Title: , , Onboard Hardware Systems, Design Document for

*“A Project”*

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Authorised for use by Date \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Dr Luis Mejias Project Coordinator

**QUT Avionics**

Queensland University of Technology

CRCSS-EESE, GPO Box 2434

Gardens Point Campus

Brisbane, Australia, 4001.

Telephone (+61 7) 3864 1772

Facsimile (+61 7) 3864 1517

e-mail RA.Walker@qut.edu.au

web <http://www.quav.qut.edu.au>

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**Executive Summary**

The onboard systems and telemetry portion of the AHNS project deals with the acquisition of data from the helicopter. Data flows to the ground station from the various onboard sensors via the onboard Robostix processor. The Robostix completes the necessary conversions and bit manipulations for output to the onboard Xbee radio modem. The data is then transmitted at a defined rate to the ground station receiver. The ground station radio modem receives the transmitted data and a MAX-232 chip converts the data from logic levels to RS-232 levels where it is then fed into the ground station PC.

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**Definitions**

|  |  |
| --- | --- |
| AHNS | Autonomous Helicopter Navigation System |
| PCB | Printed Circuit Board |
| MTOW | Maximum Take-Off Weight |
| UART | Universal Asynchronous Receiver/Transmitter |
| ADC | Analogue-to-Digital Converter |
| IMU | Inertial Measurement Unit |
| MCU | Mode Control Unit |
| PCB | Printed Circuit Board |
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# Introduction

In order to successfully achieve all platform and control based system requirements, a functional hardware system must be developed. This encompasses the actual autopilot circuit board as well as the complete power system. In addition to this, considerations need to be made in relation vibration dampening and heat dissipation. Finally, all interfaces to non PCB mounted sensors need to be designed.

## Background

The hardware used in the initial design was sourced from the initial trade studies detailed in RD/3. These initial designs were further developed throughout the course of the project.

## Scope

The purpose of this document is to detail the development and design of all parts of the onboard electronics.

# Reference Documents

## QUT Avionics Documents

|  |  |  |
| --- | --- | --- |
| RD/3 | AHNS-CT-TS-001 | Communications and Telemetry Trade Study |
| RD/4 | AHNS-SY-SR-001 | AHNS System Requirements Document |
| RD/5 | AHNS-SY-IC-001 | AHNS System Interface Control Document |

## Non-QUT Documents

|  |  |
| --- | --- |
| RD/1 | “Wiki: MikroKopter.de” 2009. [Online] Available: <http://www.mikrokopter.de/ucwiki/en/MikroKopter> [Accessed: Sep 10 2010]. |
| RD/2 | “ATmega128 Datasheet.” 2008 [Online] Available: <http://www.atmel.com/dyn/resources/prod_documents/doc2467.pdf> [Accessed Apr 23 2009]. |

In the event of any conflict between this document and any RD referenced herein, such conflict shall be notified to Dr Luis Mejias.

In the following text, RD/x identifies referenced documents, where "x" denotes the actual document.

# Onboard Systems

Before a successful design can be implemented, all relevant system requirements must be considered. The most important of these is the maximum payload requirement. If the final quad-copter system exceeds its MTOW, it will not be able to fly and consequently, very few project requirements can be achieved.

## Payload Restrictions

Several physical limitations need to be considered when determining the maximum allowable payload weight. The first of these is the total maximum thrust that is able to be produced by the propulsion system. It can been seen that if the total weight of the helicopter exceeds the maximum available thrust, the quad-copter will be unable to commence or sustain flight. In addition to this rudimentary limitation, there are other factors at work, which further impose constraints. One such factor is the ability for an aircraft to be controllable with a given weight. That is, as the flying weight approaches the limit of thrust, the motors can easily be saturated while performing certain manoeuvres. This will lead to a degraded ability to perform manoeuvres required for basic performance. It can be seen in the Mikrokopter Wiki page that the base airframe weighs 1kg. Each motor, with a selected propeller is capable of generating 500g of thrust. This means that the combined maximum thrust of the four motors is 2kg. It was decided that the MTOW should not exceed 1.4kg and hence the payload should not exceed 400g, as per the system requirement stated in RD/4. It can be seen in Figure 1 that the payload was designed to weigh 400g. A subsequent test was carried out to ensure that the quad-copter was able to perform correctly with this configuration.



Figure - Total weight of payload

## Onboard Systems Architecture

The initial design utilised the hardware selected in various trade studies during the planning phase of the project. Throughout the course of the project many revisions were made to the inital design due to hardware limitations discovered during the implementation stage. Figure 2 shows the final hardware architecture as used on the project. It can be seen that the flight computer is as the centre of the system. It manages all the high and low level control of the system. To the left of this is the MCU which acts as the pulse capture and generation unit. It can pass pulse widths straight through fomr the RC Rx to the Gyro in manual mode or generate pulses from autopilot commands during manual flight. The IMU is connected directly to the flight computer as it is seen as a critical component for maintaining attitude stabilisation. To account for the deficiency in necessary UARTs, an Arduino was used to expand this capability. Connecting to the flight computer through USB, it allows the Magnetic Compass and Camera to be connected. The camera connection is for passing optical flow data to the flight computer. This is a feature that was not implemented in 2010, but can be added to future implementations. Finally, the Arduino is also used for capturing analogue data from the ultrasonic sensor and battery voltage. There are additional ADCs available for future addition of coulomb counters and temperature sensors.



Figure - System Design Overview

# Power System Design

The autopilot power system is a fundamental component in ensuring project success. The entire system requires a constant 5 volt regulated power supply to function correctly. In 2009, a standalone voltage regulator was added to the system to provide the necessary power. This was not required in 2010 as the ESCs chosen were able to perform this role. It was observed that the ESCs were fitted with two 5 volt regulators. The LF50A regulators, shown in Figure 3, are each capable of delivering 1 amp each. This means that when they are configured in parallel, as they are on the board, they are capable of supplying 2 Amps. As these are already fitted to the ESCs, and will be mounted to the airframe regardless of use, it was decided that these would be used as the source of 5 volt power. Within this section, the 5 Volt power distribution will be known as the “low voltage power system” and the 12 Volt power distribution system will be known as the “high voltage power system”.

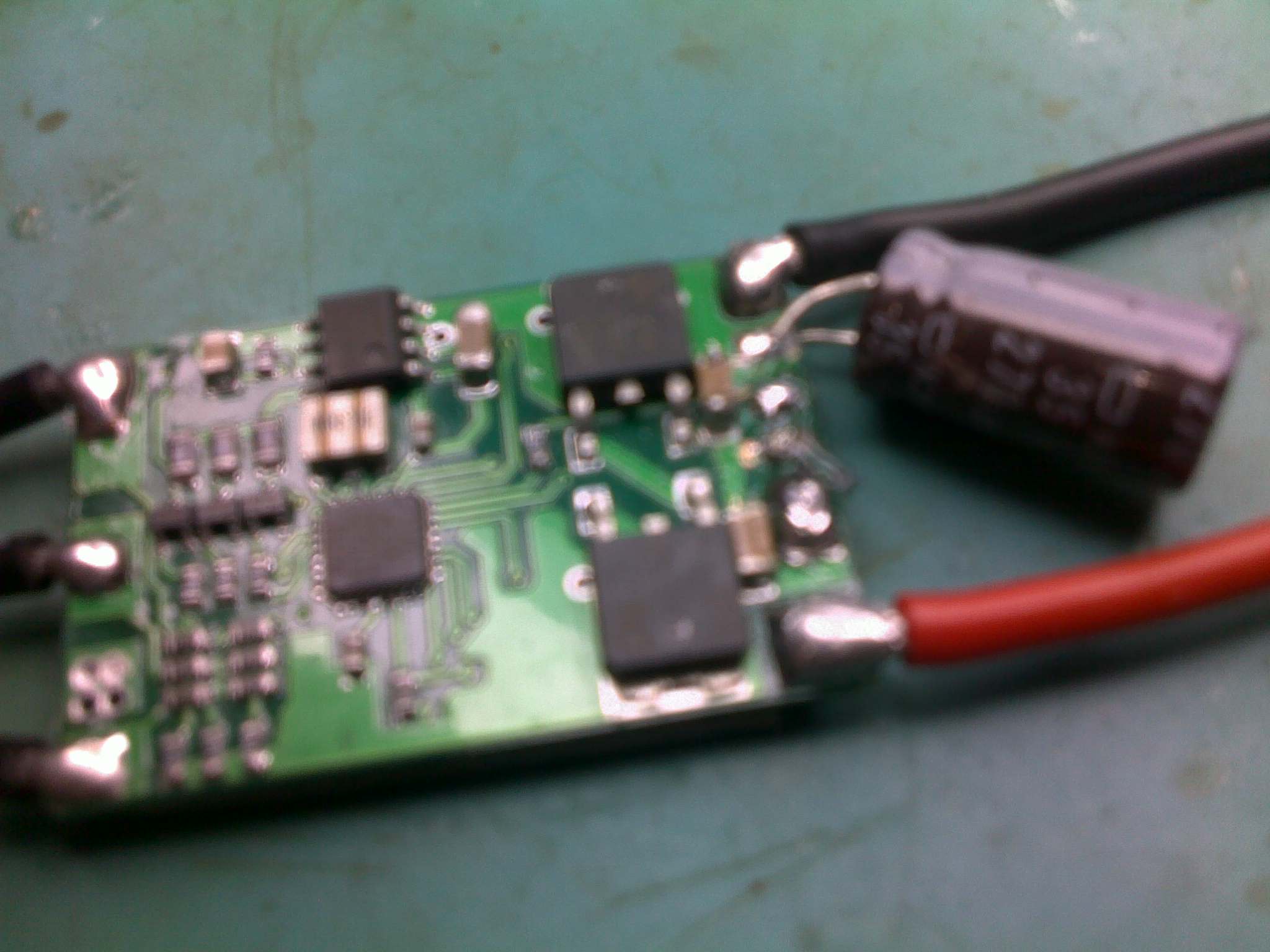


Figure - Voltage Regulators on ESC

## High Voltage Power System

The high voltage power system refers to the distribution of all 12 Volt power throughout the airframe. The source for the power is the flight battery and needs to breakout to the four ESCs. In addition to this, a line needs to be tapped off this to measure the battery voltage. Figure 4 shows a functional diagram of the high voltage power distribution system. It includes the voltage divider resistors that are required for measuring the battery voltage. This is discussed in more detail in the next section.

### High Voltage Harness

The high voltage power distribution harness, shown in Figure 4, is divided into two major but similar sections. These are the positive side of the system and the negative side. These sections were made in parallel as duplicates of each other. Once they were made, a wire was attached to mark the positive side and negative side. This is illustrated in Figure 5.



Figure - High Voltage Distribution System Schematic

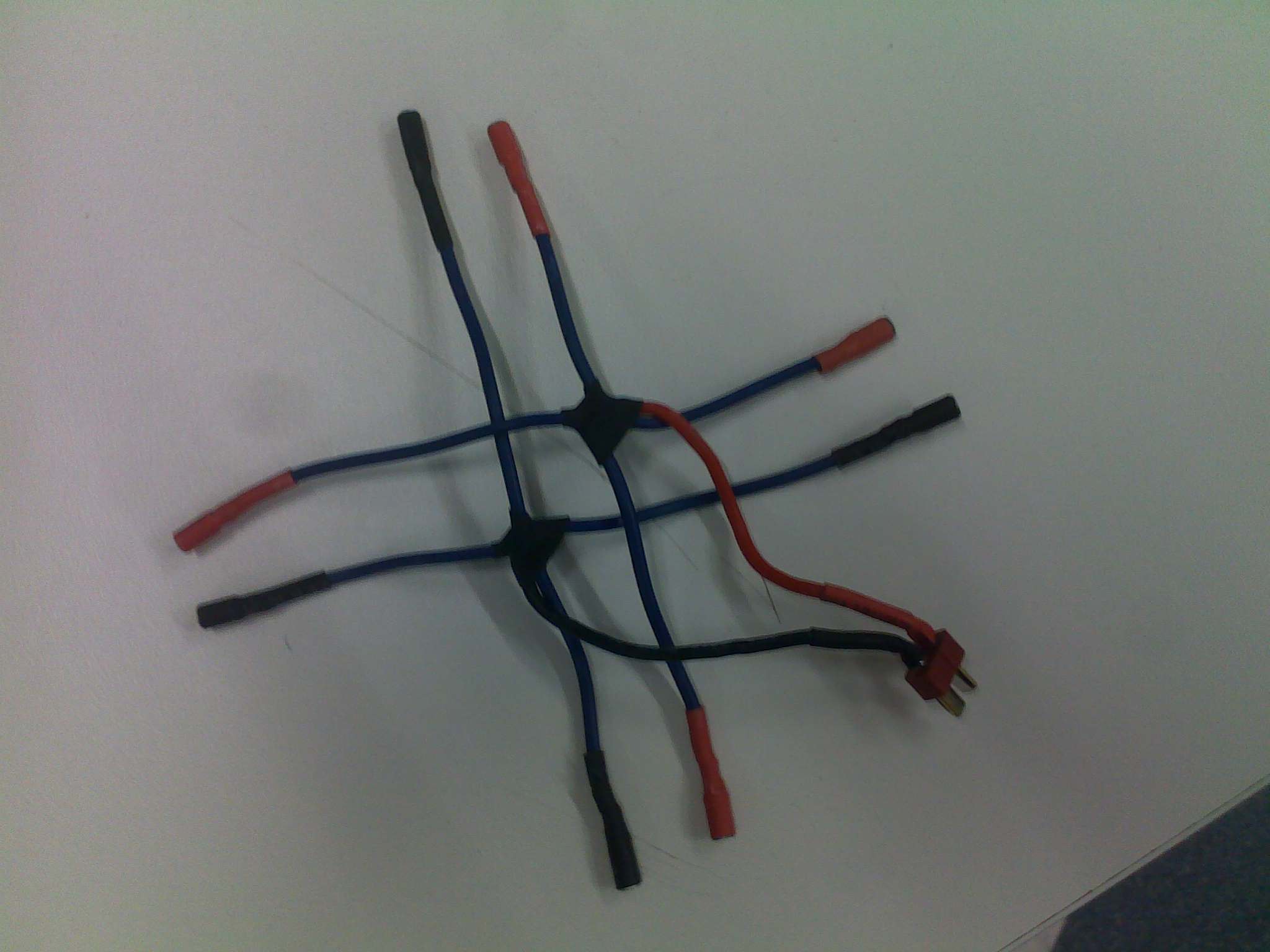
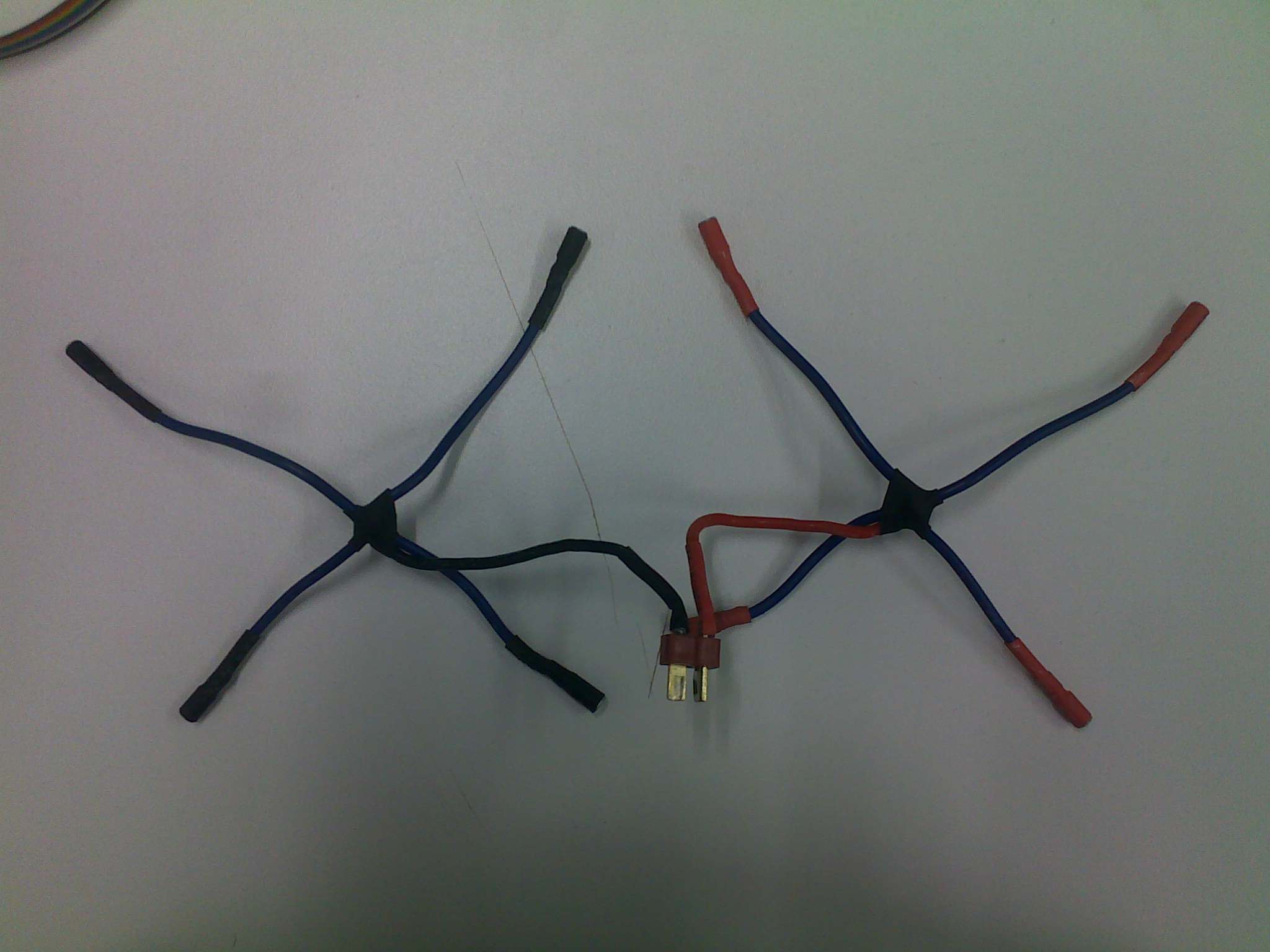


Figure - High Voltage Power Harness

### Voltage Divider

The voltage dividing resistors were made as separate modular pieces to allow for easy access during repair and maintenance. In addition to this, they are integrated into the ADC harness which also connects to the ultrasonic altimeter. The voltage divider was designed with the assumption that the maximum voltage reached on the high voltage side would be 14 Volts. The values were chosen such that they would be high enough to ensure there is negligible current through resistors, while being low enough to ensure they are not affected by the input resistance of the ADC. The final resistor values were 56k and 100k this can be seen in Figure 4. The divider can be seen in in the bottom left of Figure 5 connected to the ADC harness.

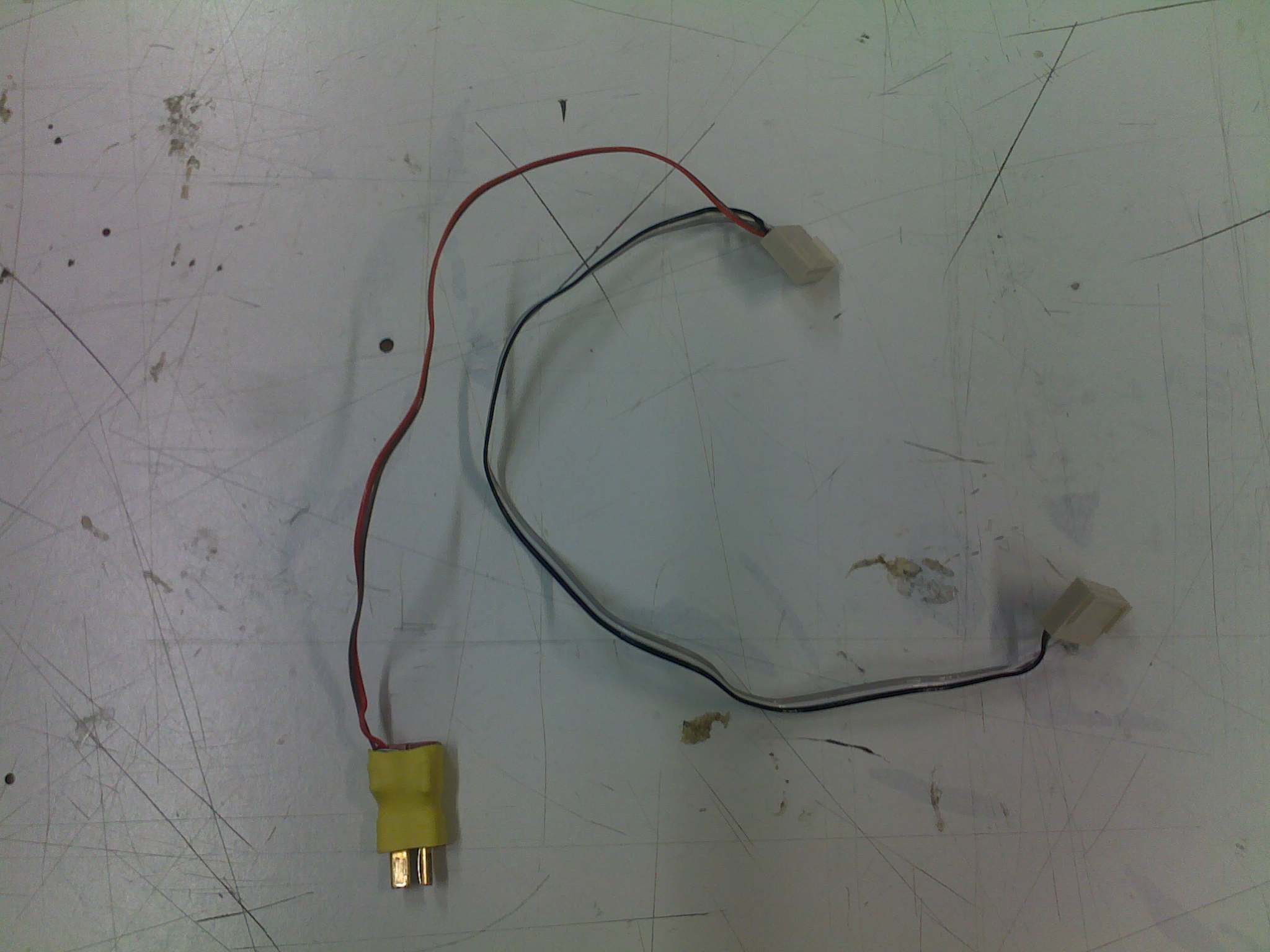


Figure - Voltage Divider Connected to ADC Harness

### Main Power Switch

The main power switch that was selected is rated at 20 AMPS. As a result is was large and difficult to mount. As with the voltage divider, it was made as a separate module that could be detached during repairs and maintenance. As the switch is illuminated, it requires the system ground to be connected to it. This can be seen in Figure 7. The switch controls the entire system. That is, if it is turned off, all electronic components are turned off. This includes the ESCs.



Figure - Main Power Switch

Once the high voltage harness, voltage divider and main power switch were made, they could be installed in airframe. The power harness needed to be installed early as it is attached ot the actual airframe. This can be seen in Figure 8.



Figure - Power Harness in Airframe

The switch and voltage divider were installed at later times. These components can be seen in Figure 9.

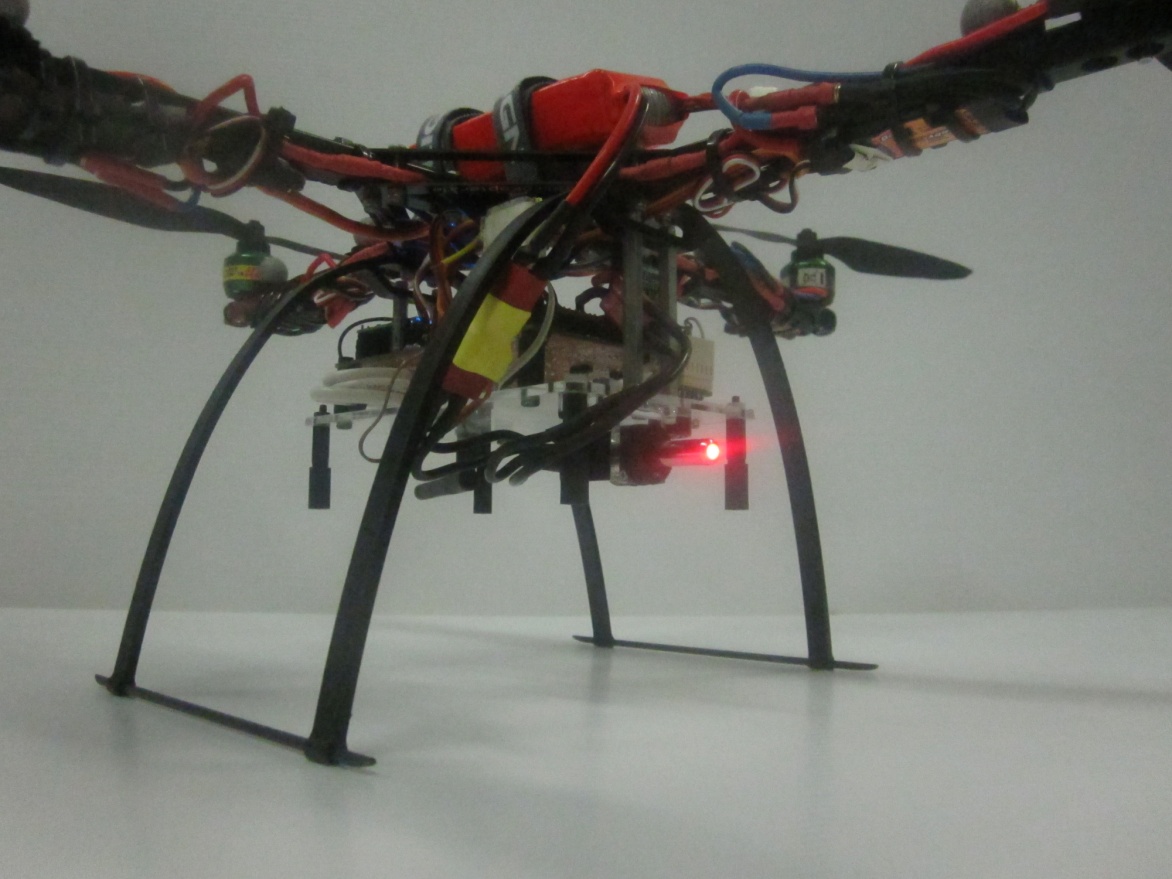


Figure - Voltage Divider and Switch on Airframe

## Low Voltage Power System

The low voltage power systems refers to all parts of the platform that operate at 5 Volts. As mentioned previously, the 5 Volt regulation is carried out by the regulators fitted to the ESCs. The LF50A regulators are fitted with short circuit and over temperature protections. This means that if either of these two conditions is met, the device shuts down to recover. Under normal circumstances this would lead to a complete power failure. In this case however, as there are four ESCs connected, each with two regulators, the system is powered by a total of eight regulars. As such, if any single regulator reaches a shut down conditions, the remaining seven will be able to continue powering the system. As each individual regulator is capable of powering the entire system, up to seven failures can occur on any one flight. Alternatively if any of the malfunctions during a flight test, the offending ESC’s power line can be disconnected and flight testing can resume with the remaining six regulators.



Figure - Low Voltage Power System

The low voltage power is connected directly to the autopilot board and is decoupled by a 100uF capacitor. The Autopilot board distributes the power to all other systems on the platform.

# Autopilot Hardware Design

Talk about autopilot design

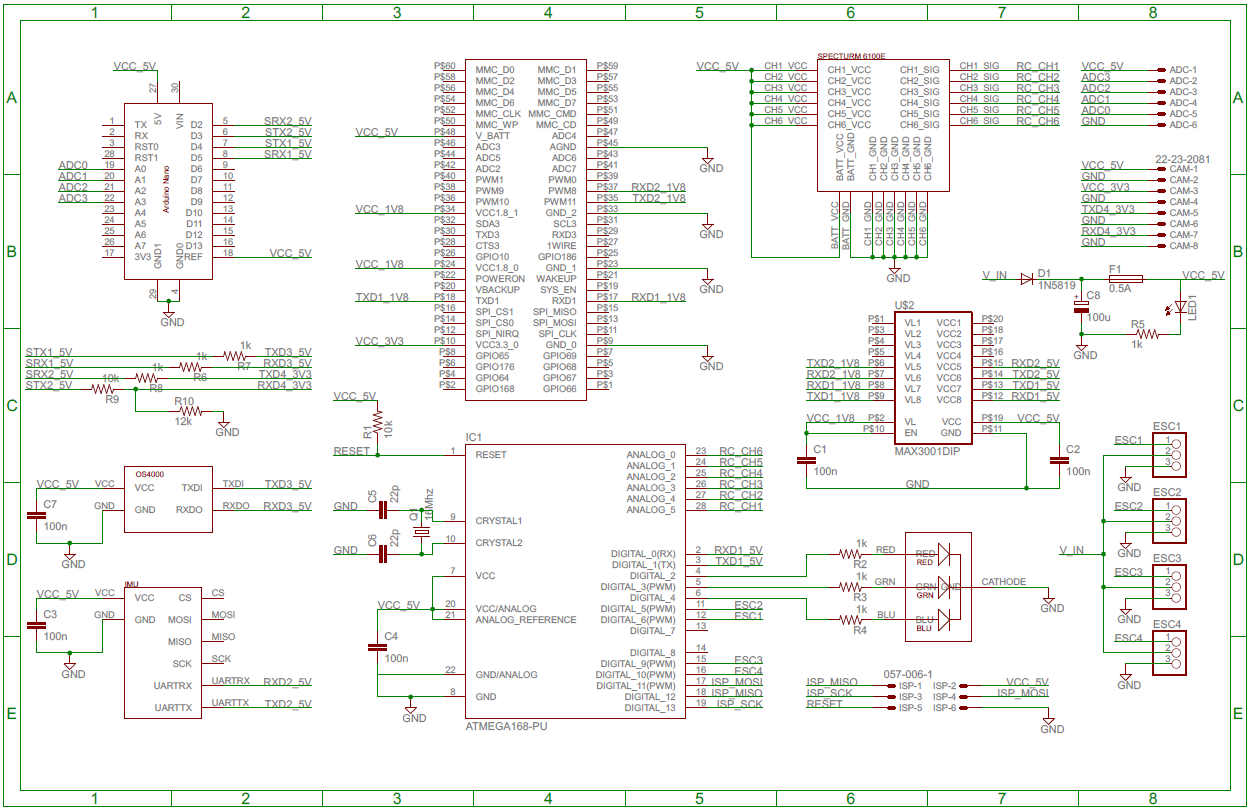


Figure – Final Autopilot Schematic

Table - Autopilot Bill of Materials

|  |  |  |
| --- | --- | --- |
|  | Component | QTY |
| Passive  Components | Resistor - 1/2W - 1k | 8 |
| Resistor - 1/2W - 10k | 2 |
| Resistor - 1/2W - 12k | 1 |
| Capacitor - 22p | 2 |
| Capacitor - 100n | 5 |
| Capacitor - 100u | 1 |
| Diode – 1N5819 | 1 |
| Active  Components | LED - TriColour - 5mm | 1 |
| LED - Red - 3mm | 1 |
| MAX3001 (on breakout board) | 1 |
| ATMEGA328 DIP28 | 1 |
| Crystal - 16MHz | 1 |
| Modules | PINTO DIP for OVERO COM | 1 |
| Arduino Nano | 1 |
| Sensor Dynamics - Inertial Measurement Unit | 1 |
| OS4000 Compass Module | 1 |
| Hardware | Header, Locking - 6PIN - Male | 1 |
| Header, Locking - 8PIN - Male | 1 |
| Header, Terminal - 3PIN - Male | 4 |
| Header, Terminal - 4PIN - Female | 3 |
| Header, Terminal - 7PIN - Female | 3 |
| Header, Terminal - 10PIN - Female | 2 |
| Header, Terminal - 15PIN - Female | 2 |
| Header, Terminal - 30PIN - Female | 2 |
| Header, IDC - 6PIN - Male | 1 |
| M205 PCB Fuse Holder | 2 |
| M205 Fuse - 1Amp | 1 |
| IC Socket - 14PIN - Narrow | 2 |

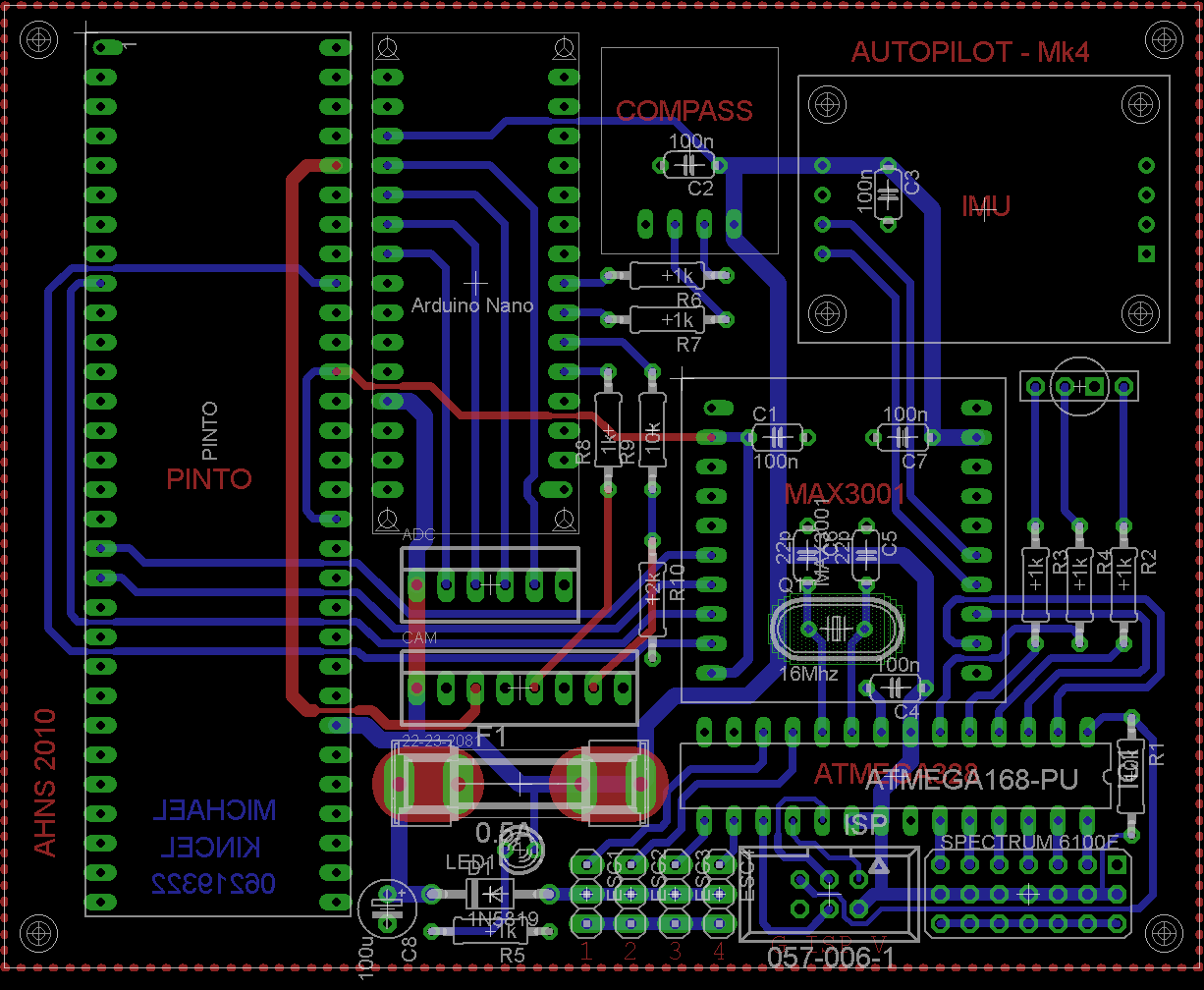


Figure - Final PCB Layout

# Altitude Sensor

In order to determine the altitude of the helicopter a Maxbotix ultrasonic altimeter was used, as shown in Figure 11. This type of sensor emits a brief ultrasonic pressure wave and measures the time delay from transmission to receiving it again. In principle, half the measured time multiplied by the speed of sound can determine an approximate distance. This sensor was mounted on the lowest electronics tray to have an unobstructed view of the ground. By contrast, an IR sensor was going to be used. This was later replaced with the ultrasonic sensor due to the potential of interference with the Vicon system. The sensor has a useable range of 15cm to 6 metres. This is inside the operating altitude of the aircraft.

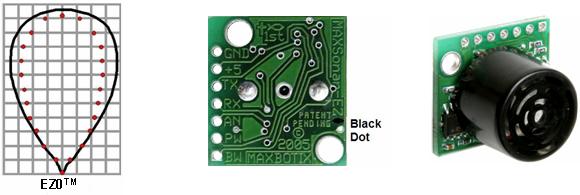


Figure - Maxbotix EZ0 Ultrasonic Altimeter

The output of the sensor is provided as an analogue voltage that changes depending on the distance. This sensor is connected to one of the analogue inputs of the Arduino. The voltage output response was characterised, and a function implemented in flight computer. This function gives accurate altitude measurements to the state estimation system. The physical connected is achieved through the analogue harness shown earlier in Figure 6.

# Heat Considerations



Figure - Mounting of Heat Emitting Components

# Vibration Dampening

Helicopter platforms are prone to vibrations. The main rotor is positioned close to the hardware and directly vibrates the helicopter frame. Isolation of the delicate sensor and processing hardware from vibration is an important consideration in the design of the mounting systems. In an early flight test the communications link was disrupted due to vibrations affecting the power connection to the radio modem. Two solutions have been implemented to prevent this occurring in future flight tests. Vibration isolating material has been implemented in the design to protect the hardware and the electrical interface to the radios has been secured more effectively.

As shown in the multilayer board provides isolation from the rigid base and yet provides a secure base to mount the hardware separated by the anti-static foam.

# Conclusions

This document has detailed the onboard systems and telemetry design. The key system components such as the Robostix Processing board, IMU, IR DME and battery sensor are connected through the main interface board. All of the onboard hardware is mounted to the helicopter using a multi layer approach to protect the hardware from the effects of vibration and electrostatic discharge. This system conforms to the requirements as specified in RD/4.