ECE 477 Final Report – Spring 2010
Team 10 – RAPTORS

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CRITERION	SCORE	MPY	PTS
Technical content	0 1 2 3 4 5 6 7 8 9 10	3	
Design documentation	0 1 2 3 4 5 6 7 8 9 10	3	
Technical writing style	0 1 2 3 4 5 6 7 8 9 10	2	
Contributions	0 1 2 3 4 5 6 7 8 9 10	1	
Editing	0 1 2 3 4 5 6 7 8 9 10	1	
		TOTAL	

Comments:

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Abstract

The RAPTORS project is a remotely operated drone aircraft with a real-time flight data acquisition system. The project retrofits an existing model airplane with a custom radio transceiver and sensing equipment for inertial and navigation data, including a GPS, barometer, gyroscope, accelerometer, and camera. This data from the plane is transmitted to a ground station transceiver via a wireless signal operating in the 430 Hz range with feedback-loop controlled signal amplification. The receiving station is connected to a laptop which displays the data onscreen in real-time. The ground station, in turn, inputs control commands from the pilot and transmits them to the aircraft. Though federal regulations forbid civilian use of unmanned aerial vehicles out of line-of-sight, this vehicle could ostensibly be used for such purposes.

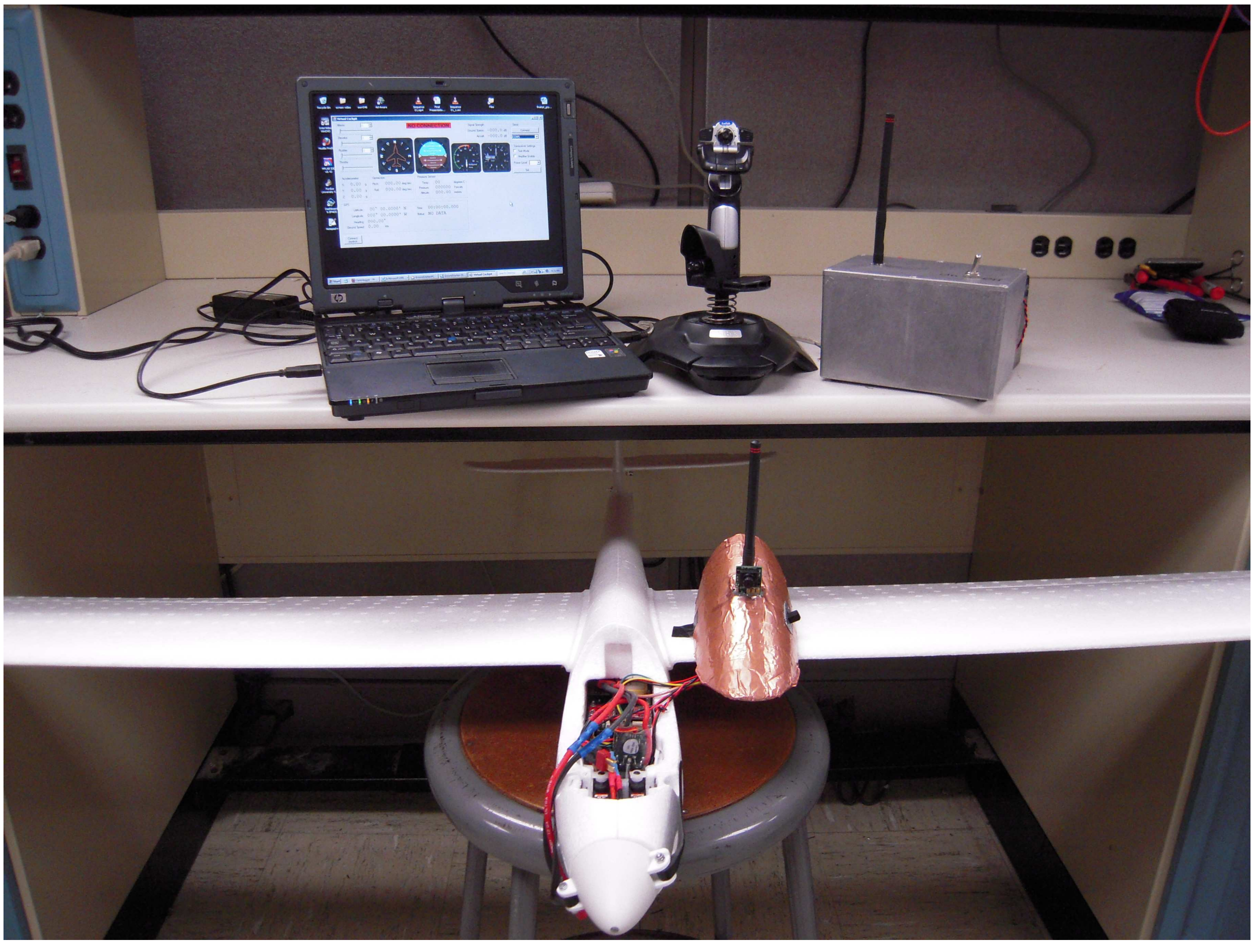
1.0 Project Overview and Block Diagram

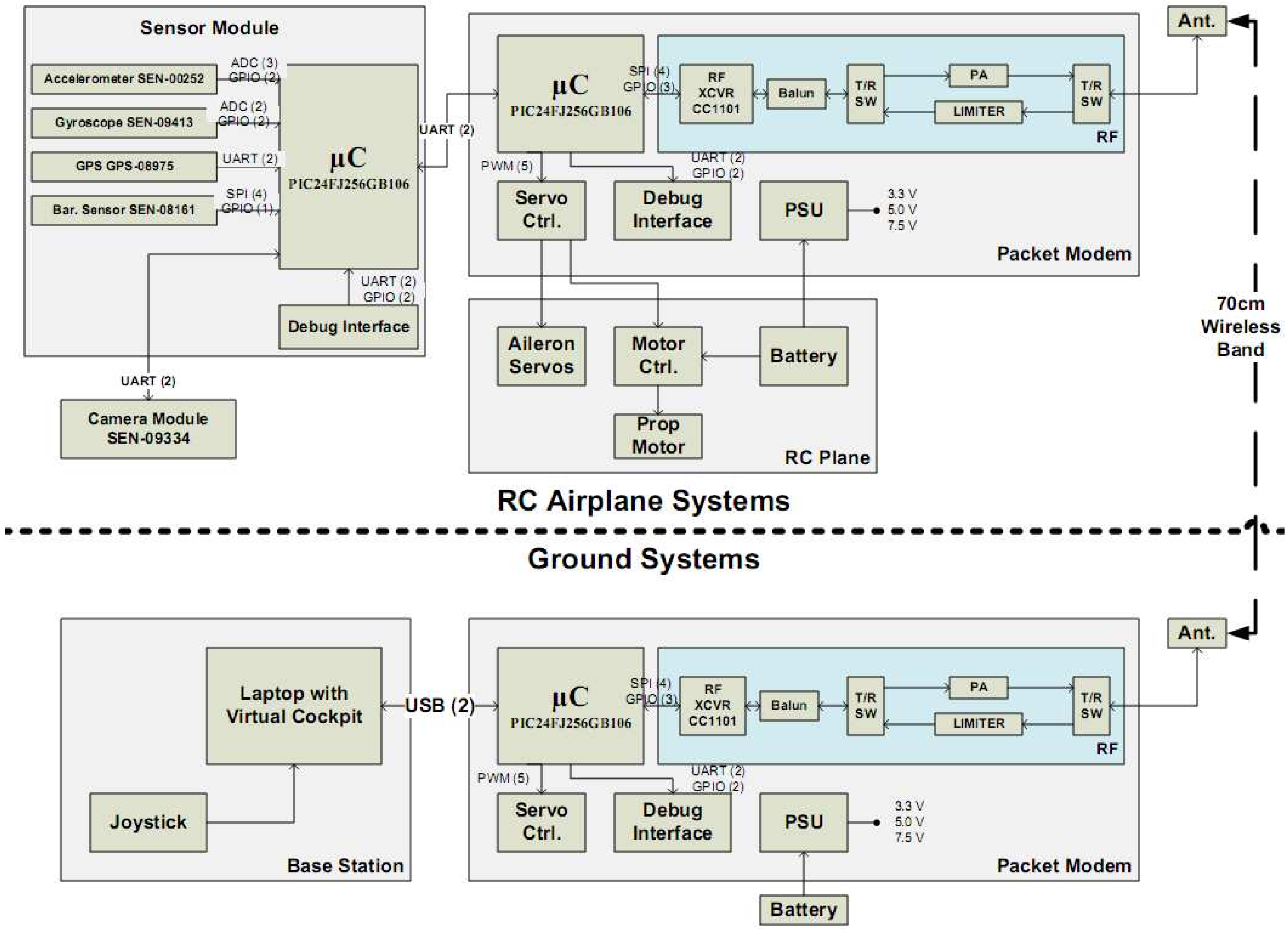
The project is comprised of four key elements: the aircraft, packet modem, aircraft inertial and navigational sensors, and the ground station. The aircraft is a foam RC airplane which was chosen based on characteristics such as stability, weight, power, and durability. The Easy Glider Pro exhibits these characteristics [1]. The packet modem directly controls the aircraft with commands via a joystick on the ground.

The design of the packet modem is based on the CC1101 RF transceiver chip from Texas Instruments [2]. The transceiver is capable of operating in the 420MHz-450MHz band at a data rate of 500 kbps. For legal operation in the US, the modem must be operated on the 70 cm amateur radio band with an amateur radio license. The transceiver is only capable of 10mW transmitting power, so a power amplifier was designed for long range transmission. A microcontroller is interfaced with the transceiver and handles packet formatting, error correction, buffering, and flow control.

The design utilizes a variety of sensing equipment including: an Accelerometer for each of the 3 axes, a MEMS Gyroscope, a GPS module, a Barometric Pressure Sensor, and a Camera. These sensors interface with the microcontroller which transmits the data to the ground station via the packet modem.

The ground station consists of a second packet modem connected to a laptop via USB. The packet modem design used in the aircraft was replicated in the ground station to simplify the design. A program is executed on the laptop which displays a virtual cockpit based on the data received from the aircraft sensors. A joystick is interfaced with the laptop to give the user real-time manual control of the aircraft. Autonomous control is not utilized.





Sensor Module
Accelerometer SEN-00252
Gyroscope SEN-09413
GPS GPS-08975
Bar. Sensor SEN-08161
ADC (3)
GPIO (2)
ADC (2)
GPIO (2)
UART (2)
SPI (4)
GPIO (1)
μC
PIC24FJ256GB106
UART (2)
GPIO (2)
Debug Interface
UART (2)
Camera Module
SEN-09334
UART (2)
μC
PIC24FJ256GB106
SPI (4)
GPIO (3)
RF
XCVR
CC1101
Balun
T/R
SW
PA
LIMITER
T/R
SW
RF
Ant.
PWM (5)
UART (2)
GPIO (2)
Servo
Ctrl.
Debug
Interface
PSU
3.3 V
5.0 V
7.5 V
Packet Modem
Aileron
Servos
Motor
Ctrl.
Battery
Prop
Motor
RC Plane
70cm
Wireless
Band
RC Airplane Systems
Ground Systems
Laptop with
Virtual Cockpit
Joystick
Base Station
USB (2)
μC
PIC24FJ256GB106
SPI (4)
GPIO (3)
RF
XCVR
CC1101
Balun
T/R
SW
PA
LIMITER
T/R
SW
RF
Ant.
PWM (5)
UART (2)
GPIO (2)
Servo
Ctrl.
Debug
Interface
PSU
3.3 V
5.0 V
7.5 V
Packet Modem
Battery

2.0 Team Success Criteria and Fulfillment

1. An ability to wirelessly transmit and receive packet data.
2. An ability to relay aircraft position and orientation utilizing inertial and navigational sensors.
3. An ability to capture images and relay them serially to the ground station.
4. An ability to control the aircraft servo motors via a microcontroller interface.
5. An ability to amplify an RF signal to 1 watt PEP of transmission power.

All five of the success criteria were fulfilled twice, once before we placed the project in its final packaging and once more after we placed the project in its final packaging. We have achieved consistent and reliable wireless communication of packet data at speeds of around 60 kilobytes per second. We relay aircraft orientation, altitude, longitude, latitude, and speed 16 times per second. We relay 1 picture per second at a resolution of 320x160. The servos are controlled via a joystick at our ground station. Our RF transmission signal has been amplified to just over 2 Watts with ½ Watt reflection.

3.0 Constraint Analysis and Component Selection

3.1 Introduction

The RAPTORS project is a remotely operated drone aircraft with a real-time flight data acquisition system. The project will retrofit an existing model airplane with a custom designed radio transceiver and sensing equipment for inertial and navigation data. The data from the plane will be transmitted to a transceiver connected to a ground station (laptop) and displayed onscreen in real-time. The ground station will, in turn, input control commands from the pilot and transmit them to the aircraft. Space and weight are going to be critical factors in the design of the custom electronics, since the boards must fit inside the aircraft, and not cause the total weight to exceed aircraft limitations. Success of this project will be judged upon the following project-specific success criteria.

1. An ability to wirelessly transmit and receive packet data.
2. An ability to relay aircraft position and orientation utilizing inertial and navigational sensors.
3. An ability to capture images and relay them serially to the ground station.
4. An ability to control the aircraft servo motors via a microcontroller interface.
5. An ability to amplify an RF signal to 1 watt PEP of transmission power.

3.2 Design Constraint Analysis

There are several design constraints that will be considered in this report. These include computation requirements, interface and peripheral requirements, power constraints, packaging constraints, and cost constraints. Furthermore, the rationale behind specific component selections will be explained and compared with other similar components. These constraints will be heavily based on three key factors, weight, space, and reliability, as these are critical in a model aircraft system.

Weight of any systems added to the aircraft must be carefully considered, as an overburdened airplane will exhibit poor flight dynamics and consume more power at cruising speed. The aircraft chosen for this project is the Multiplex Easy Glider Pro [1], along with the recommended power pack and servo pack. The motor included in the power pack is a Himax 3516-1130 brushless motor, which is capable of operating at 350W peak power. According to the manual, there is a requirement of 75W per pound of gross weight of the aircraft for sporty flight characteristics. This limits the gross weight of the aircraft to about 4.5 lbs. The aircraft loaded with standard systems has a gross weight of 1.75lbs, leaving a maximum of 2.75lbs available for any custom modifications. However, having an aircraft as light as possible will be easier to balance and also consume less power, extending the range of flight. Weight will play a key role in peripheral requirements, power requirements, and packaging constraints.

Space is very limited in a model aircraft. The Easy Glider Pro has a small electronics bay towards the front of the aircraft, which houses the servos, battery, and receiver. The electronics bay measures 6x2x2 inches. Any electronics designed in the project must be able to fit in this compartment. Space will be critical in peripheral requirements and packaging constraints.

Finally, reliability is critical in any aircraft system, as any failure in flight control systems would result in loss of aircraft control. Reliability can be obtained through considerable engineering factors, such as a large link budget in the wireless packet transceiver system, and simplicity in system design and integration. Reliability will be prevalent in computation requirements and interface requirements.

3.2.1 Computation Requirements

Computational requirements for this project will be minimal; the main purpose of the microcontrollers will be to aggregate data and reroute it between peripherals. The MCU on the sensor board will collect data from the accelerometer, gyroscope, barometric pressure sensor, GPS module and the camera if a picture has been requested. It will then transmit this data to the packet modem microcontroller via UART. The packet modem microcontroller is responsible for arranging this data in packet form, adding a checksum to the packet and transmitting it via SPI to the transceiver, as well as interpreting data received from the transceiver into servo control signals. The advantage of separating the sensor board and packet modem is that servo control of the airplane is independent of sensor and camera data. The data sent from the aircraft transceiver is sent to the base station, where it is received by the base station MCU. This MCU is responsible for checking the packet checksum, disassembling the packet and forwarding the data via a serial interface to the computer, as well as receiving information on this serial line concerning flight control data. On the computer, the received information will be transformed into visual information for the user.

3.2.2 Interface Requirements

There are two subsystems which the interface requirements will need to be described in detail: the packet modem and the sensor module. The packet modem is responsible for handling RF communications between the aircraft and the ground station, as well as control of the aircraft. The sensor module will measure the orientation and position of the aircraft and relay this to the ground station through the packet modem.

For the packet modem, interface requirements are based on communicating with the CC1101 RF transceiver chip [2], servo controllers, debugging interfaces, and an external serial communications channel. Communications with the CC1101 RF transceiver chip will require a standard 4-wire SPI interface as well as 2 GPIO pins. The servo controller interface will be composed of 8 channels which will use PWM to control the 4 plane control surfaces and the engine controller, with 3 extra for future expansion. The debugging interface will be comprised of a single RS232 channel requiring a UART peripheral and 3 GPIO's for driving LEDs. The external serial communications channel will be a TTL level UART which will interface with either the sensor module on the plane or a USB port which will interface to a laptop at the ground station for bulk data transfer of sensor and control data.

The sensor module requires interfacing with a 3-axis accelerometer, a 2-axis gyroscope, a GPS receiver, a camera module, a barometric pressure sensor, and a debug interface. The 3-axis accelerometer will require 3 ADC channels. The 2-axis gyroscope will require 2 ADC channels. The GPS receiver and camera module each have a TTL level UART interface. The camera module will break the jpeg image into 64 byte chunks when transferring it to the sensor module, thus requiring little memory on the microcontroller. The barometric pressure sensor will require a 4-wire SPI interface. The debug interface will require a RS232 channel and 3 GPIO's for driving LEDs.

Interface	Packet Modem MCU	Sensor Module MCU
GPIO	5	3
PWM	5	0
ADC	0	5
UART (x2 pins)	2	4
SPI (x4 pins)	1	1
USB (x2 pins)	1	0
PIN COUNT	20	20

Table 2.2.1 – MCU Peripheral Requirements

3.2.3 On-Chip Peripheral Requirements

The MCU in the packet modem will require 5 16-bit PWM channels, 2 UART channels operating at 115.2k baud, 1 USB, and 1 SPI channel operating at 4MHz. For the sensor module, the MCU will require 5 10-bit ADC channels, 4 UART channels, and 1 SPI channel operating at 500kHz. These requirements are shown in Table 2.2.1.

3.2.4 Off-Chip Peripheral Requirements

The MCU in the packet modem will interface with the CC1101 RF transceiver chip from Texas Instruments [2]. This MCU will also interface with the servo motors and engine controller from Easy Glider Pro Servo Pack and the Easy Glider Pro Power Pack [1]. It will also interface with a RS232 level translator and USB device interface.

The MCU in the sensor module will interface with the GPS-08975 GPS module [3]. It will also interface with the SEN-00252 3-axis accelerometer [4], the SEN-09413 2-axis gyroscope [5], SEN-08161 barometric pressure sensor module [6], and the SEN-09334 camera module [7].

3.2.5 Power Constraints

The packet modem and sensor module located on the aircraft will be powered by the on board rechargeable Lithium-Polymer battery pack which is already used to power the aircraft. The battery has a nominal voltage of 11.1V and 4200mAh capacity [1]. Majority of the peripherals on both subsystems operate with a nominal 3.3V supply, with exception to the RF power amplifier, which requires a 7.5V supply. Power regulation will be located in the packet modem, and will be shared with the sensor module. The base station packet modem will require an external power source, which could be supplied by a lead-acid or NiMH battery pack.

The major consumer of power in the system, other than the aircraft engine, will be the power amplifier in the packet modem. Presently, the design calls for a 1W power amplifier in the final stage of the RF block. A linear regulator will be used to convert the battery voltage to 7.5V as a low noise source is critical for RF amplification.

3.2.6 Packaging Constraints

The major concerns in packaging are weight and size, due to the limited space and weight capacities of the aircraft. There is a small cargo bay in the fuselage of the aircraft which the electronics must fit within, along with the existing servos, engine, and battery. Furthermore, the aircraft weighs 1.75 lbs, while the engine is capable of supporting a gross weight of 4.5 lbs while retaining a sporty flight characteristic, leaving 2.75 lbs available for our modifications.

Requirements are considerably more relaxed for the ground station equipment. Primary concern in packaging is protecting the electronics from environmental damage and normal wear-and-tear.

3.2.7 Cost Constraints

There are no commercially available complete systems that offer the same functionality as what our project will provide. Other people have built custom systems that provide similar functionality, however these are not available for retail purchase. However, the military has a few micro-UAV solutions available which are similar in functionality. For instance, the Wasp III small unmanned aircraft system developed by AeroVironment is a light-weight aircraft which can be hand launched by an individual on the ground and then controlled via a remote [8]. The aircraft has a cruise speed of 20-40 MPH and a maximum altitude of 1,000 feet. A display on the remote gives the user real-time video feed from one of the two onboard cameras. These units are relatively expensive, at a cost of about $49,000.

3.3 Component Selection Rationale

The most significant criteria for selecting the components for this project are cost and ease of integration. Each part was selected to interface easily with the microcontroller without requiring more peripherals than are available on a PIC24F series microcontroller from Microchip, which was chosen because three of our team members have extensive experience programming and debugging them. Specifically, the PIC24FJ256GB106 [9] was chosen since it meets our peripheral requirements above, particular the need for 4 UART interfaces. An alternative would be the ATmega640 from Atmel. However, the ATmega640 still only has preliminary documentation, has more I/O pins that necessary, lower clock speed, and the team has little previous experience with Atmel products.

The three-axis accelerometer, as with the other sensors, was sourced from the extensive, well-supported selection at Sparkfun. Cost being a factor, the selection was quickly narrowed down to three options: the MMA7260Q [4], which costs $19.95 and has an analog interface, the $24.95 ADXL335, and the $27.95 ADXL345, which features and SPI interface. Each of the accelerometers are sold with a breakout board from Sparkfun so research was done in acquiring the ICs and simply integrating them into the PCB design, however none were available in an leaded package. The MMA7260Q has a selectable range from 1.5 to 6g and the ADXL335 has a maximum value of 3.3g. The ADXL345 was eliminated due to cost and the complexity involved in implementing an additional SPI interface. Ultimately, the MMA7260Q was selected due to the ability to select the range.

Like the accelerometer, no gyroscope ICs were found with a leaded package. Therefore, it was determined that a breakout board from Sparkfun would again need to be implemented. The selection of two-axis gyroscopes is less extensive than that for the accelerometers, primarily varying only in range and orientation. It was determined that we would need to collect pitch and roll data, as yaw could be measured using the GPS unit. Sparkfun offers three modules to meet this specification: the LPR503AL [5], which has a maximum range of 30°/second, the LPR530AL with a maximum range of 300°/second, and the LPR5150AL with a maximum range of 1500°/second. Each interfaces with an analog interface and costs $29.95. It was determined that the aircraft may move at greater than 30°/second, but should stay below 300°/second during desired operation, so the LPR530AL was selected.

The GPS module GPS-08975 [3] has an operation voltage of 3.3V, a 5 Hz rate of update, and a TTL level serial interface. This is convenient due to its voltage of operation and the interface to the MCU. Another candidate for the GPS module was the GPS-00465 which operates at 5V, and an RS-232 level serial interface. The voltage and interface are less convenient. Since both of these modules have the same price the GPS-08975 was chosen.

As a camera the SEN-09334 [7] was chosen because it provides a 640x480 color picture. It operates at 3.3 V which is convenient for our board and transmits data serially at RS232 level. The key feature that makes this camera the best choice is that it converts the image to JPEG on the module before sending allowing us to transmit images more rapidly without compressing them ourselves in our embedded environment. Another comparable camera is the SEN-08739 which also provides 640x480 color pictures. It has a voltage operation range of 5 to 15 Volts and interfaces through RCA, which would require some sort of custom video encoding hardware.

For wireless data transmission, the CC1101 low-power RF transceiver from Texas Instruments [2] was chosen. The chip is capable of operating in the amateur radio band of 420-450MHz band with a data rate of 500 kbps. Regulations are relaxed in the amateur band and traffic is relatively light; only thing required is an amateur radio operator license and adhering to part 97 of the FCC regulations [10], including transmitting a call sign once every 10 minutes. An alternative would be the nRF24L01+ from Nordic Semiconductor, which operates in the 2.4GHz band with a data rate of up to 2 Mbit per second. The downside to this is that the 2.4GHz band is heavily used by commercial ISM products, and the design would need to comply with part 15 of the FCC regulations [11] for unlicensed devices. Part 15 regulations are considerably more stringent than part 97 regulations.

3.4 Summary

The RAPTORS project will retrofit an existing model airplane with a custom designed radio transceiver and sensing equipment for inertial and navigation data. This will be relayed to a ground station, giving a user a virtual cockpit of the vehicle. The user will also have a joystick which will also remotely control the aircraft through the custom radio transceiver. The project's design constraints described in this report covered computation requirements, interface and peripheral requirements, power constraints, packaging constraints, and cost constraints. These constraints were heavily based on three key factors, weight, space, and reliability, as these are critical in a model aircraft system.

The computation requirements, interface requirements, and peripheral requirements were chosen to keep the design simple, yet functional, as this will produce a system which is more reliable. With respect to power constraints, components were chosen such that they could operate at 3.3V, as this keeps interfacing between peripherals simple. Since the aircraft's engine will consume considerably more power than the onboard electronics, power consumption is not a big factor. Packaging constraints will need to be chosen based on weight and space, since this is sparse. Cost is also not a critical factor, since existing solutions are in the tens of thousands price range.

The rationale was also described for selection of microcontroller, accelerometer, gyroscope, GPS module, camera, and transceiver components. Alternative components were also considered for each of the components and an explanation was given for the given selection.

4.0 Patent Liability Analysis

4.1 Introduction

Project RAPTORS is largely an application of numerous, widely available components and methods, so patenting much of the system would be somewhat of a challenge as much of the project could be considered common knowledge. However, the system as a whole could potentially be patented as no literally similar patents appear to exist. Some do incorporate features and methods that could potentially infringe, and care would need to be taken to avoid this.

4.2 Results of Patent and Product Search

4.2.1 Patent #7,014,141: Unmanned airborne reconnaissance system

This patent, filed on July 12, 2002, details an unmanned aircraft designed to be easily transported into the field and flown from a power-assisted launch system. The aircraft can be controlled via a radio link to a ground station or via preprogrammed instructions and has an onboard camera for taking and transmitting images. Claim number 8, which states "An airborne reconnaissance system comprising: an airborne vehicle having a fuselage and wings adapted to be removed from the fuselage, the airborne vehicle including an onboard video camera and video signal transmitter and a flight control system to remotely control a flight of the airborne vehicle from a remote location…" [12] is the most significant that would present a concern where infringement is concerned.

4.2.2 Patent #7,289,906: Navigation system applications of sigma-point Kalman filters for nonlinear estimation and sensor fusion

This patent, filed on April 4, 2005, details a method by which a Kalman filter, in conjunction with a Gaussian approximate random variable propagation technique, can be utilized to gain a more accurate approximation of the position of an object based on noisy data. The data is gathered by means of an inertial measurement unit (IMU) and GPS systems, which may be integrated into a single package. the claims of greatest concern is number 12, which states "An integrated navigation system for estimating the navigational state of an object, … the system state space model specifying a time evolution of the system and its relationship to sensor observations, comprising: measurement sensors producing observation data in the form of noisy information about the navigational state, the measurement sensors including an integrated measurement unit (IMU) … operating to provide information for estimating a set of navigational state components that include position, velocity, attitude, and angular velocity…" [13].

4.2.3 Patent Application #20070020588: Low-cost flight training and synthetic visualization system and method

This patent, filed January 9, 2006, consists of a sensor and data storage device for collection position and navigational data from an in-flight vehicle. The data can also be transmitted directly to a ground station which can render the data in real time on a video display or simply display the information in an external software application. The claims of greatest concern include claim 1, which describes "A flight training and synthetic visualization system comprising: a. a self-contained mobile data recording unit, comprising: i. an inertial measurement means to continuously sense three-dimensional orientation of said mobile data recording unit in terms of yaw, pitch, and roll … v. a processor means to gather navigational information captured by the components of said mobile data recording unit; … c. A data transfer means for transferring said navigational information, calibration data, and status information between said mobile data recording unit and said software engine" and claim 5, which describes "The flight training and synthetic visualization system of claim 1, wherein said data transfer means is a wireless radio connection" [14].

4.3 Analysis of Patent Liability

None of the patents described in section 4.2 exactly encompass all of the features of Project RAPTORS in a literal manner, therefore literal infringement is not a concern. The project does, however, utilize similar technologies and methods to those listed, and care must be taken to ensure that they do not infringe under the doctrine of equivalents.

For the unmanned airborne reconnaissance system [12], similarities to Project RAPTORS include the aircraft's ability to take reconnaissance photos from an onboard camera and relay them to the ground via a wireless link. Further, the aircraft can be controlled via the same wireless link from the ground station. Differences to Project RAPTORS include the use of a compact launching and storage system, as well as the inability to send navigation and inertial data to the ground station. Further, Project RAPTORS does not utilize an onboard storage system for collecting data, nor an onboard automated aircraft control system.

For the navigation system applications of sigma-point Kalman filters [13], Project RAPTORS will be utilizing a Kalman filter in a similar manner to combine inertial data from our sensor unit, however, the process by which this will be accomplished will not be as sophisticated as the methods described in this patent. Further, the data utilized will only be coming from the accelerometer and gyroscope sensors, and not utilized the data coming from the GPS unit.

Finally, for the aircraft telemetry and visualization system [14], similarities to Project RAPTORS include the collection and transmission of flight and navigational data to a ground station via RF link, which is then transferred to an external computer for analysis in real-time. Differences include the lack of the ability to send control signals to the aircraft, and the inclusion of on-board data storage to be exported at a later time. Given the vast similarities between the system and Project RAPTORS' sensor and telemetry functions, this patent presents the greatest challenge to avoiding infringement.

Despite the differences between Project RAPTORS and the aforementioned patents, there is a small possibility of infringement with them, therefore care must be taken to avoid such issues.

4.4 Action Recommended

To avoid infringing on the unmanned airborne reconnaissance system [12], care must be taken to note that Project RAPTORS will not be taking continuous video and that the aircraft being used will not be utilizing an assisted launch system as the patent describes. For the Kalman filter methods [13], a different usage of the Kalman filter must be used, such as neglecting GPS data in the calculation. This would result in a slight drop in accuracy than the described method, but would avoid infringing on the patent, since the Kalman filter itself is not patentable. Finally, the patent described in [14] has not yet been granted so it is uncertain as to whether it will need to be greatly taken into consideration. If it is granted, it is possible that enough differences exist between the two devices to avoid infringement or to fight the allegations in court. Project RAPTORS provides both a control and monitoring system without providing a video overlay, as opposed to simply a data collector. Further, the concept of a simple telemetry system to relay data is not novel and is therefore not patentable in its own right.

4.5 Summary

Three existing patents and patent applications have been presented that may conflict with Project RAPTORS. The “Unmanned airborne reconnaissance system” patent [12] could potentially be a problem where infringement is concerned, unless RAPTORS does not incorporate a live video stream. Infringement on the method for using a Kalman filter [13] could be avoided by not incorporating the GPS data into the method used by RAPTORS. Finally, the patent application described in [14] could potentially cause an infringement problem, but the patent has not yet been granted.

5.0 Reliability and Safety Analysis

5.1 Introduction

There are several dangers posed by our system, ranging in risk level from the possibility of human injury to a minor annoyance. One serious hazard our vehicle could encounter is a loss of control, which is a very real possibility in the case of a wireless aerial vehicle, whether from loss of transmission or component failure. Such control loss may result in an accidental collision, either with the ground, which could result in system damage, or with a person, which has the potential to cause injury. Another potential risk is voltage regulator failure, which could cause a fire or shock hazard also resulting in personal injury. There is significant reason, then, to ensure that the system is reliable and has a very low failure rate to ensure that injury does not occur.

5.2 Reliability Analysis

On any circuit board, there are components that are more significant and prone to failure than others. Generally, these devices are characterized by either a high complexity, signified by a large number of pins, or a very high device junction temperature under load. Four components of the RAPTORS projects have been identified as being at high risk of failure.

The RF Power MOSFET [15] on the two modem boards is sourcing a high amount of current and dissipating a fair amount of heat, thus it seems an ideal candidate for failure evaluation. The MIL-HDBK-217F document [16] doesn't have a direct analog to this device, so it was assumed the transistor was operating under 400 MHz when in reality it operates at about 420MHz. The environmental conditions were also assumed to be approximately equivalent to that of an airborne inhabitable cargo area, an assumption in all the MFFT analyses. After these assumptions, all other parameters matched the entry for "Transistors, Low Frequency Si FET".

Parameter name	**Description**	**Value**	**Comments**
λ_b	Base Failure Rate	0.012	MOSFET v. JFET
π_T	Temperature Factor	1.0	1.8 °C/W @ 1W + 25°C
π_A	Application Factor	1.5	Linear Amplification < 2W
π_Q	Quality Factor	8.0	RF Plastic Package
π_E	Environment Factor	13	Airborne Inhabited Cargo.
Entire design:		1.872	Failures/10^6 hours
		60.98 years	MTTF

Table 1: RF Power MOSFET MTTF Tabulation

Another device which seems like a likely point of failure in the RAPTORS project is the PIC24FJ256GB106 Microcontroller [9], mostly due to the fact that it has the more pins than any other device in the circuit. The device itself was assumed to be a "microprocessor", with the details of its operation specifying the parameters affecting the MFFT. The junction temperature was assumed to be the worst case operating temperature under bias listed in the datasheet, about 100 °C. The manufacturing start date was assumed to date from around the same time as the original revision of the PIC24F family introductory document.

Parameter name	**Description**	**Value**	***Comments***
C1	Die complexity	0.28	16-bit MOS device
π_T	Temperature coeff.	1.5	Worst case operating temperature (100 °C) and VHSIC CMOS
C2	Package Failure Rate	0.032	Non-hermetic SMT, 64 pins
π_E	Environment Factor	4.0	Airborne Inhabited Cargo
π_Q	Quality Factor	10	Unknown Screen Levels
π_L	Learning Factor	1.0	2.5 years, 6/07 – 2/10
Entire design:		5.48	Failures/10^6 hours
		20.831 years	MTTF

Table 2: PIC24F Microcontroller MTTF Tabulation

The RF Transceiver CC1101 [2] is another significant microcircuit with high complexity and high pin count (20) that may be prone to failure for those very reasons. Analysis was conducted using the same model as the microprocessor. Since no transistor count was given for the specific device, several other similar devices were found that had comparable features with transistor counts around 1,500 transistors, thus this count was used. In addition, the worst case ambient temperature was used to find the temperature coefficient, and the initial datasheet version date was used as the starting data of manufacture.

Parameter name	**Description**	**Value**	***Comments***
C1	Die complexity	0.050	1000 – 3000 transistors = 250 – 750 gates
π_T	Temperature coeff.	0.98	Worst case operating temperature (85 °C) and VHSIC CMOS
C2	Package Failure Rate	0.012	Non-hermetic SMT, 20 pins
π_E	Environment Factor	4.0	Airborne Inhabited Cargo
π_Q	Quality Factor	10	Unknown Screen Levels
π_L	Learning Factor	1.0	3 years, 1/07 – 2/10
Entire design:		0.97	Failures/10^6 hours
		117.689 years	MTTF

Table 3: RF Transceiver CC1101 MTTF Tabulation

The 12V to 7.5V linear regulator LM317T [17] has a high possibility of failure due to the amount of voltage being regulated and the heat dissipated by this device. In tabulating the MTTF of this device, several assumptions were made, including the assumption that the regulator is a linear transistor-based microelectronic component, and a linear bipolar device as classified by MIL-HDBK-217F. The schematic was available and maximum T_J explicitly available, so these assumptions from previous MTTFs were concrete values in this particular calculation.

Parameter name	**Description**	**Value**	***Comments***
C1	Die complexity	0.010	Linear device, <100 transistors
π_T	Temperature coeff.	58	Worst case operating temperature (125 °C) and Linear Bipolar Device
C2	Package Failure Rate	0.0012	Non-hermetic DIP, 3 pins
π_E	Environment Factor	4.0	Airborne Inhabited Cargo
π_Q	Quality Factor	10	Unknown Screen Levels
π_L	Learning Factor	1.0	3 years, 1/06 – 2/10
Entire design:		5.848	Failures/10^6 hours
		19.52 years	MTTF

Table 4: Linear Regulator LM317T MTTF Tabulation

It seems that these devices are fairly reliable except for a few main parameters that are lowering the overall MTTF: the environment and quality factors. Improving the quality factor is difficult without purchasing MIL-SPEC components; this could be a viable quality improvement option. As for the environment factor, ensuring that the devices and the circuit boards are as secure as they possibly can be will go a long way toward improving the protection from environmental hazards the project receives. Additionally, extra heatsinks would not be a bad idea, since the temperature coefficient is a serious factor in most of these cases.

5.3 Failure Mode, Effects, and Criticality Analysis (FMECA)

FMECA analysis of the RAPTORS project must begin by defining criticality levels. The RAPTORS project will use a three-tiered criticality rating system, as follows:

- **Low**: No risk of personal injury or permanent system damage. Unexpected output or behavior may be experienced, but does not directly affect the safety of the system. A failure rate $\lambda < 10^{-5}$ is acceptable for such situations.
- **Medium**: No risk of personal injury, but permanent physical damage to the system is a possibility. A failure rate $\lambda < 10^{-6}$ is acceptable for such situations.

- **High**: Unexpected output, permanent physical system damage, and personal injury are all possible. High risk is incurred anytime there is any possibility of a resulting injury. A failure rate $\lambda < 10^{-9}$ is acceptable for such situations.

All failures or failure risks should fall clearly into one of these three rating categories. For a comprehensive list of possible failures, see Appendix B.

5.4 Summary

The RAPTORS project is inherently more dangerous than a number of other microcontroller applications; as a remote-controlled aerial vehicle, it has the potential for human injury through collision, which is a serious safety risk. A number of events have the potential to cause such a collision, including device failure, loss of signal, stuck port pins and erroneous configuration. Care must be taken to ensure such an event does not occur.

6.0 Ethical and Environmental Impact Analysis

6.1 Introduction

The plane is built out of Elapor Foam and contains 4 servo motors, a brushless DC motor, and is powered by a Lithium Polymer battery. Each of these parts comes with its own set of Environmental problems and Ethical issues. The ethical issues that we face with this product are based on the reliability of our parts and design as well as the customers using our product in ways other than what we intend. The environmental problems that we face are pollution and wastes from when the product is built, while the product is used, and when the product is being disposed of. The amount of electricity the product consumes is also an environmental issue.

6.2 Ethical Impact Analysis

The primary ethical challenge presented by this product is the potential for end users to use the product in ways other than the intended use. The intended use of this product is for RC enthusiasts to be able to fly a RC aircraft with the additional flight instrumentation similar to that of a real airplane. Other ethical challenges presented by this product are its potential to be hacked and how the product reacts under a variety of different operating conditions.

The aircraft can be used in many ways other than its intended purpose. It could be used for surveillance which may be viewed as an invasion of privacy. The aircraft could be flown into unauthorized airspace such as too close to an airport. Due to the size, weight limit, and power of the aircraft it could easily be outfitted to drop or shoot projectiles. Although we cannot stop the end user from using our product in these ways we must include a disclaimer with the product that states that we the manufacturer are not responsible for any misuse of the product or any damage caused by the misuse of the product.

The market to which we will be selling this product will be very narrow. The operators will probably have previous experience flying RC aircrafts. We will advise users that if they have not previously flown RC aircrafts that they should start with a simulator or trainer aircraft due to the expensive nature of our product. Users must also have an Operator's level or higher license from the FCC to operate this product. In order to obtain this license the user must have a certain level of technical knowledge. With this knowledge comes the responsibility to act in an ethical way.

Federal Communication Commission regulations state that we are unable to conceal the data that we transmit in any way. This means that the data we send must be transmitted in an obvious way which allows the product to be hacked by third parties. All products transmit on the same channel of the same frequency which means that users cannot safely operate two products at the same time and place due to RF interference. Since we must abide by FCC regulations we are unable to avoid these issues and have an obligation to notify the user of these issues.

While the product has not been extensively tested yet, before it is released we must test operating conditions for which it is safe to fly the aircraft. The user may know from previous experience that the aircraft should not be flown in rain or snow; however, we must determine what operating conditions are safe. For example, the temperature and humidity ranges that are safe must be determined. After we determine these ranges we must notify the end user in the user manual of conditions in which are safe to operate the aircraft and conditions in which are unsafe to operate the aircraft.

6.3 Environmental Impact Analysis

Components of the aircraft that could potentially harm the environment the most are the foam body of the plane, the printed circuit board and components, the motor, and the lithium polymer battery. A laptop computer is also required to use our product however the user is responsible for obtaining, using, and disposing of the laptop.

The printed circuit board and components are a major concern for the environment. The manufacturing of a PCB releases acid fumes, ammonia fumes, organic vapors, and CFCs into the air. Acid and alkaline solutions, metals such as nickel, silver, copper, and lead are also used in the process as well [20]. During the useful life of the product the PCB will not cause any harm to the environment. At the end of the product's life cycle the PCB will need to be recycled. Companies such as AERC Recycling Solutions provide free PCB recycling which is the best way to dispose of the PCB and components on it at the end of our product's lifetime.

The body of the plane is made of Elapor Foam. Elapor Foam is similar to Styrofoam however; it is much more durable and rigid. It is not biodegradable and therefore at the end of the products life must be recycled. To assist the end user in recycling the foam body we should direct them a section of our website which provides them with information on where to recycle the foam body. The foam body will not have a negative impact on environment during its useful lifecycle. During the manufacturing process of the foam chemicals that are harmful to the environment are used however the end user has no responsibility to dispose of these chemicals.

The aircraft utilizes a brushless DC motor which when manufactured releases harmful chemicals when the metal is being created. During the useful lifetime of the product the motor has no harmful effects on the environment. Disposing of the motor is easier than most of the other components because most garbage facilities extract objects such as these due to the value of them after they are recycled.

The aircraft utilizes a 3200 mAh, 3 cell lithium ion polymer battery which has a nominal voltage of 11.1 Volts. When making a lithium polymer battery lithium salts are dissolved a plastic like dry polymer film [18]. Although this product could be used safely anytime when there is enough light to see the aircraft it is not likely that it will be used more 20 minutes a day. There are also occasions when the aircraft is visible but it is inappropriate to fly, for example when there are wind gusts above 15 mph, when it is raining, or when it is extremely cold. Most RC hobbyists do not fly their planes every day. One battery charge will allow for approximately 20 minutes of flight time and requires about 2 hours to charge. This being said, the amount of energy used consumed by the aircraft during its useful lifetime is fairly small. If charged improperly or short circuited the battery can catch fire, so the user must use only the charger provided with our product and follow the charging instructions. At the end of a Lithium Polymer battery life disposing of it improperly can be harmful to the environment. The lithium if directly consumed by a person is fatal. That being said the easiest method of disposal is recycling. More and more people are becoming eco-friendly and therefore awareness of the consequences of improper battery disposal is growing. The end user can safely dispose of the battery themselves[19]. That being said, it is unlikely that the end user will put forth the effort to do properly dispose of it themselves. Many places nationwide such as RadioShack will recycle the batteries for you free of charge, so we will encourage the end user to take the battery to a place where it will be recycled.

6.4 Summary

This product faces many ethical and environmental issues; most of these issues arise from the potential irresponsibility of the end user. Although it will not solve the problem, we will need to have a disclaimer on the product that keeps us, the manufacturers, liable from any misuse of the product. Since our product broadcasts at 430 MHz in order to operate the product one must have at least a Technician Class Ham license as defined by the Federal Communications Commission. If we require the end user to provide us with their amateur radio Call Sign we can look it up on the internet to verify that they are legally permitted to operate our product. Since the end user has obtained an amateur radio license, we are assured that the end user has a certain level of technical knowledge. By providing these knowledgeable people with information on how to properly care for and dispose of our product many environmental risks will be eliminated. We can further reduce the risk by finding components that will cause less harm if they are disposed of improperly, for example using RoHS compliant parts. If we follow these guidelines we will reduce the possibility for ethical and environmental impact but it will not be completely eliminated.

7.0 Packaging Design Considerations

7.1 Introduction

Given the constrained space inside the aircraft, our hardware will be roughly limited to a 2.5" by 3.5" footprint; however, we will have substantial vertical clearance to stack the hardware. Another consideration is protection from abrupt movements of the aircraft due to crashing, etc., which may damage the hardware. The ground station will need to be portable enough to transport to the field, though the specific layout is not as constrained and will follow closely to the aircraft layout.

7.2 Commercial Product Packaging

Many hobby projects have been done related to remote aircraft control and telemetry, in addition to UAV technologies being developed by the Department of Defense and other organizations, which we are unable to analyze. A commercial model aircraft telemetry system was located and did provide insight into packaging concerns for our project. In addition, a homebrew project was found that also provided some insight into lightweight packaging considerations.

7.2.1 Product #1

Figure 7-1: Seagull Telemetry System

The Seagull Telemetry system by Eagle Tree Systems [21] is a modular data recorder and telemetry system for model aircraft, helicopter, and high-power rocketry applications. It features a 900 MHz transmitter mounted in the aircraft that connects to a wide array of airspeed, altitude, location, etc. sensors that are powered from the aircraft battery. The sensors and transmitter connect to a self-contained module via a standard pin header connection and the assembly is installed into the aircraft and relays information to a ground station. The ground station is a self-contained module which can provided data via LCD display and audible alarms. It is powered by an internal 9V battery and can be connected to a computer via a USB connection, where the data can be viewed live on a computer display.

There are numerous advantages to the Seagull system in both construction and operation. The aircraft module and all sensors are powered by the onboard battery, so no external battery is required, which would add weight. The ground station can operate independently using an LCD display and control buttons or on a computer via a USB port. The construction of the ground station appears quite robust and solid, with very good environmental and shock protection for use in the field. The aircraft module is designed for multiple applications and as such, the sensors can be easily configured to meet the user's needs through a standardized connection.

The disadvantages of the Seagull system are largely related to the aircraft module and sensors. Because the module is designed for any application in its own enclosure, weight is added to the aircraft that may have some adverse effects. Further, the sensors utilize a standard non-locking pin header connection which may fail during a hard landing. The sensors are also simply wrapped in plastic and do not appear to offer a solid mounting option to the aircraft, which may present problems.

Many of the mounting problems that may be an issue will be avoided on our project because we have the advantage of not aiming for a customizable solution and can design a system that will work only for our aircraft. This will mean that all hardware can be solidly mounted inside the fuselage without the need for its own enclosure, making the system lighter. Like the Seagull system, our system will be powered by the aircraft battery, eliminating weight and other problems that would arise from attempting to add a second battery. Further, the ground station will be constructed to be robust enough to withstand use in the field.

7.2.2 Product #2

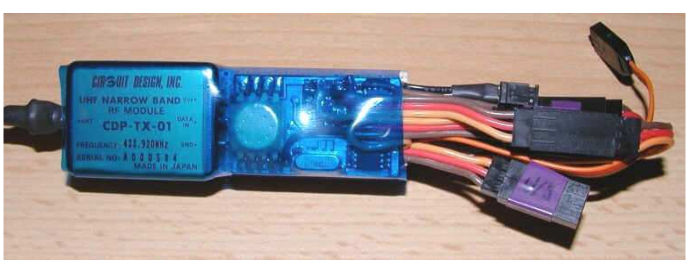


Figure 7-2: Jonas Romblad Datalogger 2

The Jonas Romblad Datalogger 2 [22] is a homebrew data collection and telemetry system. In a similar fashion to our system, it has a barometric pressure sensor for altitude detection, accelerometer, and GPS module for airspeed and location tracking. In addition, the Datalogger monitors aircraft power usage and ambient temperature. The function of this particular project differs from RAPTORS in that it is meant to track all of this data and store it within a built in EEPROM and/or transmit the data via wireless or cable to PC or palm pilot.

This system has its distinct advantages: the electronics involved are lightweight and fairly compact, so fitting them inside the plane is not a problem. In addition, both the software and hardware design are comparatively simple to implement next to our own system. However, the capabilities of this system are outmatched by the RAPTORS system: even though RAPTORS cannot log data, it is capable of wireless transmission of images and directly controlling the flight of the plane, neither of which is supported by the Datalogger 2. There are other disadvantages to the Datalogger 2 system as well. The system as it is shown on the website uses a fairly crude antenna, making transmission interruptions and difficulties seem like a distinct possibility. In addition, there is no real packaging provided for the system, making it extremely vulnerable to both abuse and environmental factors.

7.3 Project Packaging Specifications

The aircraft is the major limiting factor to the layout of the hardware. A small area is available between the control servos and battery pack in the forward fuselage, roughly 2.5 by 3.5 inches, as shown in Fig. 1. It is covered by a removable canopy, which could be hollowed to accommodate the project, if necessary [1].

To conserve space and simplify the design, two PCBs will be utilized in the aircraft, separated by a copper shielding to prevent interference. The lower board will contain the power regulators and the RF circuitry, which will be duplicated in the ground station. The upper board will contain the sensor microcontroller and connect to the sensor boards. Standoffs will be glued to the body of the aircraft and the two boards will be separated by standoffs and a copper plate to reduce the interference from the RF module. The standoffs will give a solid mechanical connection of all of the hardware to the fuselage, minimizing the possibility of damage in the event of a crash or other violent movement.

The camera module will be mounted facing forward in the canopy and a UART wire assembly will connect it to the sensor board. The aircraft antenna will be a half- or full-dipole mounted on the top of the aircraft and extending out roughly 8 inches.

For the ground station, a die cast aluminum project box [23] will be utilized containing a duplicate of the power and RF board from the aircraft. Power from a 7.5V battery will be supplied from a connector on one side of the project box, and a connection will be made to the computer via a USB port on the opposite side. An omnidirectional antenna will be mounted on the top, along with status LEDs, as needed. The ground station project box is resistant to environmental conditions and will allow for operation in the field while minimizing potential damage to the hardware. The board will be solidly mounted to a polycarbonate base using standoffs, which will then be connected to the project box. The aluminum box will also provide a ground plane for the antenna and shield the equipment from RF interference.

7.4 PCB Footprint Layout

The GPS, camera, gyroscope, accelerometer, and barometric pressure modules were all chosen as a breakout board module because the integrated circuits used are not available in packages with leads [3, 7, 5, 4, 6]. The modules will attach to the sensor board using standard headers and standoffs for support. This will also allow for easier PCB layout as we have the ability to run traces and place components under these modules, saving space. The Microchip PIC24FJ256GB106 is available in two packages, the TQFP and QFN [9]. The 64-pin TQFP was chosen because it would be smaller and has leads. For the RF transceiver chip, only one packaging option is available (QFN), which is not ideal, but does allow the possibility to be soldered to the PCB since the pads are extended to the side of the chip [2].

Due to the width and length constraints on the aircraft and to better allow for duplication of the power and RF components on the ground station, we have opted for a modular, stacked PCB configuration. On the aircraft, the power and RF board will be separated by a copper sheet and standoffs to prevent RF interference. On the power and RF boards, the sections will be separate by a large ground trace to prevent RF interference.

The dimensions for the components are as follows (dimensions in inches):

Component	Width	Length
GPS Module	1.25	1.25
Camera Module	1.125	0.8125
Gyroscope Module	0.625	0.75
Accelerometer Module	0.8	0.8
Barometric Pressure Sensor	0.75	0.688
Microcontroller	0.5	0.5
RF Transceiver	0.2	0.2

7.5 Summary

The packaging considerations for the RAPTORS project fall into two parts: the hardware on the aircraft and that on the ground station. The aircraft hardware will utilize the aircraft as its housing and be built to withstand the possible forces of the aircraft. The PCBs will be mounted in such a way to minimize weight while making the most of the limited space on the aircraft. The design will also allow the RF/Power PCB to be replicated in the ground station, which will be mounted in a die cast aluminum box to provide proper shielding and the ability to withstand use in the field.

8.0 Schematic Design Considerations

8.1 Introduction

The RAPTORS project is a remotely operated drone aircraft with a real-time flight data acquisition system. The project will retrofit an existing model airplane with a custom designed radio transceiver and sensing equipment for inertial and navigation data. The data from the plane will be transmitted to a transceiver connected to a ground station (laptop) and displayed onscreen in real-time. The ground station will, in turn, input control commands from the pilot and transmit them to the aircraft. The equipment in the plane will consist of a sensor module and a packet modem, both powered by the PSU located in the packet modem. There will be three discrete voltage levels in the system, since the transceiver, the servos and the remaining digital components all require differing voltage levels.

8.2 Theory of Operation

The sensor module subsection of the design was developed to interface with inertial and navigational sensors in the aircraft, collecting data and sending it to the packet modem via a TTL UART interface. The GPS and gyroscope units have no special operating conditions, running on the 3.3 volt power supply, where the GPS uses TTL UART and the gyroscope uses three analog voltages [3] [5]. The gyroscope has built in filter caps which will prevent aliasing in the ADC. The barometric pressure sensor will be configured to interface via a standard SPI (full duplex, 4 wire) system; the operating mode will be set to “High Speed” since it is desirable to provide the highest possible number of refreshes per second [6]. In high speed mode, the sensor is capable of 15-bit resolution, which will provide a resolution of 10 inches in elevation. The accelerometer will be operated in 4g sensing mode by controlling discrete input pins on the module from the microcontroller GPIO; the plane is not expected to exceed this range, but it may be changed in the future through simple code changes on the microcontroller [4].

The JPEG Camera module has a number of different configurable modes [7]. It is preferable to have an image with the maximum possible resolution that can be transferred to the ground station in a short time period. The picture resolution, color depth, and quality are set via the TTL level UART interface. Still pictures will be set to 12-bit color with 320x240 JPEG resolution. For a real-time picture preview feed, an 80x60 thumbnail resolution will be used. The packet size, which determines the segmentation size of picture data, will be set to the maximum supported value, which is 512 bytes, and the UART interface will be configured to run at the maximum supported rate of 115.2 kbps.

The sensor module described above sends the data, aggregated by the PIC24FJ256GB106 microcontroller, to the packet modem on the plane. The packet modem then takes this data and transmits it wirelessly through an RF transceiver operating on the 70cm amateur radio band to the packet modem located at the ground station. All together, the packet modem is responsible for three services: wireless transmission and reception of data, servo motor control, and power regulation.

The power regulation unit is responsible for powering all the components in both the packet modem and sensor module, which altogether requires three discrete supply voltage levels. A three-cell Lithium-Polymer battery was chosen as the power source for the entire plane, which has effective voltage range of 8.4V to 12.6V. From this source, three different regulators are utilized to step down the voltages to levels required for our components. For the RF amplifier stages, a linear regulator is used to step down to 7.5 VDC. For the aircraft servo motor power and control, a separate buck regulator steps the voltage down to 5 VDC. Finally, for the logic components of the system, including the sensor modules and microcontrollers, a LDO linear regulator drops the 5 volt buck regulator output down to 3.3 VDC, as only up to 500mA is expected to be consumed by the logic.

The CC1101 RF transceiver chip is extremely configurable through on-chip registers which are controlled by the microcontroller via the SPI interface [2]. There are several absolute configuration details that must be considered in the design of the schematic. A crystal will be used to supply a 26-27MHz to supply a reference signal to the transceiver chip, which will be increased using an on chip PLL in order to transmit in the 433MHz range. The transmit power output can be adjusted from -30dBm to 10 dBm, and will be varied to provide the minimum power necessary to transmit to the other packet modem. A number of other aspects of the RF transmission will be on-the-fly configurable by the microcontroller, such as the data controller and the receiver filter bandwidth. This transmission will be broadcast to an identical system in the ground station, transmitting sensor information from the sensor subsystem and receiving servo control information.

The servo control system will control the four servo motors plus the motor controller that came with the aircraft kit [1]. In order to control the angular position of each of the servos and throttle of the motor, a 20ms periodic rectangular wave with a duty cycle varied between 5-10% will be generated by the microcontroller's PWM peripheral. There will be a total of eight servo channels, four for the servos, one for the propeller motor control, and three for future expansion.

The ground station will have a second packet modem which will be a copy of the design used in the airplane to simplify design. The servo control system will exist in the design, but will remain unconnected. Instead of the UART interface used in the plane, a USB connector will allow the packet modem communicate with an external device [9]. In this case, the device will be a laptop which will display real-time sensor information and provide aircraft control signals.

8.3 Hardware Design Narrative

There are two microcontroller interfacing schemas to consider: the sensor interfacing schema and the transmission schema.

For sensor interfacing, the serial interfaces are of utmost importance. Two of the sensor modules, the accelerometer and gyroscope, provide an analog signal output, requiring usage of the ADC ports on the uC, three pins and two pins respectively [4] [5]. In addition, two general purpose I/O pins are necessary for configuration purposes enumerated in the previous section. Four SPI pins are needed for communication with the barometer module, plus one configuration GPIO [6]. The remaining ports are all general UARTs, which includes the JPEG camera module (TTL level), the GPS module (TTL level), the debug interface (TTL level), and the packet modem microcontroller (TTL level) [7] [3]. The module port assignments were chosen because they required a certain interfacing as specified by the manufacturer, and UART was chosen for the uC-to-uC communication because of its simplicity. One key advantage of the PIC24F family of microcontrollers, general I/O pins can be reconfigured on-the-fly for all microcontroller peripherals (such as UART, SPI, I2C, etc.) except USB and ADC, making pin assignment extremely flexible and fairly straightforward [9].

For uC interfacing on the packet modem and ground station subsystems, there are less interfaces, but an additional output port is used: the PWM. Five PWM port pins are necessary for controlling the servo and motor system of the plane, another three will be provided for future use. A TTL level UART will communicate with a debug interface, and a series of SPI port pins are needed to communicate with the transceiver chip. Unique to the packet modem subsystem is a TTL level UART for communication with the sensor module uC, and a set of special pins for communication via USB to a laptop are unique to the ground system. USB was chosen because our microcontroller specifically supports the USB protocol, and USB is a standard interface on all modern laptops; also, Microchip provides extensive software libraries which can be used to emulate a COM port within a Windows operating system [24].

8.4 Summary

The RAPTORS system, from a circuit standpoint, is designed to be as modular as possible, while still maintaining a fast rate of communication between the plane and the ground station, and a reasonable rate of data refresh from the sensors. An important part of modular design was utilizing components such as the plane's custom servos and a fast and configurable transceiver chip. Adding these components introduces a new design issue, since these two components require different supply voltages.

The microcontroller interfaces were selected because of either a necessity demanded by the components selected as a part of our modular design philosophy, or a desire for interface simplicity. Design is made much simpler by the microcontroller feature of reprogrammable I/O pins that can be configured to be GPIO, SPI, or UART pins, leaving only the PWM, ADC and USB interfaces to be routed to specific pins.

9.0 PCB Layout Design Considerations

9.1 Introduction

The circuit boards in the plane will consist of a sensor module board and a packet modem board, both powered by PSU located on the packet modem board. There will be three discrete voltage levels in the system, since the transceiver, the servos and the remaining digital components all require differing voltage levels. A copy of the packet modem circuit board will be used on the ground station.

There are three primary design constraints for these two circuit boards. Due to our boards being located inside of the Easy Glider Pro we are limited to a space the size of 2”x4”[1]. The second constraint is managing noise interference. With our packet modem broadcasting at 430 MHz from our plane we will be susceptible to RF interference from our own board. The final constraint is due to power. We will be operating off of the airplane’s battery.

9.2 PCB Layout Design Considerations – Overall

The two circuit boards on the plane can be divided into 4 major sections. These sections are Power Supply, RF amplifier and transceiver, Servo Control and Microcontroller, and Sensor Board. The boards are divided into these sections in an effort to keep noise from propagating from one section to another. We will also be placing a sheet of copper between the two circuit boards to keep noise from propagating between the two boards. We will utilize placing components on both sides of the board to help deal with the circuit board size limitations. As a general rule, left to right traces will be run on the top layer of the board and top to bottom traces will be run on the bottom of the board. This will help simplify running traces between components. We will also use a trace width of 12 mil for signal lines, although in the amplifier and transceiver the trace widths will vary to maintain an impedance of 50 Ohms. The maximum trace width is 61 mil which is necessary to maintain the impedance of 50 Ohms on the receive path of the wireless transmission area.

The sensor circuit board consists of the GPS module[3], the gyroscope module[5], the accelerometer module[4], the barometric pressure sensor module[6], a PIC24FJ256GB106[9], and four connectors. Two of these connect the sensor board to the camera [7]. Another section located on the Packet Modem board is the Power Supply. The main components of it are

LM2596 switching regulator (5V), the AP1117Y33L-13 voltage regulator (3.3V), and the LM317 adjustable voltage power regulator (7.5V).

The others are for debugging and programming. Since the PIC24FJ256GB106 allows peripheral pins to be reconfigured to many different pins there will be a minimal amount of trace crossing. Each peripheral must be assigned to a pin in software before the peripheral is configured. We have chosen the closest pin to each peripheral that minimizes trace crossings for all sensors and serial ports. The sensors include the Gyroscope, the Accelerometer, the Barometric Pressure Sensor, the GPS, and the Camera. The serial ports include a debug port and a port which is used for communication between the packet modem board and the sensor board. The connectors on this circuit board must be placed on 2" end facing the front of the aircraft for them to be accessible.

One section located on the Packet Modem board is the Microcontroller and Servo Control section. The main components in this section are a PIC24FJ256GB106, a MM74HCT541MTC Line driver, and 10 connectors. One connector is used to supply power to the sensor board. Another is reserved for debugging. The remaining connectors provide 8 channels which are used to drive servos on the airplane, although we are currently planning to use only 5 of them. The MM74HCT541MTC is a buffer and line driver which will be taking our eight 3.3 V PWM signals and driving them at 5 V to control servo motors.

Another section located on the Packet Modem board is the Power Supply. The main components of it are LM2596 switching regulator (5V), the AP1117Y33L-13 voltage regulator (3.3V), and the LM317 adjustable voltage linear power regulator (7.5V). We will be pouring a ground plane under this area to act as a heat sink as well as providing a heat sink for the LM317 regulator. The ground plane under the 3.3 V and 5 V power regulators are not expected to dissipate more than ½ Watt of power, which is well within the specified range, so the ground plane is only a precaution. The 7.5 V regulator however will dissipate up to 2 Watts which why a heat sink has been chosen for it.

The final section, also located on the Packet Modem board, is the RF amplifier and transceiver. This section takes up about 5 square inches of board space due to its 50 Ohm impedance line requirements. To do this we will employ a coplanar waveguide. To make this waveguide we used Wcalc to calculate our trace widths and spacing next to them [25]. This allows our traces to be shorter and narrower than would be possible if we were to use a straight trace with the same impedance. We will also divide this section of the board off with a ground trace of 80 mils to keep any signals or noise in the plane from propagating in or out of the RF portion of the board. A ground pour will also be made beneath the entire RF section to reduce noise and it is also required by the coplanar waveguide.

9.3 PCB Layout Design Considerations – Microcontroller

The PIC24FJ256GB106 uses 4 bypass capacitors of 0.1uF each which we will place on the bottom side of the board directly beneath the microcontroller. Placing these capacitors on the bottom side of the board allows us access the microcontroller pins with ease however; it also lowers the effectiveness of the bypass capacitors. The general rule applied earlier of the usage of 12 mil signal tracing will be maintained with the microcontroller. An external crystal oscillator will be used. Due to this oscillator being located on the RF board it has been decided that an 8 MHz oscillator will be used. Using an 8 MHz oscillator instead of a higher frequency oscillator reduces high frequency images, noise, and interference. This may seem slow, however, the internal PLL of the microcontroller can allow the microcontroller to run at 32 MHz if the computation power is required. The oscillator case will also be soldered to the board to reduce noise as suggested by the manufacturer.

The PIC24FJ256GB106 allows peripherals to be programmed to many different pins. Utilizing this feature allows us to place our peripherals in the direction of their respective destinations on the circuit board. Each peripheral must be assigned to a pin in software before the peripheral is configured. We have chosen the closest pin to each peripheral that minimizes trace crossings for all sensors and serial ports. The sensors include the Gyroscope, the Accelerometer, the Barometric Pressure Sensor, the GPS, and the Camera. The serial ports include a debug port and a port which is used for communication between the packet modem board and the sensor board. This vastly reduces the number of trace crosses required and simplifies the board layout process.

9.4 PCB Layout Design Considerations – Power Supply

The power supply will be operated off of a 3 cell lithium polymer battery. The main components of it are LM2596 switching regulator (5V), the AP1117Y33L-13 voltage regulator (3.3V), and the LM317 adjustable voltage power regulator (7.5V). We will be pouring a ground plane under this area to act as a heat sink as well as providing a heat sink for the LM317 regulator. This is required because the LM317 may be required to provide up to 2 Watts at 7.5 Volts. In order for this to happen we would have to transmit with 100% duty cycle. This will only occur during the testing of our amplifier. When testing the amplifier we will need to see its output in the frequency domain and measure the peak envelope power. During normal operation the transmitter is expected to operate at near 50% duty cycle, resulting in a power dissipation of 1 Watt. The 3.3 V regulator could dissipate up to 0.68 Watts under full load. We will be placing the capacitors within ¼ inch of the regulators. The power traces will be made at least 20 mils to accommodate the higher current.

9.5 Summary

The three primary design constraints for this circuit board are size, noise interference, and power. The choices of small package sizes for all components, the use of coplanar waveguides, and the utilization of both sides of the circuit board have allowed us to overcome the size constraint. The use of ground isolation, separation of the RF sections, copper plating between the boards, a lower frequency oscillator and other preventive measures should help to make our boards more noise immune. The final constraint power was dealt with by using wide traces for the power lines and the use of ground planes to help reduce noise and heat.

10.0 Software Design Considerations

10.1 Introduction

Normally, a system such as RAPTORS would involve two software designs run simultaneously in communication with each other, but the RAPTORS design split the vehicle hardware into two separate parts, each with a microcontroller, as necessitated by space limitations. Thus we have three separate software designs, each running on identical microcontroller architectures but with three different purposes: one to gather and aggregate sensor data, another to interface with and push the data out onto an RF transceiver, and the last which receives the data from the aforementioned transceiver and sends via serial to the Virtual Cockpit application. Flight control data from the user will be gathered on the ground and sent in the opposite direction. This data is to be used by the vehicle's primary microcontroller to control the motor and servos inside the vehicle.

10.2 Software Design Considerations

The software that will be driving the RAPTORS project is written in C and compiled using Microchip's proprietary MPLAB C30 compiler. This advanced compiler automatically allocates the stack and heap, and also automatically assigns variable addresses [26]. Most of this assignment is done dynamically during compilation, but there are several important regions pre-defined by the specific device being used, specifically the data and program memory locations. The location of the application code is in the flash memory regions designated as "program space". The locations from 0x0 to 0x200 are filled by the goto instruction, the reset address, and two vector tables. The application code then resides in the space from 0x200 to 0x2A9F8. The user data is contained in a separate memory, called the "data space", which also hosts the "special function registers", or SFRs, that house the addresses of the various peripherals. This SFR resides from 0x0 to 0x7FE of the data memory, while the implemented data ram lives between 0x800 and 0x47FE, giving effectively 16 kB of data memory [9]. The stack will start at the top of this space and work its way downwards as needed.

Upon initialization, each of the three boards power up their respective peripherals and begin operation; data and control packets are not exchanged until the ground station is on, and aforementioned exchange is meaningless unless the Virtual Cockpit is also activated and connected.

The main module of the software is driven by a loop which constantly polls several different flags for a TRUE condition, also called a hybrid architecture. When an interrupt occurs, the specific interrupt handler for that event is called. This handler usually either sets a flag, or sets a flag and performs a data fetch from a register. Once the flag is set, the interrupt handler exits, and the main function is free to deal with the peripheral and/or data that triggered the interrupt at its leisure. This method of driving the software through interrupt-set flags was chosen so that the code could still answer interrupt events and fetch data in a timely manner, but wouldn't need to spend an inordinate amount of time in the interrupt handler. This also allows prioritization of peripheral handling without having to use priority interrupts.

There are several different components that utilize interrupts to drive the code, and various interfacing methods connect these devices to the microcontroller. Two separate components, the accelerometer and the gyroscope, require use of the A/D peripheral to interface with the microcontroller [5,4]. Five A/D ports will be initialized for interfacing, three for the accelerometer and two for the gyroscope. They will be configured to trigger an interrupt after a single conversion, with a transition from sampling to conversion being triggered by a 50 ms timer interrupt. They will then output data in an unsigned integer form, which can then be scaled appropriately by the Virtual Cockpit.

One SPI interface on the sensor board and another on the two modem boards are required to interface with the barometer and the transceiver, respectively [6,2]. The sensor side interface is limited to 1MHz frequency, so both SPI ports will be initialized to use 667 kHz speed. Each of the two modem boards will also have 5 PWM ports initialized for servo and motor control, set to use a 20 ms period with a default 1.5 ms pulse width. The pulse width will be varied between 1.0-2.0 ms.

The GPS, Camera, and Debug modules are interfaced to the microcontroller using the UART peripheral [3,7]. The GPS UART will be initialized with a baud rate of 57600 kbps; the GPS data sheet incorrectly specifies 9600 bps. The remaining two UARTs will run at the max speed supported by the Camera module, 115.2 kbps. All three will use 8-bit data mode, with default stop bit polarity ('1') and parity settings (none). It should be noted that the sensor and the plane microcontrollers will be interfaced together using an identically initialized UART at 115.2 kbps.

Three LEDs have been interfaced to general-purpose I/Os on each board for debugging purposes. The debug interface is a UART, as mentioned above, but whereas the other UART peripherals are TTL level, the debug interface is RS-232 level and will use an external board with an external level translator. It is worth noting that the debug interface on the ground station will be taken in implementation by a Serial-to-USB cable that will be used to transfer data to and from the Virtual Cockpit application running on the laptop.

10.3 Software Design Narrative

The main module is the first module to run upon power-up. It is responsible for calling every other module at the appropriate time. It begins by calling the initialization module, and then enters a looped “if-elseif” branch structure that checks to see if interrupt handler flags have been set. It checks on a priority basis, allowing the peripherals that require the fastest response time to run the necessary module as quickly as possible. If a flag has been set, the module associated with the set flag is called; upon exiting, polling resumes at the beginning of the” if” structure. This module layout is similar in the code for all three microcontrollers, though the flags that are monitored and the functions that are called will differ. On the sensor board specifically, there is a heartbeat timer that triggers a timed function in main that runs error checking and various other pieces of code.

The initialization module is also similar across all three code versions, though it differs in the specifics of what it checks and initializes. The initialization module calls several subroutines that initialize the various peripherals, which includes making sure the timer prescaler is set correctly. Once these settings are correct, the module proceeds linearly through each of the attached peripherals and queries them to see if they were started properly. When this start-up self-check is complete, the routine exits.

The GPS module is entered when a new word has filled the GPS UART buffer. This module begins by moving the word, which represents an ASCII character, to the next available space in a long string. It then checks if the ASCII character represented by that word was “\n”. If it was, then the string is complete, and after verifying the checksum it can be shifted out to another temporary variable. From this point, the string moves into the filtering stage; for our purposes, we only want NMEA standard RMC statements. We check to see if the statement is RMC; it if it is not, we throw it out. From this point, it is shifted into the data packet as is; parsing for specific values is handled in the virtual cockpit application.

The Barometer module is triggered by the DRDY signal coming from the Barometer unit. Once entered, three memory access requests are sent to the barometer, via the SPI interface: a read from the TEMPOUT register, a read from the DATARD8 register, and a read from the DATARD16 register. The results of each of these reads are saved to separate variables. The TEMPOUT register holds the two's-complement of the 16-bit binary representation of the current temperature, and once retrieved it must be converted before being meaningful. Additionally, the two pressure data variables, one 8-bit and the other 16-bit, are joined to form an integer representing pressure. Once the instantaneous pressure and temperature are gathered, they are used in a sliding window average to smooth out the current readings. This same function then takes the resulting averaged temperature and pressure, as well as an averaged standard pressure gathered at initialization, and finds the current altitude of the plane [27], storing it as well as the temperature and pressure to the data packet.

The Camera module is triggered by the receipt of a packet on the Camera UART. Upon receipt, the packet is shifted to a temporary location to make space for the next packet, and is then inspected to ascertain the intent of the packet. If the packet requires an ACK, the AutoAck function is called, which assembles an ACK and sends it to the camera. If a new instruction is needed by the camera, this is assembled and sent out. Finally, if it is discovered that this data is a piece of picture data, it is placed into an image accumulation register until a packet is formed for sending to the modem board uC. When a packet is formed, the image accumulation register is dumped to the packet as is, even if more data is needed to fully assemble the image; image assembly will be done at a later time. The image accumulation register is then cleared.

The Analog Capture module is triggered by a conversion complete interrupt from either the Accelerometer or Gyroscope A/D converters, which occurs every 50 ms plus conversion time. It retrieves the converted value from the conversion buffer in the respective module and stores it in the global data packet.

The PWM module controls the PWM pulse width and it is triggered when an update is received from the ground station that contains an engine speed or servo position value that differs from the current value. In that case, the current values are overwritten with the new values, and the motor module computes the new pulse width for the appropriate servo(s)/motor.

10.4 Summary

It has been shown that the application code for the RAPTORS project will be comprised of three separate code versions, one to run on each of the three microcontrollers of which our project is comprised. Initialization will be run from the ground up, with the ground station syncing to the plane's main board, and then the plane board syncing to the sensor board. Additionally, once a uC has been activated by syncing, it will poll all peripherals to make sure they started properly. Once initialization has completed, each uC will use an interrupt-set-flag-based priority polling structure to collect data from various peripheral devices as soon as it is received over its respective interface. Collected data will be forwarded to the proper location. Debugging will be accomplished through a combination of development board use, plus 3 LEDs and a debugging header on each board.

11.0 Version 2 Changes

The primary change we would like to make to our design if we were given another chance would be to use a completely different camera. The primary benefit we gained by using the current camera is the JPEG compression that it provides. Ideally, in version 2 we would incorporate a streaming video similar to a webcam. If we were unable to find a video camera with compression we would have to implement our own compression algorithm, perhaps using a wavelet transform on a DSP.

Biasing of the RF MOSFET in the amplifier could use a negative feedback system so the current bias would be relatively constant, instead of the current system that is susceptible to the MOSFET heating up.

If we had another chance to design the system, we would like to either add another transceiver chip or find a different transceiver chip in order to be able to implement full-duplex communication. The current TI chip we're currently using constrains operation to half-duplex, and it would be immensely helpful to continuous operation to be able to achieve a simultaneous up- and down-link.

It would have been nice to incorporate a Kalman filter to combine the gyroscope data with the accelerometer data to provide more accurate pitch and roll measurement of the aircraft. This was not implemented because it was considered an extraneous luxury and would eat up a lot of processor power if implemented on the microcontroller.

Another change we could feasibly make would be to use a publicly documented amateur radio protocol, which would allow for greater data bandwidth. Currently, we are classified as an undocumented protocol, which means we can only use a 100kHz channel. Alternatively, we could use spread spectrum to achieve greater bandwidth and still maintain our current protocol. This would have an added bonus of noise immunity.

We would have liked to move our altitude calculation system to the ground station. The current calculation relies on a initial sampling of the pressure when the sensor board is first switched on; it compares this initial pressure sampling to the current sampling to calculate the altitude. However, the way we have things programmed, the sensor board resets under certain conditions (on purpose), so the initial pressure capture is replaced with a new capture in the middle of the air, confusing the altitude calculation. If we take the pressure comparison sample and store it on the Virtual Cockpit and do the calculation there, it would keep altitude constantly accurate. Another improvement that could be made is to also check the altitude from the GPS module. Although the altitude is in meters above sea level, when the product is first turned on and the GPS locks we will know our elevation above sea level. We can then subtract that initial value from the plane's reading during flight to obtain another altitude measurement. The GPS is only accurate within 3 meters however it could be used to provide a sanity check.

12.0 Summary and Conclusions

The objective of the RAPTORS project was to be able to deliver the following: an RC plane outfitted with control, data gathering, and proprietary wireless modem systems; a ground station with the same wireless modem designed to transmit control signals to and receive sensor data from the aircraft and that interfaces with a PC running a proprietary control application; and a Windows executable that interprets control data from a joystick and sends it to the ground station and receives the sensor data from the ground station and displays it in a visual manner. All the deliverables are in their final and complete state and are fully functional; the only exception is the collection of camera data, which is functional but unreliable.

Collectively, the Team RAPTORS members gained experience in several different fields throughout the process of design and construction. Some of these include embedded systems design and programming, C# programming, RF and amplifier design, PCB design and manufacturing processes, system design with respect to packaging constraints, intelligent component selection, amateur radio licensing processes and regulations, and RC plane navigation.

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Appendix A: Individual Contributions

A.1 Contributions of Jeff Kubascik:

Early in the project, Jeff extensively researched into the RF aspect of the project. He researched into FCC regulations to ensure legal operation of the packet modem. He discovered that an Amateur Radio license would allow use of the 420 MHz - 450 MHz with up to 1 W of transmission power, according to FCC part 97. Since the project would use an unspecified digital format, the regulations would limit the channel bandwidth to 100 kHz. Jeff also sourced a RF transceiver IC from Texas Instruments which would allow operation in the 420 MHz – 450 MHz band with a wireless data rate of up to 500 kbps.

Jeff also did extensive research into RF amplification. He discovered that a two-stage amplifier would be required to get the gain needed for at least 1W transmission. For the first stage, he found an IC from RFMD which would provide 13.2dB of gain. For the second stage amplifier, a more involved design was required due to the high RF power involved. He found a RF N-channel MOSFET which can handle up to 3W transmission. To use the MOSFET, he designed impedance matching networks using inductive traces and capacitors to match the gate and drain impedances to 50 Ω, so there was minimal reflection interfacing with the antenna and the RF transceiver. Then he did detailed analysis using MATLAB and Advacned Design System by Agilent to verify it.

Jeff did the majority of the schematic capture for the RF portion of the packet modem. He made schematic symbols and footprints for the RF transceiver IC, amplifier IC, RF MOSFET, and the microcontroller. He also did the layout of the packet modem circuit board, including the RF amplifier, RF transceiver, power supply and digital logic, and soldered all the components on both packet modem boards, with exception of the RF transceiver, RF MOSFET, and USB connector.

On the software side, Jeff wrote the code which interfaced with the CC1101 RF transceiver chip. This code handled data flow between the microcontroller and the FIFO buffers inside the chip, since the buffers were only 64 bytes in length and packets could be up to 254 bytes in length. This involved a complex state machine with extensive error trapping, as loss of RF communications would result in the plane crashing. Jeff also wrote code which handles packet assembly and disassembly on the UART interfaces between the packet modem and the PC or sensor module, which is complied on both packet modems and the sensor module. Jeff also helped develop the packet formats and wrote code on the packet modem which handles packet routing.

A.2 Contributions of Joe Trefilek:

Joe's major contributions to the project included selecting sensors for the sensor board, completing the sensor board schematic, assisting Paul with the sensor board PCB design, working on the aircraft module hardware and assembly, and making the Virtual Cockpit application. To do this, he worked closely with his teammates and assisted them in whatever ways were necessary. He completed the packaging considerations and patent liability homeworks.

Joe began the semester researching and selecting accelerometer, gyroscope, and barometric pressure sensors to monitor the aircraft's orientation and altitude. After researching potential sensors and sensor modules, he narrowed down the search by estimating the maximum readings that would be received from the aircraft. From there, it was a matter of weighing the cost and ease of implementation to select the modules that were ultimately used.

Next, Joe began working on the schematic for the sensor board. This first entailed recording the interfacing requirements for each sensor module and other peripherals that needed to connect to the sensor board microcontroller. Next, microcontroller pin assignments were determined based on the available peripherals, with effort taken to group the pins as closely as possible to the ones for the same module. This would make the PCB layout a bit easier than if the pins were assigned arbitrarily.

After completing the remaining connections that needed to be made on the schematic and adding the remaining components, Joe assisted Paul with designing the PCB layout as he was more experienced at designing circuit boards. During this process, it was determined that the pin locations for a few of the sensor modules needed to be moved to make the process of designing the PCB easier. Joe worked to resolve this situation in a similar manner as during the initial schematic design, using the list of interfacing requirements he had compiled earlier.

For homework 4, Joe began considering the packaging constraints of the project. It was decided that the aircraft module would entail two boards stacked on top of each other, and Joe began looking into the hardware that would be required to accomplish this. Once the boards were completed and the plane was built, he worked out how to fit the boards together, requiring some deviation from the original plan to account for interference due to the location of the sensor modules and incorrectly sized holes in the PCB.

As the specification for the data packets was finalized, Joe began work on the Virtual Cockpit application, which would be used to generate command packets and display data and camera packets from the aircraft. This first entailed finding a way to interface the joystick with a C# application. Next, a method was developed to parse an arbitrary packet as it came in from the serial bus, determine its type, and process it. This was made a bit more difficult by the changing of the packet specifications and relied on a great deal of discussion with Matt and Jeff. From there, better ways to display the data were implemented, including a set of graphical gauges that Jeff found. Further, after discussing flight dynamics with an experienced model aircraft pilot, an exponential control system was implemented, which give more precise control at lower values, but still allows for the full range of motion.

A.3 Contributions of Paul Scheffler:

Paul was tasked with designing the power supply system, writing the peripheral software to interface with sensors, design and layout of the sensor printed circuit board, and the final aircraft packaging. He was also tasked with assisting Matt in the development of packet transmission software for the sensor board. Paul completed the PCB layout design considerations homework and the Ethical and Environmental Impact Analysis.

Due to the various power requirements the project’s logic, amplifier, and servo control system 3 different voltage levels were required. Paul was tasked with providing the required power while keeping the footprint of the circuit as small as possible and keeping the project within budget. There were many strict requirements involved with the design of the power supply. The 7.5 volt power supply has a very small noise tolerance because it is amplifying the RF transmissions. This means that a switching regulator cannot be used, so a linear regulator must be used. The 7.5 volt power supply will also be dissipating up to 2 Watts of power which brings its own heat issues. The 5 volt power supply had to provide up to 2 amps of current to power the servos and the 3.3 volt regulator which it turn powered the 3.3 volt logic.

Paul was responsible for designing and laying out the sensor board PCB. This included working with Joe to make the schematic. This included creating footprints for components located on the sensor board. Due to some overlapping parts some footprints on the sensor board were created by Jeff. Due to the space limitations imposed by the plane the sensor board was made as small as possible. The final dimensions were 3” x 5”.

Due to previous experience working with Microchip microcontrollers, Paul worked, with the assistance of Matt, to write the peripheral software for the UART, the PWM, and the ATD. Each of these peripherals presented their own unique problems that had to be debugged. After the peripheral software was written, Matt took to the lead writing the sensor software which converted the captured data into meaningful data. Paul still assisted in the debugging of the sensor board software. After Paul also ported some functions written by Jeff to the sensor module which were used to correctly format, build, and calculate the checksum of packets. These packets were then sent to the packet modem board in the plane which forwarded them to the ground station.

Paul was responsible for putting the aircraft module into its final packaging. The final packaging was made possible by removing a small portion of foam to allow the battery to slide back an extra 3 inches. This allowed the packet modem board to slide into the plane. An unforeseen problem caused by this is that it threw the center of gravity very far towards the back of the plane. Many cables had to be made to allow packing to possible which Jeff assisted Paul in making. To counteract this 2.5 oz of lead weights were added to the nose of the plane.

A.4 Contributions of Matt Rockey:

As the leader of the software aspect of the project, Matt was tasked with outlining and implementing the microcontroller software. He also shared website creation and maintenance responsibilities with Joe, and took charge of getting documentation implemented by its assigned due date.

Early in the design process, he focused mostly on research relating to programming, poring over the datasheets for the 5 sensors to which the microcontroller would be interfacing, and examining the protocols for data extraction or UART communication. Once he had determined the method and means of communication for each one, he began to outline both initialization and data retrieval code for each one.

At the same time, it was necessary to create a website for the team. Joe had created a basic shell of a website, but it lacked a certain visual aesthetic, and many necessary links were missing. Matt went through and updated the website, adding drop-down menus, adding links to various documents on the server, and aggregating the datasheets on the server. As an extra help, Matt also helped keep everyone aware of getting homework submitted on time, and made valid contributions to generalized discussions of system functionality, such as the merits of various antenna placement or failsafe systems.

The acquiring of a development board allowed Matt to begin software development, but development did not begin in earnest until the PCB had been manufactured. It was at this point that he began to transform his pseudo-code into actual C code to be compiled in MPLAB. From that point on, he had a hand in most of the software development, with the exception of the transceiver chip interfacing and the packet modem packet handling software. His development involvement included sensor interfacing, packet and handshaking design, UART peripheral API design, data organization and parsing, and timing structure.

Once software writing had finished, debugging was a serious issue, and Matt was a key player in getting the code to the point where it was functional. Each of the sensors had various issues to work out before they communicated properly with the microprocessor, and Matt worked assisted with the debugging on most of these issues.

Once the debugging period had finished, Matt also took a lead in getting the user manual and final report documents completed and ready for submission. He wrote a good portion of these documents, and was responsible for the formatting and submission of these documents as well.

Appendix B: Packaging

Figure B-1
Modular Construction of the Aircraft Electronics.

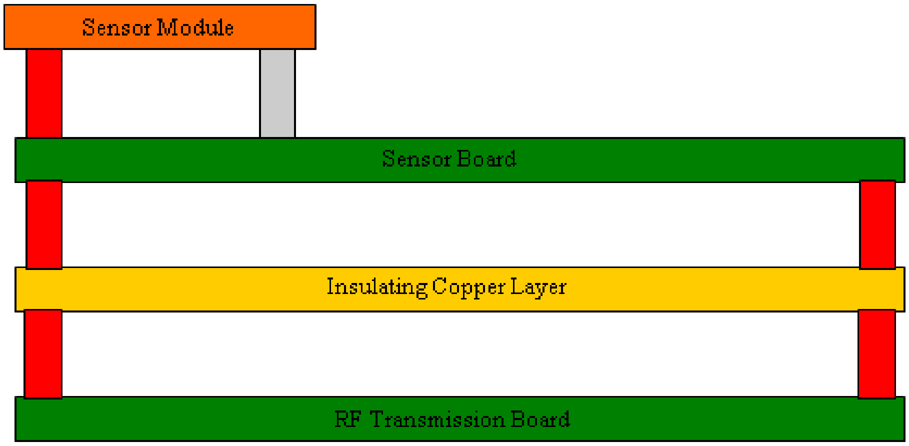


Figure B-2
Available volume in aircraft.

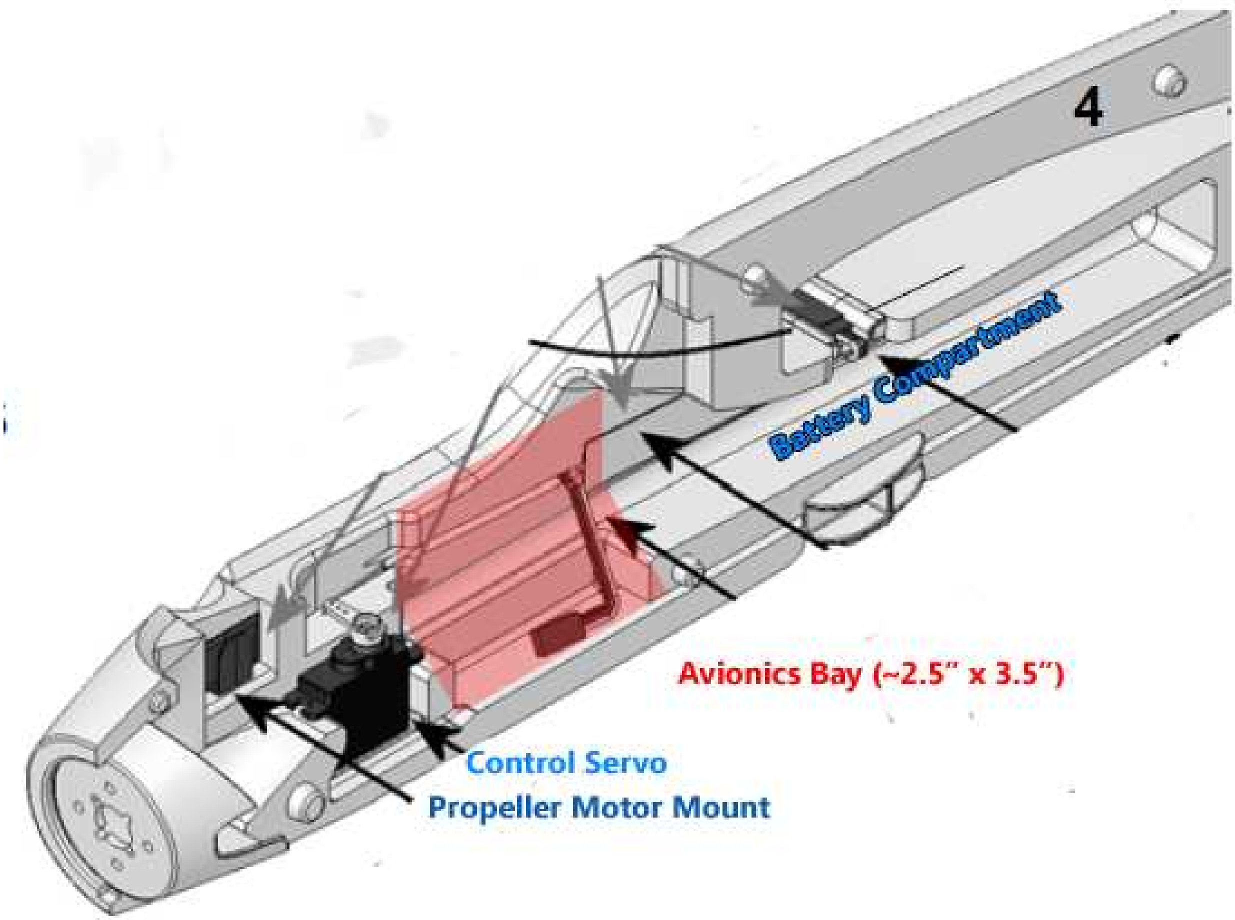


Figure B-3
General Component Layout for Packet Modem

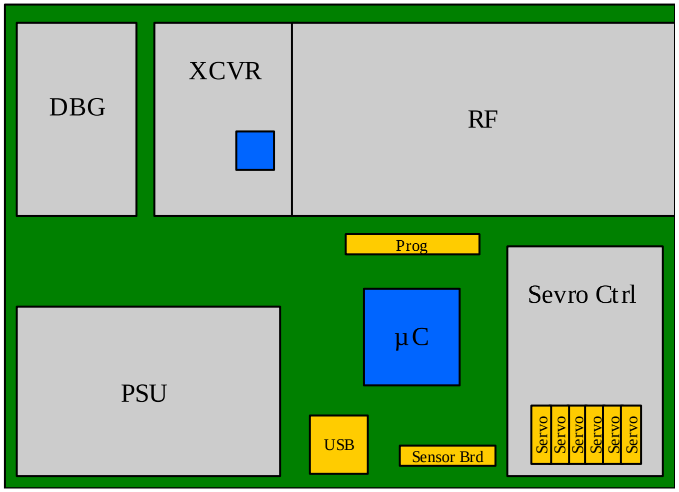


Figure B-4
General Component Layout for Sensor Board

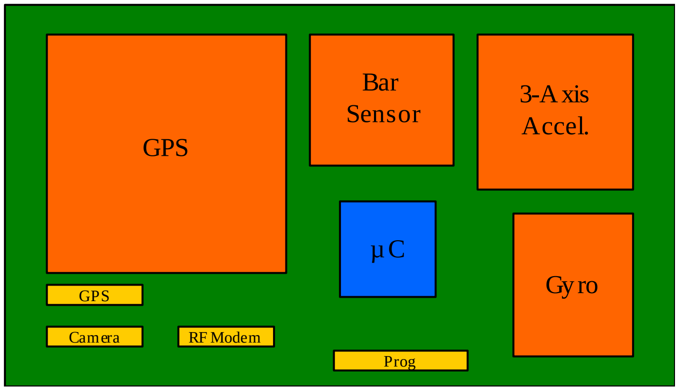


Table B-1: Project Packaging Specifications

Aircraft

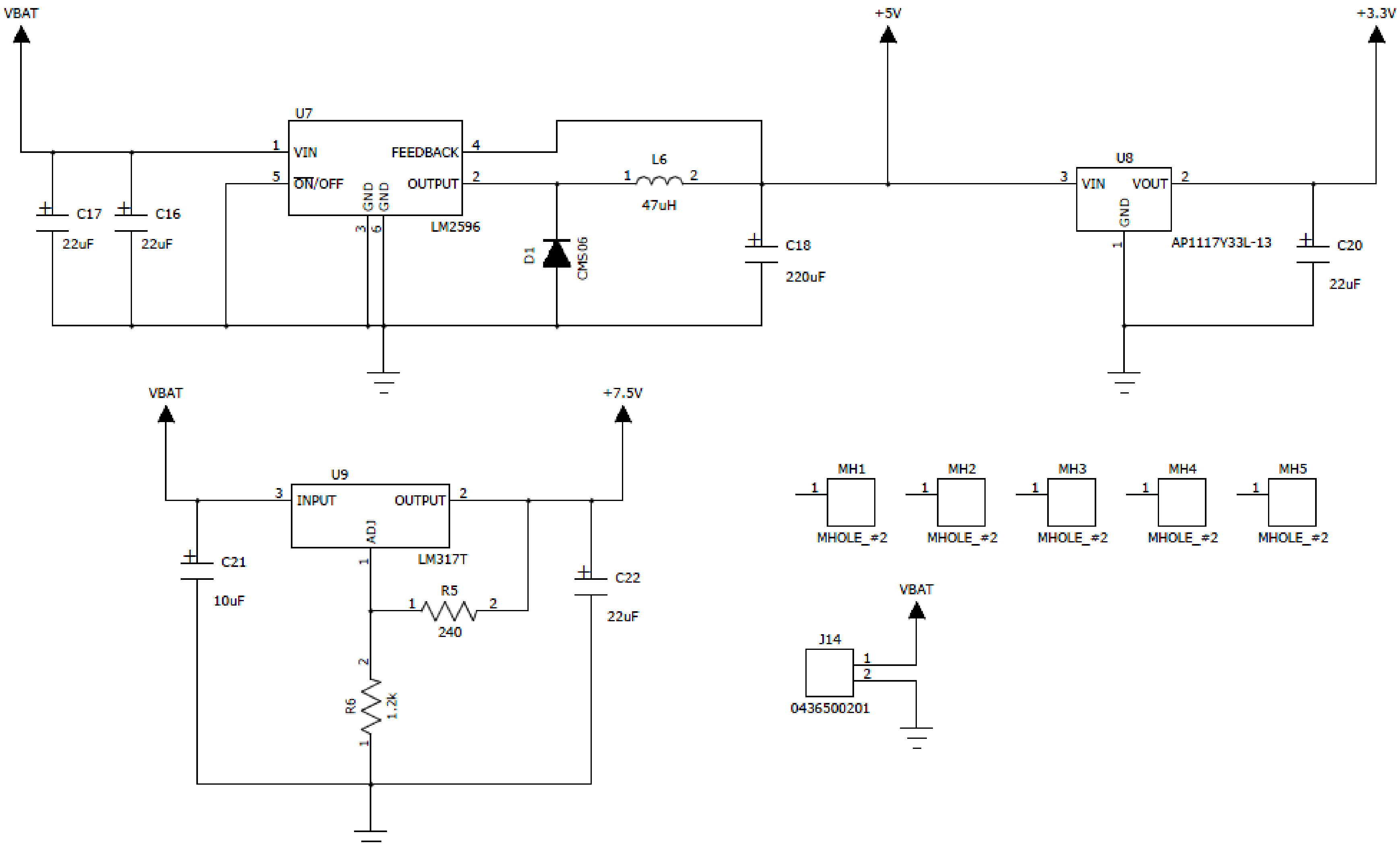
Item	Qty.	Price	Total
18-8 SS PHILLIPS MACHINE SCREW, 2-56 THREAD, 7/8" LENGTH	1 pack	$4.66	$4.66
18-8 SS MACHINE SCREW HEX NUT, 2-56 THREAD, 3/16" WIDTH, 1/16" HEIGHT	1 pack	$2.77	$2.77
18-8 SS PHILLIPS MACHINE SCREW, 4-40 THREAD, 1/4" LENGTH	1 pack	$3.47	$3.47
18-8 SS MACHINE SCREW HEX NUT, 4-40 THREAD, 1/4" WIDTH, 3/32" HEIGHT	1 pack	$2.75	$2.75
ALUMINUM ROUND SPACER, 3/16" OD, 5/8" LENGTH, #2 SCREW SIZE	15	$0.27	$4.05
ALUMINUM ROUND SPACER, 3/16" OD, 1/8" LENGTH, #4 SCREW SIZE	12	$0.20	$2.40
ALUMINUM ROUND SPACER, 3/16" OD, 3/8" LENGTH, #2 SCREW SIZE	12	$0.24	$2.88
		TOTAL	$22.98

Ground Station

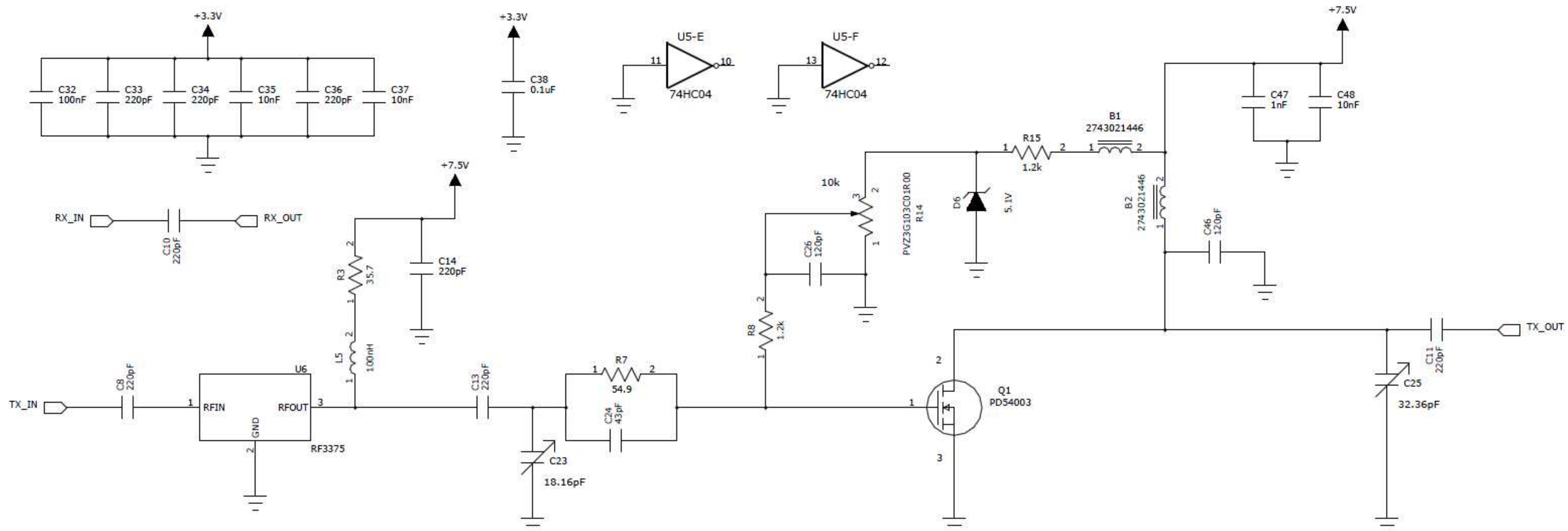
Die Cast Aluminum Enclosure – 6.73” x 4.76” x 3.98” $18.00

(Hammond Manufacturing 1550E, holes cut by team at no cost to accommodate power input, USB cable, and antenna)

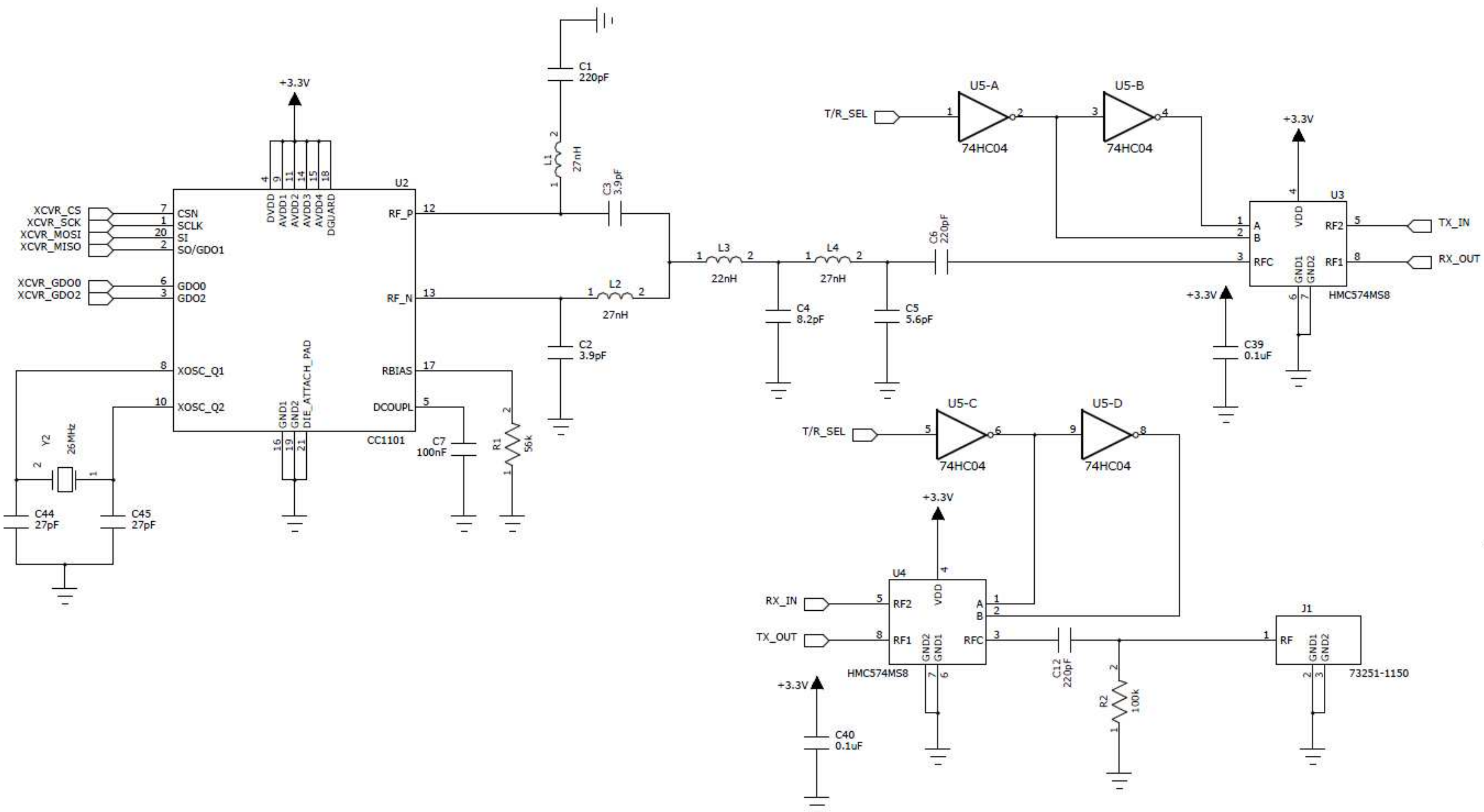
Appendix C: Schematic



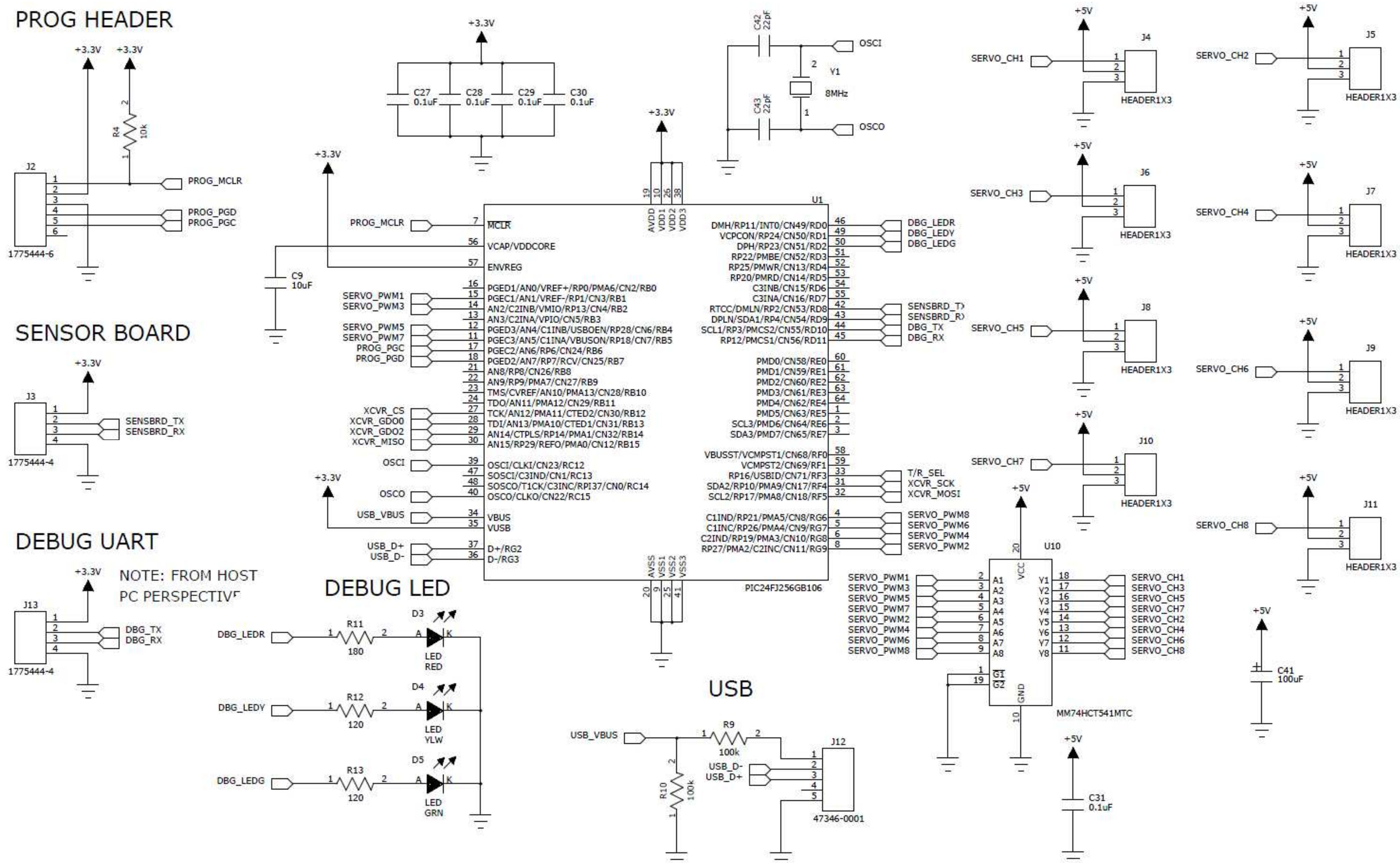
C-1: Power Subsystem



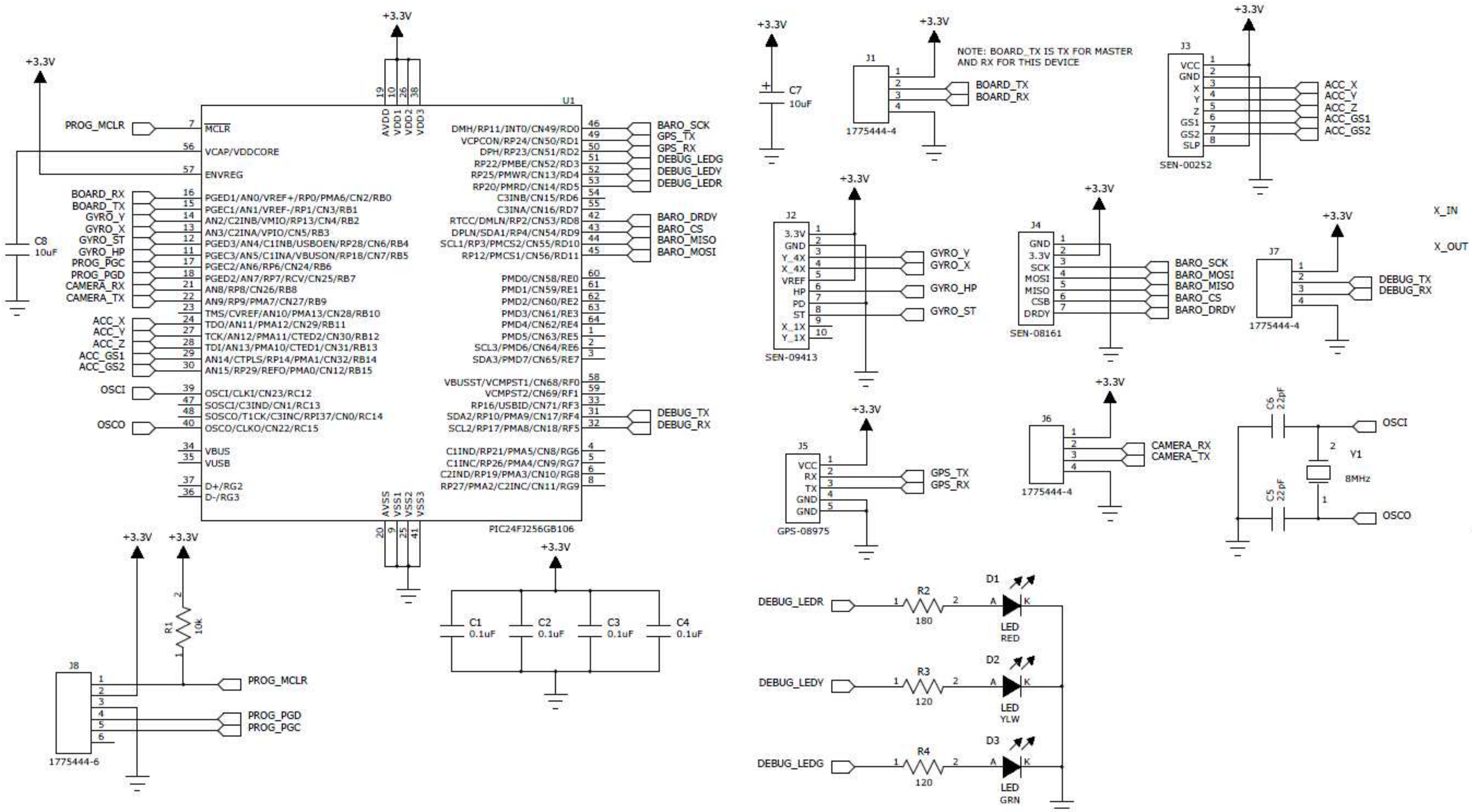
C-2a: Transceiver Subsystem (Part A)



C-2b: Transceiver Subsystem (Part B)



C-3: Modem Microcontroller Subsystem



C-4: Sensor Subsystm

Appendix D: PCB Layout Top and Bottom Copper

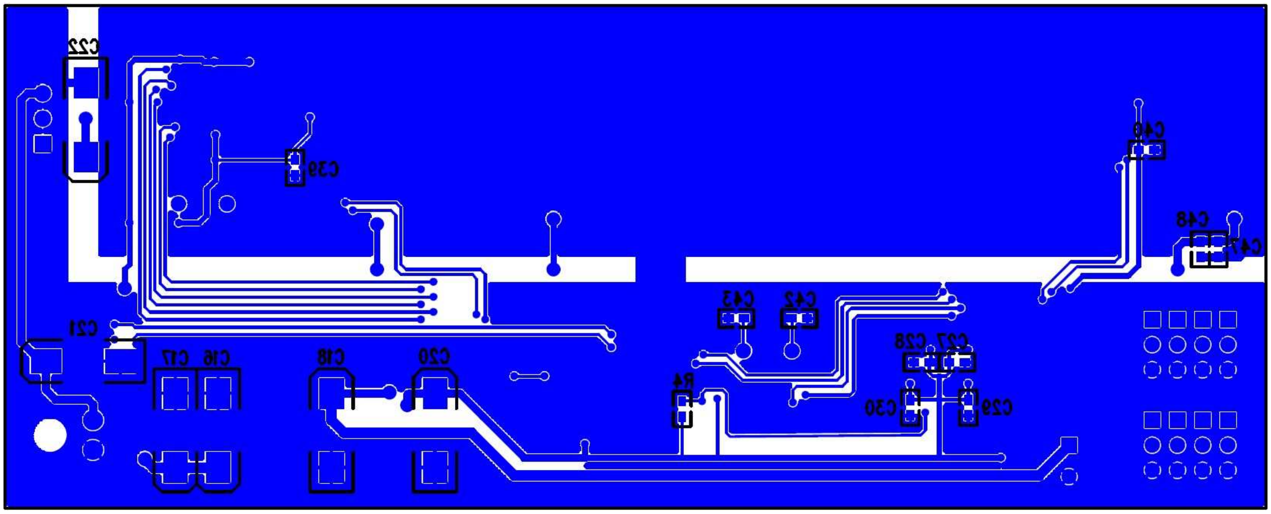


Figure D-1: Packet Modem Layout Bottom Copper

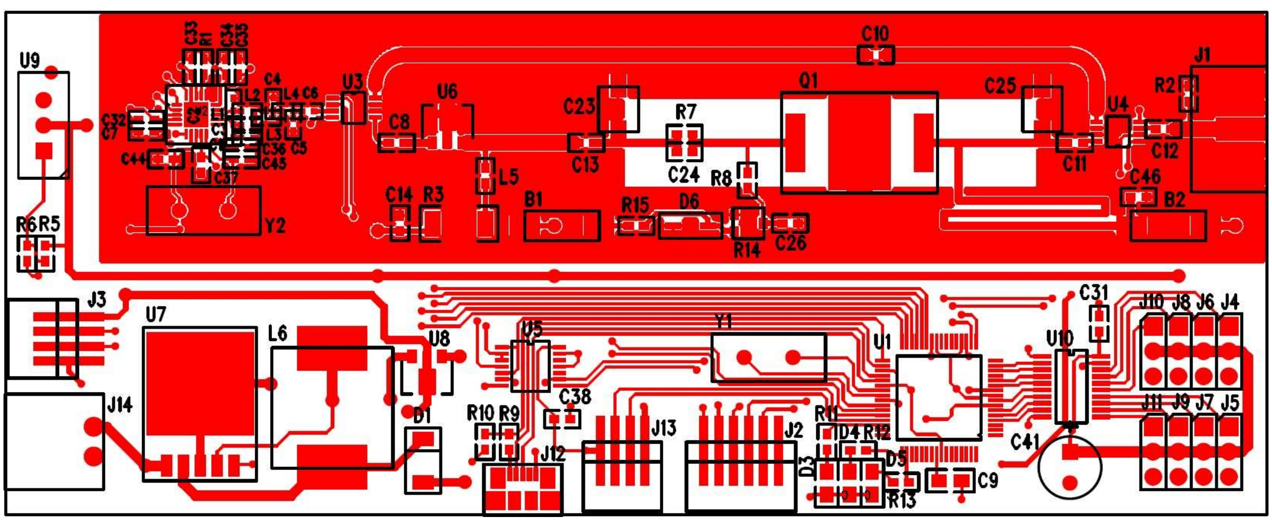


Figure D-2: Packet Modem Layout Top Copper

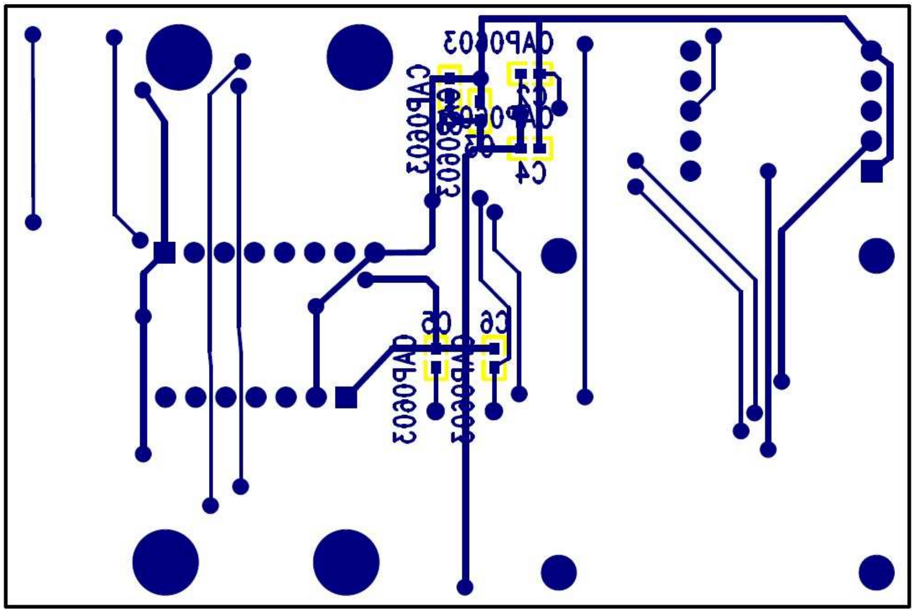


Figure D-3: Sensor Board Layout Bottom Copper

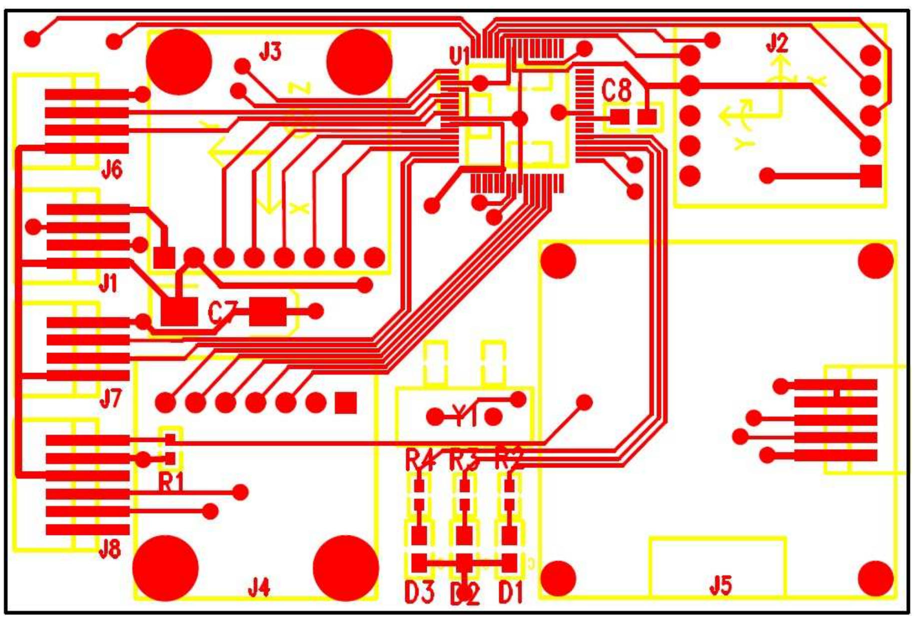


Figure D-4: Sensor Board Layout Top Copper

Appendix E: Parts List Spreadsheet

Description	Source	Part #	Qty	Order Qty	Unit Price	Ext Price
Gyro Breakout Board - LPR530AL Dual 300°/s	SparkFun	SEN-09413	1	1	29.9500	29.95
Triple Axis Accelerometer Breakout - MMA7260Q	SparkFun	SEN-00252	1	1	19.9500	19.95
Breakout Board - MEMs Barometric Pressure Sens	SparkFun	SEN-08161	1	1	34.9500	34.95
32 Channel LS20031 GPS 5Hz Receiver	SparkFun	GPS-08975	1	1	59.9500	59.95
JPEG Color Camera - UART Interface	SparkFun	SEN-09334	1	1	54.9500	54.95
ANTENNA 433MHZ 1/4 WAVE SMA	Digikey	ANT-433-CW-HWR-SMA-ND	2	2	9.9800	19.96
Heat Sink for LM317, Very Large	Digikey	CR493-ND	2	2	0.5000	1.00
EMI/RFI Suppressors & Ferrites 95 OHM BULK	Mouser	623-2743021446	4	5	0.1200	0.60
PIC24FJ256GB106	Microchip	PIC24FJ256GB106-I/PT	3	6	0.0000	0.00
CRYSTAL 8.00 MHZ 18PF 49US	Digikey	X164-ND	3	4	0.5800	2.32
CRYSTAL 26.000 MHZ 18PF HC49US	Digikey	887-1029-ND	2	3	0.4600	1.38
TRANS RF N-CH FET LDMOST PWRSO10	Digikey	497-5295-5-ND	2	2	10.9800	21.96
Low-Power Sub-1GHz RF Transceiver	TI	CC1101RTKR	2	5	0.0000	0.00
5 Watt SPDT T/R Switch SMT, DC - 3 GHz	Hittite	HMC574MS8E	4	10	2.7400	27.40
IC HEX INVERTER CMOS 14-TSSOP	Digikey	74HC04DTR2GOSCT-ND	2	3	0.5300	1.59
IC AMP HBT GAAS GEN-PUR SOT-89	Digikey	689-1021-1-ND	2	2	3.4000	6.80
IC REG SIMPLE SWITCHER TO-263-5	Digikey	LM2596S-5.0-ND	2	2	5.1800	10.36
IC REG LDO 1.0A 3.3V SOT89-3	Digikey	AP1117Y33LDICT-ND	2	3	0.9500	2.85
IC REG ADJ 1.5A 3 TERM TO-220	Digikey	LM317TFS-ND	2	3	0.5700	1.71
Buffers & Line Drivers Octal 3-STATE Buffer	Mouser	595-SN74HCT541PWE4	2	3	0.4200	1.26
IC DRVR/RCVR MULTCH RS232 16SOIC	Digikey	296-13094-1-ND	1	1	2.1000	2.10
CAPACITORS			112	220		31.67
CONNECTORS			69	169		50.84
DIODES			17	25		8.19
RESISTORS			37	105		6.92
INDUCTORS			12	20		10.34
					TOTAL	409.0000

Table E-1: Parts List

Appendix F: FMECA Worksheet

POWER SUBSYSTEM

Failure No.	Failure Mode	Possible Causes	Failure Effects	Method of Detection	Criticality	Remarks
1A	Short circuit across any regulator	Regulator failure, Diode D1 failure	Unpredictable system behavior in all subsystems, overvolting, fire and risk of shock	Observation	High	Human injury risk, not only from loss of plane control, but from fire and shock as well.
1B	Open circuit across Linear Regulator LM317T	Regulator failure, Solder joint failure	Loss of power to transceiver subsystem	Observation	Medium	Loss of functionality, but the motors will continue to function.
1C	Open circuit across Linear Regulator AP1117V33L-13	Regulator failure, Solder joint failure	Loss of power to significant portions of all subsystems	Observation	High	Complete loss of functionality, loss of control, possible loss of motor power, injury possible
1D	Open circuit across Buck Regulator LM2596	Regulator failure, Solder joint failure	Loss of power to all subsystems but the transceiver	Observation	High	Loss of power to motors causes current trajectory to be locked in, injury possible

Table F-1: FMECA Analysis of Power Subsystem

TRANSCEIVER SUBSYSTEM

Failure No.	Failure Mode	Possible Causes	Failure Effects	Method of Detection	Criticality	Remarks
2A	Transceiver CC1101 configuration erroneous	µC UART Tx failure, code bug, transceiver error, noisy circuit	Failure to transmit control information, transmitting on wrong frequency, transmitting with wrong power	Observation / None	Medium	One externality occurs if transmitting on the wrong channel causes interference with another amateur radio band operator.
2B	Reflected RF	Incorrect impedance matching with antenna, vibrations changing value of variable resistors / capacitors,	Loss of transmission, multiple component failure within subsystem	Observation	Medium	Loss of transmission

Table F-2: FMECA Analysis of Transceiver Subsystem

MODEM MICROCONTROLLER SUBSYSTEM

Failure No.	Failure Mode	Possible Causes	Failure Effects	Method of Detection	Criticality	Remarks
3A	µC clocking failure	Oscillator failure, µC oscillator input pin stuck high, µC catastrophic failure	Loss of direct control, loss of servo and motor power	Observation	High	Potential for human injury through plane-person collision, due to lack of control and power
3B	LED output pins stuck high/low	µC port failure, µC catastrophic failure	Debug LEDs show incorrect status	Observation / None	Low	
3C	Short across bypass capacitors	Overvolting bypass capacitors, bypass capacitor failure	Subsystem failure due to undervoltage from extra ripple	Observation	High	May assume a failure in the power subsystem. Low power can cause loss of control, causing injury.
3D	PWM port pins stuck high /low	µC port failure, µC catastrophic failure	Loss of engine and servo control, unexpected servo and engine behavior	Observation	High	Assumes a sanity check is not performed
3E	Board-to-Board UART port pins stuck high/low	µC port failure, µC catastrophic failure	Loss of communication with sensor module	Observation	Low	Sensor data will not be available to the user in this case, but no physical damage will result

Table F-3: FMECA Analysis of Packet Modem Microcontroller Subsystem

SENSOR SUBSYSTEM

Failure No.	Failure Mode	Possible Causes	Failure Effects	Method of Detection	Criticality	Remarks
4A	µC clocking failure	Oscillator failure, µC oscillator input pin stuck high, µC catastrophic failure	Loss of sensor subsystem communication and sensor data	Observation	Low	Does not directly cause device failure
4B	LED output pins stuck high/low	µC port failure, µC catastrophic failure	Debug LEDs show incorrect status	Observation / None	Low	
4C	Short across bypass capacitors	Overvolting bypass capacitors, bypass capacitor failure	Subsystem failure due to undervoltage from extra ripple	Observation	Low	May assume a failure in the power subsystem
4D	Board-to-Board UART port pins stuck high/low	µC port failure, µC catastrophic failure	Loss of communication with modem subsystem, sensor data not sent	Observation	Low	No resulting physical damage

Table F-4: FMECA Analysis of Sensor Subsystem