A Flight Data Recorder for Radio-Controlled Model Aircraft

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Declaration

I Andre Fred Du Plooy hereby declare that the following research information is solely my own work. This thesis is submitted for the requirements for the Magister Technologiae: Engineering: Electrical to the Department Electronic Engineering at the Vaal University of Technology, Vanderbijlpark. This dissertation has never before been submitted for evaluation to any educational institute.

Andre Fred Du Plooy

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- My brother in law, Mr Johan Snyman, who is a great active enthusiast of the model aircraft sport and has provided plenty of information and guidance.

Dedication

This study is dedicated to my loving wife Tanya, who has so patiently endured the course of my studies and given me the support needed to accomplish a task as time consuming and strenuous as this one, as well as supporting me in the task of life.

Abstract

In the ever growing sport of model aircraft, pilots are challenged with many obstacles. In the division of gliders, one of the biggest problems is the loss of model aircraft. Pilots launch their aircraft off mountain tops and if the aircraft crashes below, the pilot must make use of his best estimates in order to locate the aircraft. This either takes several hours, or the aircraft is never recovered. Pilots are also at a loss with regard to real time data, such as, but not limited to, battery levels, fuel levels, altitude and speed. Model aircraft competitions are also limited to the best estimate of officials.

In this work, an attempt has been made to design and develop a remote tracking device for model aircraft. This device will retrieve Global Positioning System (GPS) co-ordinates from the aircraft and relay them to the pilot on the ground. In the event of a crash, the pilot will retrieve the last GPS co-ordinates and then proceed to the location to collect the aircraft. An attempt will also be made to design add-on telemetry components that will allow for measurement and transmission of battery levels, fuel levels, altitude, G-Force, orientation, acceleration, wind and ground speed.

Some of the data retrieved from the Flight Data Recorder (FDR) in trial 1 are; maximum altitude above sea level of 2139.20 m, maximum speed over ground which was 57.34 m/s, and the average battery voltage for transceiver and servos was 15.2 V.

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3D	Three Dimensional
ASK	Amplitude Shift Keying
CPU	Central Processing Unit
FDR	Flight Data Recorder
FSK	Frequency Shift Keying
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
I/O	Input/Output
LCD	Liquid Crystal Display
LDO	Low Dropout
LIPO	Lithium-Polymer
LNA	Low Noise Amplifier
MIPS	Millions of Instructions per Second
MSK	Minimum Shift Keying
MSSP	Master Synchronous Serial Port
Ni-Cd	Nickel-Cadmium
Ni-MH	Nickel-Metal Hydride
PCB	Printed Circuit Board
PSK	Phase Shift Keying
RAM	Random Access Memory
RC	Radio Controlled
RX	Reception

SPI	Serial Peripheral Interface
TX	Transmission
UAV	Unmanned Aerial Vehicle
UHF	Ultra High Frequency
USART	Universal Synchronous/Asynchronous Receiver/Transmitter
VCO	Voltage Controlled Oscillator
VUT	Vaal University of Technology

Chapter 1 Introduction

1.1 Background

‘The Black Box: An Australian Contribution to Air Safety’ (Warren et al. 2010) was an article detailing the birth of the common day Flight Data Recorder (FDR). A Melbourne honors’ thesis entitled, “The ARL ‘Black Box’ Flight Recorder” (Sear 2001), also outlined in-depth the development of the first FDR by David Warren. According to the article, the British were experiencing several crashes with their then famous Comet, which was the first jet-powered airliner. Aircraft engineers and scientists were perplexed by the matter and several meetings were held to determine the possible causes. The article explained how Dr David Warren of Aeronautical Research Laboratories in Melbourne came up with the idea of creating some sort of protected device that could record the crew’s conversation prior to the accident. This could then be used to aid in crash investigations. In 1954 a report was written called "A Device for Assisting Investigation into Aircraft Accidents", and in 1958 Dr Warren went on to manufacture the device in a project called the “ARL Flight Memory Unit”. It could record four hours of pilot voice and instrument readings. The original device is depicted in Figure 1.

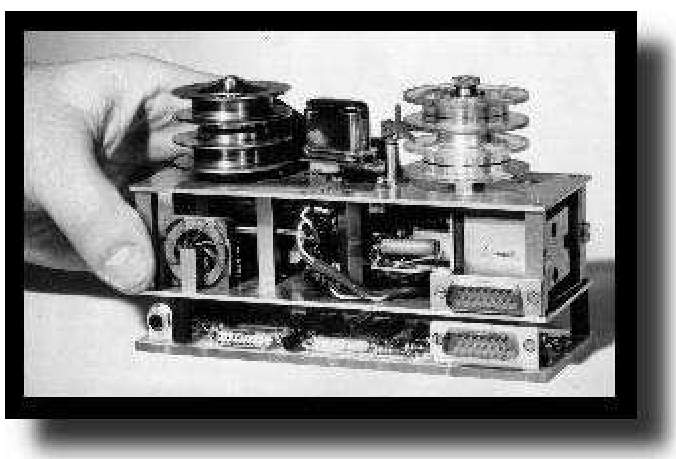

Figure 1: Dr David Warren’s 1958 ARL Flight Memory Recorder

The history of the first attempt to control an unmanned vehicle by radio waves can be traced back to Nikola Tesla in 1898 (Newcome 2004). Tesla obtained a patent for his remote control which he used on a small boat exhibited at Madison Square Garden. This patent served to be the basis for contemporary robotics. Thomas J Mueller, of the University of Notre Dame, wrote a paper “On the Birth of Micro Air Vehicles” (Mueller 2009). Muller documents the history of unmanned aerial vehicles (UAV) from early history through to modern micro air vehicles, indicating that the first successful UAV appeared to be the “Kettering Bug” developed by Charles Kettering and demonstrated by Lawrence Sperry. However, it was not remote controlled. The first successful radio control (RC) drone was demonstrated in 1934 by the Air Ministry in Britain, called the “Larynx”. Most of the interest in UAV’s came from a military perspective and large amounts of funding was generated for this purpose. The same paper references the first successful RC model aircraft flight on June 10, 1936. The first RC model aircraft contest was held in the US in 1937, with the first British RC model aircraft competition in 1949.

Research and development of these RC model aircraft has grown rapidly over the past few years, developing into a fulltime hobby for many enthusiasts (Eagle 2008:22-23; Ehlers 2008:17-18; Moolman 2008:25-26; Renecle 2008:11-13; Swart 2008:5-6). These model-sized aircraft resemble their real life counterparts in almost every detail, including avionics and aerodynamics. Sophisticated RC model aircraft, including the body and all electronics, may cost upwards of $17 500 and prove time consuming in manufacturing (Parker 2008; Snyman 2008). The pilot controls the aircraft via a remote control panel while the aircraft goes through its maneuvers below 3000 m above the ground. Sporting contests began to be staged for these RC model aircraft which raised various issues and problems that needed to be solved (Armitage 2009).

1.2 Problem statement

One of the most commonly experienced problems by RC pilots, and more specifically by RC glider pilots, is the loss of their model aircraft on the slopes of mountains or in dense forests, often requiring hours of painstaking searching (May 2007:28-34; Randolph 2007:86-94). Successfully recovering this expensive piece of equipment proves cumbersome. This is often due to the loss of radio-frequency (RF) communication (the model aircraft is pushed beyond the range of communication) or the depletion of fuel aboard the model aircraft (RC Airplane World

2010). Low battery voltage may also cause a loss of RF communication, leading to disaster and financial loss (Miller 2010:1-12).

1.3 Research Objective

The purpose of this research project is to design and develop a FDR to monitor the flight path and performance of a RC model aircraft. This will help to keep the pilot informed of the electromechanical status of all components in order to a make informed decisions during flight time. This process is highlighted in Figure 2. The recorder should have the properties of being light weight, cost-effective and easily marketable among RC model aircraft enthusiasts. Its power consumption must be relatively low to prevent unnecessary drain on the power supply aboard the model aircraft.

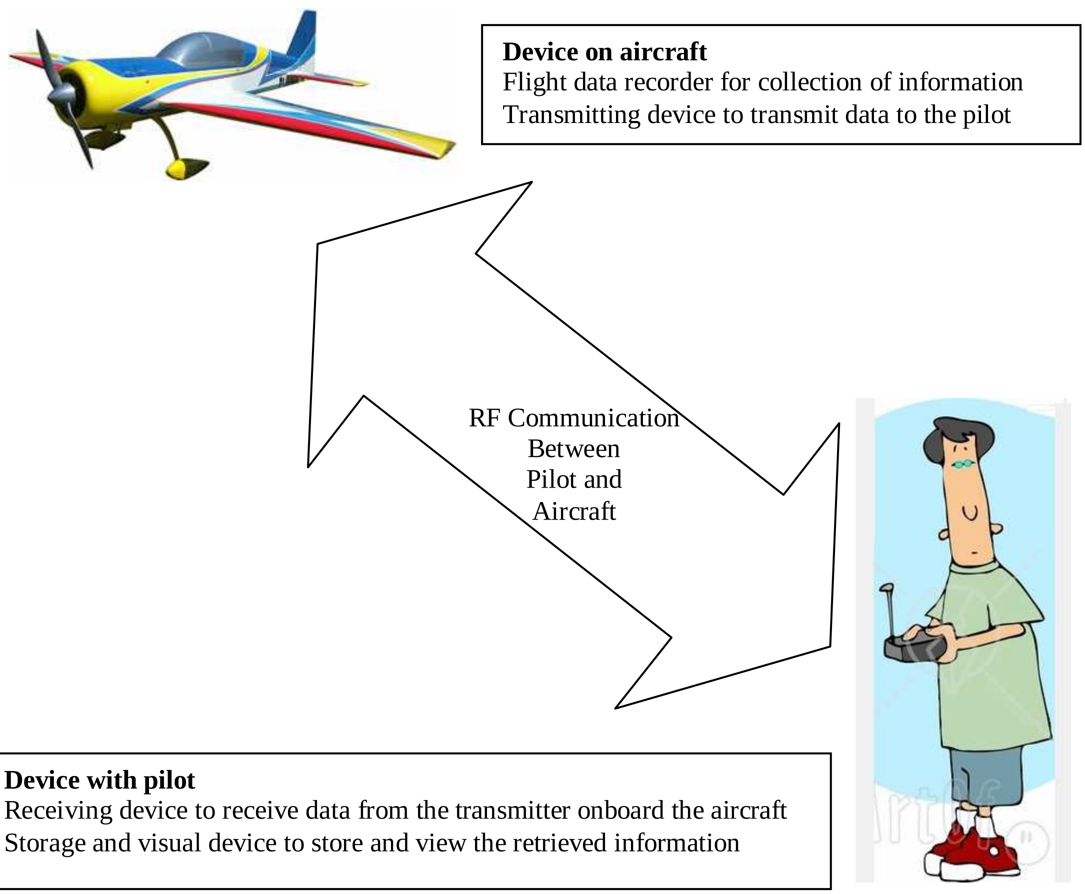

Figure 2: FDR for radio-controlled model aircraft

This FDR is designed to retrieve GPS co-ordinates from the model aircraft and relay them to the pilot on the ground. In the event of a crash, the pilot may review the last GPS co-ordinates and then proceed to the specified location to retrieve the model aircraft. The recorder transmits performance data to the pilot regarding battery voltage, fuel levels and speed. The aim of the research project is to identify components and technologies that are already available and then utilize these in conjunction with each other in order to achieve the research objective.

1.4 Important Definitions

Flight Data Recorder: An electronic device fitted to an aircraft for collecting and storing information concerning its performance in flight. It is often used to determine the cause of a crash (Collins 1982).

Tracking: Tracking involves using the information obtained from a data recorder or telemetry device to follow any moving target, device or living thing (Pratt et al. 2003).

UAV/UAS: A UAS is an unmanned aircraft (UA) with all of the associated support equipment, control station, data links, telemetry, communications and navigation equipment, etc., necessary to operate the unmanned aircraft (Federal Aviation Administration 2009).

1.5 Value of the research

This FDR for RC model aircraft will enable pilots to enhance the monitoring of the flight path, thereby detecting specific warning signs which could lead to disastrous implications. For example, the pilot could lose control of the model aircraft, if it exceeds the maximum distance of communication, which in turn will crash and subsequently incur unnecessary repair costs. These costs may be adverted if the pilot has been warned by the FDR that it is reaching the maximum distance of communication. This also holds true for fuel levels and battery voltages. Substantial financial losses may therefore be averted through use of this FDR. One other area of potential use would be in the accurate measurement of speed, altitude and flight path of model aircraft at sporting contests. This recorder has the possibility of being **patented** and manufactured locally at Vaal University of Technology (VUT) for use on other RC devices such as robots, rockets, model boats and gliders.

1.6 Outline of the thesis and the research methodology

Chapter 2 provides a theoretical analysis of current telemetry and tracking devices with regard to their cost, weight and power consumption. A comprehensive literature review was undertaken to determine which devices were light-weight and cost-effective for this research. Theoretical analysis of electronic components that are available for the research was also done. This helped determine which devices could be used to decrease the cost and weight while increasing the efficiency of the FDR. Chapter 3 presents the circuit design, by means of computer aided software, which was used to combine the FDR onto a single printed circuit board (PCB). The manufacturing of the prototype PCB is also discussed along with faultfinding procedures. Software development, for the collection of data on-board the model aircraft for processing purposes, is further discussed in this chapter. Chapter 4 covers field testing of the FDR on a model aircraft which is used in RC sporting contests. The results (cost, weight, efficiency, flight paths and performance data) of the field tests are documented in this chapter. Based on the findings from the field tests, recommendations are made in Chapter 5.

1.7 Delimitations

No attempt has been made to design a new GPS receiver for the purpose of tracking the RC model aircraft. The research project makes use of existing GPS receivers that are commercially available and that can be readily incorporated into the FDR. It was also not viable to design and build the transceiver from scratch. There are many commercial transceivers available for implementation into the FDR. Accelerometers, 3D motion sensors, orientation sensors and fuel sensors were commercially available, and were not designed.

1.8 Summary

The inability of RC model aircraft pilots to monitor live telemetry during flight time often leads to unintentional accidents or financial loss. The development of a cost effective FDR that captures telemetry and GPS information, relaying it immediately to the pilot on the ground, enables the pilot to exercise more control over the model aircraft, avoiding possible disaster and subsequent financial loss. The FDR may provide the pilot with valuable information to utilize for post-flight diagnostic purposes.

Chapter two will review the various parts of a model aircraft with regard to their functionality and operation. An investigation into current devices available on the market will also be done and a comparison of these products will be conducted. A theoretical analysis of the components required for the FDR to work correctly will further be presented.

Chapter 2 Theoretic analysis and literature survey of the Flight Data Recorder

2.1 Introduction

The main parts that make up a RC model aircraft will be discussed so as to understand their functionality. An analysis of commercially available RC model aircraft FDR devices is presented with regard to cost, application and disadvantages. Focus is then directed to electronic components and modules which are currently available in order to design and build the FDR.

2.2 Various parts of model aircraft

Figure 3 shows the various parts of a RC model aircraft. The main parts controlling a model aircraft are the ailerons, flaps, elevators and rudder. The ailerons control roll which is the movement by which an aircraft makes a rotation about its longitudinal axis without altering its height or direction. The flaps increase lift and drag, assisting in the takeoff and landing procedures by enabling the model aircraft to use shorter run ways than normally required. The elevators control the pitch of the aircraft, which is the deviation from a stable flight attitude by movement of the longitudinal axis about the lateral axis. The rudder, also known as the vertical stabilizer, controls the yaw of the aircraft, which is the movement of an aircraft about its vertical axis (Benson 2010). Figure 4 illustrates the roll, yaw and pitch of a model aircraft (Benson 2010). The engine drives a propeller which is responsible for thrust on the model aircraft, which will increase or decrease speed. Housed within the body of the model aircraft are servos which are operated on different channels and are connected to the ailerons, flaps, elevators, rudder and throttle. These servos are crucial to flight and operate with power from the battery. The operation of these servos, as well as the battery power level, need to be monitored in order to avoid power loss. Consistent monitoring of the servos as well as the battery power level needs to be maintained in order to ensure sustained flight and control of the model aircraft.

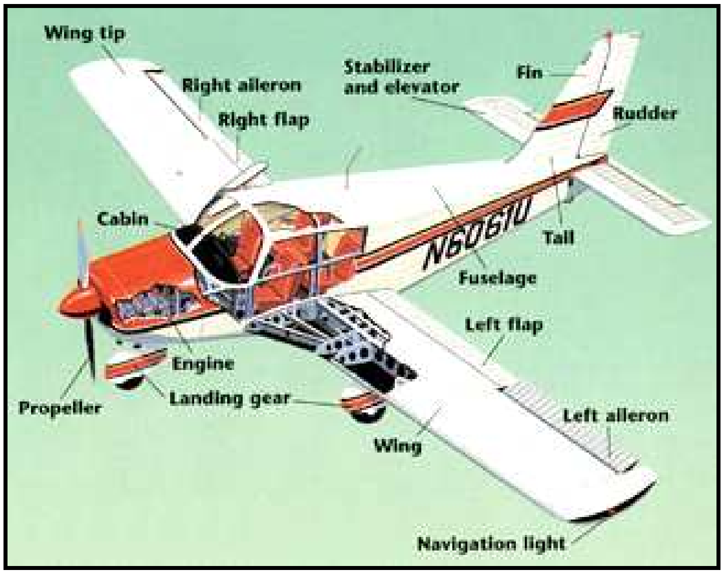

Figure 3: Parts of a RC Model Aircraft (NASA 2009)

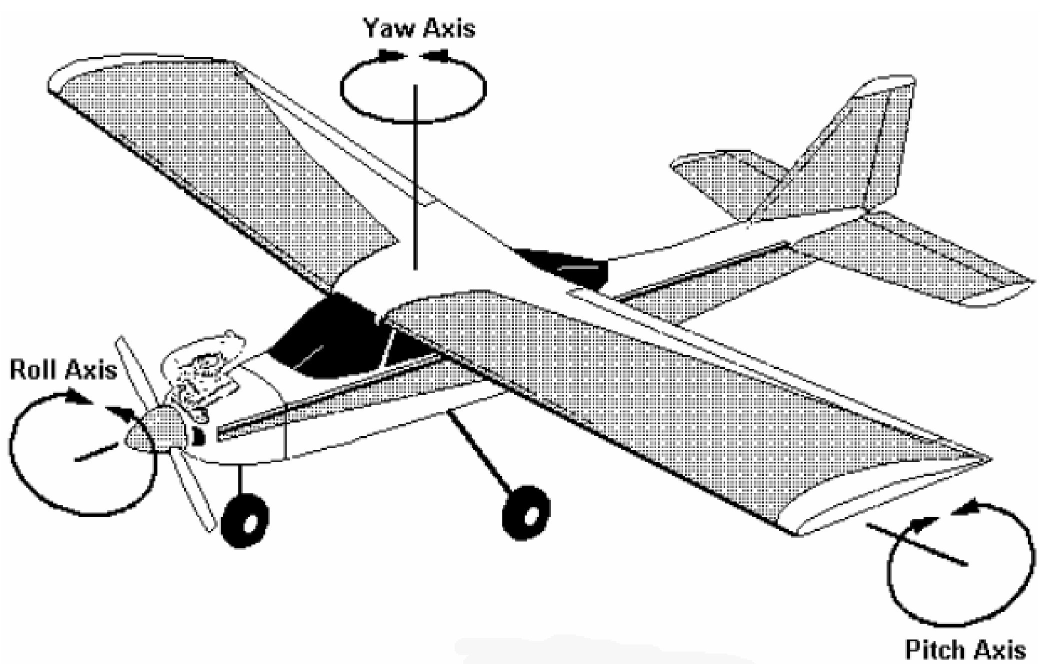

Figure 4: Aircraft axes of rotation

Sufficient fuel is required to keep the engine running and the fuel level needs to be monitored. The flight path taken by the model aircraft will determine the GPS co-ordinates and altitude. The maximum distance of the radio link between the pilot and the model aircraft will determine if the pilot will continue to have control over the model aircraft.

2.3 Literature of current devices

The following commercially available devices, some were discussed in Du Plooy (2012), make it possible to monitor the servo current and battery power. They allow for tracking of GPS co-ordinates and altitude, which can be used to calculate if the maximum radio link distance between pilot and model aircraft has been exceeded:

- Eagle Tree Telemetry System
- RC T2000
- TeKnol UAV Flight Control System (FCS)

2.3.1 The Eagle Tree Telemetry System

The Eagle Tree Telemetry System is manufactured in America by Eagle Tree Systems (2012). The device consists of an Eagle Tree Seagull Dashboard (Figure 5) and a RC-LOG Pro Data Logger (Figure 6).

Figure 5: Eagle Tree Seagull Dashboard

The Seagull Dashboard consists of an LCD for telemetry display and programming buttons for alarm alerts. The RC-LOG Pro Data Logger has multiple input connecters for various sensory inputs. It stores all telemetry data and has a transmitter which sends data to the Seagull Dashboard. The range of the standard 900 MHz transmitter is 2 km, and the 2.4 GHz allows for up to 3 km. There is also a 1 W transceiver available in the 900 MHz spectrum which has a range of 22 km which can be doubled through the use of an external Yagi-Uda antenna. The device, although limited to one way communication, does allow for 65536 unique transmission ID's which are manually programmable allowing for multiple users of the same device type. Scherre (2007:10-23) discusses the implementation of the Eagle Tree Telemetry System and comments on the difficulty encountered when importing the device from the USA. The Eagle Tree Telemetry System allows for several add-on sensors for telemetry monitoring. These include exhaust gas temperature, G-force input, servo inputs, altitude sensor, airspeed sensor, battery voltage, RPM sensor and temperature sensor. It also allows for a GPS module. Several technical reviews have been written regarding the Eagle Tree Telemetry System (RCGroups.com 2009a; RC-LOG 2010) and it seems to be the most recommended RC FDR on the market. The components and accessories required for the Eagle Tree Telemetry System to conform to the requirements of this research project would be; the Dashboard, the RC-LOG pro data logger, GPS module, motor sensor, electric expander, servo current logger and G-force expander. Table 1 shows the specifications for the Seagull Telemetry System.

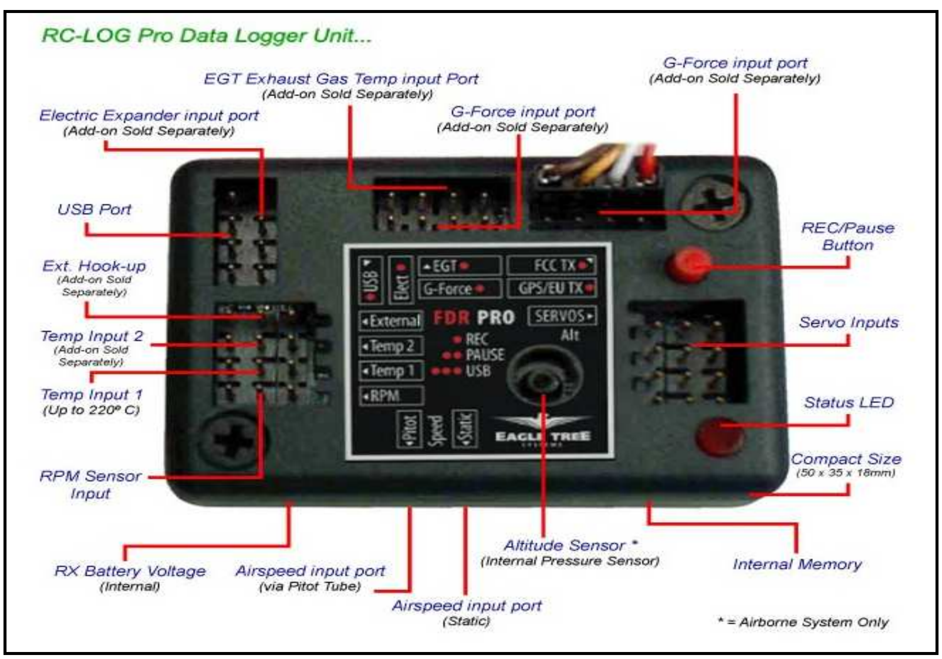

Figure 6: Eagle Tree RC Log Pro Data logger

Table 1: Eagle Tree Telemetry System Specifications

Operating Voltage	4.35 V – 7 V DC
Power Consumption	<35 mA at 4.8 V
Frequency Range	900 MHz 2.4 GHz
Operating Range (Line of Site)	900 MHz ±2 km 2.4 GHz ±3 km
Altitude Measurement	0 – 9600 m
Speed Measurement	6 km/h to 467 km/h
Dimensions	50 mm x 35 mm x 17 mm
Weight	43 g
GPS Module Type	n/a
GPS Co-ordinates	n/a
Average System Cost	$394.98 for the 900 MHz $544.98 for the 2.4 GHz

The Seagull Tree Telemetry system has been used by the Colorado University Design-Build-Fly team and has been documented in their report (CUDBF 2007:88). Although the Eagle Tree Telemetry System has many features and is widely used, it has some disadvantages that have been identified especially for the South African market. The main disadvantage would be the cost of the system, which is above the average South African model aircraft enthusiast's budget, not to mention import costs and duties. The one way communication is also a severe limitation.

2.3.2 RC T2000

RC Electronics (2009) provides another real time FDR being the RC T2000 (Figure 7), which is used in conjunction with the RC Altimeter #3 PRO (Figure 8). The RC T2000 allows the connection of the RC GPS (Figure 9). The RC T2000 operates on a 433 MHz two way communication link. The range is stated as being more than 1 km. The specifications of the RC T2000 are shown in Table 2.

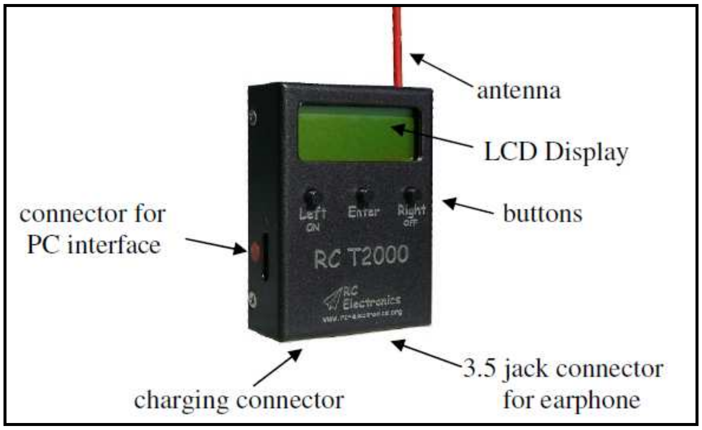

Figure 7: RC Electronics RC T2000

Table 2: RC T2000 Specifications

Operating Voltage	4 V to 20 V DC
Power Consumption	76 mA
Frequency Range	433 MHz
Operating Range (Line of Site)	±1 km
Altitude Measurement	-3100 m – 3100 m
Speed Measurement	n/a
Dimensions	Logger = 33 mm x 20 mm x 9 mm GPS = 19 mm x 19 mm x 7 mm
Weight	17 g
GPS Module Type	Unknown
GPS Co-ordinates	n/a
Average System Cost	$556.25

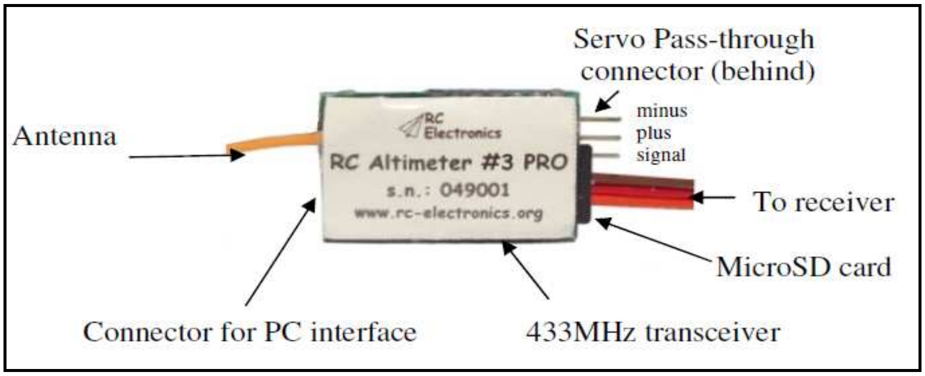

Figure 8: RC Electronics RC Altimeter #3 PRO

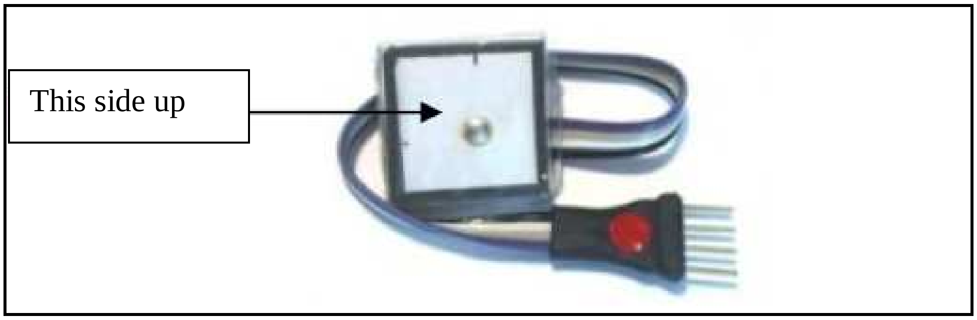

Figure 9: RC Electronics RC GPS

The RC T2000 has a very high cost and caters more for the high end model aircraft enthusiast. It also has the logistical problems and financial costs associated with importation, similar to the Seagull Telemetry System.

2.3.3 The TeKnol UAC Flight Control System

The TeKnol UAV Flight Control System with INS/GPS (Figure 10) differs from the previous two systems in one specific point, being that it was specifically designed as an autopilot module. In order to operate as an autopilot, it would require all the telemetry data in order to make the correct calculations. It consists of an autopilot board which houses the microprocessor responsible for calculations and decisions. In its default configuration, it uses five channels to control the ailerons, rudder, elevator, throttle and manual/automatic flight control switch. The TeKnol specifications are shown in Table 3.

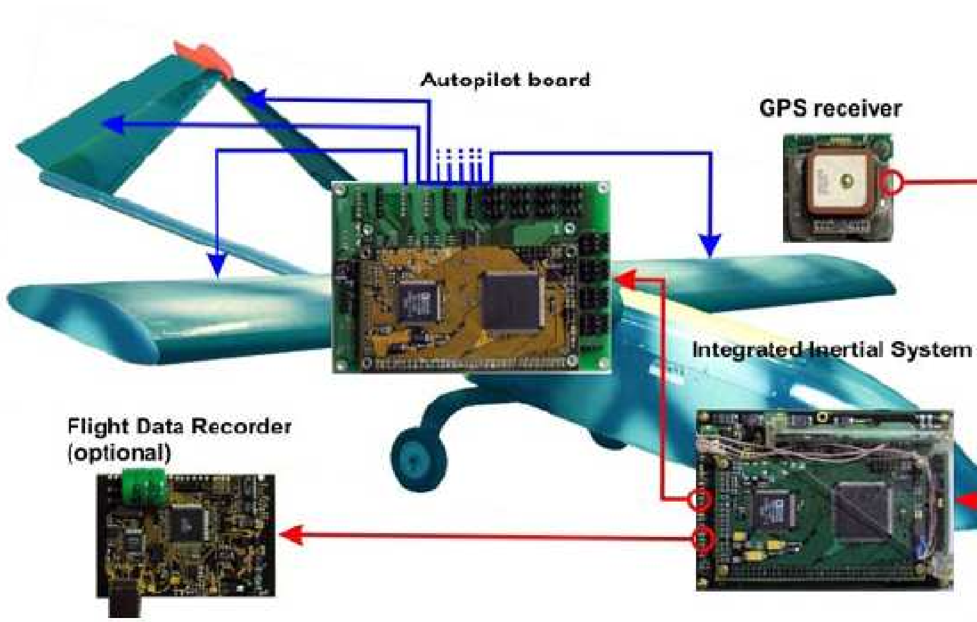

Figure 10: FCS - UAV Flight Control System with INS/GPS (TeKnol 2009a)

Table 3: The TeKnol UAC Flight Control System Specifications

Operating Voltage	12 V to 27 V DC
Power Consumption	185 mA
Frequency Range	n/a
Operating Range (Line of Site)	±1 km
Altitude Measurement	0 – 6000 m
Speed Measurement	n/a
Dimensions	153 mm x 73 mm x 56 mm
Weight	320 g
GPS Module Type	Trimble Lassen IQ GPS receiver
GPS Co-ordinates	WGS-84
Average System Cost	$827.32

The TeKnol system is targeted more specifically at the UAV market and is not suited to the average model aircraft enthusiast. The main purpose of model aircraft is to control it manually, determining the flight path aerial manoeuvres by choice. The TeKnol system caters more for autopilot scenarios associated with UAV flight. The device is also more costly as it focuses more on military and research applications. An advantage of the system is that, if desired, it can be implemented as a failover autopilot system that could possibly assist in crash prevention. It has been tested successfully in five different aircrafts (TeKnol 2009b).

2.3.4 Comparison of three current systems

The advantages and disadvantages of each system can been seen in Table 4.

Table 4: Comparison of current devices

FDR Device	Advantages	Disadvantages
Seagull Telemetry System	Multiple Telemetry Interfaces Long Range (2 – 3 km)	Cost One way communication Must be imported
RC Electronics RC T2000	Light Weight	Cost Must be imported
The TeKnol UAC Flight Control System	Auto Pilot Function	UAV Specific Applications Cost Must be imported

The main disadvantages of the three devices are the cost and the fact that they need to be imported into South Africa. This places them out of reach of the average model aircraft enthusiast. Based on these factors, it was decided to design and build a new package that can be locally produced at a low-cost making it available for all local model aircraft enthusiasts. This will allow for customized development and additional peripherals after production and implementation. The prototype package will be sufficient to cater for the most basic FDR, but will provide a platform on which many more features can be developed.

Having evaluated the three different devices and features which were listed in Tables 1, 2 and 3, focus now shifts to devices that can be housed on-board the model aircraft as the size, weight and power consumption is critical.

2.4 Theoretical analysis of components

Figure 11 shows the basic layout of the proposed FDR for the aircraft and Figure 12 highlights the pilot device on the ground. Each of these sections will be discussed consecutively.

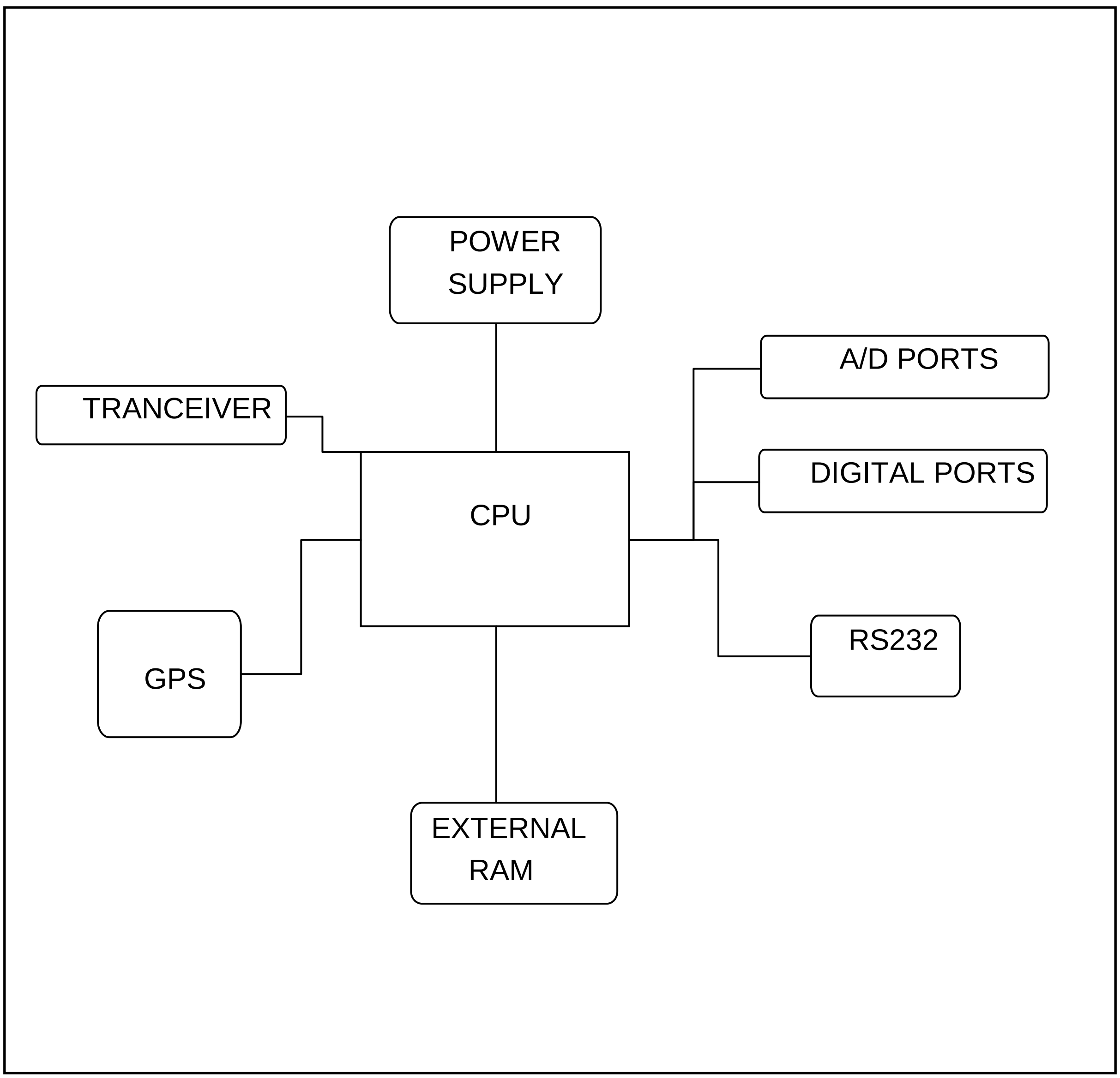

Figure 11: Basic FDR model aircraft layout

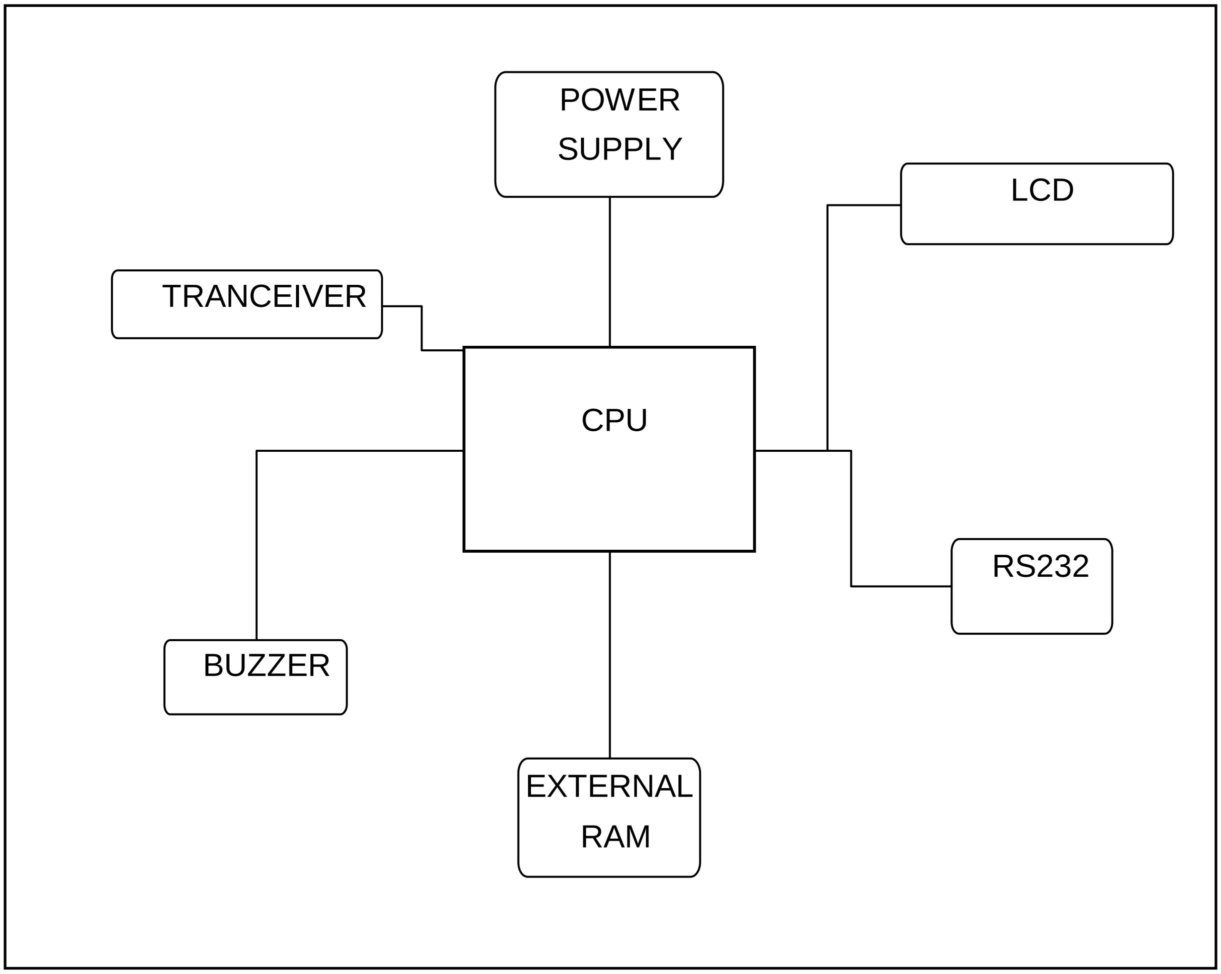

Figure 12: Basic FDR pilot control layout

2.4.1 GPS module

GPS modules have become very small and compact and their power consumption has been reduced drastically. Current advances in Global Navigation Satellite Systems (GNSS) allow for very small GNSS receivers with high sensitivity. There are currently three GNSS systems available; the GPS system (USA), the Global Navigation Satellite System (GLONASS) from Russia and the GALILEO from the European Union (Zogg 2006). The GNSS system has three segments. Firstly, there is the space segment which comprises all satellites in the system; secondly, there is the control segment which consists of all ground stations involved in the monitoring of the system; thirdly, the user segment, which consists of all military and civilian users. The GNSS module forms part of the user segment. An overview of the three available systems is depicted in Table 5. A basic block diagram of a GNSS module is shown in Figure 13, courtesy of U-Blox's Essentials of Satellite Navigation (Zogg 2006).

Table 5: Overview of three GNSS systems (Zogg 2006)

	GPS	*Glonass*	*GALILEO*
Start of development	1973	1972	2001
1st Satellite Launch	Feb. 22, 1978	October 12, 1982	December 28, 2005
Number Satellites	Minimum: 24 / Maximum: 32	Planned: 24 + 3 passive reserves	Planned: 27 + 3 active reserves
Orbitals	6	3	3
Inclination	55°	64.8°	56°
Altitude	20,180 km	19,100 km	23,616 km
Orbital Period	11 hours 58 min	11 hours 15.8 min	14 hours 5 min
Geodetic Data	World Geodetic System 1984 (WGS 84)	Parametry Zemli 1990 (PZ-90)	Galileo Terrestrial Reference Frame (GTRF)
Time System[10]	GPS-Time	Glonass-Time	GST (GALILEO System Time)
Signal Characteristic	CDMA[11]	FDMA[12]	CDMA
Frequencies	2 frequencies, with with a 3rd frequency planned	24	2 frequencies, with with a 3rd frequency planned
Encryption	Military Signal	Military Signal	CS and PRS services
Services	2 (civilian + military) / 4	2 (civilian + military)	5
Responsibility	US Department of Defense	Russian Defense Ministry	Civilian Governments of the EU
Integrity Signal	Currently none but planned	none	Planned

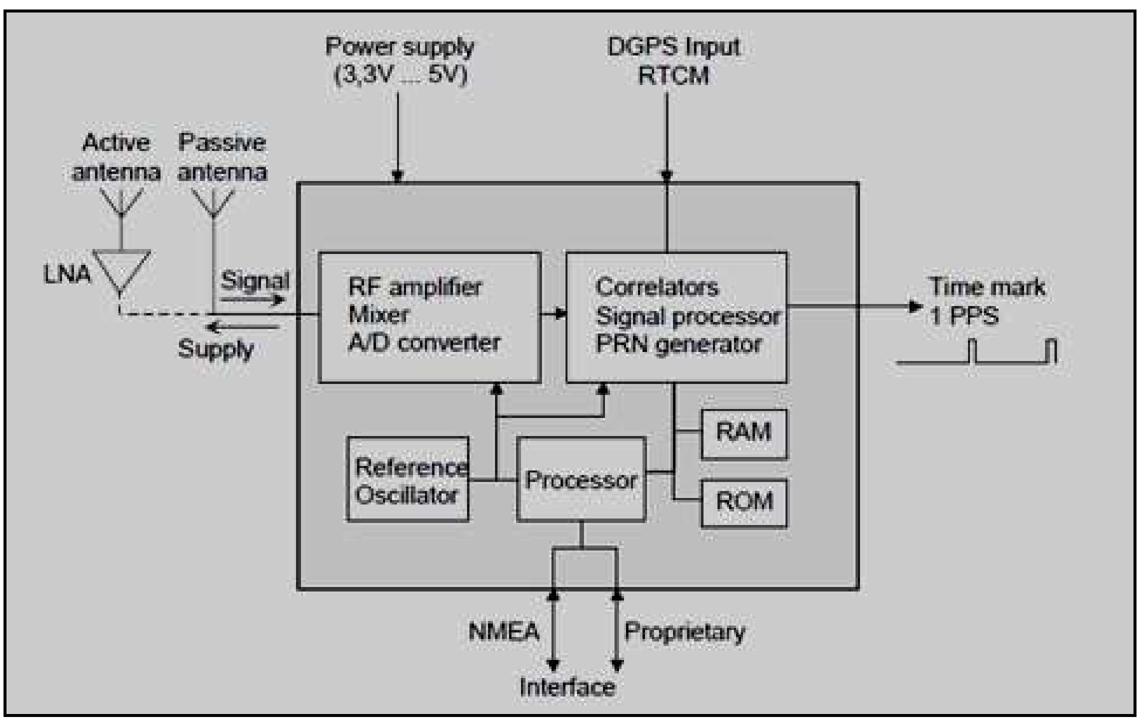

Figure 13: Block Diagram of a GNSS module (Zogg 2006)

GNSS modules attempt to capture the weak signals from a minimum of four satellites and then use this to determine 3D (three dimensional) positioning. It also captures the time signal sent. From this data, other variables, such as speed and acceleration can be calculated. The GNSS module plays the most crucial role in the FDR, as it is the primary means by which the GPS co-ordinates of the model aircraft will be obtained. The following GNSS models available from U-blox: LEA-5, NEO-5, TIM-5H have been chosen as they have been successfully used in GPS navigation (Coopmans et al. 2008:3).

2.4.2 Central Processing Unit (CPU)

The microprocessor is the heart of the design. It is primarily responsible for the operation of all modules and sensors connected to the FDR. It is also be the "brain" of the device. It is responsible for the setup and initialization of all connected components. It also retrieves all necessary information required to determine GPS co-ordinates and sensory levels. It runs pre-calculated programs and then translates this information into data that can be displayed on a Liquid Crystal Display (LCD), and also stores data in memory for later use. Most microprocessors are available with high computational performance, low economical pricing and low power consumption. Recent advances in technology have also paved the way for very small size microprocessors. PIC16C5X, PIC16F877, PIC18F1220/1320, PIC18F2X1X/4X1X & PIC18FXX20 are ranges of microprocessors available from Microchip. The PIC 18F (Yu-zhuang et al. 2009:1) series and PIC16F877 (Qian et al. 2007:1584-1587) series have proven reliable by other researchers.

2.4.3 External memory

The flash memory required for external data storage has been the easiest component to integrate into the FDR. The high demand for memory storage devices across a wide range of industries has led to compact and low cost flash memory chips. The primary function of the flash memory is the storage of all data obtained and processed by the microprocessor. Details of flash memory devices can be obtained from Spansion (2009), Intel (2009), Silicon Storage Technology (2009), Macronix (2009), ST Microelectronics (2009) and Atmel (2009).

2.4.4 Transceiver

The transceiver forms the vital part of communication, transmitting data between the microprocessor on-board the model aircraft and the microprocessor on the ground with the pilot. The high demand for wireless communication in security, information technology, programmed logic controllers, production lines and many other industries has led to compact and low cost transmitters, receivers and transceivers. A basic block diagram of a typical transceiver is shown in Figure 14. Most transceivers available on the market have a self-contained module with a Serial Peripheral Interface (SPI) for programming and setup requirements.

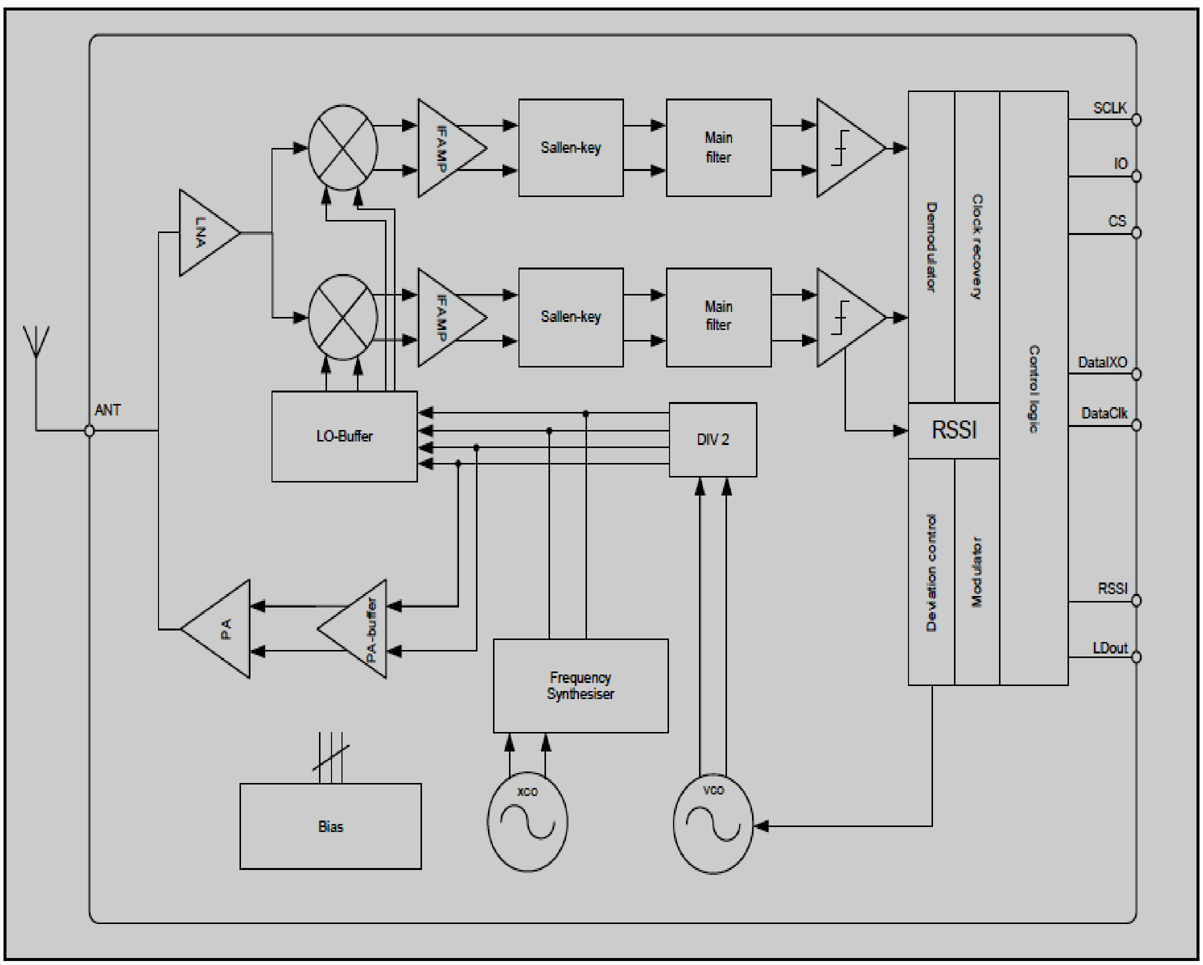

Figure 14: Block Diagram of a Micrel MICRF620 Transceiver (Micrel 2009)

The SPI port is connected to a SPI port on the microprocessor. There is also an I^2C port which is connected to the microprocessor and carries all data that is to be sent or received via the transceiver. Although most transceivers have built in band-pass filters, additional external filters can be implemented to help reduce unwanted noise. The Micrel MICRF620 transceiver was suggested by the engineers of Sabertek due to their success experienced using this module in RF applications (Petkovski 2008).

2.4.5 Power supply

The power consumption of the FDR must be kept at an acceptable level in order to drive all components efficiently and to ensure that power consumption can be sustained for the duration of a planned flight. Currently, there are many types of batteries available on the market that may be used for the power supply. The type to be used will depend largely on the application. There is the standard primary cell or dry batteries, such as Zinc-Carbon or the longer lasting Alkaline types. The latter types are used extensively in household appliance due to their availability and low cost. These are not suitable for the FDR, as they can only be used once and then must be discarded. Furthermore, they only have a limited yield of energy. Then there are the secondary cells or rechargeable batteries which include the Lead-Acid, Nickel-Cadmium (Ni-Cd), Nickel-Metal Hydride (Ni-MH) and Lithium-Polymer (Lipo). The demand for highly stable and efficient power supplies has led to the availability of small size and low cost semiconductor devices and integrated circuits required for power supply design. Ni-Cd and Ni-MH batteries can be recharged 600 – 800 times (Practical Action 1994). While the Ni-Cd batteries can stand up to more abuse, the Ni-MH batteries have a higher capacity/weight and are more environment friendly. Lipo batteries have a better charge retention, discharging when not in use at 5% per year. However, overcharging can cause explosions and short circuits will cause fires. Taking into account the features of the rechargeable batteries available, it was decided to use Ni-MH batteries for the FDR. The Ni-MH has led to an eco-friendly, high capacity and long life battery which aids in the design of reliable portable digital devices (Windarko et al. 2010:181-186). Sensory devices are readily available for all types of applications in the electronics industry. The sensory devices required for the FDR can easily be selected out of the vast pool of resources from many current manufacturers.

2.5 Summary

The fundamental components of RC model aircraft have been analyzed. The operation of these parts and their relation to flight has been clarified. The basic functionality of the FDR has been established and the reason for its emergence identified. The current availability of model aircraft FDR has been investigated and was reviewed according to application, pricing and complexity. The components that make up the basic FDR have been discussed so as to understand what is required to enable the design of a FDR for RC model aircraft. The next chapter covers the actual design of the FDR in full detail.

Chapter 3 Design of the Flight Data Recorder

3.1 Introduction

Commercially available data recorders and the critical parts of a model aircraft were presented in chapter 2. The functionality and disadvantages of these commercially available data recorders were mentioned along with the need for a stable, light-weight, efficient and cost effective FDR for this research project. In this chapter, the design procedure for each component required for the complete FDR is discussed in detail with regard to functionality and purpose. The schematic diagram of the physical layout will be shown from conception to final Printed Circuit Board (PCB).

3.2 Design analysis

The three crucial components of the FDR are the microprocessor, the GPS module and the transceiver (see Figure 15). The microprocessor is the central point of the system connected to the GPS module, memory storage, transceiver and other sensory devices. The microprocessor must handle all the programming code while the GPS module handles all the GPS co-ordinates, speed and altitude calculations. The transceiver relays all gathered information to the ground unit for storage on the external memory device. Other sensory devices aid with acceleration, fuel level and battery level indications.

3.3 The preferred design

It was decided to first produce a development board four times larger than the final PCB that would to be installed into the model aircraft. This decision was taken so that it would make it easier to troubleshoot design flaws on the PCB and also allow for future alternative product development. The PCB for both the transmitter (on the model aircraft) and receiver (with the pilot) were made identical, in order to simplify the design and initial troubleshooting. The development board further served as a platform for future development and allowed for quick and easy modification of the design as required. The development board contains a microprocessor, power supply, GPS module, external RAM for storage purposes, general input and output ports, RS232 connector for computer programming, and a LCD (see Figure 15).

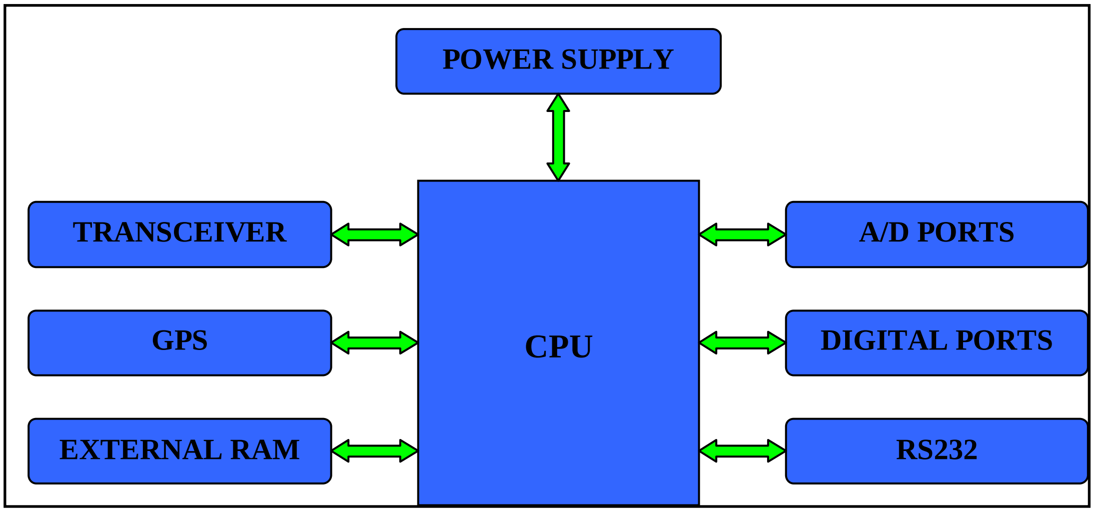

Figure 15: FDR model aircraft layout

3.4 Laboratory design

The **microprocessor** chosen was the PIC18F6720 from Microchip (2008) as it can process 10 Millions of Instructions per Second (MIPS) which is more than sufficient for the programming instructions required. The microprocessor also offers two Universal Synchronous/Asynchronous Receiver/Transmitter (USART) ports and a Master Synchronous Serial Port (MSSP) module which supports both SPI and I^2C. The microprocessor has nine general Input/Output (I/O) ports and 12 analogue-to-digital ports. The PIC18F6720 was used successfully by Dobre and Bajic in their wireless Smart Object (Dobre et al. 2007:4).

Engineers from SS Telecom have done a lot of development using the PIC18F6720, and have had great success with the microprocessor on their SS-79 Direct Air Interface ISDN to GSM multiplexer (SS Telecom 2009) devices which require high stability and reliability (Cronje 2009). The SS Telecom engineers were consulted in the initial design phase of the FDR. The **GPS module** which was chosen is the U-Blox 5 receiver , and more specifically the LEA-5S (U-

Blox 2008). The LEA-5S was chosen out of all the LEA-5 modules as it supports all the applications required for the FDR and it offers the best functionality of all the LEA-5 modules. The basic features of this module are shown in Table 6.

Table 6: Basic features of LEA5 GPS modules

	Voltage Range (V)	Thickness (mm)	50-channel engine	KickStart	SuperSense	FW Update / FLASH	Low Power Modes	GALILEO	UART	USB	SPI	DDC	AssistNow Online	AssistNow Offline	Dead Reckoning	Raw Data	Precision Timing	1PPS	CFG Pins	Reset Input	Antenna Supply	Antenna Supervisor
LEA-5H	2.7-3.6	3.0	✓	✓	✓	✓	P	F	1	1		1	✓	✓				✓		✓	✓	✓
LEA-5S	2.7-3.6	3.0	✓	✓	✓		P		1	1[1]		1	✓	✓				✓	1	✓	✓	✓
LEA-5A	2.7-3.6	3.0	✓		✓		P		1	1[1]		1	✓	✓				✓	1	✓	✓	✓
LEA-5Q	2.7-3.6	2.4	✓	✓	✓		P		1	1	1	1	✓	✓				✓	3	✓		
LEA-5M	2.7-3.6	2.4	✓		✓		P		1	1		1	✓	✓				✓	2	✓		
LEA-5T	2.7-3.6	3.0	✓	✓	✓		P		1	1		1	✓	✓			✓	✓		✓	✓	✓

P= Planned
F= Firmware upgrade required when GALILEO system is operational

The initial **transceiver** which was chosen was the MICRF620 from Micrel (2009) which incorporates a 434 MHz ISM band transceiver module. The module has been successfully implemented in the RF applications (Nadler 2009:17). It has a fully programmable PLL frequency synthesiser, consisting of a voltage controlled oscillator (VCO), a crystal oscillator, a dual modulus prescaler, programmable frequency dividers, and a phase detector. By the time the prototype PCB had been developed and the implementation of the transceiver completed, one of the MICRF620 modules had been damaged. It was not possible to replace them as the item was no longer in production. It was therefore decided to change the transceiver. It was then decided to use the AX5051 from Axsem (2008). It can be successfully integrated into RF applications such as one channel audio walkie-talkies (RF Design 2009). This is an advanced multi-channel single chip Ultra High Frequency (UHF) transceiver that can be configured to be used in both the 400-465 MHz and 800-930 MHz bands. It offers several modulations in both Transmission (TX) and Reception (RX) mode such as Amplitude Shift Keying (ASK), Phase Shift Keying (PSK), Minimum Shift Keying (MSK) and Frequency Shift Keying (FSK). It supports data rates from 9.6 kbps (FSK, MSK) up to 600 kbps (ASK, PSK). It has a receiver sensitivity of -108 dBm which results in a 5 km line of site operation. Overall, the AX5051 offers more flexibility and features than the MICRF620.

3.5 Detailed design

3.5.1 Development platform

The microprocessor development platform was laid out on a 10 cm x 10 cm dual layer PCB. The computer software used to do the design layout was Design Explorer 99, used under Colubritec's license as the purchase of an original license was not viable for this research project. Colubritec are the manufacturers of Tracker (2009) vehicle tracking devices. Design Explorer 99 has also been used successfully by other researchers (Guzik et al. 2001:2). The first section which was designed was the power supply shown in Figure 16 below. The power requirements for the microprocessor, external RAM, GPS Module and OP-AMPS are 3.3 V DC. The LCD and RS232 chip require 5 V DC. A MAX1626 (Maxim Integrated 2007) step down switching controller

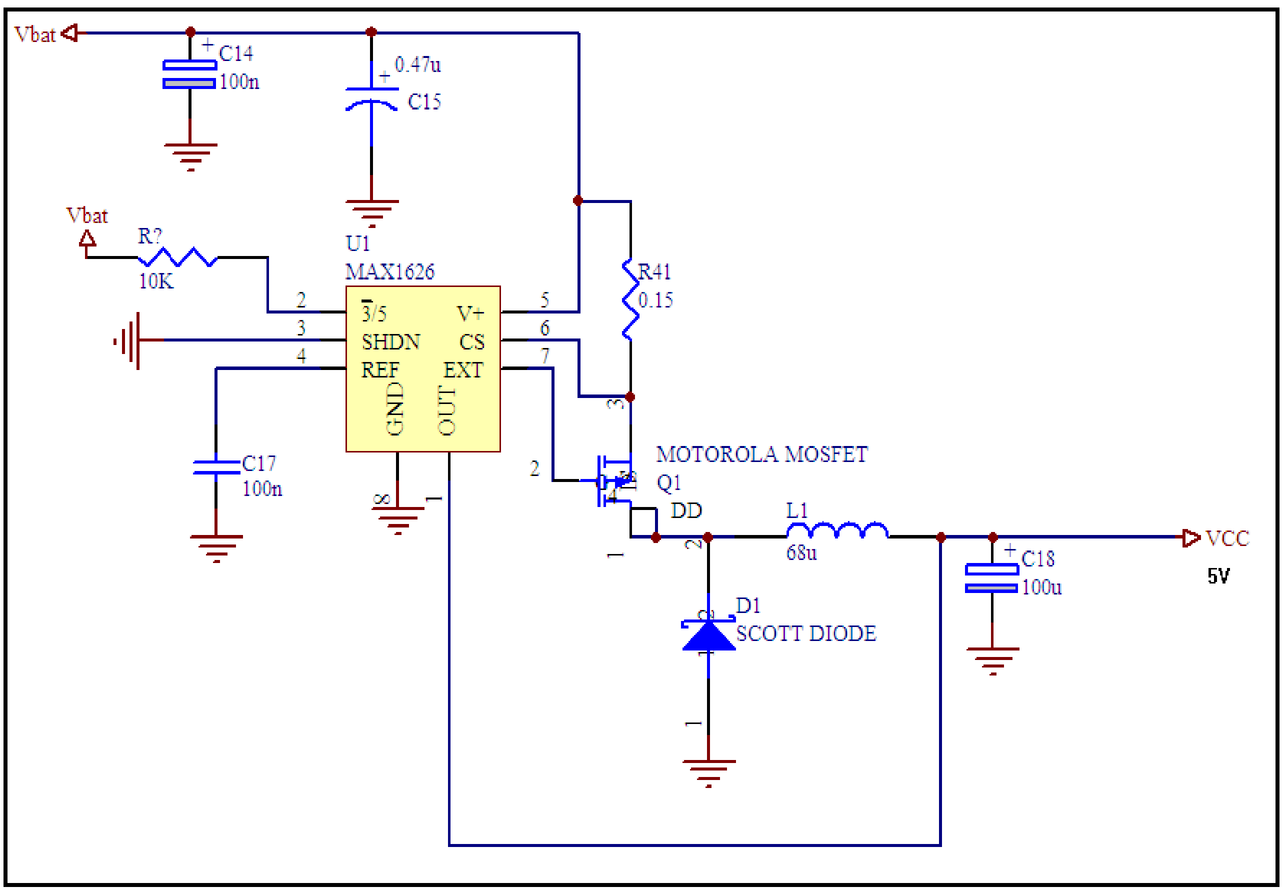

Figure 16: 5 V Power supply layout

allows for a 3 – 16.5 V input with a 5 V (VCC) output. The 5 V (VCC) is then fed into a MCP1700 3.3 V (Maxim Integrated 2007) low dropout (LDO) voltage regulator to provide a reliable 3.3 V (Vdd) supply. This 3.3 V (Vdd) supply is then used to feed a MCP1700 2.5 V LDO voltage regulator which provides a 2.5 V (Vdrf) supply. The 2.5 V supply required to power the MICRF620 module later became redundant. These both are shown in Figure 17.

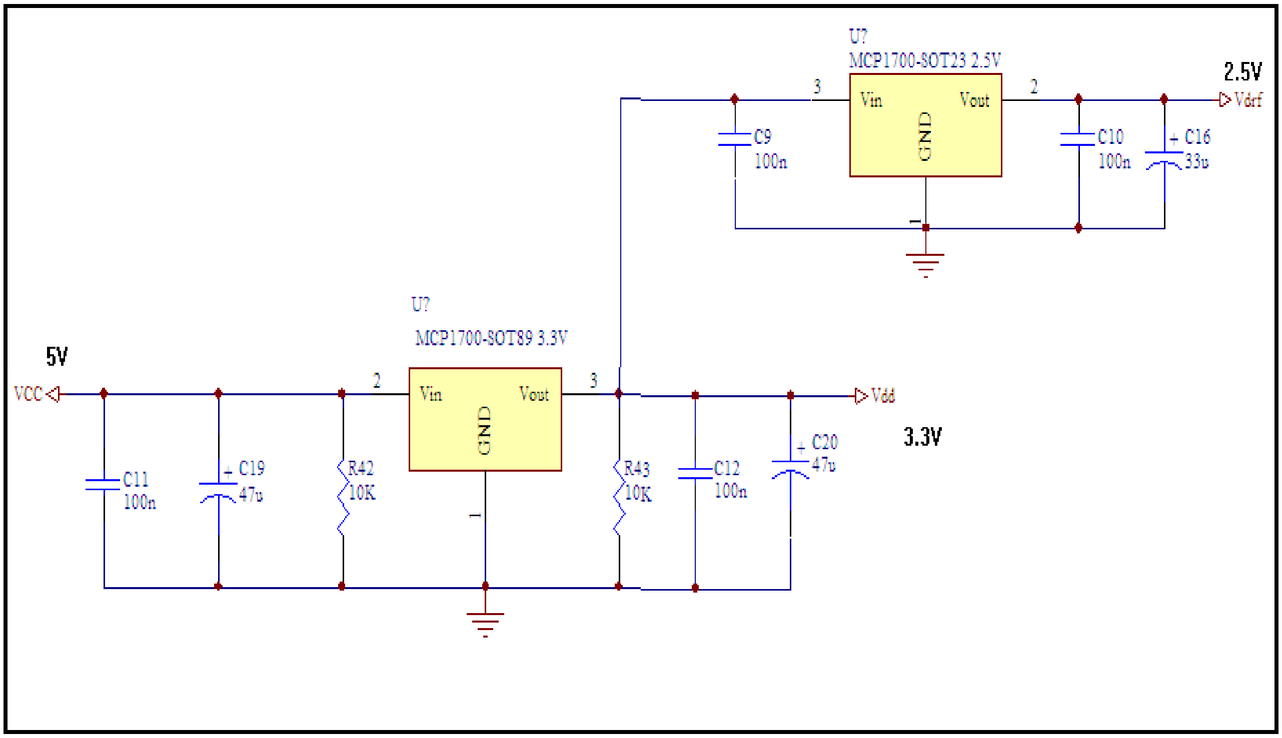

Figure 17: 3.3 V and 2.5 V power supply layouts

The next logical step, having addressed the power requirements, was the layout of the microprocessor and peripherals required to program the microprocessor for further development. This required a J-TAG (see Figure 18) or programming port which was used to upload programming code to the microprocessor. The software package used for the programming code was MPLAB IDE v8.00, together with the MPLAB ICD 2 programming module. The MPLAB ICD 2 is synonymous with PIC programming and used by many engineers (Ferrari et al. 2007:4; Rodamporn et al. 2007). All programming has been done in C, as this is the default programming language used in PIC microprocessors. A MAX232ACPE (Maxim Integrated 2007) module was added in order to provide the interface between the microprocessor and an external PC RS232 port. This is connected to the microprocessor on the USART2 port (see Figure 19).

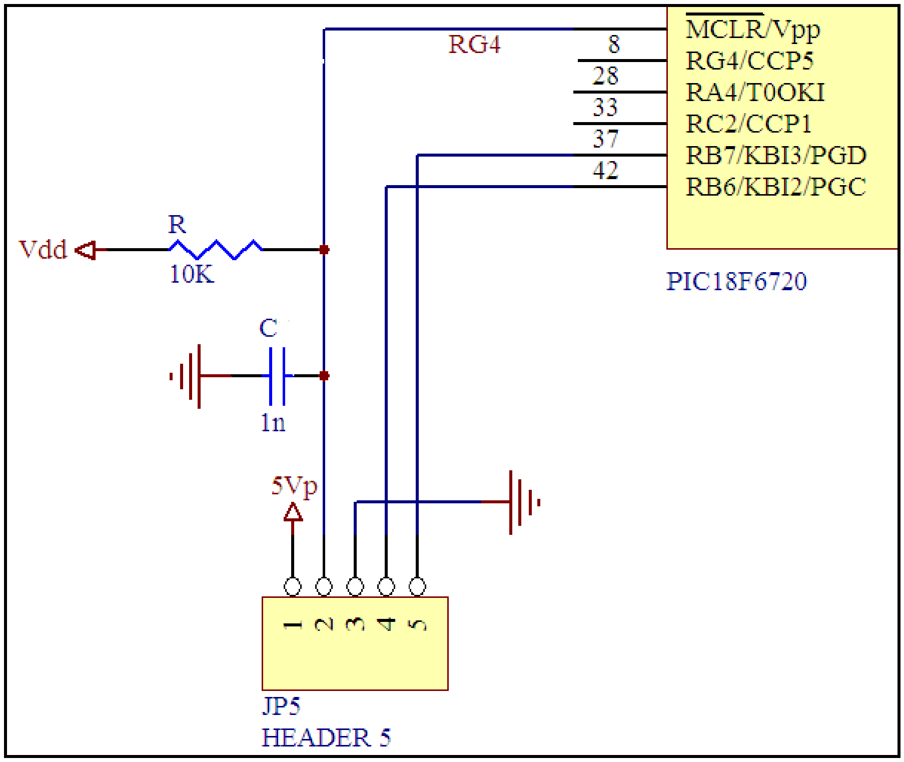

Figure 18: J-Tag interface layout

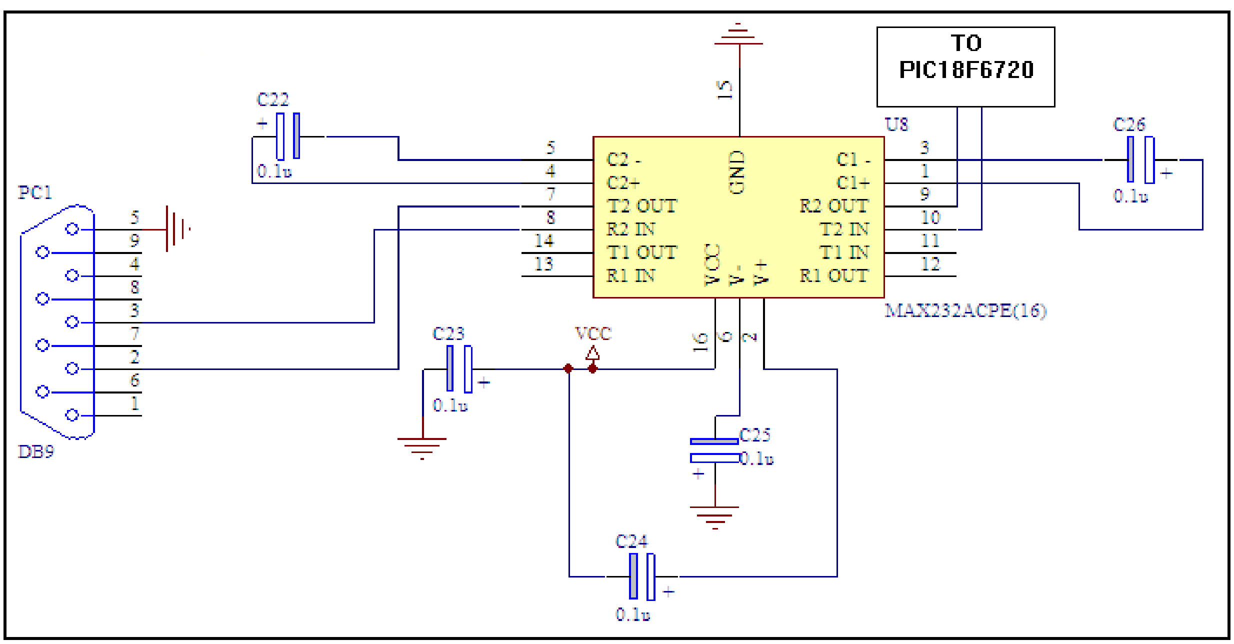

Figure 19: MAX 232ACPE Layout

The LCD chosen was a standard MC1602X (Wayton Technology Company 2009) for the purpose of displaying the required data. The MC1602X is a widely available off-the-shelf product, being cost-effective and simple to implement. It has a 16 bit 2 line character display housed in 59.0 mm x 29.3 mm x 10 mm frame. Microprocessor ports RG0, RG3, RG4 and RD0-RD7 were dedicated for connection to the LCD (see Figure 20).

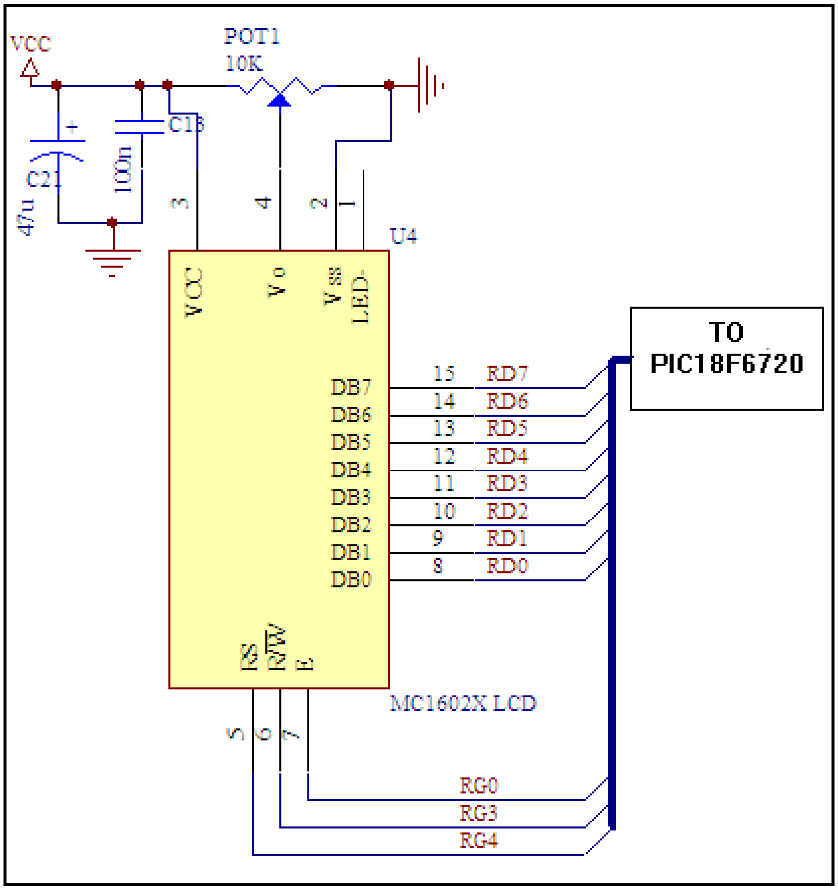

Figure 20: MC1602X LCD layout

Microprocessor ports RE0-RE7 were dedicated to digital I/O ports on a 10 pin male header while ports ANO-AN7 were dedicated to the OP-AMPS for analogue-to-digital conversations. The OP-AMPS chosen were the TL082 (National Semiconductor 2009) which is a wide bandwidth dual junction field-effect transistor input operational amplifier. It is a low-cost high-speed device that has been used reliably in many electronic applications (Colvin 1994:3). The initial layout allows for four TL082 devices providing eight OP-AMPS. Figure 21 shows the layout of one of the OP-AMP's on a TL082 which is duplicated on all OP-AMP's.

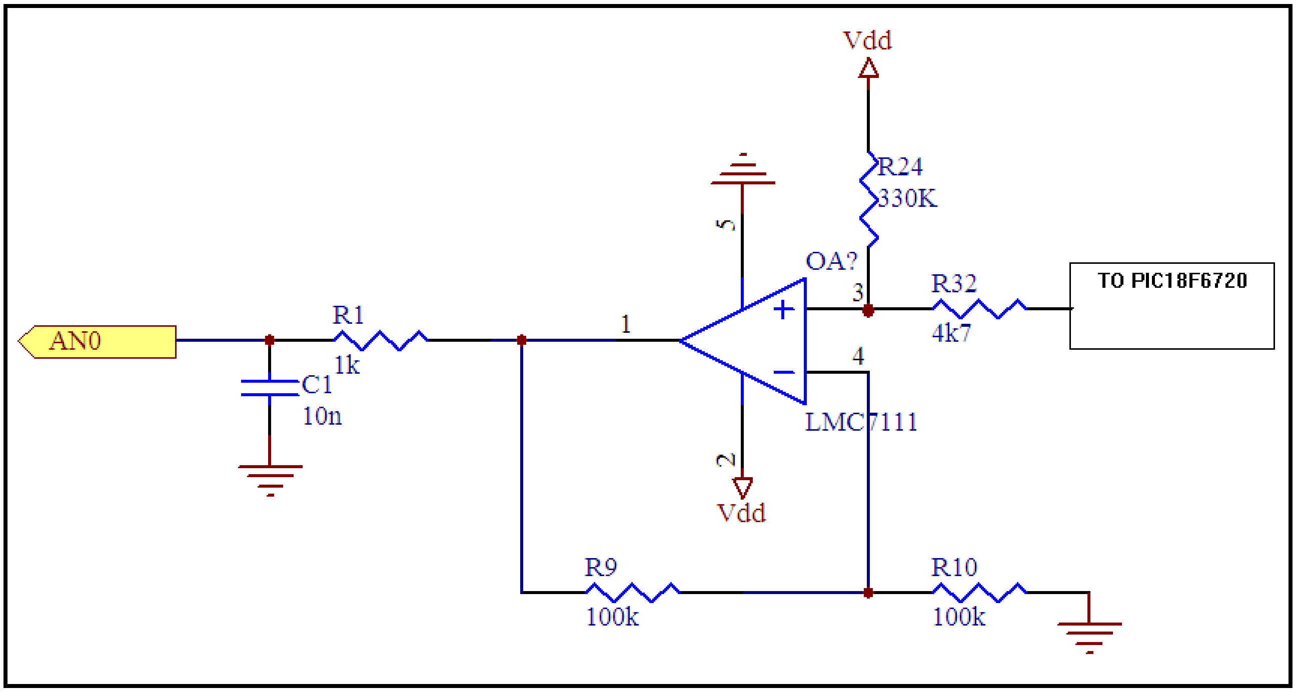

Figure 21: Layout of single OP-AMP on TL082

The external RAM is a SST25VF016B (Silicon Storage Technology 2009) 16 Mbit serial flash connected to the microprocessor via the SPI port on RC3, RC4 and RC5. It provides for 100 000 read/write cycles with expected data retention of 100 years. The U-Blox GPS is connected to the processor on the USART1 port while the AX5051 transceiver is connect to the same SPI port as the external RAM. Utilization of the SPI port by either the external RAM or the AX5051 transceiver is done by using their relative chip select pins. Protection for accidental selection of both devices is provided by logical gates using 74HC00 and 74F125 modules.

3.5.2 Integration of GPS

Once the development board had been finalized, the GPS module was added along with an active patch antenna incorporating a Low Noise Amplifier (LNA) preamplifier in order to provide better satellite tracking and receiver sensitivity. According to antenna manufacturer Taoglas (2008), “It is the highest performing solution of all antenna types”. The U-blox GPS is a drop in device that is connected via its RS232 port to the microprocessor USART1 port which immediately starts to track satellites and provide GPS co-ordinates when powered. C code was then written to display all the data received on a PC screen while only displaying GPS co-ordinates on the LCD as can be seen in Figure 22. The GPS polled satellite data every second. Figure 23 shows the layout of the U-blox GPS module on the PCB.

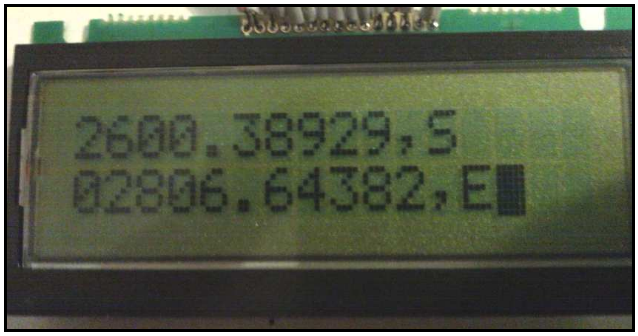

Figure 22: LCD displaying GPS co-ordinates

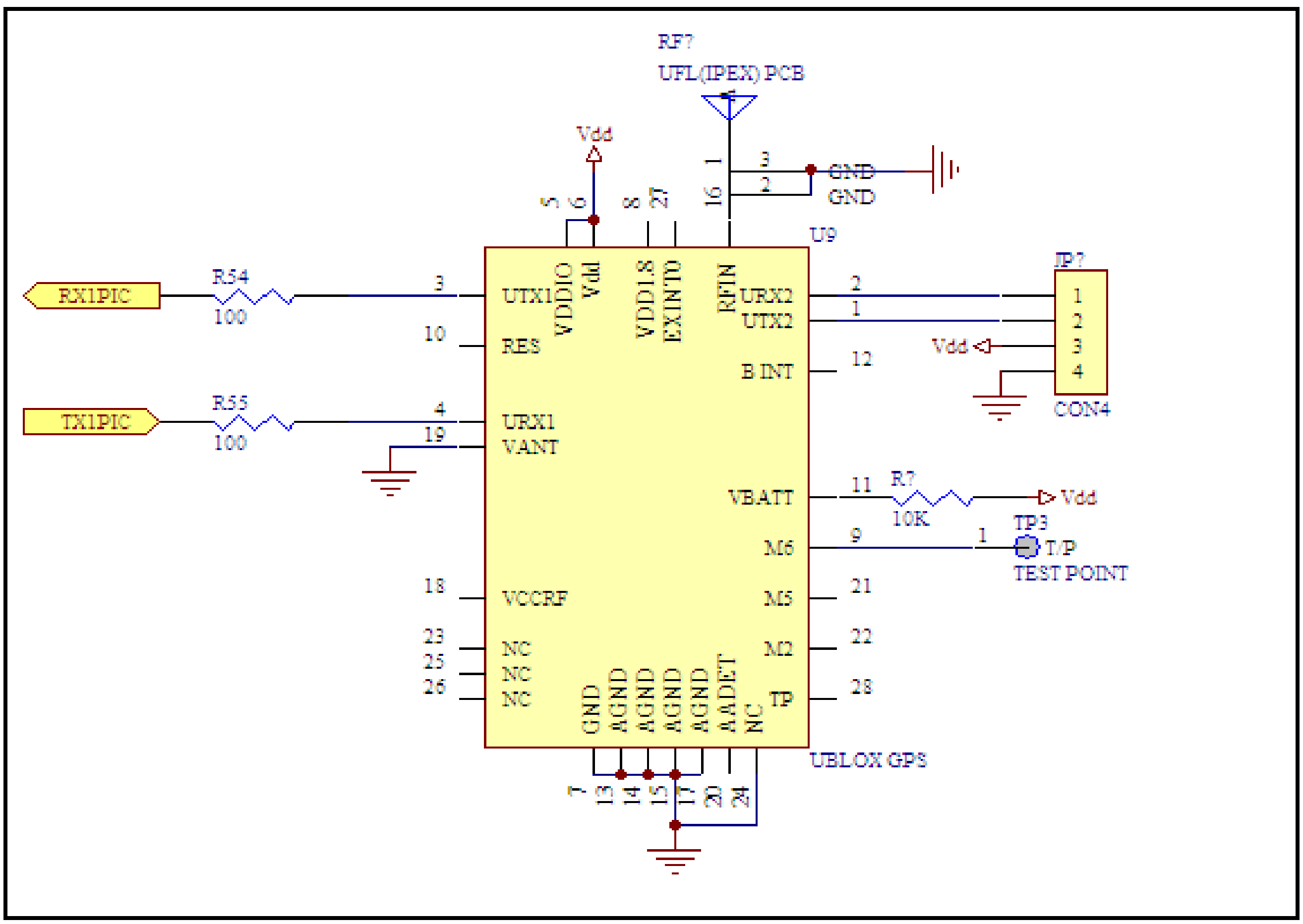

Figure 23: U-blox GPS Module Layout

3.5.3 External RAM

The next step was to add the External RAM (Figure 24) to the development board for storage purposes. Communication was established via the microprocessor SPI port and test verification read and write codes were written in order to test the operation of the RAM module. Auto storage code was then written in order to be able to write constant batches of GPS data to the external RAM. The initial code would poll the GPS data from the GPS module and then write all data collected directly to the external RAM. The data was also transmitted over the RF link to the ground receiver where it was also stored on external RAM. This data could later then be downloaded for analysis purposes. A larger data storage device was required as all the transmitted data was also stored onboard the aircraft. C code was therefore written that would filter all the data received from the GPS module and only store and transmit the desired data. Filtering of the GPS data would then reduce the amount of space utilized on the external RAM and therefore increase the amount of GPS co-ordinates that could be stored.

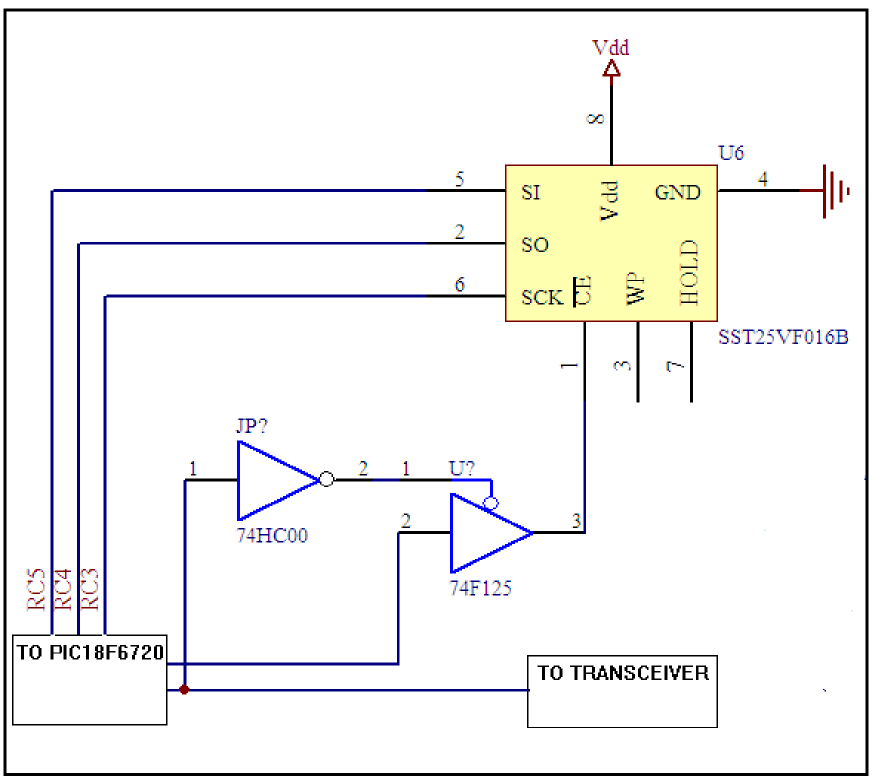

Figure 24: Layout of external RAM

Additional code was implemented to track the location of memory written on the external RAM, so that if the microprocessor was reset it would not be able to overwrite existing data. Code was also written to display the last line of GPS co-ordinates in the event of a power failure.

3.5.4 The speed sensor

Due to budget and time constraints it was decided not to add an external independent speed sensor. It was rather decided to use the GPS data received from the GPS module in order to calculate the speed. The velocity measurement on the U-Blox GPS is accurate to 0.1 m/s which is sufficient for this research project (U-Blox 2008).

3.5.5 Fuel level sensor

The fuel level sensor proves to be one of the most difficult sensors to implement. Traditional fuel level/pressure sensors are available for use in larger automobile and aircraft tanks, but the small scale of the RC model aircraft tank provides a challenge. Pilots have suggested drilling a hole in the tank and using a probe to measure a continuous circuit (RCGroups.com 2009b). When the fuel drops below the probe, the circuit is broken and this is used as an indication of low fuel. However, this will only work in non-inverted flights. Another alternative is to place two thin copper plates on the inside of a fuel tank on opposing sides. The fuel between the plates will act as a dielectric and the capacitance can be measured. The capacitance will be higher when the tank is full and lower when it approaches empty. This can then be used to calculate a capacitance to fuel ratio. It was decided to keep the low fuel sensor simple and universally adaptable to many model aircraft types. A simple test tube type cylinder was attached to the fuel tank. Attached to the bottom of the tube is a 5 V contact. A simple spring loaded contact is also attached near the bottom of the cylinder which is connected to a digital input output port on the microprocessor. A magnet attached to a floating cork is placed in the cylinder. This is shown in Figure 25. As the fuel level in the fuel tank drops so the level in the cylinder will also drop. When the fuel level drops to a level determined to be low, the magnet will cause the spring loaded contact to close and the place 5 V on the digital port. This will flag the processor that the fuel level is low and this can be transmitted to the pilot on the ground.

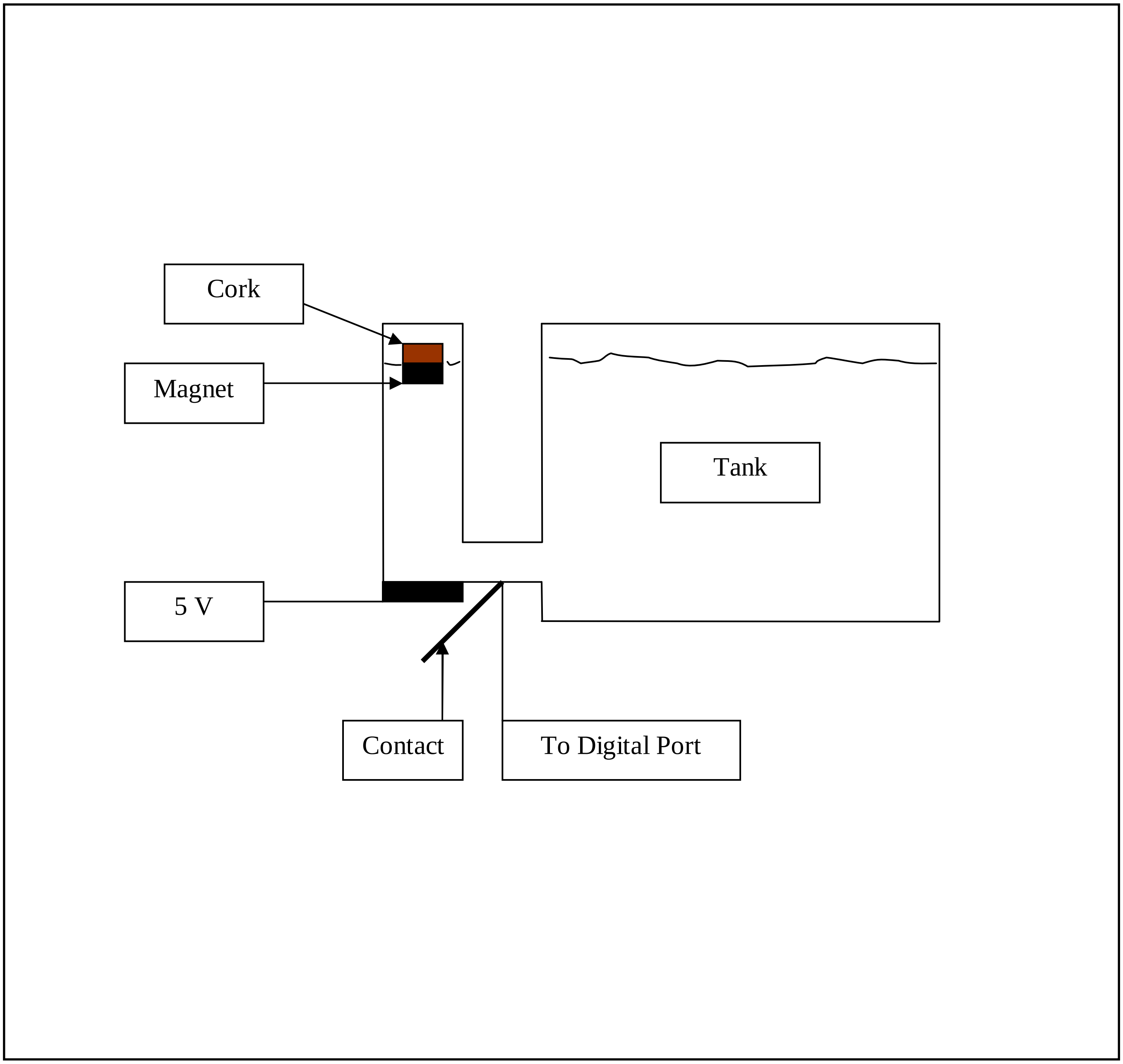

Figure 25: Low fuel level indicator

3.5.6 Battery level sensor

One of the ports on the existing TL082 Op-Amps was reserved for monitoring the battery level of the model aircraft. Programming code written to read the A/D input displays the relevant voltage level on the LCD and also stores it to memory. The TL082 allows for a differential input voltage of ±30 V and an input voltage range of ±15 V. Most model aircraft power supplies range between 7 – 12 V. The TL082 provides an internally trimmed input offset voltage and JFET input devices have large reverse breakdown voltages from gate to source and drain removing the need for clamps across the inputs.

3.5.7 Orientation sensor

The orientation can be obtained from the GPS module which eliminates the need for additional sensors for compass bearing readings. This will also assist the pilot in the event of a distant crash, giving the pilot an idea of the last known course and direction of the model aircraft. Programming code was written for the manipulation and processing of this GPS data which is also written to memory and displayed on the LCD.

3.5.8 Warning buzzer

A simple buzzer was employed to warn the pilot about any critical parameters, such as low battery, approaching the maximum altitude or approaching the maximum distance of communication. The programming code activates the buzzer until the critical parameter has been neutralized. This warning buzzer is located on the ground device to allow the pilot to respond to any critical alarms.

3.5.9 Servo failure

The servos are usually connected to the ailerons, rudders, elevators, flaps and throttle on the RC model aircraft. When in flight all servos, with exception of the throttle, are activated at least once every two seconds. This is because the pilot is constantly adjusting flight path and speed. In order to determine server failure, programming code is written to read the current measurements on the servers constantly; if no current can be read for more the two seconds the microprocessor will activate the alarm buzzer and display a warning on the LCD. The microprocessor will clear the alarm if current is measured again within two seconds of the initial alarm. This helps to eliminate false alarms where pilots may chose a flight path of level flight for longer than two seconds which does not require adjustment via the servos.

3.5.10 Integration of GPS failure

This is again controlled by programming code within the microprocessor. If no GPS co-ordinates are received from the GPS module for longer than three seconds, the warning buzzer will sound and a warning message is displayed on the LCD informing the pilot that GPS readings are no longer available. The GPS module polls satellite data every second and if three consecutive polls have not provide GPS data then the module is deemed to have an error. The pilot can then make an informed decision to land the aircraft and rectify the problem.

3.5.11 Implementation of the transceiver

The transceiver (Figure 26) is the final communication link between the RC model aircraft and the pilot. All data collected by the microprocessor onboard the aircraft is saved to memory and

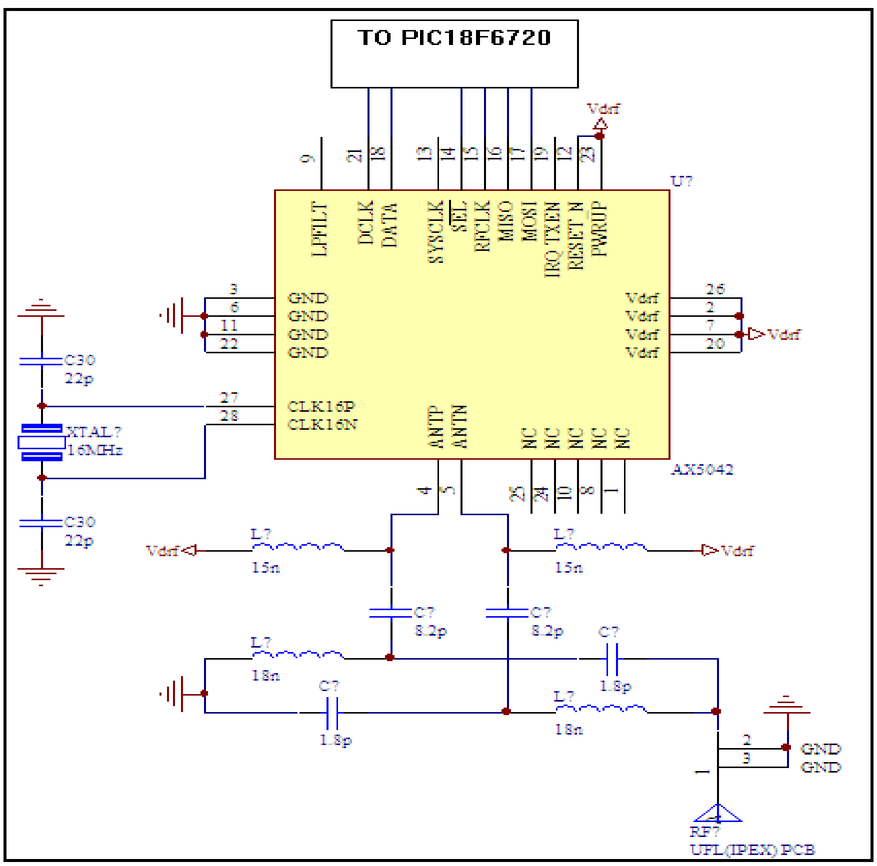

Figure 26: Transceiver layout

transmitted over the RF link to the receiver held by the pilot on the ground. The PIC18F6720 microprocessor on the receiver side will retrieve all data and process it.

3.6 Optimization of maximum distance of operation

In order to increase the standard distance of operation, a 9 to 15 dBi Yagi-Uda antenna can be fitted to the SMA adapter on the AX5042 transceiver on the ground station receiver side. Figure 27 shows a simple dual band 824 - 1000 MHz and 1700 - 2170 MHz 11 dBi gain Yagi-Uda antenna. The Azimuth Gain can be seen in Figure 28. This specific model is the LPDA-A0021 available from Poynting Antennas (2009). The Yagi-Uda antenna has been proved to be very helpful and reliable in RF Electronics (Radio-Electronics.com 2009).

Figure 27: Poynting LPDA-A0021

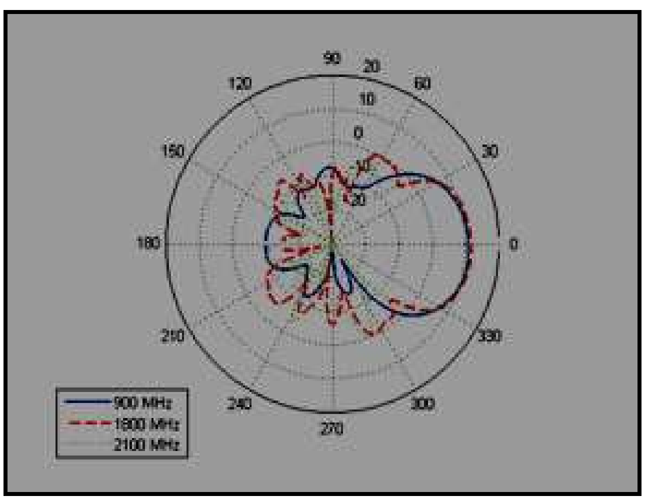

Figure 28: Azimuth gain of LPDA-A0021

3.7 Preliminary final design

The complete development board is shown in Figure 29. The main sections of the Development Board are the PIC18F6720 microprocessor, the RF segment, the external RAM and the U-blox GPS. The schematic for the full layout of the Development board, the power supply and A/D OP-AMPS have been placed in Annexures A, B & C respectively.

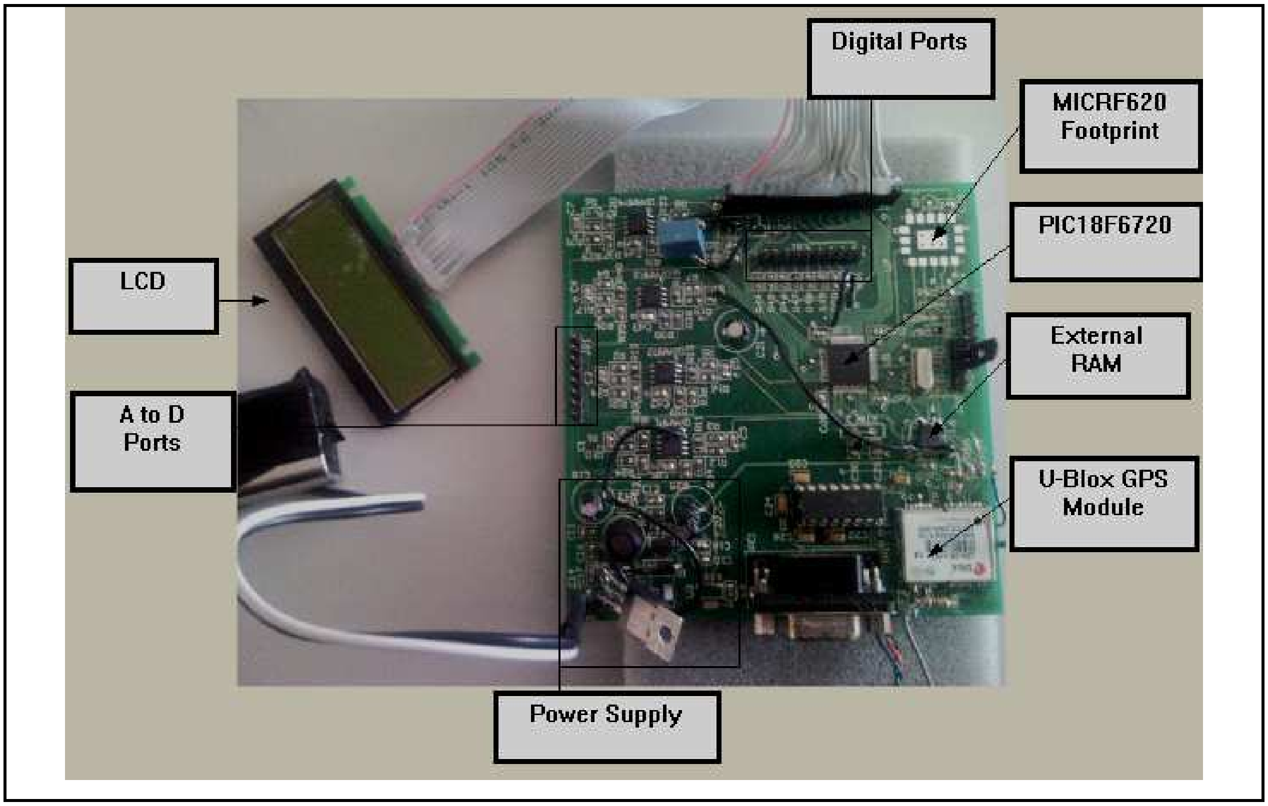

Figure 29: Complete development board

3.8 Conclusion

In chapter 3, the specific parts required for the FDR were discussed along with specific modules that were selected for the development board. The actual development board was manufactured and the required programming code for the microprocessor was successfully written and implemented. In chapter 4, the test results of the FDR inside a laboratory will first be given followed by actual field tests to determine if the initial operating requirements have been attained.

Chapter 4 Implementing and Testing the Flight Data Recorder

4.1 Introduction

Chapter 3 covered an in-depth discussion on the physical construction of the FDR consisting of the microprocessor, GPS module, power supply, transceiver, memory storage and other sensory devices. Chapter 4 presents the implementation of the FDR unit in the field, and documents all test results obtained from the different flight plans.

4.2 Constraints of experimental testing

The experimental testing has proved that GPS co-ordinates and telemetry data can be successfully transmitted from the model aircraft to the pilot on the ground. Optimization of the development board was not done, as it has already been designed within acceptable parameters for on-board model aircraft testing. Actual crash testing of the model aircraft was also not done.

4.3 Methods of evaluation

4.3.1 Technical evaluation methods

The actual testing of the FDR was conducted in three phases. Phase one involved testing the FDR in a laboratory. Phase two involved testing the FDR on-board a model aircraft without the transceiver present. Phase three involved testing the FDR on-board a model aircraft with the transceiver functioning.

The laboratory testing phase was actually an initial phase which was conducted every time a new component was added. The basic functionality of the specific component was tested and adjustments to the design made as required. In the first main laboratory test, the basic development board was manufactured and the power supply, GPS module, PIC, external RAM, LCD and all I/O ports were tested for basic functionality and operation. Figure 30 and 31 shows the oscilloscope measurements of the 5 V and 3.3 V powers supply outputs respectively.

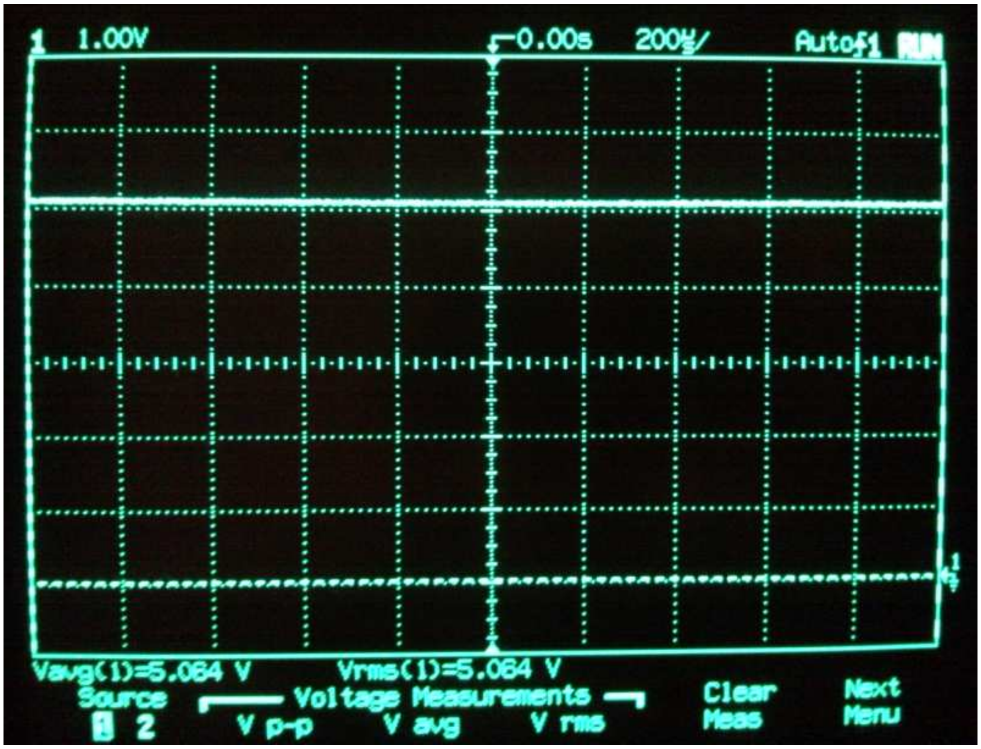

Figure 30: 5 V oscilloscope output

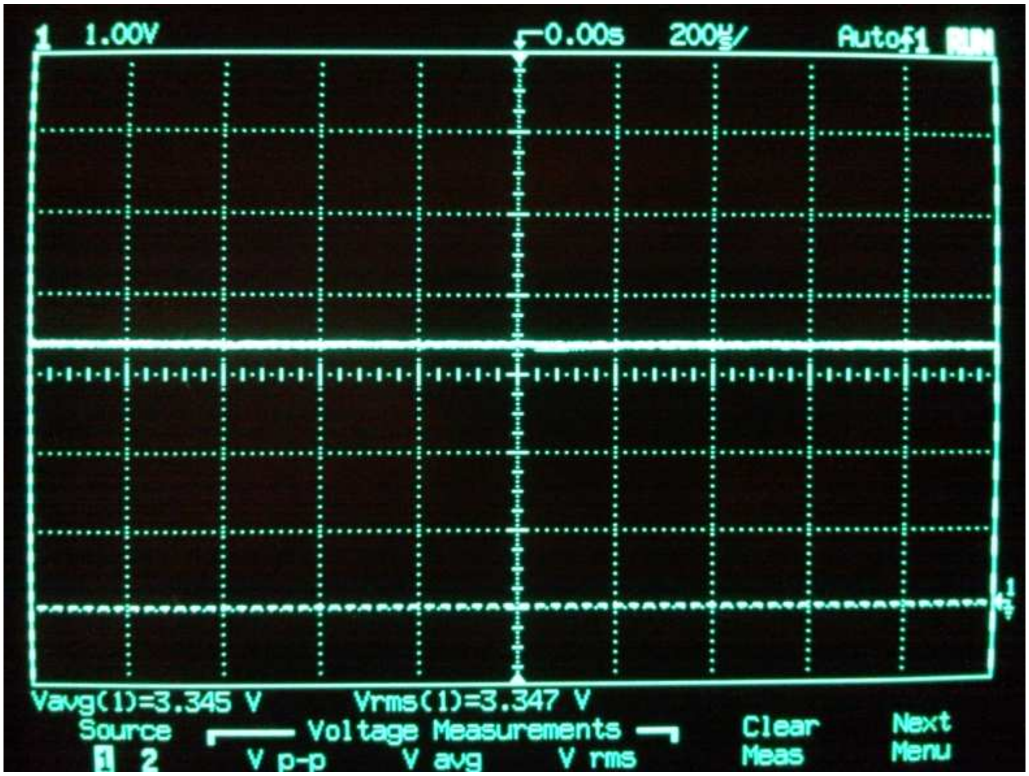

Figure 31: 3.3 V oscilloscope output

GPS data was retrieved and stored in the external RAM while being displayed on the LCD and also on the RS-232 port connected to a laptop. The data was then successfully retrieved out of memory. The next step in this phase was to place the FDR development board into a car and take a 20 minute drive down the highway and back while logging data. This data was then successfully retrieved from the FDR. The planned path is shown in Figure32a. The drive path of the car plotted in Google Earth is shown in Figure 32b. These figures prove the accuracy of data.

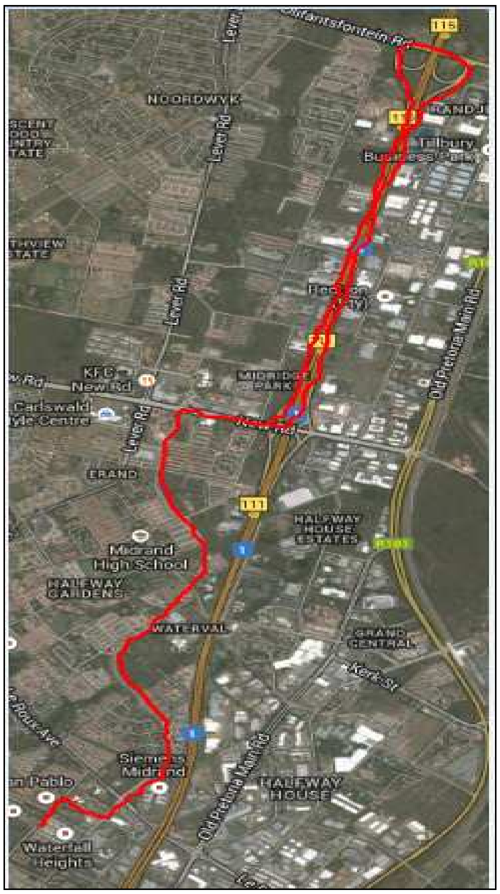

Figure 32a: Car planned path

Figure 32b: Car Google drive path

In phase two, the FDR development board was placed into a model aircraft shown in Figure 34 allowing the FDR to log live data on two consecutive flights. These flight trials took place at the TEKSA RC Model Club in Trichardt on the 26th December 2009 (see Figure 33). This data was then successfully retrieved from the external memory and is presented in Table 7. This data was then plotted using Google Earth and can be seen in Figure 35 and Figure 36 for the two flight trials. At this point the transceiver had not been connected.

Figure 33: TEKSA RC Model Club

Figure 34: FDR on board model aircraft

Figure 35: Google Earth flight path one

Figure 36: Google Earth flight path two

Table 7: Prototype trial flights one and two

Telemetry	**Trial one (10 min)**	**Trial two (11 min)**
Minimum altitude above sea level (m)	1637.80	1426.1
Maximum altitude above sea level (m)	2139.20	1692.3
Maximum speed over ground (m/s)	57.34	46
Minimum signal to noise ratio (dBHz)	24.41	24.7
Maximum signal to noise ratio (dBHz)	42.50	44
Fuel used for the duration of the flight (ml)	150	165
Average battery voltage for transceiver and servos (V)	15.2	15.1

The third test phase involved incorporating the transceiver, fuel sensor and buzzer into the overall system. Once these components had been added and the basic laboratory testing had been completed, then the actual flight trials could be started. The flight trials were done at the TEKSA RC Model Club on the 27th May 2012. On these flight trials, the FDR was tested on an electric glider where it was strapped to the glider and protected with bubble wrap (see Figure 37). The FDR development board with the transceiver is shown in Figure 38.

Figure 37: Electric glider with FDR

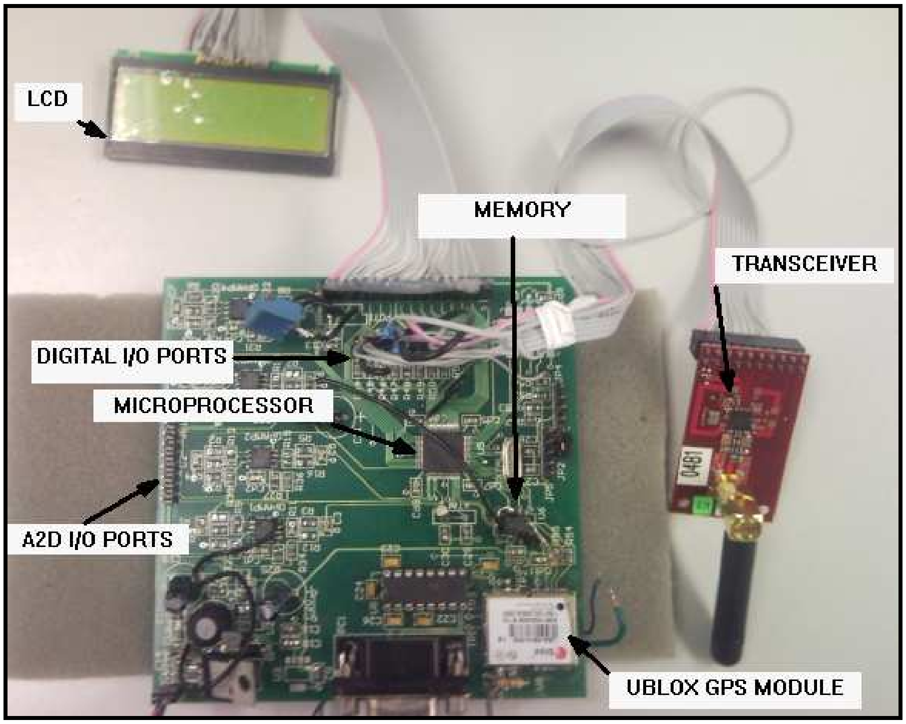

Figure 38: Development board with transceiver

Two successful flight trials of three minutes each were done. The flight data from the glider (shown in Figure 39) was stored on board the RAM in the FDR and transmitted simultaneously to the pilot on the ground. The Google Earth flight paths of trials three and four are shown in Figures 40 and 41. The flight data for trials three and four were then successfully retrieved and are plotted in Table 8.

Figure 39: Electric glider in flight

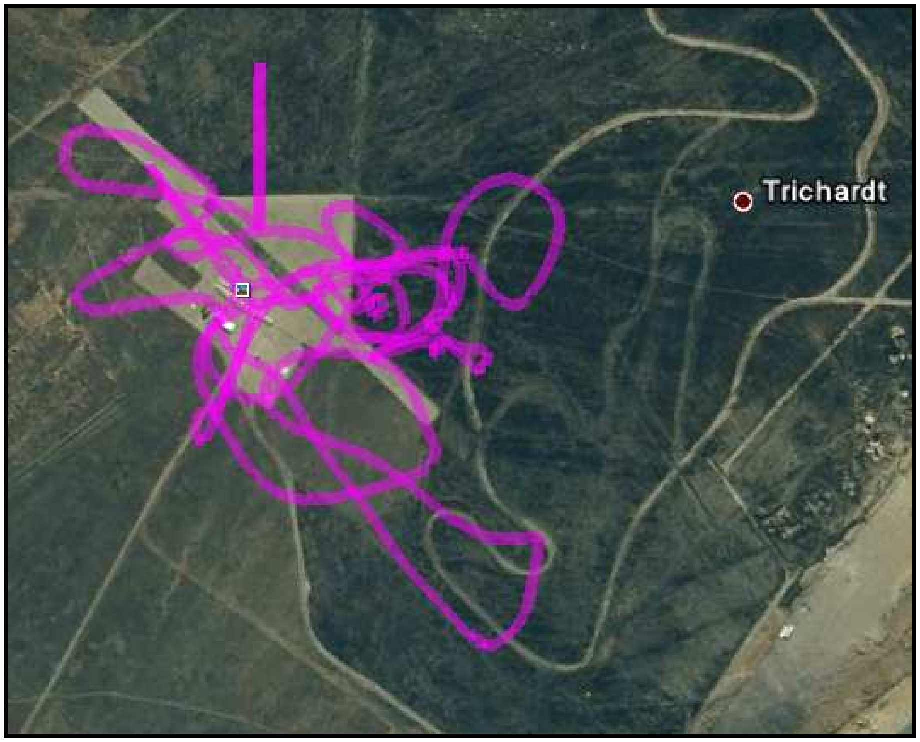

Figure 40: Google Earth flight path three

Figure 41: Google Earth flight path four

Table 8: Prototype trial flights three and four

Telemetry	**Trial three (3 min)**	**Trial four (1 min)**
Minimum altitude above sea level (m)	1529.40	1548.00
Maximum altitude above sea level (m)	1639.90	1616.20
Maximum speed over ground (m/s)	25.68	16.44
Minimum signal to noise ratio (dBHz)	13	29.09
Maximum signal to noise ratio (dBHz)	44	40.00
Fuel used for the duration of the flight (l) *electric glider therefore n/a	n/a	n/a
Average battery voltage for transceiver and servos (V)	11.2	11.0

4.3.2 Economical evaluation methods

Three commercially available data collection devices were considered in Chapter 2 based on their pricing and availability to the average model aircraft enthusiast. A decision was made to design and build a new development board on which the FDR could be based that would meet all the technical requirements, be economically affordable and reliable. The cost of all three commercially available devices and the newly developed FDR are shown in Table 9. From this it can be seen that the cost of the newly developed FDR is approximately half that of other commercially available products. This costing is based on a single prototype which is more expensive than in the case of mass production.

Table 9: Cost comparison of devices

Device	**Cost**
Seagull Telemetry System	$394.98 - $544.98
RC Electronics RC T2000	$556.25
The TeKnol UAC Flight Control System	$827.32
Newly developed FDR	$225.50

Table 10: Breakdown cost of newly developed FDR

Component	**Cost**
Transmitter (model aircraft) PCB	$75.25
Receiver (pilot) PCB	$75.25
U-Blox GPS Module	$20
2 x Axsem 5051 transceivers	$15
PIC18F6720	$5
Remaining components	$35
Total FDR Cost	$225.50

4.4 Conclusion

The technical evaluation of the FDR development board has proven that technical data can be successfully captured and stored while being relayed in real time from the model aircraft to the ground receiver. The economical evaluation has shown that it would be more cost effective to produce the FDR locally, making it more accessible to the average model aircraft enthusiast in South Africa. The costing would be further reduced when undertaking mass production. The cost of local production further outweighs the cost of import duties associated with the Seagull Telemetry System, RC Electronics RC T2000 and The TeKnol UAC Flight Control System. Chapter 5 presents conclusions and recommendations with regard to the design and development of the FDR and other possibilities for research.

Chapter 5 Conclusions and recommendations

5.1 Introduction

Chapter one considered current difficulties that model aircraft enthusiasts experience when their model aircraft crashes afar off, leading to time consuming searches and high repair costs. The history of the FDR was documented and the basic operation discussed. The need for a FDR for model aircraft in order to assist the pilot to prevent crashes was established. The synonymous relationship between UAV and model aircraft was highlighted in order to better understand the development and operation of both platforms. In chapter two, the various parts of the model aircraft which assist in flight and control were discussed. A survey was done on three different commercially available FDR's which were compared with regard to their advantages, disadvantages and cost. The main components of the FDR were identified and their operation discussed. The reason for designing a new FDR was highlighted.

The detailed design of the new FDR was documented in chapter three. The component selection process and design of the FDR development board was given along with the software programming features. Actual field tests of the FDR were documented in chapter four. Actual flight trials were recorded with telemetry data such as GPS co-ordinates, speed, altitude, battery level and servo operation. This data was successfully recorded and transmitted over the radio link to the pilot's receiver module on the ground.

5.2 Conclusion

The transceiver section of the FDR has proven to be the most difficult to implement. As mentioned in section 3.4 the hardware failure of the MICRF620 module resulted in a change of the FDR design to accommodate the new AX5051 module. The PCB footprint had already been done for the MICRF620, in order to integrate the AX5051 ports use was made of spare digital ports and c-code was written to create the virtual SPI port required to work with the AX5051. The fuel level indicator proved difficult to implement as many different setups are available for fuel level measurement and low level indication. It was decided to implement a simple early warning system utilizing a floating magnet that will activate a contact when the fuel level is at a predetermined low level.

The main objective of the research was to design and develop a FDR to monitor the flight path and performance of a RC model aircraft. This FDR needed to be light weight, cost effective and also be able to provide early warning of high risk situations such as low fuel and low battery power. It also needed to aid in the recovery of lost aircraft. In chapter four these issues have been addressed. Four successful trial runs were made and the altitude, speed, GPS co-ordinates and battery voltages were retrieved from the ground unit. The buzzer for early warning had been implemented for high risk situations. The cost price for the product for the FDR was $225.50 which proved to be $169.48 less that the cheapest alternative products researched. The product with battery only weighs in at 190 g and has proven to not interfere with either of the trial model aircraft performances. With all GPS data received in the event of a crash it would make recovery of the model aircraft simple.

5.3 Recommendations

The time period for this research spanned three years due to time constraints and other external responsibilities. During this time, research and development on many of the components used in the FDR have progressed and enhanced components are now available. These enhanced components could further reduce the size and weight of the current FDR which could then be used on even smaller RC model aircraft, such as toy models used by small children.

Another recommendation would be to market this FDR among amateur glider pilots who have the habit of losing their model aircraft on mountain slopes. This would further assist the amateur glider pilots to monitor and record their individual progress as the telemetry data can be stored for future analysis.

In order to increase the ease of operation, voice recognition commands can be implemented. The ground receiver unit could also include an earpiece that can relay telemetry data via audio speech to the pilot, removing the need to monitor a LCD display. Permission to use the model aircraft FDR in sporting contests for accurate data recording should be obtained from the relevant aviation authorities as the data could be used by contest judges.

The development board for the FDR has proved to be a valuable tool in understanding the operation of the GPS system as well as RF transmission. This FDR development board could further be used as a teaching tool for students to enhance their understanding of all the concepts associated with flight data telemetry.

The FDR can be further developed by including an auto pilot/ recovery mode of operation. If a pilot feels that control of the model aircraft has been lost, then they can switch to this mode which will place the aircraft in a circular flight path above the pilot. Once the aircraft has stabilized, then the pilot can resume control and land the aircraft successfully.

All the requirements specified in the research objective have been met by the FDR.

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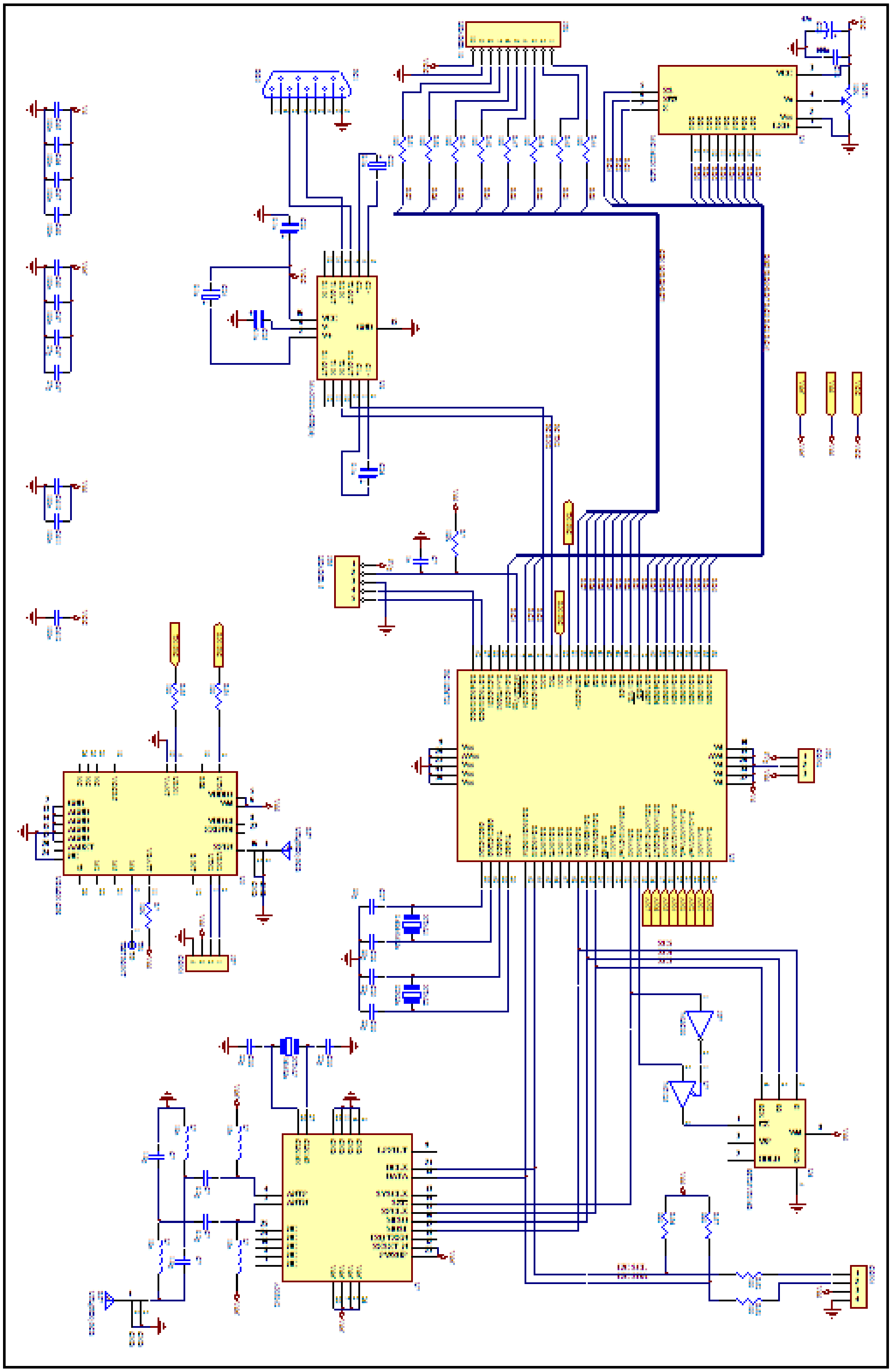
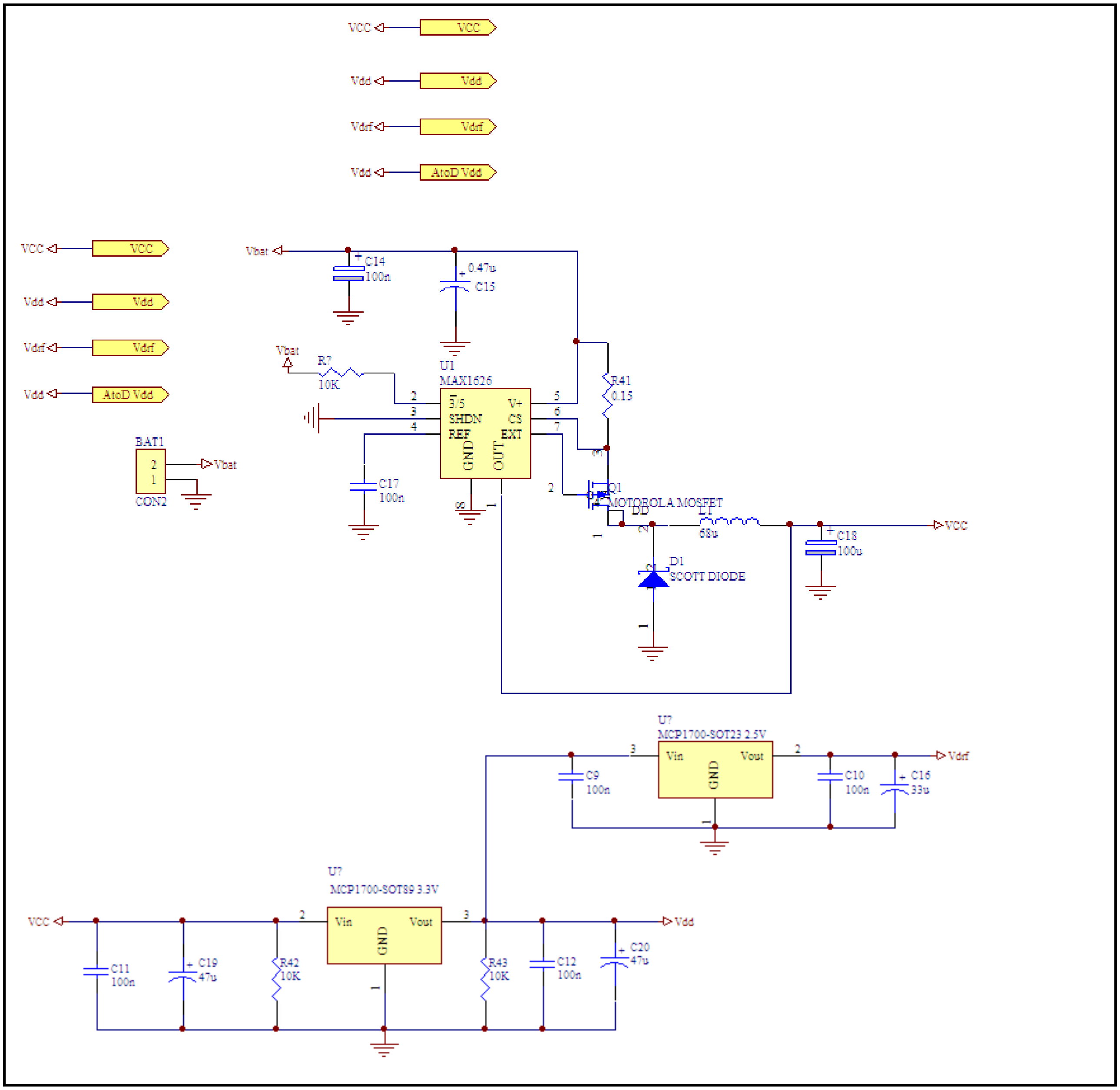
ANNEXURE A Full layout of development board



ANNEXURE B Development board power supply



ANNEXURE C A/D converter with OP-AMPS