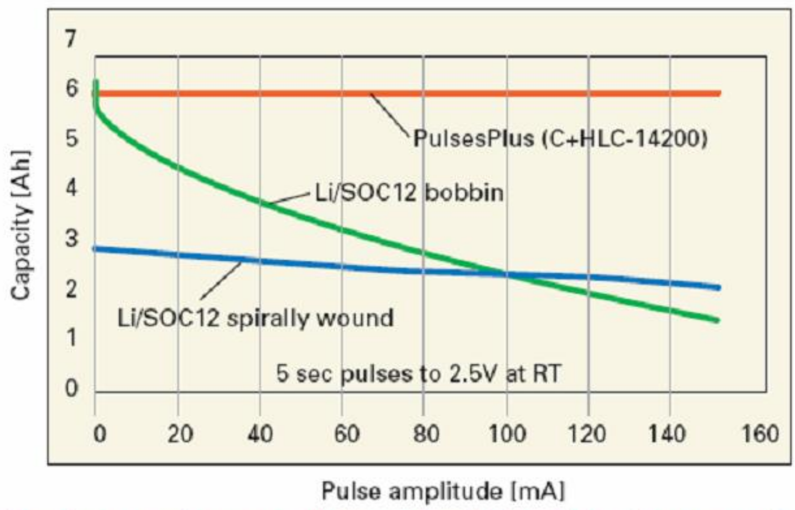


Figure 8.3: Discharge Characteristics of typical lithium batteries

battery then recharges the rechargeable battery/supercapacitor. A company called Tadiran has designed a hybrid-lithium battery called Pulses-Plus which does exactly that. Since the construct is in-built in the battery, reliability of the system is very high compared to a system that we may build. Also the typical leakage of the supercapacitor in parallel is about $1\mu A$. Which is much lower than other commercially available supercapacitors or rechargeable batteries. Two Tadiran 8.5A-h batteries will be put in parallel for the system.This battery is designed for systems where low background currents are combined with high current pulses. Performance of the PulsesPlus batteries can be seen from the graph given in figure (8.4).



Discharge characteristics of a PulsesPlus battery, in the form of available capacity as a function of pulse amplitude, compared to conventional lithium-based bobbin and spirally wound batteries.

Figure 8.4: Performance of Pulses Plus

Selected Battery has following specs:

- Open circuit voltage is = 3.67V
- Max 1s current pulse to 3V = 3A
- Max pulse length @ 0.5A = 1000s
- Nominal current = 3mA
- Weight = 100g
- Temperature range = $-40°$ to $85°$C
- Capacity retention after 10years = 93%

8.2 Alternatives to lithium batteries

Since the first animal we are targeting is elephants, we do not have a strict weight constraint. Hence batteries with higher voltage such as energizer batteries (3 in series, 4.5V nominal). In such a case criticality of the circuit can be easily met. But, such a solution will be definitely larger (about 3 times compared to lithium battery solution).

Chapter 9

Design of The Final Board

9.1 The Idea - Stackup

The final board is a **stackup** of 3 PCBs and each PCB is a double sided PTH board having 1.6mm thickness.Its dimension are **6cm** $\times$ **5cm**.After developing the embeddded software on the prototype board, the final board was designed. The following points were taken into consideration while designing:

- Compactness
- Robustness
- Mechanical stability
- Modularity.

A flat PCB would have made the board size large as the GSM module dimensions are 4.2cm $\times$ 3.2cm. The GPS patch antenna's dimensions are 2.2cm $\times$2.2cm. Also the GPS antenna requires a large ground plane for better sensitivity. It was also necessary to isolate the RF section of the GPS from the rest of the circuit. Hence it was decided to go for a stackup design and thus maximum space utilization was achieved. **Another advantage of stackup design is modularity. Later in the next versions of the collar if it is decided to use a better GSM or GPS chip the whole hardware need not ne redesigned. Only the respective card needs to be designed.**

9.2 Stackup Design

The placement of the various components on the boards is as follows:

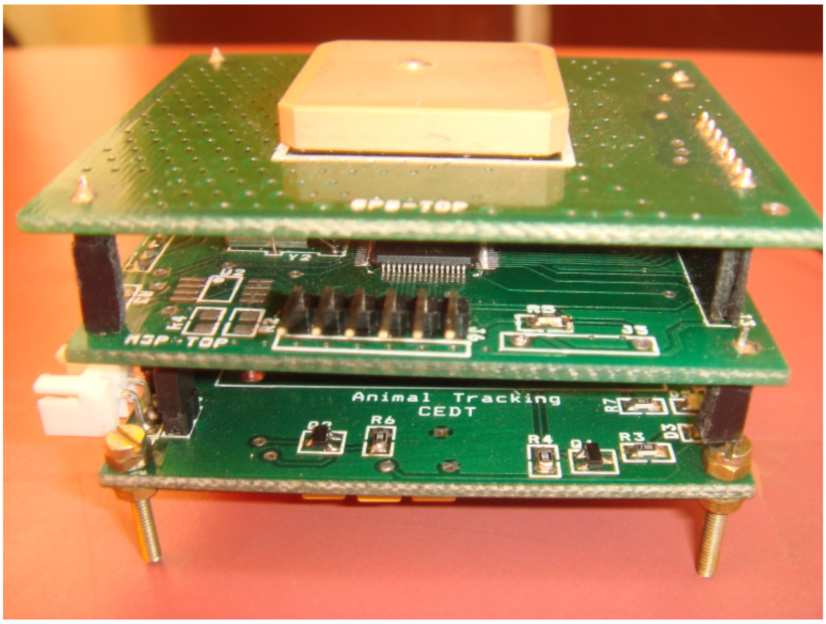


Figure 9.1: Final Board

- The GPS patch antenna was placed on the top for better signal strength. So, the first board in the stackup is the GPS board with the UBLOX GPS chip mounted at the bottom. Connections from the GPS board run down to the controller board.

- The middle board is the controller board. It has connections running up to the GPS board and down to the GSM board. The controller board has a JTAG connector. Also it has connectors to the adapter board for configuring the collar.

- The last board in the stackup is the GSM board. The GSM antenna has a long cable which carries the antenna to the top and will be later stuck to the enclosure. The battery connector is placed on this board. Since GSM consumes 2A current peaks, it was decided to place the power on this board to avoid running long power lines. In the final product there is no need for power connector. The battery wires can be directly soldered. The SIM card connector is placed to the bottom layer of the GSM board for the ease of replacing the SIM card.

Chapter 10

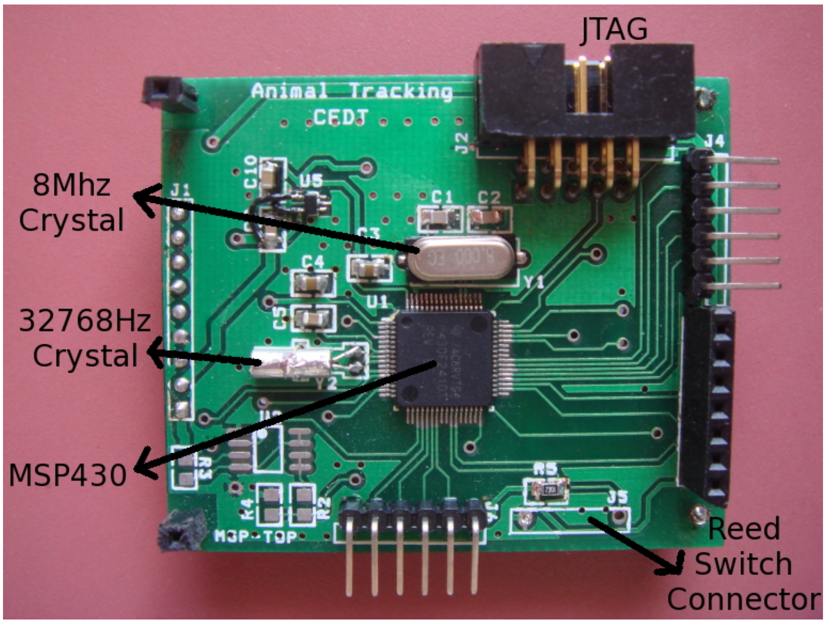
Layout Design of Final Boards

10.1 Layout of the Controller Board

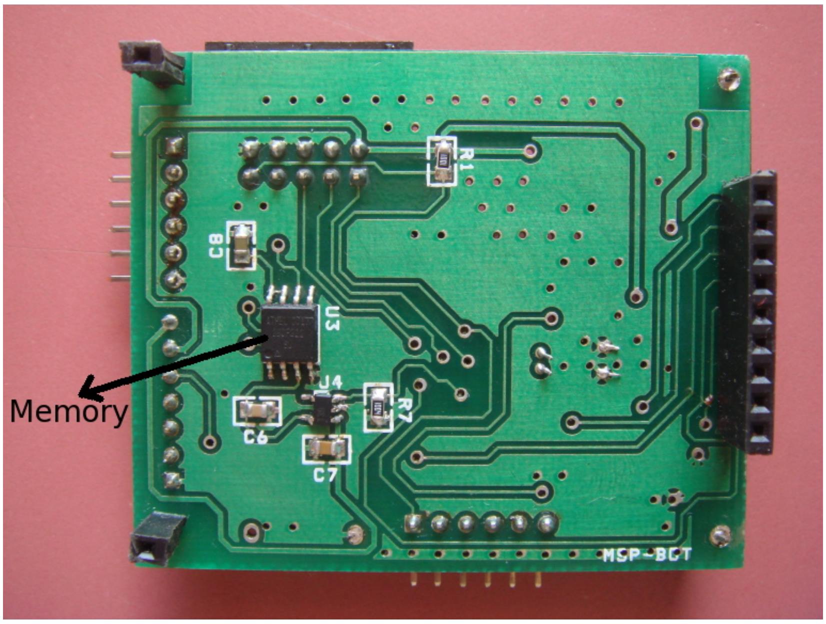
The critical area for layout design in controller board was the layout of the crystals of the controller.

10.1.1 Layout of the crystals of the controller

- Signal traces between the MSP430 pins, the crystal and, the external capacitors are kept as short as possible. This minimizes parasitic capacitance and sensitivity to crosstalk and EMI.
- In the 2-layer board, there are no digital-signal lines on the opposite side of the PCB under the crystal area.The opposite side of the PCB is filled with clean ground and also connected this ground to AVSS(analog gnd) of the MSP430.
- The crystal housing is connected to ground.
- Other digital signal lines, especially clock lines and frequently switching signal lines, are kept far away from the crystal connections.This is because the crosstalk from digital signals may disturb the small-amplitude sine-shaped oscillator signal.
- To reduce the parasitic capacitance between XIN and XOUT , these signals are routed as far apart as possible.
- The crystal traces are guarded with ground traces (guard ring). This ground guard ring must be clean ground. This guard ring is connected to AVSS of the MSP430 with a short trace.

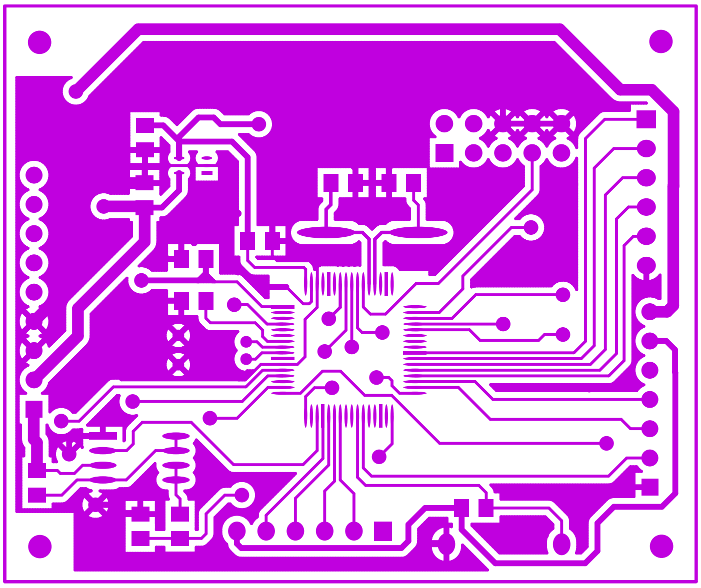


(a) Top View

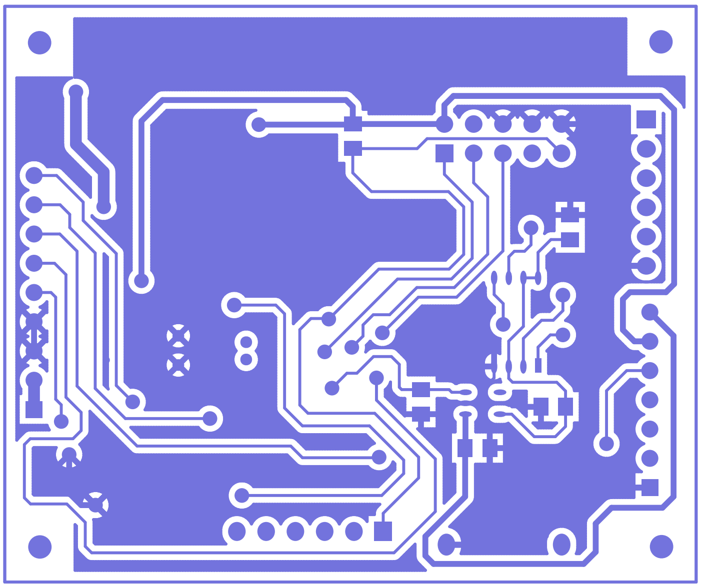


(b) Bottom View

Figure 10.1: Controller Board

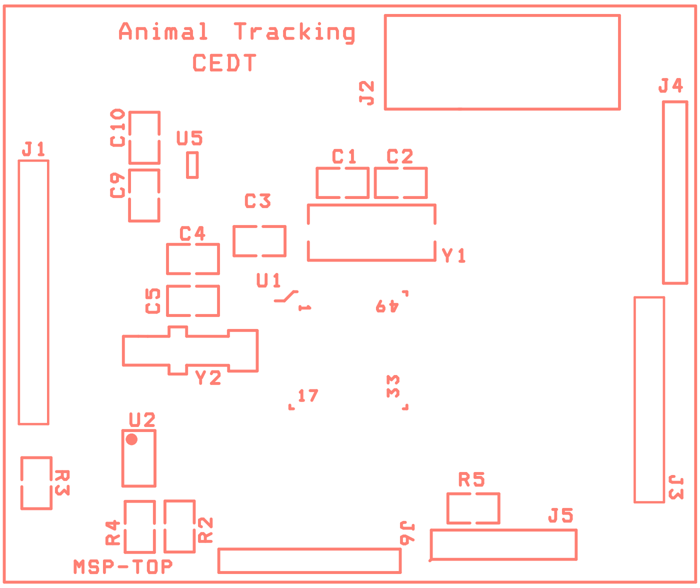


(a) Bottom Layer

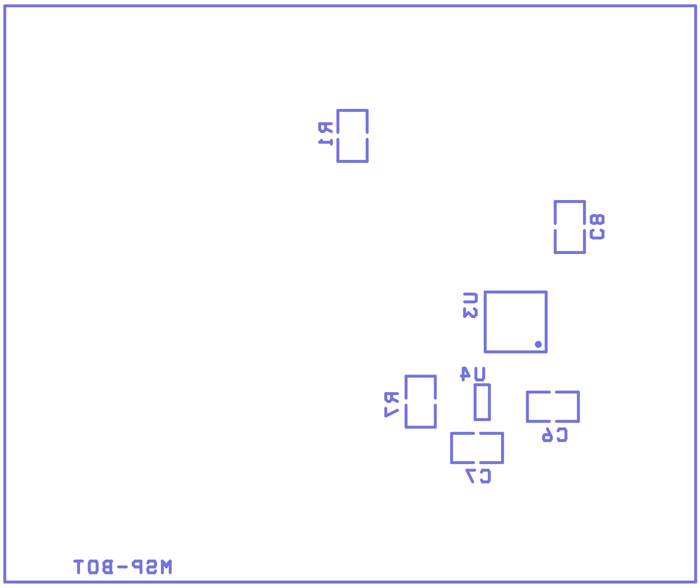


(b) Top Layer

Figure 10.2: Controller PCB Layout, Top and Bottom Layers



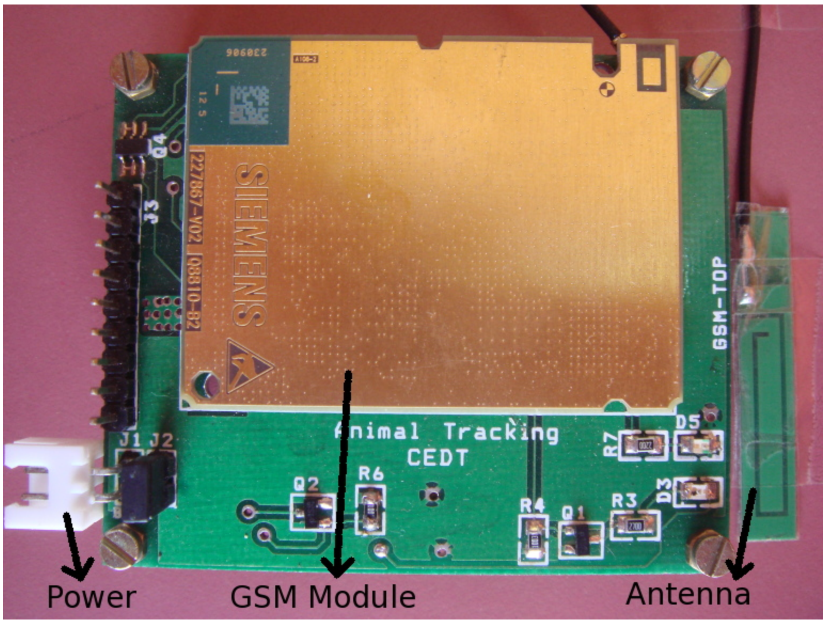
(a) Silk Screen Top



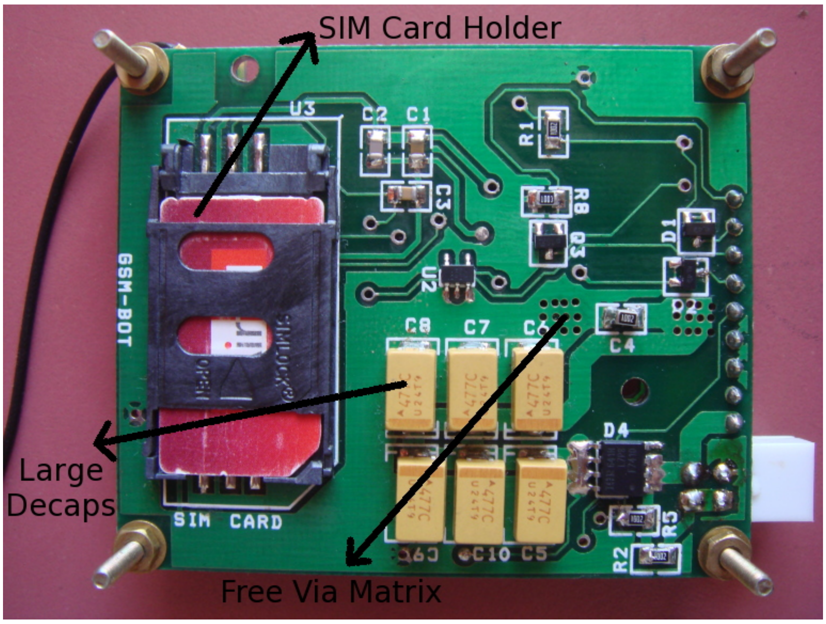
(b) Silk Screen Bottom

Figure 10.3: Controller PCB Layout, Top and Bottom Silk Screen Layers

10.2 Layout of the GSM Board



(a) Top View



(b) Bottom View

Figure 10.4: GSM Board

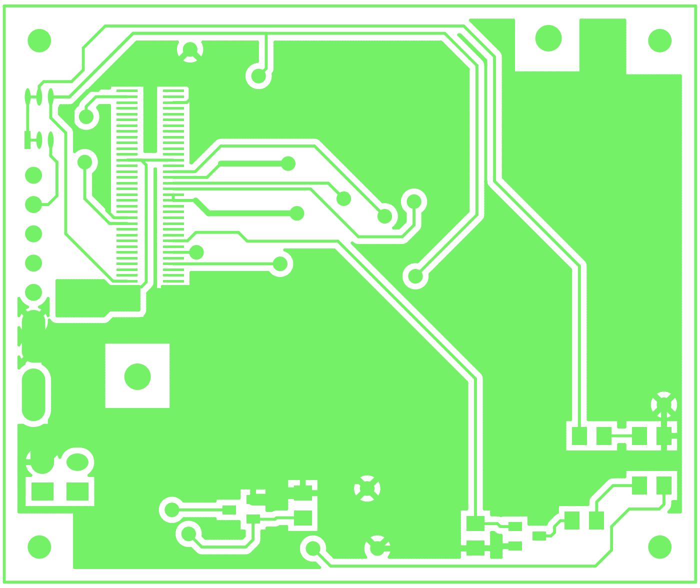
The critical area for layout design in GSM board was the power supply layout and SIM card layout.

10.2.1 The power supply layout of the GSM Board

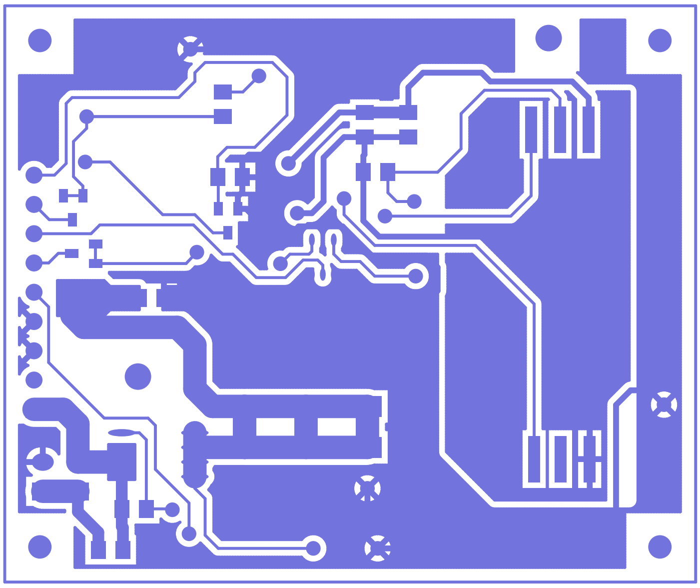
- The Vcc line from the battery to GPRS is going to carry 2A. Hence to reduce the PCB track resistance the width is made 2cm.
- The length of the track is also kept very small.
- Six 470μF capacitors are required for the GSM's power supply and because of lack of space they were placed on the bottom layer. The GSM module is placed on the top layer. To reduce the impedance from Vcc pin of the module to the capacitors a free via matrix was provided.

10.2.2 SIM card layout

- The SIM card connections are kept short.
- The SIM card has a separate ground supplied by a pin CCGND of the GPRS. Hence the SIM is having a separate copper area connected to CCGND.

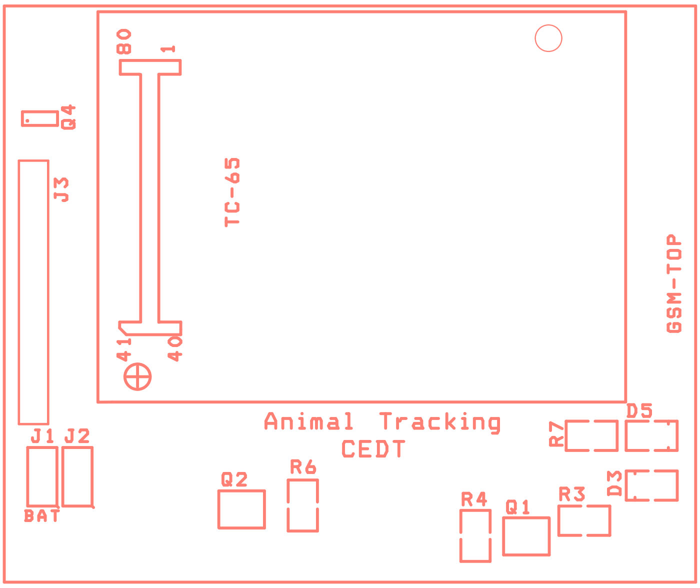


(a) Top Layer

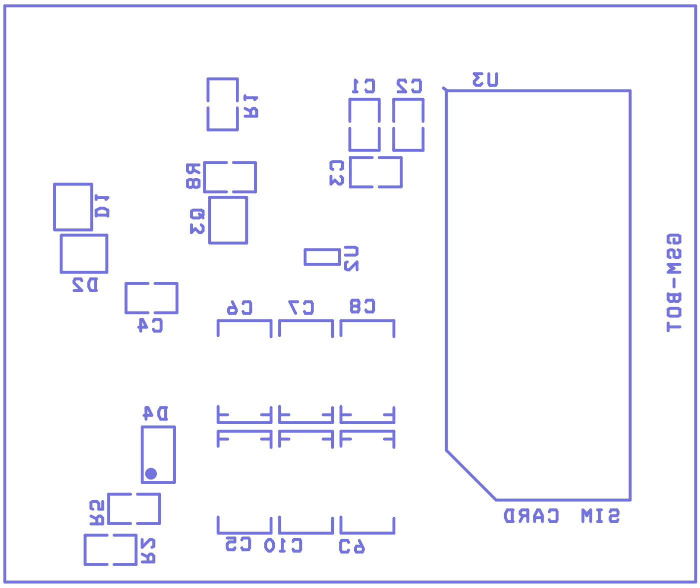


(b) Bottom Layer

Figure 10.5: GSM Board, Top and Bottom Layers



(a) Silk Screen Top Layer



(b) Silk Screen Bottom Layer

Figure 10.6: GSM Board, Silk Screen Layers

10.3 Layout Design of GPS

GPS signals at the surface of the Earth are about 15dB below the thermal noise floor. Signal loss at the antenna and the RF connection must be minimized as much as possible. When defining a GPS receiver layout, the placement of the antenna with respect to the receiver, as well as grounding, shielding and jamming from other digital devices are crucial issues and need to be considered very carefully.The various design aspects are discussed below:

- **Placement**
  The placement of the GPS Receiver on the PCB is very important to achieve maximum GPS performance. The connection to the antenna is made as short as possible to avoid jamming into the very sensitive RF section.RF critical circuits are clearly separated from any other digital circuits on the system board. The receiver digital part is positioned towards digital section of the system PCB.

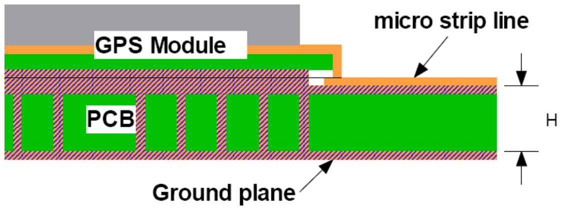


Figure 10.7: PCB build-up for Micro strip line on 2-layer PCB

- **Antenna Connection and Grounding Plane Design**
  The antenna RF connection is on the PCB and connects the RF-IN pin with the antenna feed point.There needs to be good shielding for digital lines.The edges of the ground area are terminated with a dense line of vias.The reference ground circuit has to be kept as far away from vias of signal traces .Also, the ground plane should be free from digital supply return currents in this area. On a multi layer board, the whole layer stack below the RF connection should be free of digital lines (See figure 10.7). This is because even a solid ground plane provides only limited isoltion.The impedance of the antenna connection has to match the 50 Ohm impedance of the receiver. To achieve an impedance of 50 Ohms, the width W of the micro strip has to be chosen depending on the dielectric thickness H, the dielectric constant er of the dielectric material of the PCB and on the build-up of the PCB.

- **General design recommendations given in the User's manual**
  - The length of the micro strip line should be kept as short as possible. Lengths over 2.5 cm (1 inch) should be avoided on standard PCB material and additional shielding.
  - Distance between micro strip line and ground area on the top layer should at least be as large as the dielectric thickness.
  - Routing the RF connection close to digital sections of the design should be avoided.
  - To reduce signal reflections, sharp angles in the routing of the micro strip line should be avoided. Chamfers or fillets are preferred for rectangular routing; 45-degree routing is preferred over Manhattan style 90-degree routing.
  - Routing of the RF-connection underneath the receiver should be avoided. The distance of the micro strip line to the ground plane on the bottom side of the receiver is very small (some 100 μm) and has huge tolerances(up to 100%). Therefore, the impedance of this part of the trace cannot be controlled.
  - Many vias should be used to connect the ground planes.
  - In order to avoid reliability hazards, the area on the PCB under the receiver should be entirely covered with solder mask. Vias should not be open.

- **Design Calculations of Antenna Micro Strip**
  To design wave-guides on printed circuit boards freeware tool - AppCAD from Agilent was used.It can be downloaded from `http://www.hp.woodshot.com/`.

  Thus the distance between the microstrip and the ground plane adjacent to it(i.e. ground plane on the same layer)should be 10mils and track width should be 1.25mm so that the impedance of the track is 50Ω.

- **Checkpoints for design of the micro strip**
  - The micro strip must be 50 Ohms and it must be routed in a section of the PCB where minimal interference from noise sources can be expected.
  - In case of a multi-layer PCB, use the thickness of the dielectric between the signal and the 1st GND layer (typically the 2nd layer) for the micro strip calculation.

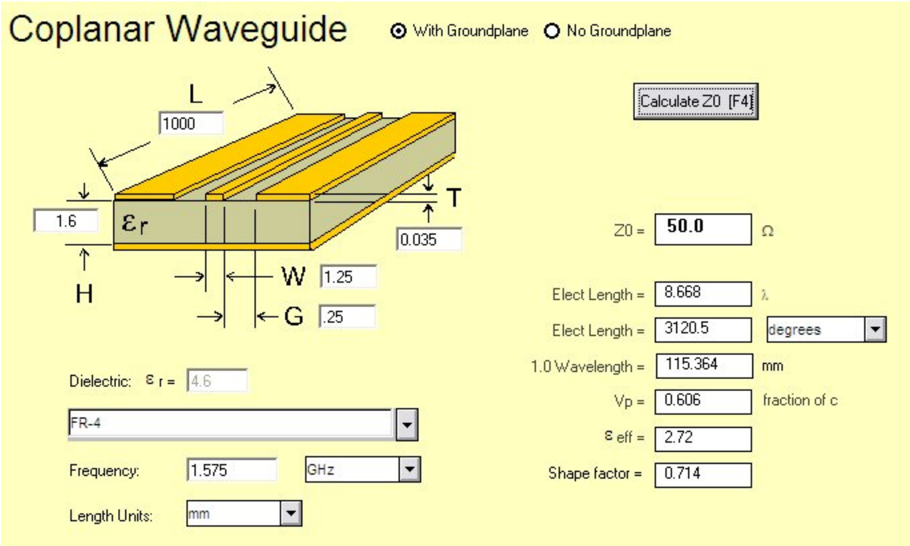
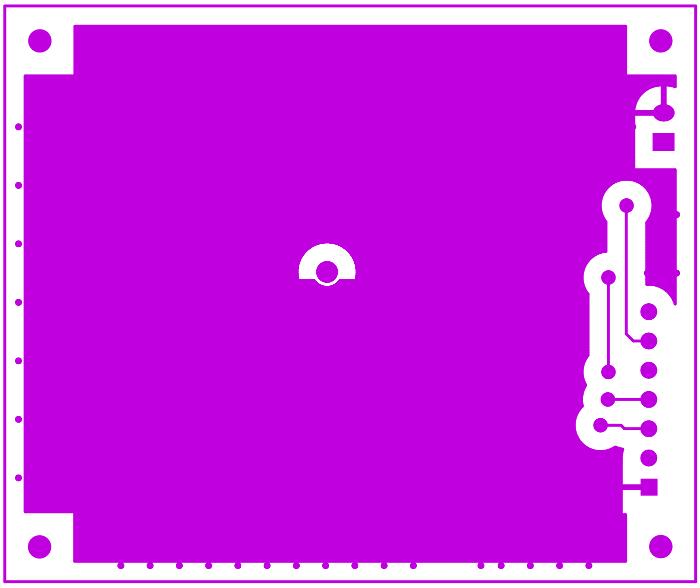


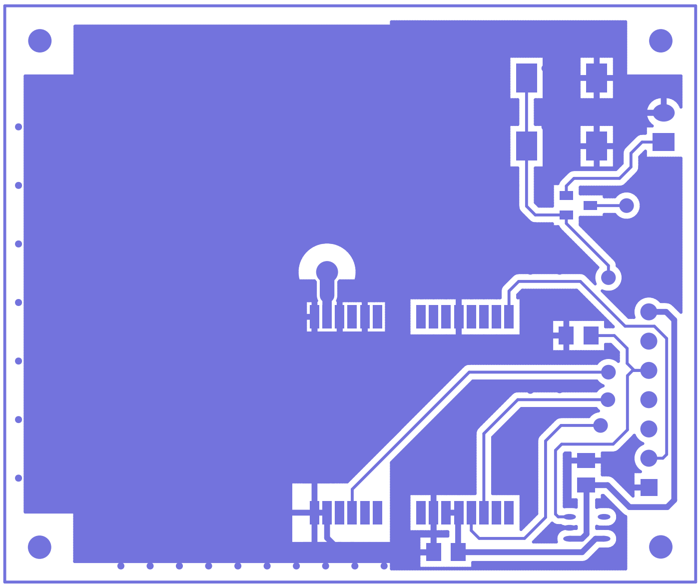
Figure 10.8: Waveguide design using AppCad from Agilent

- If the distance between the micro strip and the adjacent GND area (on the same layer) does not exceed 5 times the track width of the micro strip, use the 'Coplanar Waveguide' model in AppCad to calculate the micro strip and not the 'micro strip' model.

As a rule of thumb, for a FR-4 material the width of the conductor is roughly double the thickness of the dielectric to achieve 50 Ohms line impedance.For the correct calculation of the micro strip impedance, one does not only need to consider the distance between the top and the first inner layer but also the distance between the micro strip and the adjacent GND plane on the same layer.

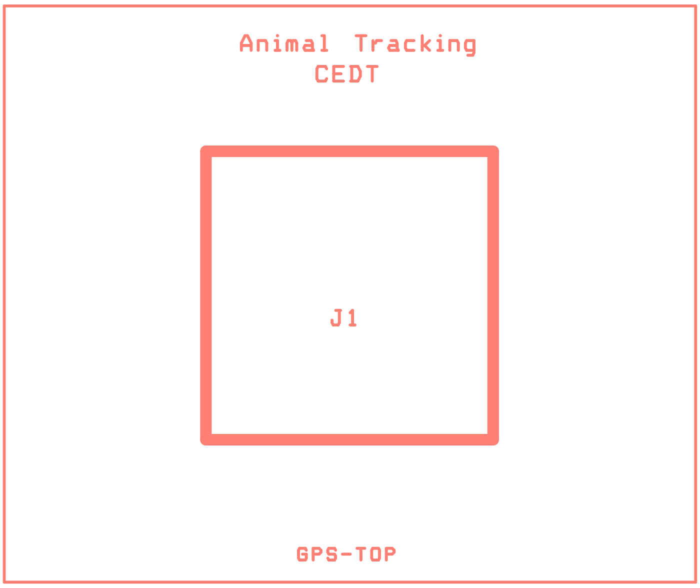


(a) Top Layer

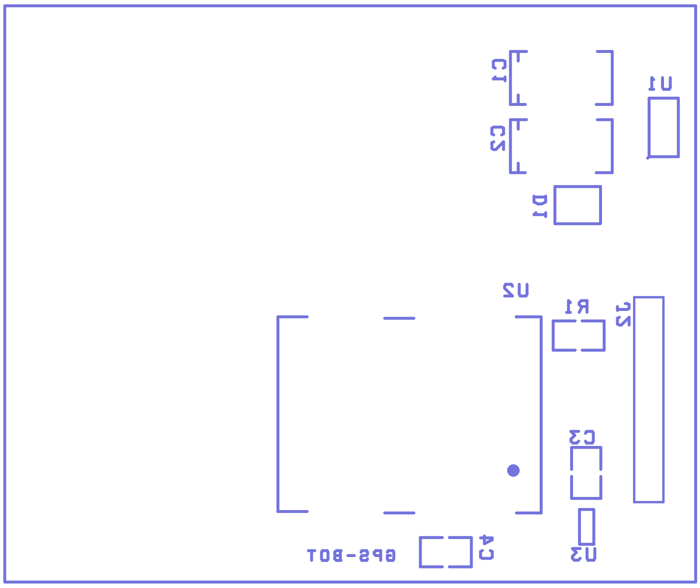


(b) Bottom Layer

Figure 10.9: GPS Board, Top and Bottom Layers



(a) Silk Screen Top

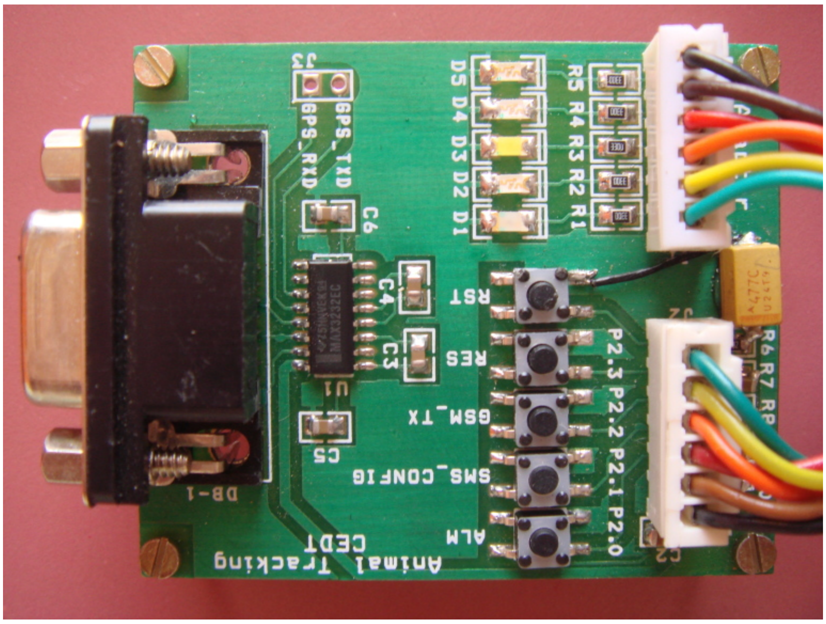


(b) Silk Screen Bottom

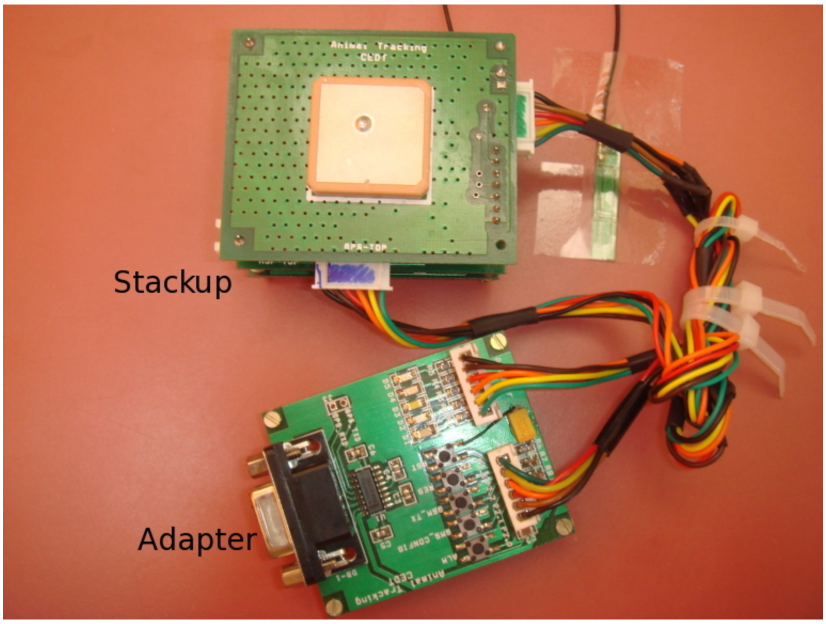
Figure 10.10: GPS Board, Top and Bottom Silk Screen Layers

10.4 Need For Adapter Board

The adapter is just used to configure the collar.

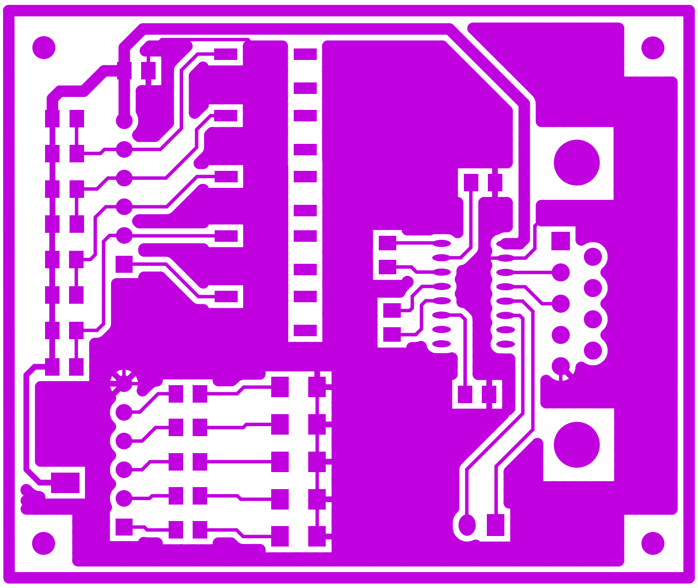


(a) Top View

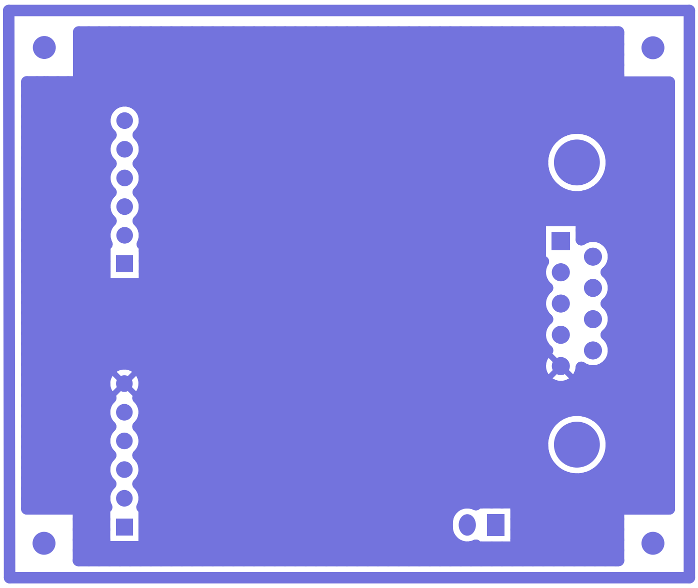


(b) Bottom View

Figure 10.11: Adapter Board



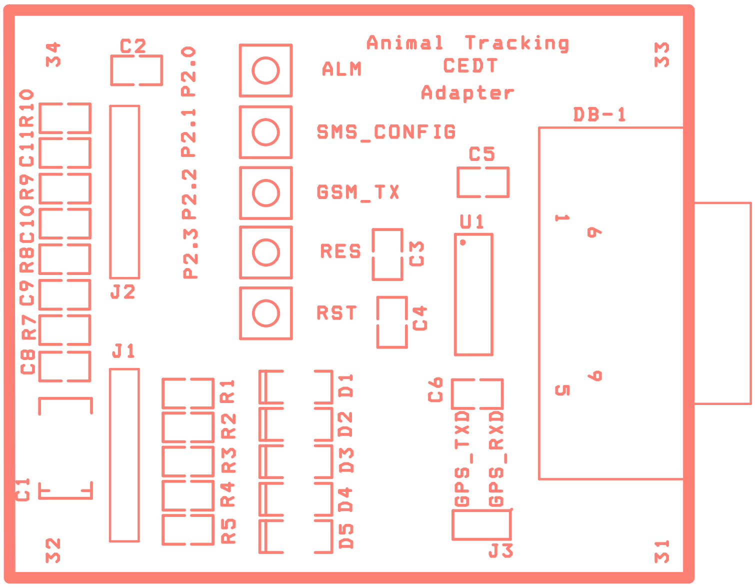
(a) Top Layer



(b) Bottom Layer

Figure 10.12: Adapter Board, Top and Bottom Layers

Figure 10.13: Adapter Board, Top Silk Screen Layer



Chapter 11

Bill of Materials

11.1 Controller Board - BOM

ITEM NO.	VALUE	QTY.	PART REF.
1	15pF	2	C1 C2
2	10u	3	C3, C4, C5
3	0.1u	3	C6, C7, C9
4	4.7u	1	C8
5	0.47u	1	C10
6	CON9	1	J1
7	CON10B	1	J2
8	GPS-CON	1	J3
9	CON6	2	J6, J4
10	CON2	1	J5
11	1K	1	R1
12	10K	4	R2, R3, R4, R5
13	1M	1	R7
14	MSP430F2418	1	U1
15	IRF7317-DualNP	1	U2
16	AT25DF321	1	U3
17	TPS73230	1	U4
18	TPS79730	1	U5
19	8MHz	1	Y1
20	32.768KHz	1	Y2

11.2 GPS Board - BOM

ITEM NO.	VALUE	QTY.	PART REF.
1	470u	2	C1, C2
2	10u	2	C3, C4
3	BAT54C/SOT	1	D1
4	PATCH-ANTENNA	1	J1
5	CON7	9	J2
6	1M	1	R1
7	Button Cell	6	U1
8	LEA-4T	1	U2
9	TPS73230	3	U3

11.3 GSM Board - BOM

ITEM NO.	VALUE	QTY.	PART REF.
1	100n	1	C1
2	33p	1	C2
3	1n	1	C3
4	10u	1	C4
5	470u	6	C5, C6, C7, C8, C9, C10
6	BAT54S/SOT	2	D2, D1
7	Red	1	D3
8	IRF7410/SO	1	D4
9	Green	1	D5
10	CON2	2	J1, J2
11	CON9	1	J3
12	Si2302DS	3	Q1, Q2, Q3
13	Si3443DV	1	Q4
14	R1, R2, R5	3	10K
15	R3	1	270
16	R4, R6, R8	3	100K
17	R7	1	220
18	TC65	1	U1
19	SN74AHC1G25	1	U2
20	SIM	1	U3

11.4 Adapter Board- BOM

ITEM NO.	VALUE	QTY.	PART REF.
1	470u	1	C1
2	10u	4	C2, C9, C10, C11
3	0.1u	4	C3, C4, C5, C6
4	CAP NP	1	C8
5	DB-9	1	DB-1
6	Green	5	D1, D2, D3, D4, D5
7	CON6	2	J2, J1
8	CON2	1	J3
9	330	5	R1, R2, R3, R4, R5
10	10K	4	R7, R8, R9, R10
11	MAX3232	5	SW1, SW2, SW3, SW4, SW5
12	Green	1	U1

Chapter 12

Software overview

The main concerns in software design have been the following...

- Energy optimization on the collar.
- Hassle free installation.
- User friendly interface in the form of application software and website.
- make SMSs as fast and lowcost as possible.
- A fast and reliable server system that will co-ordinate between all the components

The components designed to meet the above mentioned requirements are...

- Embedded Software
- SMS Server
- Main Server
- User Application Software
- Website

12.1 Choice of development tools

The embedded software has been designed using the IAR embedded systems IDE for MSP430 in C++. This platform was chosen instead of the free, open source tool 'MSPGCC' because the versions of MSP430(MSP430F2XX series) we used in the project are not yet supported by MSPGCC.

The Main server, SMS server and the GUI Application have been designed using the Qt4 library in C++. As wikipedia quotes it:*Qt (pronounced "cute") is a cross-platform application development framework, widely used for the development of GUI programs (in which case it is known as a Widget toolkit), and also used for developing non-GUI programs such as console tools and servers.* Qt4 is open source and free. Qt4 provides the signals and slots mechanism for handling events which helps makes the code much more neat and scalable compared to most other libraries. Qt4 also has huge support in terms of libraries required to access databases, to handle XML files and to do network programming. All the above mentioned applications work on all platforms such as Linux, Windows and Mac.

The website was designed using the Joomla framework using PHP and Javascript. Joomla is open source and free. It provides a good interface for developing and remotely maintaining a website. It has an administration interface which is simple enough so that once the website is developed, most of the maintainance can be done without coding.

12.2 Embedded Software

The components of embedded software are:

- **GSM**:
  - Drivers for the GSM module
  - AT command parser for the GSM modem
- **GPS**:
  - Drivers for GPS
  - GPS message(NMEA format) parser
- **Controller**: Main state machine for controlling the different modules
- **External Flash Memory**: Drivers for the external memory

12.2.1 Optimizations done in embedded software for reducing energy consumption

After optimizing the hardware for low power consumption by taking care of the standby currents, the embedded software needs to have optimal design so as to complement the hardware.

- **Optimizations in GPS software:**
  - When the GPS module is switched on, the NMEA protocol messages start appearing on the UART of the controller.There are many NMEA messages out of which only a few are required to get the fix information.Hence, in the one time initilizations of the module, all the messages are disabled.And only the necessary messages are queried during parsing.This reduces a significant overhead of parsing.The parsing time should be reduced because during the parsing the GPS module is ON which consumes 40mA on an average.Also if all messages are disabled there will definitely be less power consumption by the GPS module.
  - Also there is a TIMEPULSE pin on the GPS module which outputs pulses every one second when a fix is obtained.Thus, this TIMEPULSE pin is an indication of whether a fix is obtained or not.The controller goes into sleep till this TIMEPULSE pin gives an interrupt.
- **Optimization in GSM software: SMS transmission using PDU mode**
  SMS can be transmitted in two modes: text mode and PDU(Protocol Data Unit) mode.
  - **What is PDU mode?**
    * The PDU mode offers to send binary information in 7 bit or 8 bit format. It is helpful if the data to be sent are compressed data, binary data or even a custom encoding scheme of the characters in the binary bit stream can be used.
    * Although it is easier to use AT commands in SMS text mode, it supports fewer features of SMS messaging than SMS PDU mode. This is because there is not complete control over the header values and message body in SMS text mode. Some tasks, although can be done in text mode, require the programmer to have knowledge about PDU mode and TPDU. For example, to request a status report from SMSC in SMS text mode, bit 5 of the first octet of the SMS-SUBMIT TPDU has to be set to 1 by the AT command +CSMP. In PDU mode bits can be set or reset in the message header to get the required functionality but in text mode separate AT commands have to be issued.

* SMS PDU mode is more commonly supported by GSM/GPRS modems and mobile phones than SMS text mode. Text mode is nothing but simply the endoding of the bit stream represented by the PDU mode.

- **Why go for PDU mode?**
  * The GPS fix data are binary data. If a GPS fix location is to be transmitted using text mode, ASCII strings will have to be transmitted. To maintain the accuracy of the latitude and longitude values, the ascii string for latitude and longitude individually will become 13 bytes. Whereas, in binary mode for the same precision the latitude requires 4 bytes. Thus transmitting ASCII strings is inefficient and costly in term of energy.
  * We are using 8-bit data coding scheme and class 1 messages.
  * Also we are setting a bit which requests acknowledgement from the server.
  * The validity period of the SMS can also be set. The Validity Period parameter value indicates the time period for which the short message is valid, i.e. for how long the SMSC(Short Message Service Center) shall guarantee its existence in the SMSC memory before delivery to the recipient has been carried out. Thus we are setting this value to a maximum of 63 weeks.
  * There is one more advantage of using PDU mode. When a SMS is received, there is a bit indicating whether there are any more messages pending for the modem in the SMSC. This is a very useful information. Depending on the value of this bit we can take the decision of remaining on or switching off.

12.2.2 System Flow Chart

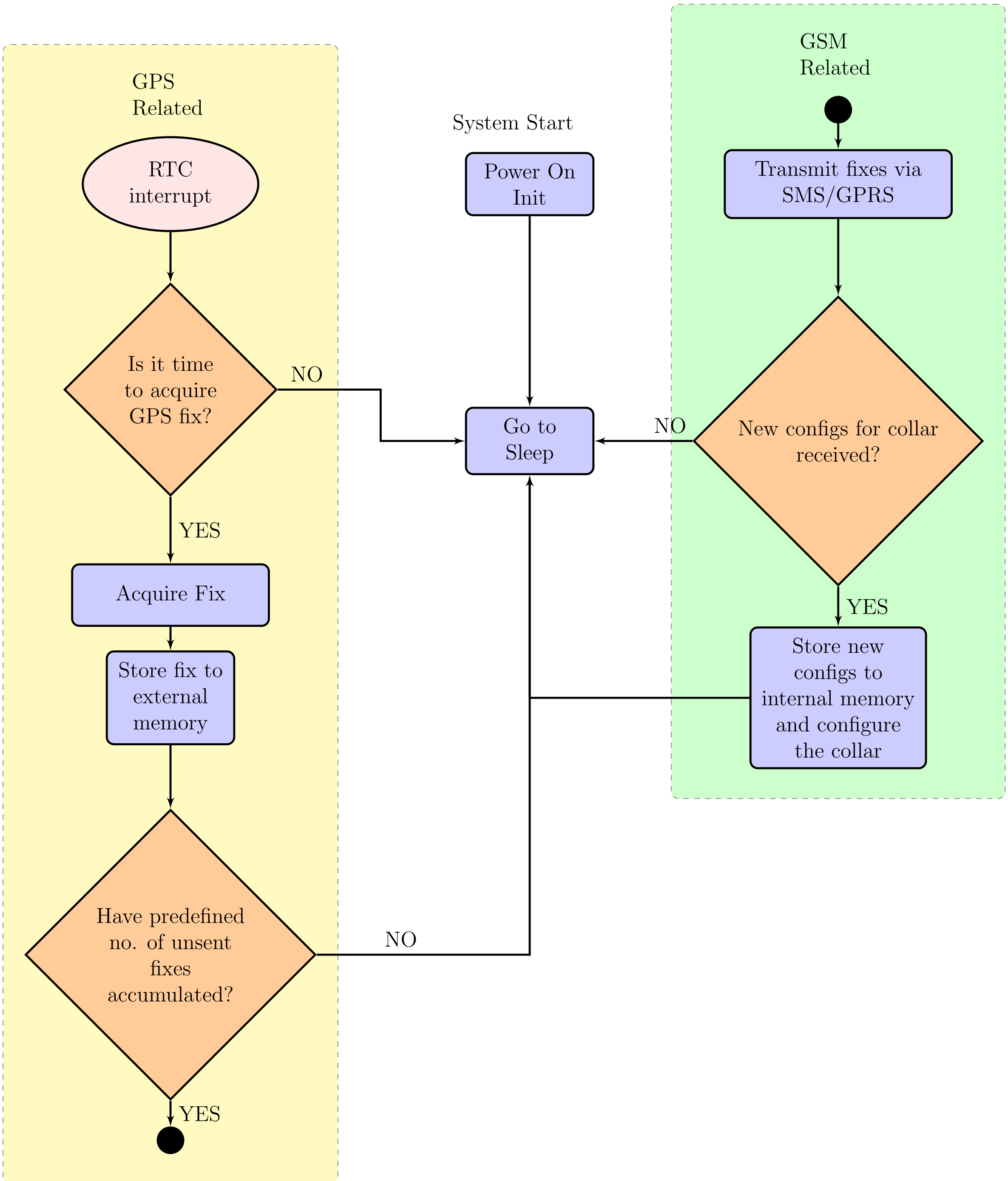


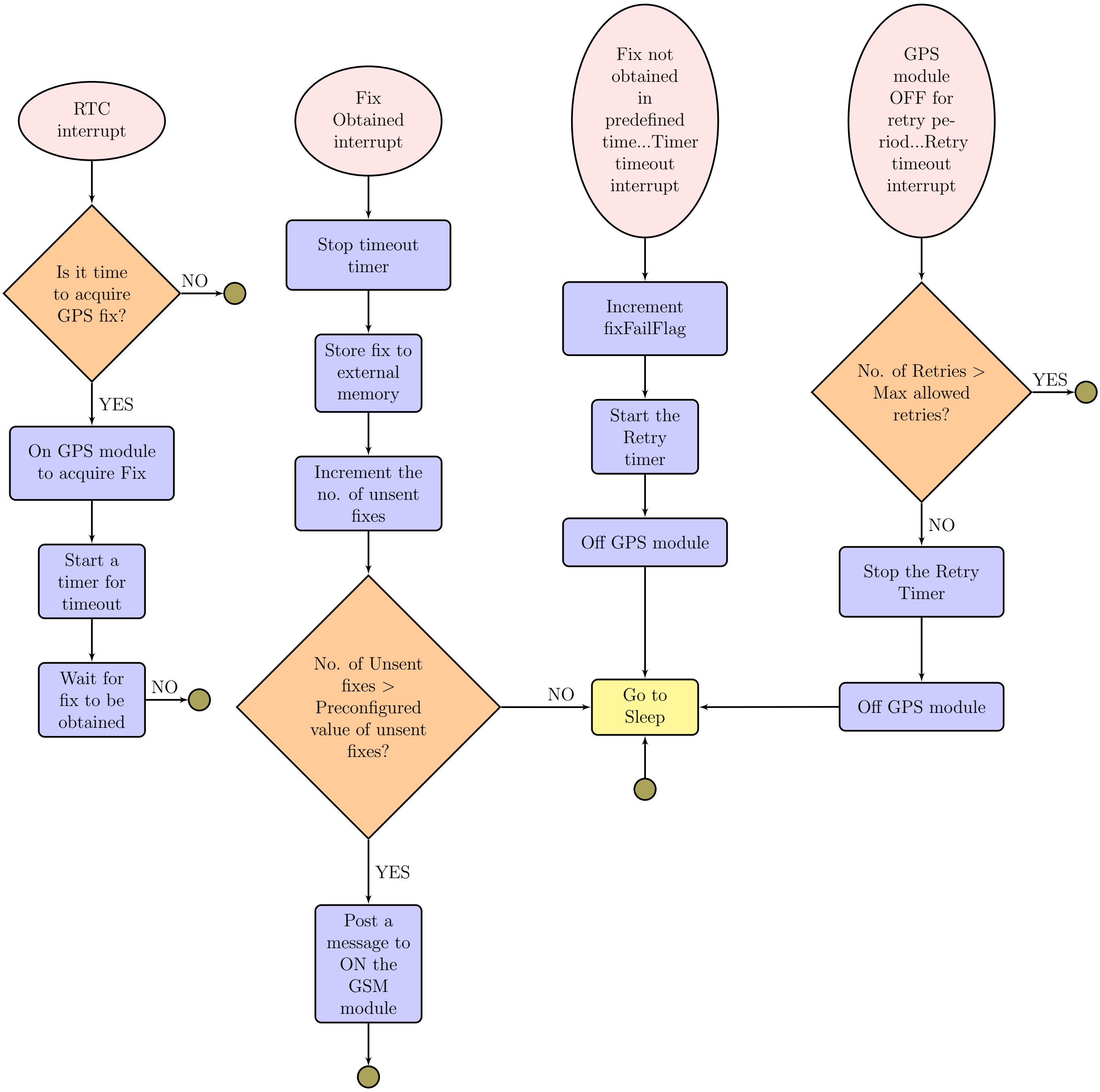
Figure 12.1: System Flow Chart

- **Power on Init**:
  - Disable interrupts.
  - Initialize controller ports.
  - Initialize the RTC crystal and the DCO of the controller.
  - Initialize global variables.
  - Initialize controller UARTs which talks to GSM and GPS.
  - Initialize the SPI drivers for external memory.
  - Initialize the flash inside the controller for storing configs.
  - Initialize the collar configs data structure – if valid configuration is present in internal flash then load them otherwise load default configuration.
  - Initialize th RTC timer.
  - Initialize the GPS soft timer for timeout after every 15mins.
  - Enable Global Interrupts.
  - Start the RTC timer.
  - Enable the "REED Switch" interrupt on port of controller.
  - Enable the "Acquire Alamanc" interrupt.
  - Enable the "Wait for Config SMS" interrupt on port pin of controller.
  - Go to sleep.
- **GPS**:
  - A RTC interrupt for GPS occurs every 15 mins.
  - Configurations contains an array of time values (which are sent by the server). For example if fix is to be obtained every 2 hrs. from 8.00am then the array will contain a bit pattern indicating fix has to be taken at 8.00am, 10.00am, 12.00pm, 2.00pm and so on .... The RTC time is checked against this array to find out whether it is time to acquire a GPS fix. The GPS acquires a fix and stores the fix value in the external flash.
  - The GSM comes up only if the number of unsent fixes is greater than or equal to 2, 4, 8, 16, or 64. This value is configurable through the server.
  - After acquiring every fix the GPS has the job of checking if the number of unsent fixes is greater than the preconfigured value. Only then the GPS will post a message to ON the GSM.
  - The system processes the next posted message or goes off to sleep.

- **GSM**:
  - The server specifies the preferred transmission mode-SMS , GPRS or IntelliTransmit.
  - The transmission takes place accordingly.
  - If new configurations from the server are received then they are stored in the internal flash of the controller.
  - The system processes the next posted message or goes off to sleep.

12.2.3 GPS Flow Chart

Figure 12.2: GPS Flow Chart



The software flow of the GPS system is as follows:

- **GPS**
  - A RTC interrupt will switch ON the GPS appropriately.
  - When the GPS is switched ON a timeout timer is also started. It might so happen that when the GPS is switched ON the animal is under canopy of dense foliage. A timeout value of 3 mins is kept. If a fix is not obtained in 3 mins switch OFF GPS and the number of failed attempts is incremented.
  - After the GPS is switched OFF start a retry timer. The retry period is specified in the configurations. The GPS is OFF for the retry period.
  - When the retry period is over, once again an attempt is made to acquire fix.
  - This goes on till either a fix is obtained or till the maximum number of allowed attempts gets exhausted.
  - If a fix is not obtained, the fix data structure in external memory is filled with all zeros. This is a indication to the server after it decodes the message that there was a failure to acquire fix at that instant. This is a good debugging information. It will help the user who is configuring the collar to tweak the parameters like maximum number of retries, retry period, etc and ensure that a fix is obtained in case the number of failures to obtain a fix increases.

12.2.4 GSM Flow Chart

The software flow of the GSM system is as follows:

- **SMS**:
  - User can configure the preferred transmission mode as SMS.
  - The size of one GPS fix including 1 byte of message ID is 21 bytes. We are using the binary mode SMS and not the text mode SMS for data transmission since data can be compressed to a large extent in binary mode. Binary mode SMS is called Protocol Data Unit mode. Maximum size of SMS using 7-bit GSM alphabet and PDU mode is 140 bytes. Hence the maximum number of fixes per SMS is 6($6 \times 21 = 126$). Battery status message is 3 bytes. Hence one battery status can also be sent along with 6 fixes.
  - The PDU mode SMS is made using the unsent fixes. 'Acknowledgement required' bit is set which ensures that the SMS server

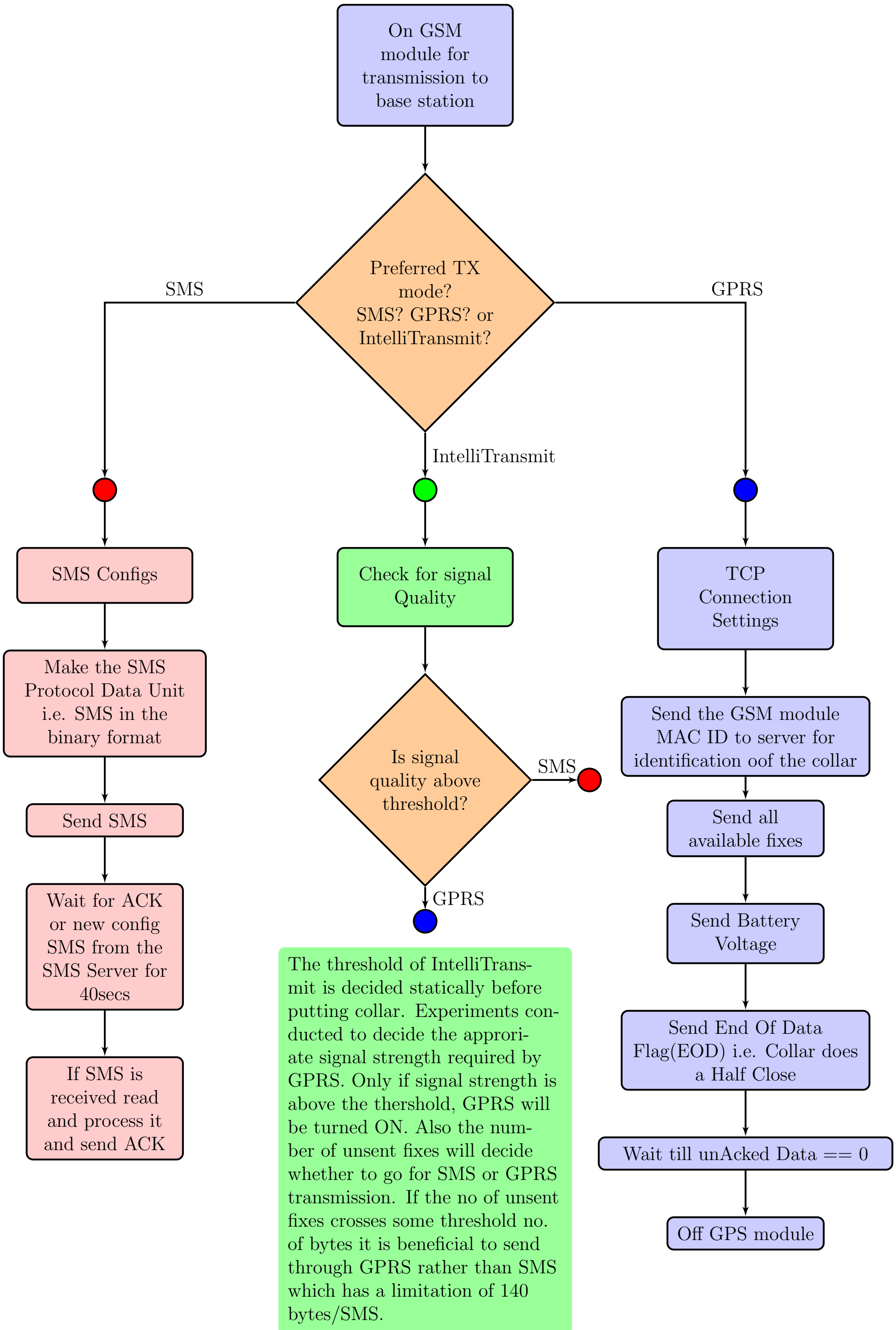


Figure 12.3: GSM Flow Chart

sends an ACK. When a ACK is received from the server, that particular fix is marked as sent.
  - After sending a SMS, the collar waits for 40secs to receive an ACK or any configuration SMS from the server.
  - If a SMS is received, the type is identified - Acknowledgement(Delivery Report) or a normal SMS. If it is a normal SMS, the mobile number is checked. Only SMSs from the SMS server are accepted all others are rejected.

- **GPRS**:
  - User can configure the preferred transmission mode as GPRS.
  - In GPRS a TCP connection is established with the Main Server which is having a public IP.
  - The connection and service settings include specifying the access point address which depends on the service provider used, configuring the connection for binary mode, etc.
  - After a socket is opened, the collar sends IMEI(International Mobile Equipment Identity) number.This number is unique to the GSM modem.It is like the MAC ID. It is necessary to send this number during GPRS transmission because the server needs the identify which collar is trying to open a TCP connection. If the IMEI no is not valid, the server will reject the connection.
  - All the unsent fixes can be transmitted when the TCP connection is established. Battery voltage is also transmitted.
  - The reliable TCP connection ensures that all data have reached the server.
  - After all the data from the collar side are transmitted, it sends a End of Data(EOD) flag. This is noting but a half close done by the collar. This tells the server that the collar will not send any further data. But it can receive data.
  - If the collar receives new configuration then it loads the configuration.
  - The collar waits till all the data sent by it are acked. After all data are acked the collar closes the TCP connection.

- **IntelliTransmit**:
  - In this mode the collar decides whether the signal quality is appropriate to send a SMS or establish a GPRS connection.

– If the signal quality is very good then it will look at the amount of data. If the amount of data is more than a threshold it will attempt a TCP connection.

12.3 Messages transferred between the Collar, Main Server and SMS Server

The messages that are transferred between the collar and SMS Server or Main Server are:

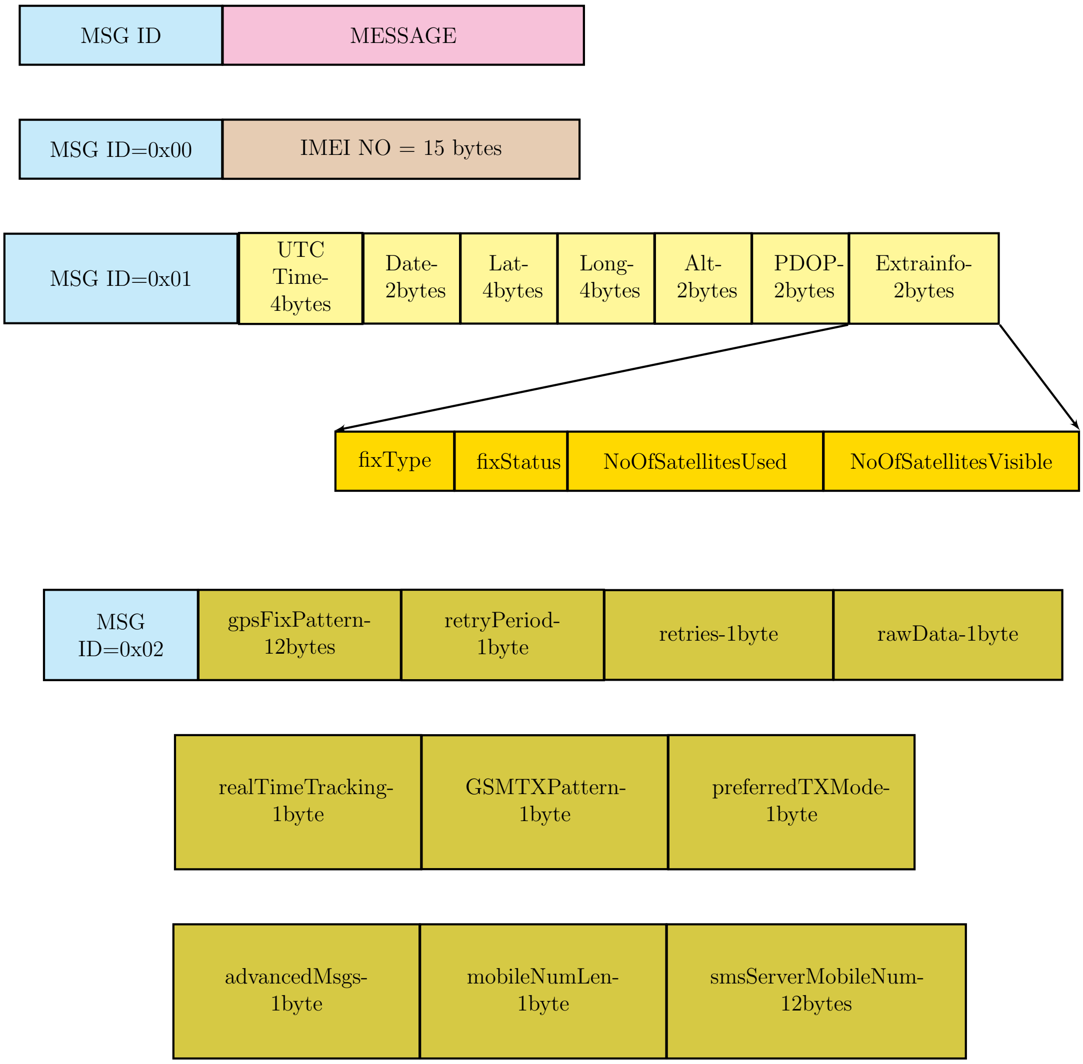


Figure 12.4: Different Messages between Collar and Server

- **IMEI MSG : MSG-ID = 0x00:**
  This is always sent from the collar to SMS Server/Main Server.It is the MAC ID of the GSM modem.It is a unique 15 digit number which is associated with every GSM modem.It is independent of the SIM card put.The total message length including the message ID byte is 16 bytes.
- **GPS FIX MSG : MSG-ID = 0x01:**
  This message is always sent from the collar to SMS Server/Main Server.It contains the GPS location information of the collar.GPS fix information is 20 bytes.The total message length including the message ID byte is 21 bytes.
- **CONFIG MSG : MSG-ID = 0x02:**
  This message is always sent from the Main Server to the Collar.The configurations are 32 bytes long.The total message length including message ID byte is 33 bytes.

12.4 SMS Server

12.4.1 Overview

As discussed in the embedded software the collar decides to communicate to the main server using SMS or GPRS. When the collar decides to use SMS for transmission it does it through an SMS server. The SMS server thus acts as a proxy for the main server. When it receives an SMS it immediately forwards the message to the main server. The main server then replies to the message. When the reply is received the SMS server converts the reply into an SMS and sends it to the collar. The delay involved in connecting to the main server and getting the reply is negligible compared to rest of the SMS transaction. An alternate solution would have been to put the SMS server along with the main server itself. But it would mean that if a collar is in Assam and the main server in Karnataka, then the SMS being a national SMS, would have taken more time and costed more money. Also it would mean a lot of load on one single SMS Server. This is critical because SMSs take a long time to receive and send(about 2 seconds and 5 seconds respectively). Now, in the current architecture, since the SMS server could be placed in Assam itself, the SMS will be local. Hence transactions will be faster and will cost less money. Also there could be many such SMS servers distributed all over the world so as to decrease the load on the main server.

12.4.2 Components

- Serial-Port driver
  This layer helps in communicating with the serial port device(modem in this case).

- Modem driver
  This layers sits on top of the Serial-Port Driver. It communicates to the modem using the AT command set.

- Message handler
  This layer handles the messages to and fro. It forwards the received SMS to TCP session manager. When it receives a message from TCP session manager, it makes an SMS and sends it to the Modem driver. It uses a sub-component called PDU-SMS encoder-decoder to decode and encode PDU SMS.

- TCP Session manager
  The top most layer in the SMS server which communicates to the main server. It opens a connection to the main server(if not open) when a message is received from the Message handler. It sends back the reply from main server to the Message handler. Whenever there is a long period of inactivity(set to 30 minutes but variable), it closes the connection to the main server and then re-opens as and when required.

12.5 Main Server

12.5.1 Overview

The main server software is central to the entire system. It maintains the database of all animals and users. It serves the requests of SMS server and application softwares. It also directly serves the requests of collars when the collars use GPRS to directly connect to main server. The main server has the following components...

- SQL Database interface

- User application interface

- SMS server interface

- GPRS interface

12.5.2 SQL Database Interface

This provides all the API necessary to handle the database. All the other components use this layer to write or read into the database. It uses a MYSQL server as its backend. MYSQL was chosen because it is open source and free. MYSQL was found to be sufficient to meet all the desired functions.

Structure of the database

- Summary(database)
  - users(table)
    - Name
    - User ID
    - E-mail
    - Contact number
    - password
  - animals(table)
    - Name
    - Species
    - Forest
    - number
    - tracker's name
    - admin user
    - installation date
    - description
    - IMEI
    - SMS server number
  - permissions(table)
    - User
    - Animal
    - Permission
- A number of databases named AT('Collar Number'). 'AT' is used as a prefix to the collar number.
  - Fixes(table)
    - longitude

    * latitude
    * altitude
    * fix time
    * fix date
    * advanced info such as fix accuracy, no of satellites visible, etc.
  - Configurations(table)
    * fix times
    * transmission times
    * transmission choice (GPRS, SMS, Auto)
    * choices of raw data, realtime tracking, advanced messages
  - Status reports(table)
    * battery voltage
    * GSM bit error rate
    * GSM signal strength
  - Notes(table)
    * note type
    * note
  - Logs(table)
    * log

Apart from the fields mentioned above. All the tables contain timestamp field which is used for synchronizing an application software.

12.6 User application interface

This interface helps applications all over the world to synchronize data with the server. It also handles user authentication. It uses the timestamps in database entries to synchronize data.

12.7 SMS server interface

This interface receives messages from the SMS server and decodes them. It then writes the decoded data into the database. It also sends a configuration whenever a new configuration is waiting to be sent to the collar.

12.8 GPRS interface

This interface provides a direct communication to a collar through TCP/IP connection. It waits for connections from a collar and when it gets a client it identifies the collar by matching it's IMEI number(first message from the collar). It then writes all the received data into the database. It also sends a configuration if necessary. Note that IMEI number identification is necessary only in the case of a GPRS session and not in the case of an SMS session because there is no way to know the mobile number of a GPRS client since the GPRS client has a dynamic IP. Both the SMS server interface and GPRS interface have a common set of API for handling collar messages so that minimum repetition is maintained in the code.

12.9 User Application Software

12.9.1 Overview

The user application software provides a GUI front end for the user. A GUI front end apart from the website was considered necessary because it provides a more responsive interface with more features. It also can interface with Google-Earth$^{(TM)}$ which is much more powerful than Google-Maps online. It uses an XML backend so that advanced users can use them much more productively than the GUI. Whenever a user application is online, it periodically contacts the server for updates(to and fro). It uploads any new configurations, notes, changes in animal details and user details. It downloads new fixes, status reports etc.

12.9.2 Components

- Front End GUI
- Backend XML interface
- Synchronizer

12.9.3 Front End GUI

The front end GUI has the following modules...

- Animal choosing interface - left panel

- Status Tab - Shows the last fix, battery status and other advanced status elements.
- Configurations Tab - Gives an interface for changing the configurations of the collar.
- Fixes Tab - Shows the fixes in a table. It can also display the fixes on Google-Earth.
- Notes Tab - User can write notes of various types.
- Logs - Used for viewing the activity log.

12.9.4 Backend XML interface

The XML interface provides a common method of storage and retreival of local data. It is used by all the other components for any storage or retrieval of data. The data stored in XMLs include fixes, configurations(both present and past so that reverting is easy), notes, status reports and logs. It also helps the GUI in interacting with Google-earth using the KML file format. KML file format is infact an XML format used by Google-Earth.

12.9.5 Synchronizer

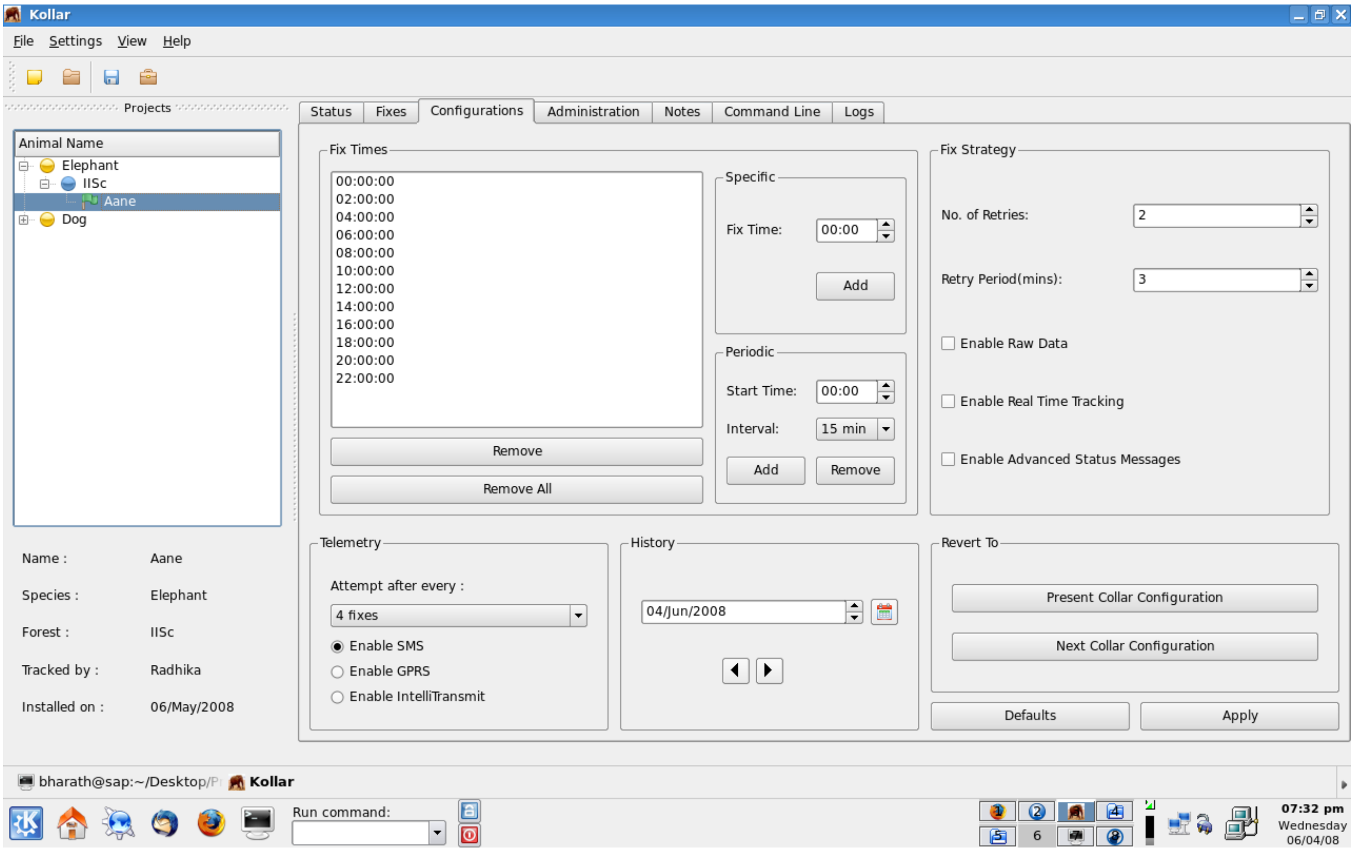
The synchronizer has two components.

- Downloader Uses timestamps for updates. It sends the last updation timestamp to the server. The server responds with all the data that have changed after the timestamp. The downloader then uses XML interface to write the changes. It then informs the GUI if necessary so that the GUI can refresh.
- Uploader The GUI writes all the changes made into a file. The uploader uses this file to upload all the changes to the server.

Both the Uploader and Downloader are seperate threads from the GUI. This is done so that the GUI does not become non-responsive at any point of time.

12.9.6 Snaphot of the GUI

Figure 12.5: A view of configurations tab in GUI



12.10 Website

12.10.1 Overview

The website has almost the same features as that of the application software. It has been made in addition to the application software so that people on the move can use it. It can also be later used to increase the enthusiasm among people about animal tracking. But precautions have to be taken in such a case so that animals don't fall prey to people who may use such information for hunting animals. The website has a Google-maps interface instead of the Google-earth application interface for user end application software. Also the history of configurations will be available only on the Application software. The XML files containing data will also not be available on the website. Hence it is not as powerful for study as the application software.

12.10.2 Snapshots of the website

Figure 12.6: A view of Animal Details on the website

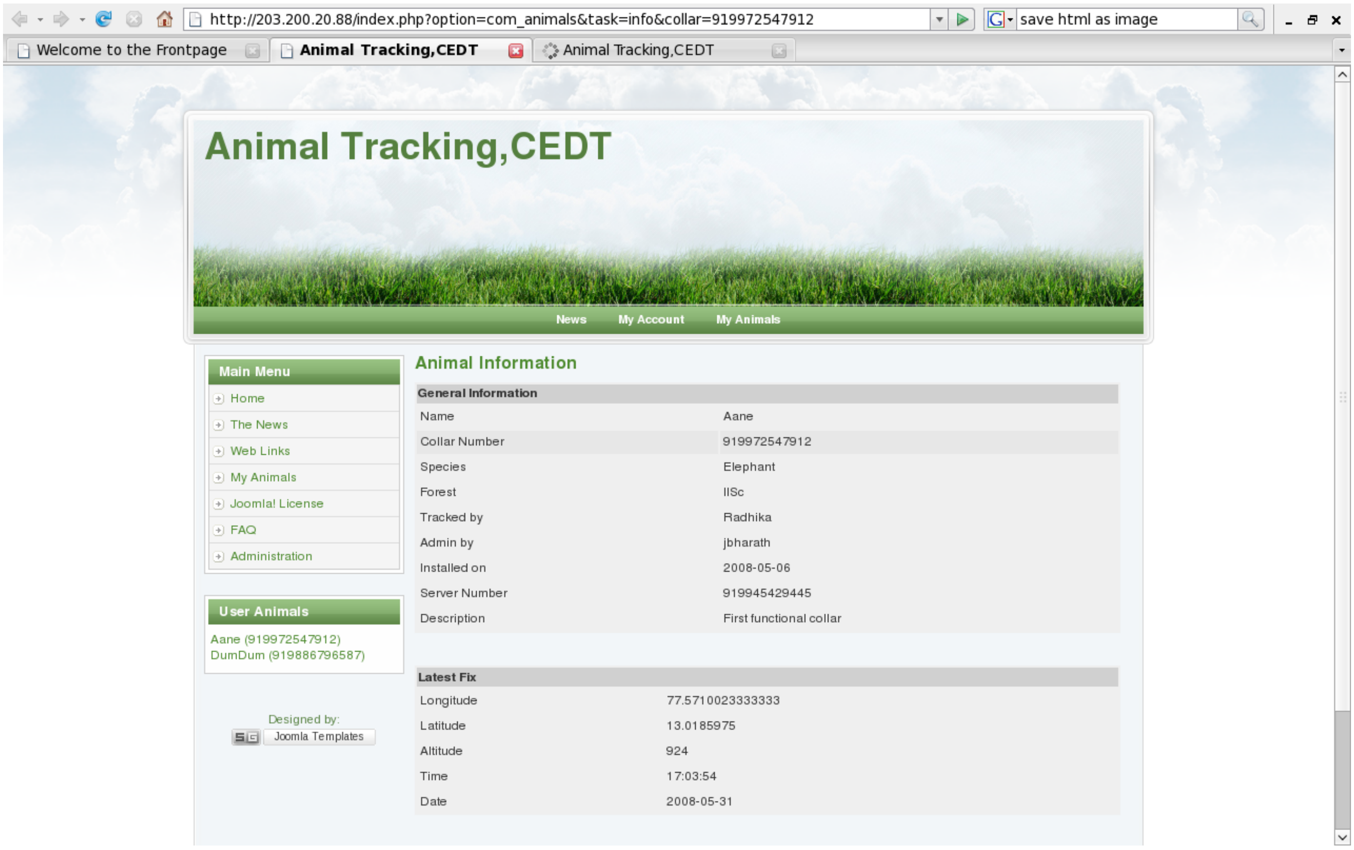
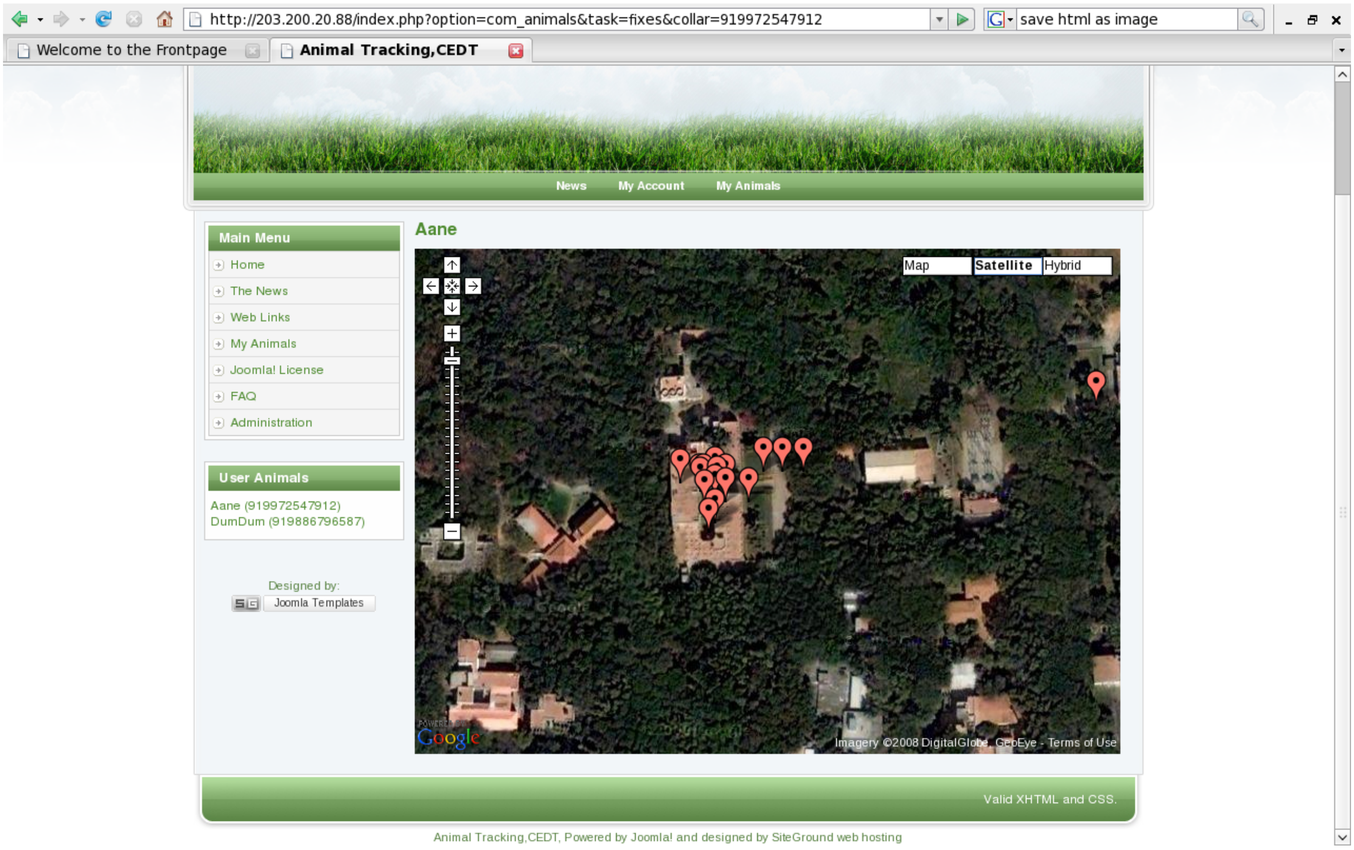


Figure 12.7: A view of configurations tab on the website



Chapter 13

Energy Measurements

It is necessary to know the cost in terms of energy for transmitting a SMS, sending data over TCP, establishing a TCP connection, etc. This will help us estimating the lifetime of the collar. Also it will tell us whether SMS is to be preferred over GPRS or vice versa. For doing these measurements, we used supercapacitors. The specifications of the supercap are 120F, 2.3V. Since the system requires 3.6V, 2 capacitors were put in series. These supercapacitors will be used like a battery for the system. They were charged using a resistor. The idea is to send SMS or take GPS fix using these capacitors as power supply. Then measure the voltage dip. $C \times \Delta V = I \times t$ gives the charge or A-secs.

13.1 Calculation of capacitance of Supercapacitors

To find out the exact capacitance, the two series capacitors were charged till 3.6V and then discharged for 600secs through a 23.4Ω resistor.

$$V_f = V_i e^{-t/\tau} \tag{13.1}$$

Using equation(13.1), the capacitance value was calculated to be 63F

13.2 Energy measurements for GPS

These measurements are done to find out the energy consumption for taking a GPS fix. The results are as shown in Table(13.1). These measurements were done unser following conditions:

- Warmstart - The GPS module has no valid ephemeris.
- Open sky and under concrete.
- No of fixes = 10.

By taking measurements for acquiring fix under concrete, we are trying to simulate very dense foliage cover in forests. Fix under concrete is the worst case scenario for GPS. Concrete attenuates the GPS signals more than a thick foliage.

Table 13.1: Energy measurements for GPS

Conditions	**Initial Voltage(V)**	**Final Voltage(V)**	**Time(secs)**
Open sky	4.384	4.047	417
Under concrete	4.041	3.702	445

Calculations: Calculation of A-secs for open sky condition for 1 fix:

$$\begin{aligned} C \times \Delta V &= 63F \times 0.337V \\ &= 21.231 \text{ A-secs} \\ &= 0.589 \text{ mA-h} \end{aligned}$$

Calculation of A-secs under concrete condition for 1 fix:

$$\begin{aligned} C \times \Delta V &= 63F \times 0.339V \\ &= 21.357 \text{ A-secs} \\ &= 0.593 \text{ mA-h} \end{aligned}$$

$\boxed{\textbf{Energy cost to obtain 1 fix in open sky} = 0.589 \text{ mA-h}}$

$\boxed{\textbf{Energy cost to obtain 1 fix under concrete} = 0.593 \text{ mA-h}}$ From the above results it can be seen that, there is very little difference between the two experiments, suggesting a very good performance under low signal conditions. This would need to be further verified by carrying out the same measurements under thick canopy cover.

13.3 Energy measurements for GSM

By the GSM measurements we intend to compare the cost per byte in terms of energy for SMS and GPRS.

13.3.1 Energy measurements for switch ON and OFF the GSM Modem

These measurements are done to find out the energy consumption while switching ON and OFF a GSM modem. After power up the GSM requires some time to acquire network and do network registration. It takes roughly 30secs for the SIM card to get ready. Thus we can see that switching the module ON and OFF adds a significant overhead. Thus by these experiments we intend to find out the energy cost of switching ON and OFF the modem. The results are as shown in Table(13.2).

Table 13.2: Energy measurements for switch ON and OFF of GSM modem

Initial Voltage(V)	**Final Voltage(V)**	**Time(secs)**
4.329	4.161	195

Calculations: Calculation of A-secs for switching the modem ON and OFF

$$\begin{aligned} C \times \Delta V &= 63F \times 0.168V \\ &= 10.584 \text{ A-secs} \\ &= 2.94 \text{ mA-h} \end{aligned}$$

$$\boxed{\textbf{Energy cost per switch ON and OFF of the GSM modem} = 0.588 \text{ mA-h}}$$

13.3.2 Energy measurements for SMS communication

We intend to find out the energy cost of transmitting a SMS. The measurements are shown in Table(13.3). This experiment was done under following conditions:

- 10 SMSs are transmitted continuously.
- Length of each SMS=140 bytes

Table 13.3: Energy measurements for transmitting SMS

Initial Voltage(V)	Final Voltage(V)	Time(secs)
4.052	3.934	195

Calculations: Calculation of A-secs for transmitting SMS

$$C \times \Delta V = 63F \times 0.118V$$
$$= 7.434 \text{ A-secs} \qquad = 2.065\text{mA-h}$$

Subtracting the energy required to ON and OFF the modem from above equation Hence the cost to transmit 10 SMSs is 2.065 - 0.588 = 1.477mA-h.
Energy cost per SMS = 0.147 mA-h
Energy cost per byte via SMS = 0.010 mA-h

13.3.3 Energy measurements for establishing a TCP connection

We intend to find out the energy cost of GPRS communication. The measurements are shown in Table(13.4). This experiment was done under following condition:

- For this measurement the module was switched ON, then TCP connection was established and then TCP connection was closed followed by switching off the modem.
- This sequence was repeated 5 times

Table 13.4: Energy measurements for establishing TCP connection

Initial Voltage(V)	Final Voltage(V)	Time(secs)
4.288	3.913	210

Calculations: Calculation of A-secs for establishing TCP connection

$$C \times \Delta V = 63F \times 0.375V$$
$$= 23.625 \text{ A-secs}$$
$$= 6.562\text{mA-h}$$

Energy cost for establishing TCP connection = 1.31 mA-h

13.3.4 Energy measurements for GPRS communication

We intend to find out the energy cost of GPRS communication. The measurements are shown in Table(13.5). This experiment was done under following condition:

- 100KB of data was transferred from the collar to server.

Table 13.5: Energy measurements for data transfer over GPRS

Initial Voltage(V)	**Final Voltage(V)**	**Time(secs)**
4.423	3.608	210

Calculations: Calculation of A-secs for data transfer of 100KB over TCP

$$\begin{aligned} C \times \Delta V &= 63F \times 0.815V \\ &= 51.345 \text{ A-secs} \\ &= 14.2625\text{mA-h} \end{aligned}$$

Subtracting the cost for establishing the TCP connection from cost to send 100KB = 14.262 - 1.312 = 12.95mA-h
Hence, Cost for transmitting 100KB over TCP = 12.95mA-h
Energy cost per byte = 0.000129 mA-h

13.4 Conclusion from Energy Measurements

From the measurements we can see that the cost per byte for GPRS is less. Now, we calculate the break-even point for transmitting data optimally.

$$\begin{aligned} &(\text{SMS Overhead}) + (\text{Cost of SMS per byte}) \times \text{X} = \\ &(\text{GPRS Overhead}) + (\text{Cost of GPRS per byte}) \times \text{X} \end{aligned}$$

Using the values from above measurements we obtain, **X =73.**

Thus, if the data to be transmitted is more than 73 bytes then it is energy efficient to use GPRS for communication.

Chapter 14

Industrial Design

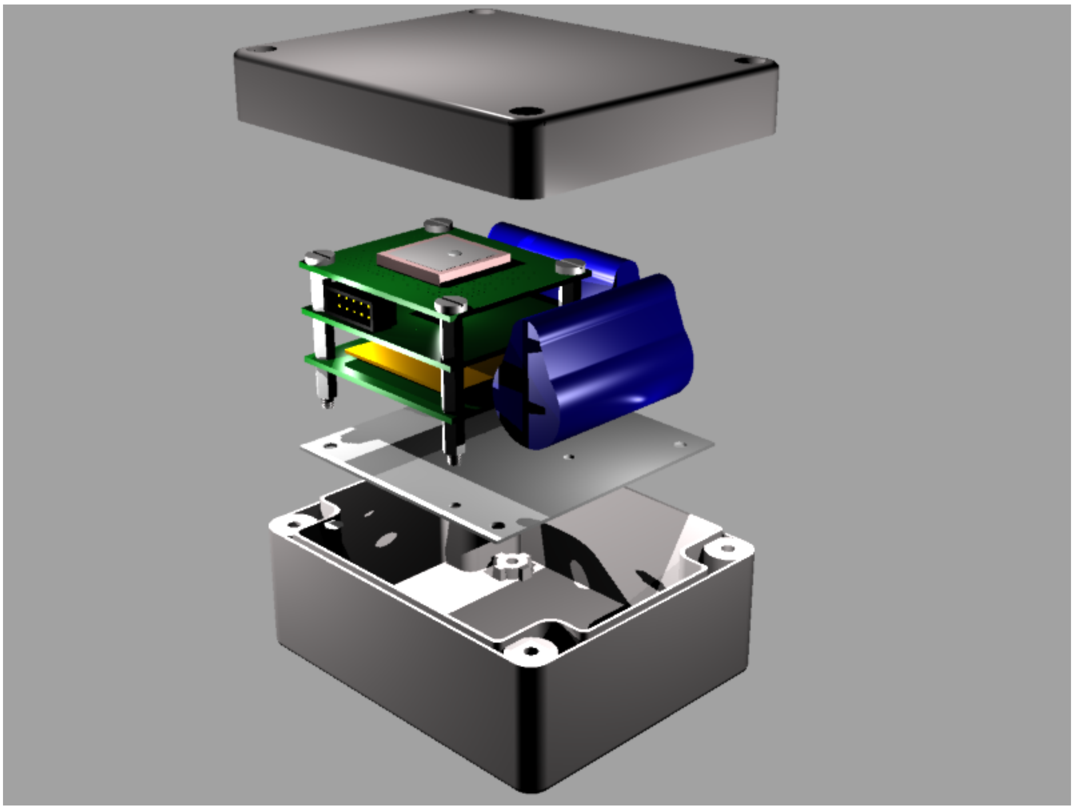


Figure 14.1: Exploded view of the entire product

The details of box chosen is shown is shown in figure(14.2),(14.3),(14.5).The box specification is IP class 68. Hence it is protected against dust and long periods of immersion in water.A matching plate is designed to fit the PCB.

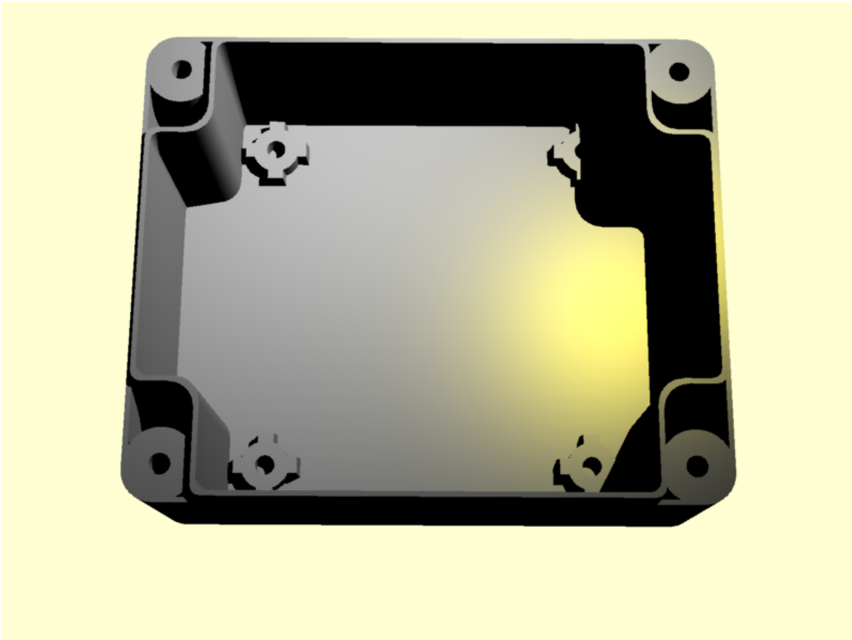


Figure 14.2: Inside the box

There will be a marking on the box for placing the REED magnet. The REED magnet needs to be held in place tightly so that it does not fall off during transportation. This can be ensured by putting a cello tape around the box.

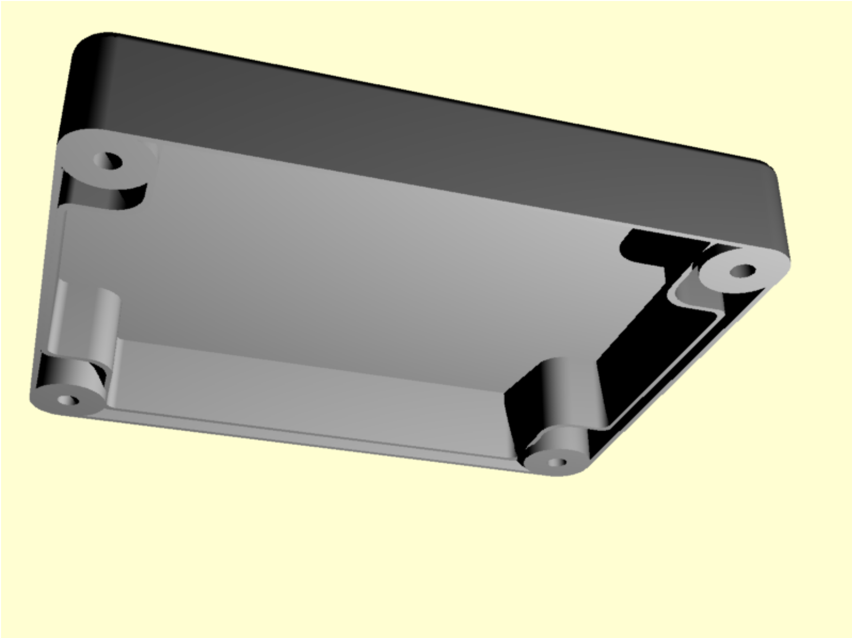


Figure 14.3: Cover of the Box

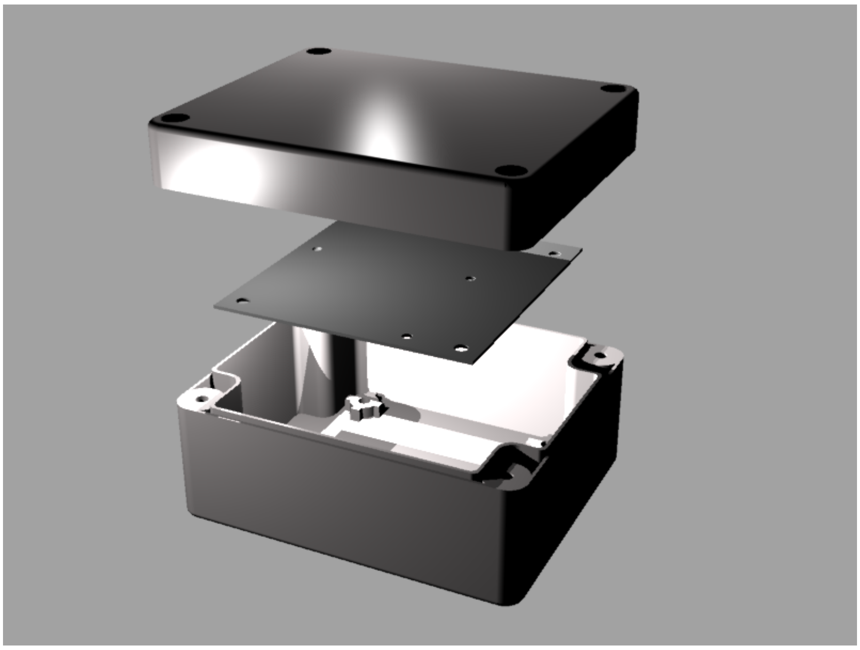


Figure 14.4: Box with the Matching Plate for PCB Fitting

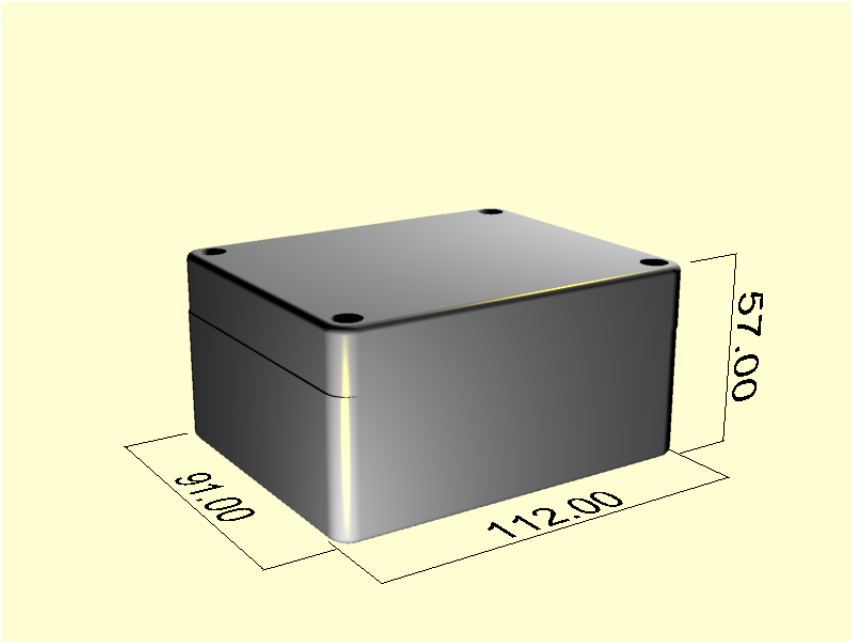


Figure 14.5: Dimensions of the Box

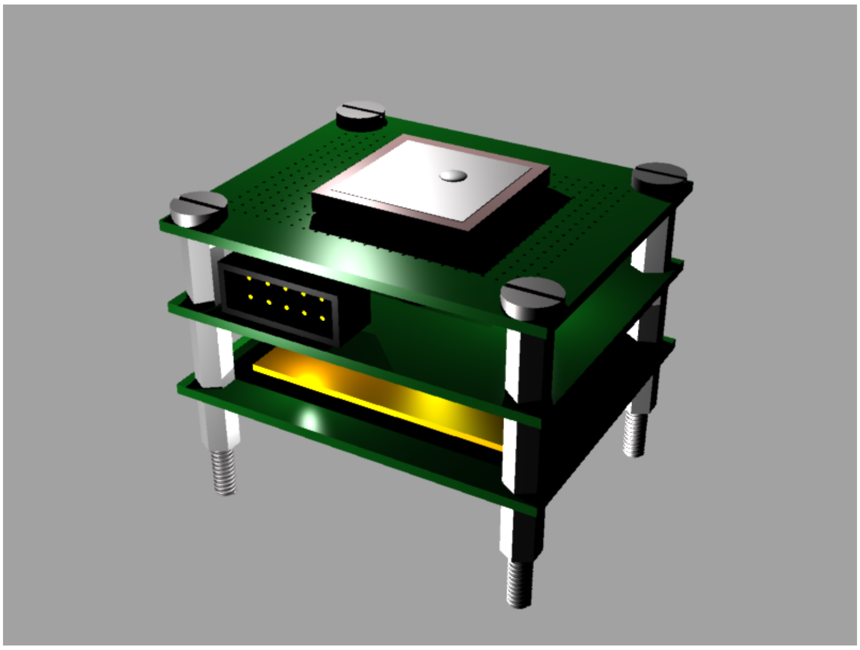


Figure 14.6: PCB Stackup Model

A stackup design is used to save space. The inter-board connections are soldered to ensure reliablity. The 3-D model of the PCBs with the connector placements is shown in figure(14.6). The batterries are placed as shown in figure(14.7),figure(14.8).

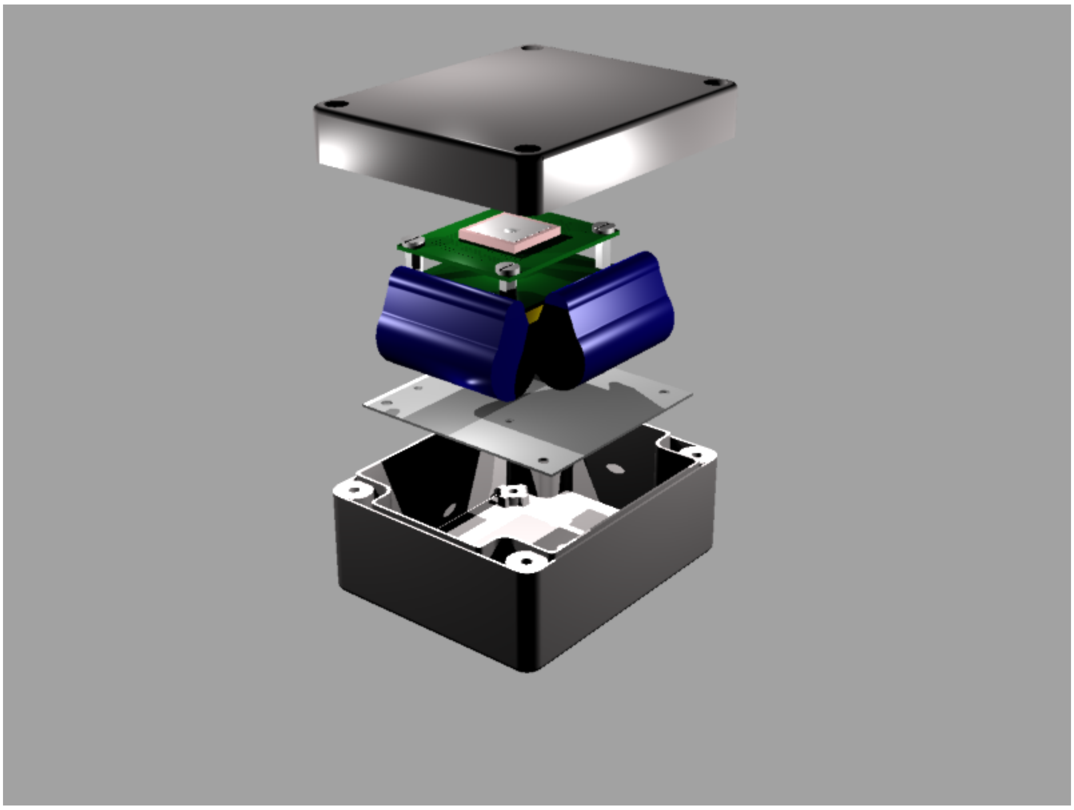


Figure 14.7: Exploded view of Battery and PCB Placement

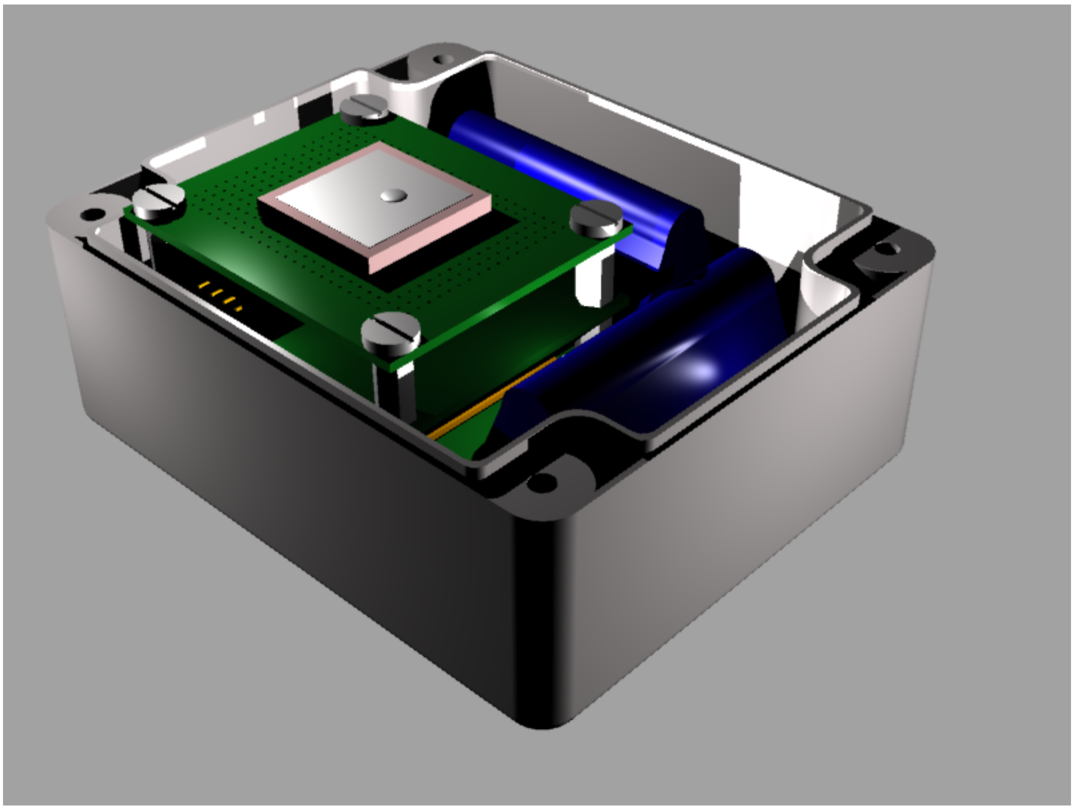


Figure 14.8: All components inside the Box

Chapter 15

Demonstration Plan

- Demonstrate the module functionality in the lab.
- Move in a vehicle in IISc with the collar module.
- Show the real time data immediately on Google Earth
- GUI for the system will help the user change the parameters.
- Show the same on the website.

Chapter 16

Deployment Guide

Follow the steps below for installation and deployment.

- Make a project in the application software or on the website. For further instructions help is available in the respective places. Also configure as per requirements using the configurations facility.
- Build the stack-up as seen in the exploded views of the ID Section after populating all boards.
- Connect the adapter board for configuring.
- Plugin a valid SIM-Card on the bottom most board.
- Move to a place having good view of the sky.
- Plugin a power supply(preferably batteries) with rated Voltage greater than 3.4V and less than 5.5V. Rated current should be a minumum of 3A.
- Press the button named "ALM" on the adapter board and wait for about 20 minutes.
- Press the button named "SMS_CONFIG" and wait till the orange LED switches on. This LED is an indication that the collar is ready to receive the config SMS.
- To test if everything is fine, press the button name "GSM_TX". The Module should now switch on the blue LED and switch it off once the fix is taken. It will then switch on the white(if GPRS is configured) or red(is SMS is configured) LED and transmit a fix. You should be able to confirm it using the application software or the website. Wait till all the LEDs other than the green one turn off.

- You may now remove the power supply.
- The next step is to put it in the box and pot it in some weather-proof material along with the batteries.
- Place a magnet near the box to make sure that the module stays inactive. There will be a marking on the box for placing the REED magnet.
- When the box is fitted into a collar and the collar is ready for deployment, remove the magnet to activate the module.
- Happy Tracking!!

Appendix A

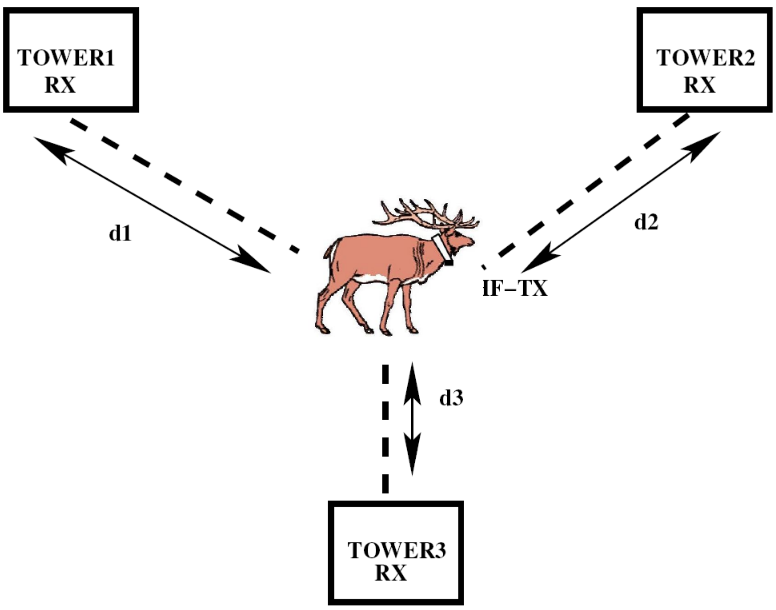
Various Tracking technologies

A.1 VHF Based Systems

Location determining techniques mainly consists of two types:Triangulation and Trilateration.

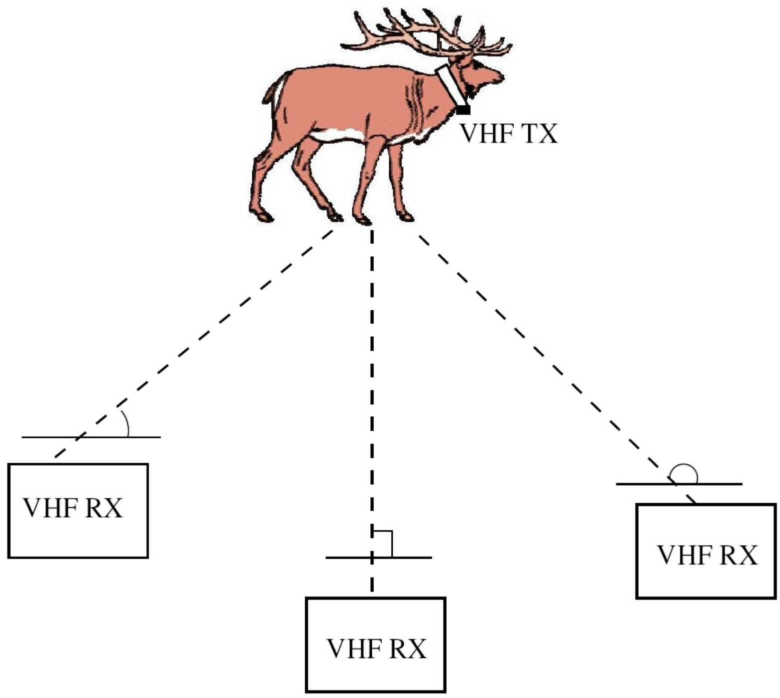
- **Triangulation:** Triangulation uses the angular position of an object from three or more references.

Figure A.1: Trilateration in VHF systems



- **Trilateration:** Trilateration uses the range of an object from three or more objects. These systems use signal strength of the received signal to calculate the distance from the tower.These typically may consist of loop antenna systems which are looking for the direction in which the signal strength of the transmitter is maximum. Simple geometric calculations can then yield the position.Three circles of radius d1, d2 and d3 intersect in a unique point to give theposition.

Figure A.2: Triangulation in VHF systems



Advantages of VHF based location systems vs. GPS based location systems:

- **Cost:**Cost of VHF systems is lesser than GPS systems, though with time, the gap is shrinking. One should note here that this is only as far as the costs of units that are commercially marketed are concerned. Otherwise the costs of building a GPS based system have considerably reduced due to larger GPS applications.

  For a comparison of commercially available units, A VHF system costs around 200−400 A GPS system costs around 2000−4000 (http://www.wildlifenews.alaska.gov/)

- **Use lesser battery:** Since they are light on batteries more real-time tracking is possible. But in case GPS, even 10 fixes per day is enough to drain the batteries in about 6 months in the existing collars.

Disadvantages of VHF based systems:

- Setting up of permanent towers in jungles is both unethical and difficult.It will also prove to be a costly solution if any permanent infrastructure has to be put up.
- In the case of not putting a permanent infrastructure, manual tracking has to be done by carrying a detector. This is a very cumbersome process.
- Signal range of the transmitters is often limited, which further drives the need for aerial locations to be taken, especially in complex habitat/terrain.
- Costs usually limit the total amount of data (i.e., number of locations per animal) that can be collected. General distributional patterns and habitat use of the animals may be detected, but detailed movements are difficult to determine.
- The money saved in costs of the unit are often redirected to other costs associated with data collection (e.g., fixed-wing flight time, vehicle fuel, labour needed to collect locations)

With the technological development GPS is getting cheaper and better.Hence a solution in GPS has got better future prospects.

Advantages of GPS systems:

- More accurate and reliable locations (most of the time!).
- The ability to collect multiple locations per day at pre-determined times (specified by the user) without the added cost of flight time, personnel, vehicle expenses, etc.
- Data can be directly downloaded (or uploaded) into a computer system and then translated onto spatial maps using modern Geographic Information Systems (GIS).

Considering all the above factors we arrived at selection of GPS technology for the collar.

Appendix B

Various Transmission Technologies

- **ARGOS:** ARGOS is a satellite-based system which collects processes and disseminates environmental data from fixed and mobile platforms worldwide. ARGOS has the ability to geographically locate the source of the data anywhere on the earth utilizing the Doppler Effect.ARGOS is Low Earth Orbit (LEO) satellite system. It is at located at 850Km.100 minutes is the revolution period. There are 50 receiving stations all over the world to collect the data transmitted by these satellites.ARGOS can be used for finding location and for transmitting the data to the satellite when it is in view so that the base station can receive it. The use of ARGOS for tracking or for communication was ruled out because of following reasons:
  - Very poor accuracy in range of few kilometres.
  - In ARGOS system, the collar on the ground is a transmitter which will keep on sending data during the window period (i.e. period when the satellite is visible). The transmitter on the ground has to expend lot of energy during this process.
  - Also the window period is uncertain. Hence the transmitter has to retransmit data couple of times hoping that data is received by the satellite when it is overhead. Hence we have not considered ARGOS even to establish a ground link because of unreliability and huge power consumption by the transmitter in this process.
- **GSM:** Communication to base can be done in the following ways using GSM:
  - Text mode SMS : This is the usual way in which SMS is sent. But

only printable characters can be sent. Therefore special schemes will have to be devised to escape the control characters which will in turn increase the data size. SMS modes require least signal strength. Hence, can offer greater coverage in remote areas.

  - SMS in PDU mode : PDU stands for protocol description unit. In this mode SMS can contain any binary data. Hence escaping control characters is not a problem. This is more conservative in terms of number of bytes transferred. Hence energy wise more efficient. It is therefore better than Text mode SMS in every way.
  - Fax/Data call : These are reliable methods compared to the SMS modes because the connection is established. But Signal strength required is also higher compared to SMS mode. Hence it could pose problems in remote areas where GSM signal strengths are very low. But higher data rates can be achieved.

- **GPRS:** General Packet Radio Service (GPRS) is a Mobile Data Service available to users of Global System for Mobile Communications (GSM).GPRS is packet-switched. Hence it supports IP and hence some stacks like TCP/IP. This makes it easy to use for two way communication.Also uploading data to a centralised server becomes easy with GPRS.

Appendix C

Study of GPS

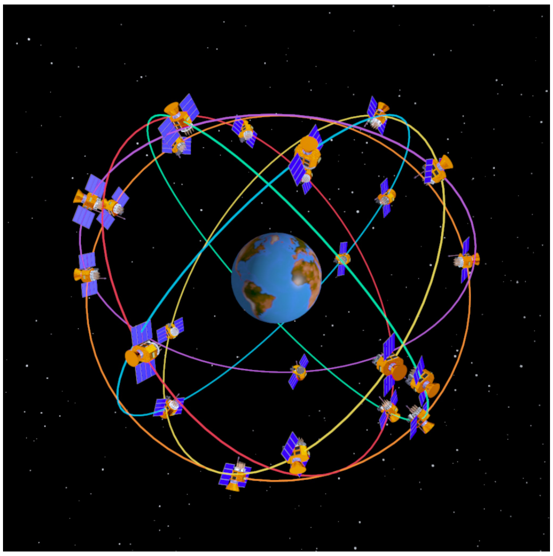


Figure C.1: Constellation of GPS satellites

GPS: The Basic Idea

GPS consists, nominally, of a constellation of 24 operational satellites. This Constellation, known as the initial operational capability (IOC), was completed in July 1993.To ensure continuous worldwide coverage, GPS satellites are arranged so that four satellites are placed in each of six orbital planes. With this constellation geometry, four to ten GPS satellites will be visible anywhere in the world, if an elevation angle of $10°$ is considered. As discussed later, only four satellites are needed to provide the positioning, or location, information. GPS satellite orbits are nearly circular (an elliptical shape with a maximum eccentricity is about 0.01), with an inclination of about $55°$ to the equator. The semi major axis of a GPS orbit is about 26, 560 km (i.e., the satellite altitude of about 20, 200 km above the Earth's surface). The corresponding GPS orbital period is about 12 sidereal hours (11 hours, 58 minutes).

C.1 Trilateration In GPS:

Two spheres intersect to make a circle. This circle intersects another sphere to produce two points. In order to determine which point is the user position, one more satellite is needed. With three spheres we can obtain two points - one close to earth and one in space. We can easily discard the one in space and user position can be uniquely determined. Thus, given that the clock on the earth's receiver is in perfect synchronism with the GPS satellite clock we can accurately determine the position using three satellites.But there is clock bias and clock drift errors and the clock on earth is not very accurate. Hence there are 4 unknowns, namely-x-co-ordinate, y-co-ordinate, z-co-ordinate of the satellite and the time of the satellite. Therefore, to solve for 4 unknowns we require 4 satellites for accurately determining the user position.With 3 satellites we are solving for three unknowns namely-x, y and time. We cannot determine the altitude. Hence we get only 2-D accuracy with 3 satellites.

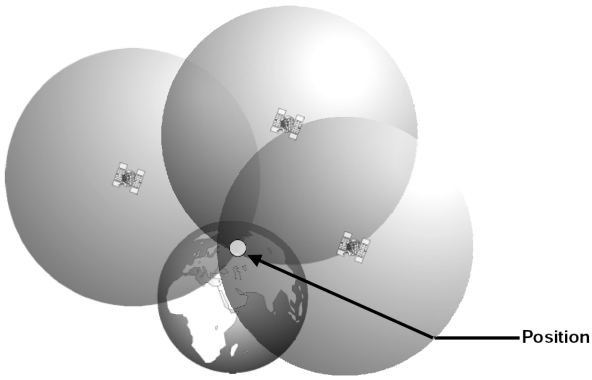


Figure C.2: Trilateration in GPS

C.2 GPS Errors And Biases

There are various perturbations which cause the GPS satellites to drift from their predefined orbits. Perturbations affecting are:-Gravitational effects due to moon, sun and other heavenly bodies and solar drag

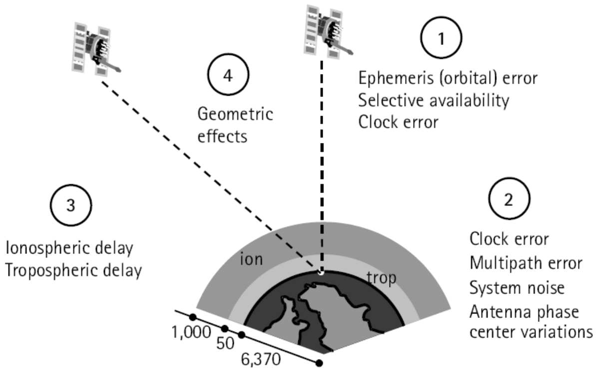


Figure C.3: GPS Errors and Biases

C.2.1 GPS Ephemeris

Satellites move in a path having a predefined equation. But satellite positions keep on drifting with time. The GPS satellite positions included in the broadcast satellite navigation message are predicted from previous GPS observations at the ground control stations. Typically, overlapping 4-hour GPS data spans are used by the operational control system to predict fresh satellite orbital elements for each 1-hour period. As might be expected, modelling the forces acting on the GPS satellites will not in general be perfect, which causes some errors in the estimated satellite positions, known as ephemeris errors. Nominally, an ephemeris error is usually in the order of 2m to 5m.The range error due to the combined effect of the ephemeris and the satellite clock errors are of the order of 2.3m deviation.An ephemeris error for a particular satellite is identical to all GPS users worldwide. However, as different users see the same satellite at different view angles, the effect of the ephemeris error on the range measurement, and consequently on the computed position, is different. This means that combining (differencing) the measurements of two receivers simultaneously tracking a particular satellite cannot totally remove the ephemeris error. Users of short separations, however, will have an almost identical range error due to the ephemeris error, which can essentially be removed through differencing the observations.

Ephemeris error = Clock errors + Orbital drift errors

C.3 Almanac

The almanac consists of coarse orbit and status information for each satellite in the constellation .It takes around 12.5 minutes for 24 satellites to send their almanac information. The purpose of the data is to assist in the acquisition of satellites at power-up by allowing the receiver to generate a list of visible satellites based on stored position and time, while an ephemeris from each satellite is needed to compute position fixes using that satellite. In older hardware, lack of almanac in a new receiver would cause long delays before providing a valid position, because the search for each satellite was a slow process. Advances in hardware have made the acquisition process much faster, so not having almanac is no longer an issue. An important thing to note about navigation data is that each satellite transmits only its own ephemeris, but transmits almanac for all satellites.

C.4 The GPS Message

The GPS message is a continuous stream of data transmitted at 50 bits per second. Each satellite relays the following information to Earth:

- System time and clock correction values
- Its own highly accurate orbital data (ephemeris)
- Approximate orbital data for all other satellites (almanac) System health, etc.
- The navigation message is needed to calculate the current position of the satellites and to determine signal travel times.

The data stream is modulated to the HF carrier wave of each individual satellite. Data is transmitted in logically grouped units known as frames or pages. Each frame is 1500 bits long and takes 30 seconds to transmit. The frames are divided into 5 subframes. Each subframe is 300 bits long and takes 6 seconds to transmit. In order to transmit a complete almanac, 25 different frames are required. Transmission time for the entire almanac is therefore 12.5 minutes. Unless equipped with GPS enhancement, a GPS receiver must have collected the complete almanac at least once in order to calculate its initial position.

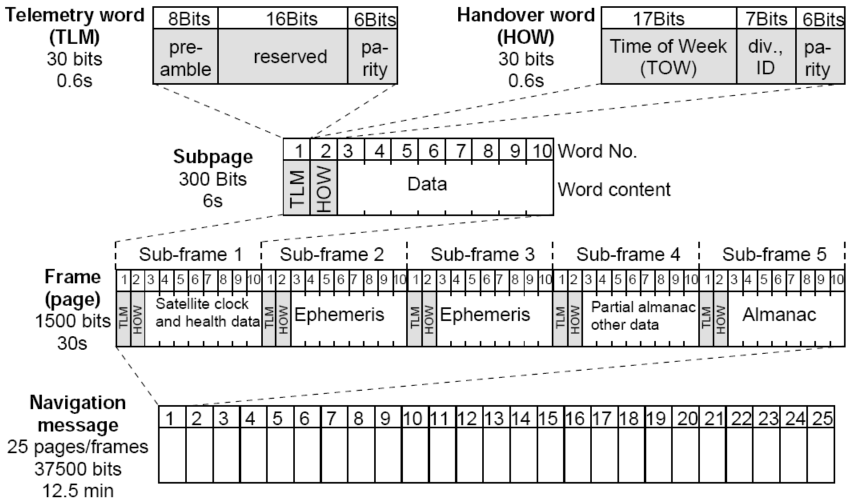


Figure C.4: Triangulation in VHF systems

C.4.1 Structure of Navigation Message

A frame is 1500 bits long and takes 30 seconds to transmit. The 1500 bits are divided into five subframes each of 300 bits (duration of transmission 6 seconds). Each subframe is in turn divided into 10 words each containing 30 bits. Each subframe begins with a telemetry word and a handover word (HOW). A complete navigation message consists of 25 frames (pages). The structure of the navigation message is illustrated in Figure(C.4) Subframe 1 contains the time values of the transmitting satellite, including the parameters for correcting signal transit delay and onboard clock time, as well as information on satellite health and an estimate of the positional accuracy of the satellite. Subframe 1 also transmits the so-called 10-bit week number (a range of values from 0 to 1023 can be represented by 10 bits). GPS time began on Sunday, 6th January 1980 at 00:00:00 hours. Every 1024 weeks the week number restarts at 0. This event is called a ‘week rollover’.Subframes 2 and 3 contain the ephemeris data of the transmitting satellite. This data provides extremely accurate information on the satellite’s orbit.Subframe 4 contains the almanac data on satellite numbers 25 to 32 (N.B. each subframe can transmit data from one satellite only), the difference between GPS and UTC time (leap seconds or UTC offset) and information regarding any measurement errors caused by the ionosphere.Subframe 5 contains the almanac data on satellite numbers 1 to 24 (N.B. each subframe can transmit data from one satellite only). All 25 pages are transmitted together with information on the health of satellite numbers 1 to 24.

C.5 What is Raw Data?

Every subframe contains the satellite clock time (without the correction for clock bias and drift errors) which can be used to calculate coarse distance of satellite from the receiver which is nothing but the pseudo range.So with help of pseudo ranges from the 3-4 satellites we can estimate our position.The accuracy will be very poor (in Kms. depending upon the accuracy of the clock of the receiver) because there is no ephemeris correction applied.Pseudo ranges take very less time to download. Pseudo ranges can be transmitted to the base stations.Now there is a facility provided by IGS (International GNSS service) which is voluntary federation of more than 200 worldwide agencies that pool resources and permanently store GPS & GLONASS station data to generate precise GPS & GLONASS products.From sites like (http://igscb.jpl.nasa.gov/components/prods.html), we can download the ephemeris for a particular time and date.With facility of these sites and the pseudo ranges from the receiver, at the base station exact latitude, longitude, altitude and time can be calculated.The advantage here is we don't have to expend energy by keeping the receiver on the elephant collar switched on to download ephemeris.A GPS satellite transmits its own ephemeris data; the broadcast lasts for 18 secs and repeats after every 30 secs.This is a major concern in our project because the ephemeris download takes minimum of 18secs and maximum of 30secs(in most cases 30 secs).

Bibliography

[1] rocessor User Guide - MSP4302xx - http://focus.ti.com/mcu/docs/mcuprodtechdoc.tsp?sectionId=95&tabId=1207&familyId=912&techDoc=6&documentCategoryId=6

[2] PS Antaris 4 system integration manual - http://www.u-blox.com/customersupport/antaris4_doc.html

[3] iemens TC-65 AT command set - http://www.google.co.in/search?q=siemens+at+command+set

[4] iemens application developers guide - http://www.google.co.in/search?q=Siemens+AN24+application+note

[5] ammu Reference - http://www.gammu.org/wiki/index.php?title=Main_Page

[6] t Reference - Qt4Assistantandhttp://trolltech.com/products/qt/

[7] oomla Reference - http://www.joomla.org/

[8] YSQL Reference - LinuxinfoPagesandhttp://www.mysql.com/

[9] HP Reference - http://www.php.net/