Utah State University

Passive Tracking Device
– Senior Project –
Final Report

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1 Executive Summary

The PTD is a Passive Tracking Device that allows users to receive SMS messages updating them on the current location of an All Terrain Vehichle (ATV). Passive solutions differ from active solutions in that they require less power and are less expensive for the users on a monthly service contract. This device is targeted for enterprise use to help track large fleects of ATVs. This document provides an overview of the components and methods used to create the PTD and discuss design tradeoffs during the design process. The PTD completed the specifications from the *Specifcation Document* and was a valid proof of concept for future Passive Tracking Device development.

The PTD is composed of four primary subsytems. These subsystems include the: Microcontroller, Cell Module, GPS Module, and Power Regulator. The microcontroller receives the raw GPS data from the GPS Module, converts this data into a human friendly form, and composes and transmits an SMS message to a pre-determined cell number. For further details see the Methods section of this document.

Although originally developed for enterprise use throughout the design of the PTD it has been realized that the PTD can also function just as well for personal use for tracking both ATVs and full-sized vehichles. The price of the PTD and cell service are inexpensive enough for the general public as well as small and large businesses.

2 Introduction

There are many businesses that use ATVs (All Terrain Vehicles) to accomplish their work. These businesses range from contruction companies to civil engineering firms, to the National Forest Service. Many times the larger the company the harder it is to manage the fleet of vehicles. The task of keeping track of these vehicles is further compounded by human error as well as geographical isolation and dispersion of resources. These businesses need a device that facilitates the management of their fleet.

2.1 Introduction

There are many tracking solutions available for public and enterprise use but they generally all have the same problem. They are active tracking solutions. This means that the vehicle being tracked can only be tracked in real-time. The client of one of these active solutions could use the monitoring software to see on a map the location and movements of the vehicles in their fleet. While there are applications where active monitoring is necessary there are some major drawbacks to such a system. Three of the largest drawbacks are:

1. Active systems require large amounts of power and physical space
2. Active systems are quite costly
3. There are applications that don't require real-time updates of vehicle location

This means that the tracking bug itself is responsible for periodically transmitting it's location to the client. From the client's side, the client can only see the last known location of the vehicle. The PTD is a passive tracking solution that is targeted to counter these drawbacks of active solutions by functioning in low-power environments that do not require real-time updates and at a reasonable cost. By targeting markets that don't require active solutions the tracking bug can be made cheaper, smaller, more power efficient, and provide a cheaper solution overall for the customer. [1]

2.2 Problem

The PTD is targeted at making this task considerably easier. The PTD, once installed in an ATV, uses the internal battery of the ATV to periodically transmit it's location to the managing individual. This will help monitor vehicle usage as well as recover vehicles in the event of theft.

3 Methods

In this section I will expound upon each of the sub-systems and explain in greater detail their function and components. The Passive Tracking Device consists of four subsystems:

- **Microcontroller** - I chose the Tiva-C TM4C123G for prototyping this project because it has plenty of serial UART communication modules as well as an internal 3.3 V generator that can be used to power the Copernicas 2 GPS Module. It is also operates in a fairly low power range.

- **Cell Module** - I chose the Adafruit FONA 1946 Cell Module. The FONA Cell Module was chosen because of it's ease of prototyping and compatability with all 2G and 3G GSM Cell Networks. It is also controlled via a UART communication module to send text messages. This Cell Module also happened to be at the most attractive price point when compared to other Cell Modules. This Module makes use of the SIM 800L cell component which was previously looked at as a viable option for this project because of it's commonality in standard cellular devices. [2]

- **GPS Module** - I chose the Trimble Copernicas 2 GPS Module. The Copernicas 2 GPS Module requires a 3.3 V voltage source for power and uses a serial UART communication module operating at 4800 BOD to communicate it's location to other systems. [3]

- **Power Regulator** - I chose to purchase the DROK Adjustable Switching Voltage Regulator for the purpose of prototyping this project. This DROK Regulator makes use of the Texas Instruments LM2596 Switching Regulator which I had previously chosen as my target regulator. This prefabricated module made the task of prototyping manageable. I also chose this power regulator because of it's adjustable functions that would later allow me to use it on other projects and because it can source a maximum of 3 amps. [4]

3.1 Microcontroller

The Tiva-C microcontroller operates at 16 MHz by default. I chose to use this default setting of 16 MHz because a higher clock frequency was not necessary and if I had increased it then it would have

[1] See the Problem and Objectives sections of this document for information regarding this topic.

[2] Included in this subsystem of the project it should be noted that a small lithium ion battery for transmission power stability, an SMA ducbill cell antenna, and a uFL to SMA adapter are required to complete this subsystem.

[3] Note that this subsystem requires a GPS antenna that uses the common SMA connector. This is in addition to the Cell Module antenna because the two antennas operate on very different bands of communication.

[4] The PTD does not come close to 3 AMPs but I wanted this feature for future prototyping

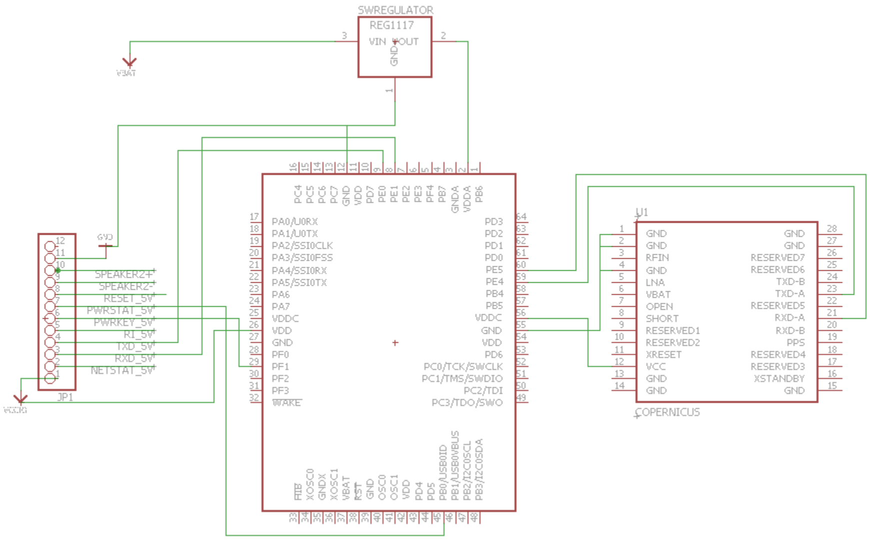

Figure 1: PTD Wiring Diagram

required more power. I chose to activate three of the available eight UART communication modules for the PTD. I needed one UART module for each of the following: receive GPS location from GPS Module, send formatted GPS location as a message to the Cell Module for SMS tranmission, and one to allow the client easy cell number destination configuration for text messages. I chose to use interrupts instead of pulling a status bit for each of the UART modules to make code more understandable and maintainable. To better understand how the microcontroller is connected to the other components of the PTD please see Figure: 1.

3.2 Cell Module

The Adafruit FONA 1946 Cell Module has a BOD detecting UART module that detects the transmission speed from the communicating system and replies at the same speed. Because of this convenient feature I used 4800 BOD to communicate with the Cell Module because the GPS Module requires 4800 BOD. This allowed me to simplify my configuration for all UART modules by using the same speed configuration. This module uses the common AT command set to control cellular functions. To connect to a valid US cell network a pre-paid T-Mobile SIM card was purchased because of the low price point and lack of annual contract. This SIM card costs 10 cents per message. With this cost the PTD can send an SMS message update once every 8 hours for only 30 cents a day. This is much cheaper than other options on the market today.

3.3 GPS Module

The Trimble Copernicas 2 GPS Module works well because of it's easy "plug and play" set up. Upon receiving power this module initializes and after a few seconds begins to transmit locational data every second at a rate of 4800 BOD. The microcontroller is responsible for parsing this string and translating it into a more human readable GPS location to be sent via SMS to the client.

3.4 Power Regulator

I selected the LM2596 Texas Instruments Switching Regulator because of it's low-idle power loss as well as it's voltage range and current operating output. When looking to buy the individual LM2596 components the spec sheet made it clear that external capacitors, inductors, diodes, resistors, and potentiometers needed to be purchased separately in their desired configuration in order to correctly control the output voltage of the Switching Regulator. To avoid this headache during the prototyping phase I opted to buy the DROK Switching Regulator which comes preassembled with the desired components. Both the microcontroller and the Cell Module require a 5V source to operate. The LM2596 regulator provides this necessary voltage regulation from a typical ATV battery which normally are 12V 11Ah batteries. From the beginning switching regulators were preferred over linear regulators due to the improved power characteristics from a switching power regulator. The constant power dissipation of a linear regulator makes them undesirable for low power operation.[5]

4 Results

This section outlines the requirements and results of the tests for those requirements.

4.1 Item Definitions

The PTD consists of 4 main subsystems, namely:

- Cell Network Interface
- Global Positioning System
- Controller Circuit
- Power Converter/Regulator

The PTD system will be a passive system, meaning that the PTD will power down to a very low power state while not in use. At an appointed trigger it will power up and transmit it's location to the PTDs owner via a cell network. There is no plan for the owner of the PTD to be able to activate the device externally. The PTD shall opperate in this power-up, transmit location, power-down sequence.

The PTD designed follows the block diagram in Figure: 2 which shows that all sub-system functions have been used to complete with the clients expectations.

4.1.1 Interface Description/Functional Block Diagram

The PTD used a micro-controller to act as a intermediary logic location for the signals between the GPS and Cell Module. All UART communication used in the project is configured to run at 4800 BOD. The block diagram of the PTD can be seen in Figure: 2.

4.2 Characteristics

The following section provides a technical summary of the PTD's characteristics.

[5] This is a part of the PTD that would need to be custom manufactured on a large scale manufacturable PCB

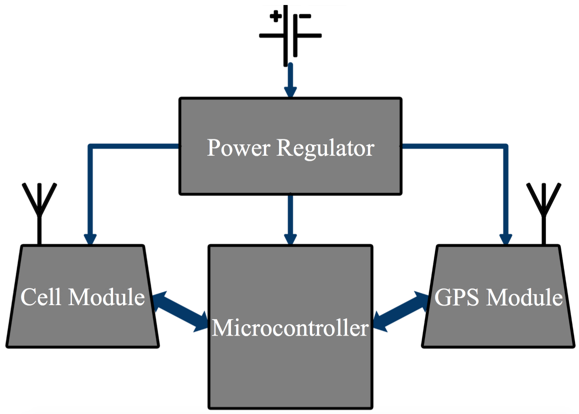

Figure 2: PTD Block Diagram

4.2.1 Performance Characteristics

To comply with the specification document the PTD must complete tests or justify adaquitly that the device will complete the tests at a later stage of developement.

4.2.1.1 Physical Characteristics

The PTD shall meet the following physical requeirements:

4.2.1.1.1 Form Factor

The PTD shall conform to the following form factor: 16cm by 8cm by 5cm.

Test - The PTD shall be placed in an small box of dimention stated in requirements.

Result - Failed: The PTD measures 10.5cm by 6.5cm by 5.5cm. These dimensions do not fit inside a box of the specified dimensions.

4.2.1.2 Electrical Characteristics

The PTD shall meet the following electrical requirements:

4.2.1.2.1 Power Constraints

The PTD shall operate using the power provided by a standard ATV battery, specifically, 12V 11Ah battery.

Test - The PTD shall function with only the power provied by an ATV battery. The PTD shall also be tested while the ATV's engine is actively running and under normal operation. requirements.

Result - Passed: After hooking the PTD to the ATv it functioned properly using only the ATV battery.

4.2.1.2.2 Prototype Connections

For the purposes of proof of concept the PTD may make use of a breadboard to connect the components.

> **Test** - The PTD shall have connections that function, The design of these connections is not specified in the *Specification Document*. requirements.
>
> **Result** - Passed: The manner of connecting the components together was not specified and therefore is an automatic pass.

4.2.2 Environmental Characteristics

4.2.2.1 Natural Characteristics

The PTD shall meet the following natural evironmental characteristics. The PTD shall meet the requirements of this specification during and after exposure to any combination of any of the following natural environments. The PTD may be packaged to precluded exposure to any environments that would control the design.

4.2.2.1.1 Temperature Rating

The PTD shall function between 0° C and 40° C.

> **Test** - The PTD shall be tested for full functionality at both ends of the temperature spectrum. requirements.
>
> **Result** - Passed: The PTD was tested at the high of 40° C and the low of 0° C. It passed under both conditions.

4.2.2.2 Induced Environment Characteristics

The PTD shall meet the following induced evironmental characteristics. The PTD shall meet the requirements of this specification during and after exposure to any combination of any of the following induced environments. The PTD may be packaged to precluded exposure to any environments that would control the design.

4.2.2.2.1 Shock Test

The PTD shall withstand mechanical shocks of 3 ft drop test 5 times onto concrete.

> **Test** - The PTD shall function after the drop tests. requirements.
>
> **Result** - Passed: The PTD functions after drop test.

4.2.2.2.2 Vibration Test

The PTD shall withstand vibrations of 1 ocilations per second with an amplitude of 1.5cm for 1 hour.

> **Test** - The PTD shall function after the vibration test is performed. requirements.
>
> **Result** - Passed: The PTD functions after vibration test.

4.2.2.2.3 Dust Test

The PTD shall function in a dusty environment, specifically, the shock and vibration tests shall be repeated after 15 grams of fine sand is applied to the device.

> **Test** - The PTD shall function after the dust test is performed. requirements.

> **Result** - Passed: Shock and Vibration tests were repeated after applying dust and PTD continues to function.

4.3 Electromagnetic Interference

The EMI shall be measured and shall meet the requirements found in

- The United States (US) FCC Part 15-2008.
- Canada's Industry Canada ICES-003:2004 Issue 4.

This is to allow for legal manufacturing and usage is the United States and Canada.

5 Discussion

This section is designed to discuss the *Results* section of this document. The methods of testing and possible design modifications resulting from testing will also be covered here.

5.1 Characteristics

The following section provides a technical summary of the PTD's characteristics pertaining to the *Results* section.

5.1.1 Performance Characteristics

To comply with the specification document the PTD must complete tests or justify adaquitly that the device will complete the tests at a later stage of developement.

5.1.1.1 Physical Characteristics

The PTD shall meet the following physical requeirements:

5.1.1.1.1 Form Factor

The PTD shall conform to the following form factor: 16cm by 8cm by 5cm.

This is the single section from the *Specification Document* that was not achieved durring the testing phase of this project. After talking to the client it was desided that the reason for the specified dimmensions was to allow for a prototyped solution. When this project moves to the next phase of developement where custom PCBs will be manufactured with all of the components on the same board the form factor will be well within the needed size constraints for this project. It was therefore decided not judge this project as a failure as a result of failing to meet the form factor requirements.

5.1.1.2 Electrical Characteristics
The PTD shall meet the following electrical requirements:

5.1.1.2.1 Power Constraints
The PTD shall operate using the power provided by a standard ATV battery, specifically, 12V 11Ah battery.

The PTD was designed with these power constraints in mind and it is able to operate given an ATV battery. It should be noted that the PTD expects that the ATV battery is in good working condition. Oridinally when testing the PTD the Battery functioned perfectly. This was back in September. As temperatures in Logan began to drop the upon ingition of my motorcycle the PTD began to reset itself. This was caused by the momentary drop in the power provided to the PTD from the battery. This is not a flaw in the PTD but an example of the importance of using a ATV battery in good working condision. My Motorcycle batter is about 5 years old and should soon be replaced.

5.1.1.2.2 Prototype Connections
For the purposes of proof of concept the PTD may make use of a breadboard to connect the components.

Originally the PTD was prototyped using a bread board but for reasons that will be discussed in the *Drop Test* section the design of the prototype was altered to use perf-board to better secure connections between components. This completes and exceeds the specifications.

5.1.2 Environmental Characteristics

The following sections outlines the Environmental Characteristics associated with the PTD.

5.1.2.1 Natural Characteristics
The PTD shall meet the following natural evironmental characteristics. The PTD shall meet the requirements of this specification during and after exposure to any combination of any of the following natural environments. The PTD may be packaged to precluded exposure to any environments that would control the design.

5.1.2.1.1 Temperature Rating
The PTD shall function between 0° C and 40° C.

These tests were done at very different times of the developement. The hot test of 40° C was done in late September and the cold test of 0° C was done in December. To complete with the hot test I created a chamber out of a cardboard box. I used my wifes hair dryer as the heat source, and here instant read cooking thermometer to verify the temperature. I then ran the GPS antena out the window and verified that at 40° C, which is 104° F, the tracking bug functioned. The cold test was a little less involved. I waited until a cold winter night and took the PTD out to my patio and left it for 3 hours. The PTD functioned fine durring and after each of these tests.

5.1.2.2 Induced Environment Characteristics

The PTD shall meet the following induced evironmental characteristics. The PTD shall meet the requirements of this specification during and after exposure to any combination of any of the following induced environments. The PTD may be packaged to precluded exposure to any environments that would control the design.

5.1.2.2.1 Shock Test

The PTD shall withstand mechanical shocks of 3 ft drop test 5 times onto concrete.

This test was pretty straight forward. My plan was to drop the PTD on my kitchen floor which is concrete as see what happend. I was a little hesitant because at the point of this testing the PTD was still developed using a bread board. Upon dropping the PTD the components and wires practically exploded out of the bread board. They still functioned after the reconnection of all the components but because of this experiment and to make the PTD more compact and clean looking I used perf-board to create a new more permainant structure for the PTD. The rest of the drop tests were completed after the change of structure and were more successful.

5.1.2.2.2 Vibration Test

The PTD shall withstand vibrations of 1 ocilations per second with an amplitude of 1.5cm for 1 hour.

This test was the worst test for me to complete because it took my active attention for a solid hour. Luckily I used this time to catch up on one of my favorite tv shows during the time that I was shaking the PTD. The PTD functioned fine after this test. This test was done after the perf-board modifications. [6]

5.1.2.2.3 Dust Test

The PTD shall function in a dusty environment, specifically, the shock and vibration tests shall be repeated after 15 grams of fine sand is applied to the device.

Like most American households I didn't have a food scale available so I used a little math to estimate the volume of dirt necessary to represent 15 grams. I know that 4 grams of sugar is about one teaspoon. Using this rough estimate I used my wife's measuring spoons[7] to gather 4 teaspoons of dirt which I placed in a box with the PTD. I then closed up the box and repeated the shock and vibrations tests. I modified the vibrations test this time to avoid having to manually shake the PTD for an hour, so I placed the PTD and dust box on our dryer and did some laundry. This simulated the same vibration time as the manual test did earlier in the testing phase. I then used an air compressor to clean off the PTD before verifying that the PTD worked and function was not degraded by the stress.

[6] It is actually a lot harder than expected to shake something for an hours straight.
[7] I don't think my wife enjoys it when my experiments infringe on her cooking utensils.

5.2 Electromagnetic Interference

The PTD was create with components that all comply with the electromagnetic interference standards described in

- The United States (US) FCC Part 15-2008.
- Canada's Industry Canada ICES-003:2004 Issue 4.

and because the normal function of the components was not changed the completed project also conforms to with these standards without needing to be tested.

5.3 Project Schedule

The PTD schedule changed drastically during the design process. This was in part due to being away from school and not having the labs and equipment available but also that I lost steam in the summer and took a month break. Figure: 3 shows the initial schedule which also left room for the some extra developement such as an enclosure and a web site user interface. These features would be essential if I was to immediately market the PTD but were found to be too time consuming during the school year.

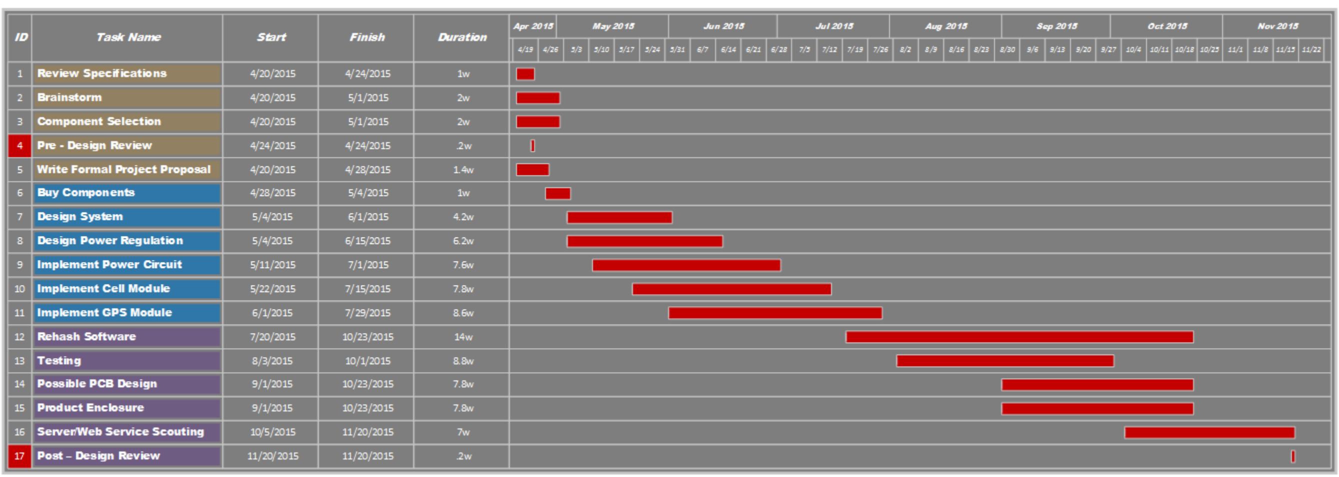

Figure 3: PTD Predicted Schedule

Figure: 4 shows the actual flow of my project with some of the un-implemented optional features removed. There were also some unforseen bugs in the code that needed to be addressed during the *Rehash* section. I was very glad that I gave myself more time than needed to finish the software. The time in between the final testing and the presentation was used to create the documents necessary for the Senior Design class.

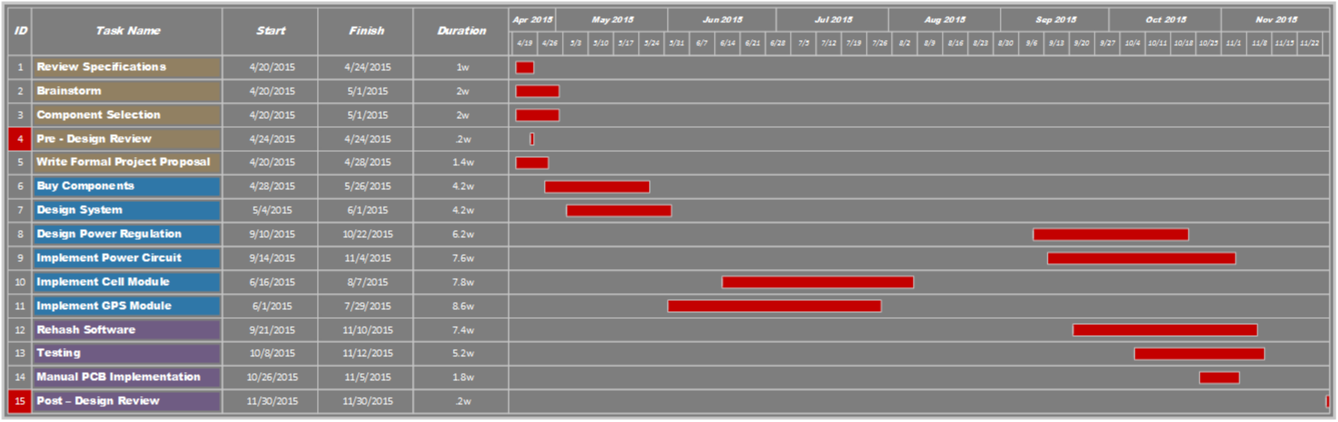

Figure 4: PTD Actual Schedule

6 Conclusion

The PTD functions well as a passive tracking solution. It also completed all of the specifications from the spec document. The PTD will also be much less space intensive when all components are manufactured on a single custom PCB. A year ago when I began looking at possible component candidates for this project there were not microcontrollers with cell functionality on a single board, but this is not the case today. There are now solutions such as the Particle Electron that are a microcontroller couples with a cell module on the same board. This would allow easier integration into a tracking device as well as lower the power necessary for the device. It would also reduce the cost. Before moving to large scale manufacturing of the PTD these new alternative components should be explored for possible cost and functionality benefits.

To complete this project I decided to make use of the Code Composer Studio (CCS) development suite. I chose CCS primarily because I had never worked with it before and decided to make use of the opportunity to become familiar with another Integrated Design Environment (IDE). This proved to be helpful and detremental to this project's success. It turns out that CCS does not play well with multi-file projects and that it incorrectly performs dynamic memory operations on the microcontroller even when it advertises that it does these operations correctly. This caused me much time and frustration debugging operations that were syntactically correct but that CCS was implementing incorrectly. To fix these problems I re-wrote many parts of this project in later phases. I think that the PTD is a valid proof of concept of cheap, low power, passive tracking devices that could be used to monitor personal and enterprise vehichles in a cost effective manner. Overall I rate this project as a success.