Dr. Lutz,

Your generosity, dedication, and contribution in knowledge and insight into the project is greatly appreciated. Each Team CapHAB member has expressed on numerous occasions how greatly they enjoyed the opportunity to work on such a project. This project would not have been nearly as successful without your enthusiasm.

Thank you for attending our presentations on April 28th, and 29th at the NASA Space Grant Symposium. Due to feedback received after each of the presentations, we believe that each of the presentations went well. Numerous attendees at each of the presentations remarked that the presentation was an exceptional tradeoff between simplicity and detail. Although we were unable to attend the poster session between 1:30 and 3:30PM on April 28th, fortunately the team constructed a large poster board that was then placed at the capstone conference poster session for visitors to view.

There have been several changes to the project budget since the previous report. Some include adding items to the budget that had previously not been documented. The first items included were utilized in the first balloon payload. The HOBO data loggers and software were used in both payloads and cost $407.00. The Canon ELPH and film used in the first launch cost a total of $57.39. The last of the first launch budget items are the wire, 5W 4-ohm resistors, and SPST switches from the first payload heating subsystem for a cost of $47.65. The Yaesu VX-2R and microphone adapter costs were adjusted to match the accurate costs. An increase from a projected cost of $160 to a total cost of $373.41. The last minute failure of the 2 Gb memory card lead to the purchase of a replacement 2 Gb memory card for $108.10. The cost of the antenna was unknown in the last budget. The new budget includes the cost for the M2 antenna kit for $98.91. Other budget additions include $21.62 for components at Digikey, $10.55 for the RCEPP2, and $14.66 for Sun Will Tech. These changes increase the budget from $1049.75 to a new total of $1860.30.

One of the most beneficial components a project like this affords is the large amount of experience that can be gained. Team CapHAB has found that the we gained experience in six key areas through this project. We found the most valuable experience gained was how to better manage project time schedules. Other teamwork keys were how to properly distribute tasks and simply get along amongst team members. Technically we became quite experienced with taking apart and modifying digital cameras, knowledge and design of wireless telemetry systems and how to design proper and useful data logging subsystems. These experiences will provide each of us with valuable knowledge for our future engineering careers. Thank you again for your benevolent assistance throughout this project and we look forward to completing the future launch!

Sincerely,

Rob Hough

Rob Conant

Andrew Prosory

Jad Lutfi

Team CAPHAB
Rob Hough – Andrew Prosory
Jad Lutfi – Rob Conant

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Final Report

Capstone High Altitude Balloon Satellite Payload

Contents:

Section 1

Background

Project Overview

Similar to projects completed over the last several years around the country, and for the purposes of promoting space research, interest, and the education of undergraduate engineers, the NAU/NASA Space Grant Administration has requested the design, launch and retrieval of a small payload on a high-altitude weather balloon. Fitting with the main purpose of educating undergraduates, the project will involve students in the full design-build-fly-operate-analyze cycle of a space mission.

The payload satellite will be designed to measure various atmospheric parameters as a function of altitude up to 100,000 feet, and correlate the data to a series of images. These images will help characterize the earth's surface features, cloud structure and curvature.

The payload satellite will be battery powered, equipped with APRS transmission hardware, timing circuits, data loggers, temperature sensors, a digital camera, a pressure sensor, and accelerometers. The electronics designed must function within the environment maintained by the container, specifically the rapidly changing and extremely low temperatures and pressures. Along with being thermally consistent, the payload container will be mechanically stable to facilitate the operation of the electronics during high levels of shock and vibration. It also must connect securely to the balloon-tether provided by Arizona Near-Space Research (ANSR). The photo and atmospheric data will be stored in the satellite and easily downloadable once the balloon payload is recovered. Recovered data will be analyzed with the assistance of the Space Grant and ANSR teams. APRS data will be transmitted throughout the flight.

Figure 1.1: Satellite Payload

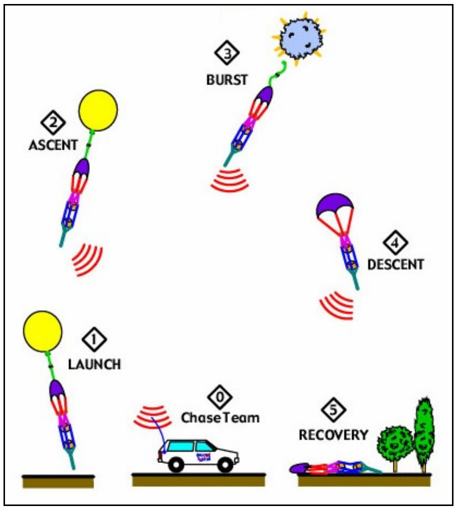

Figure 1.2: Balloon Flight Profile

Design Description

The CAPHAB satellite is restricted to 1-foot cube and the entire system has a weight limit of 3 pounds in order to meet launch criteria provided by Dr. Lutz and Arizona Near-Space Research (ANSR). The design system will be broken down into 5 subsystems: structure, sensor, digital imagery, tracking and power. The structure subsystem will include the container for all the system components and the thermal insulation of our cube.

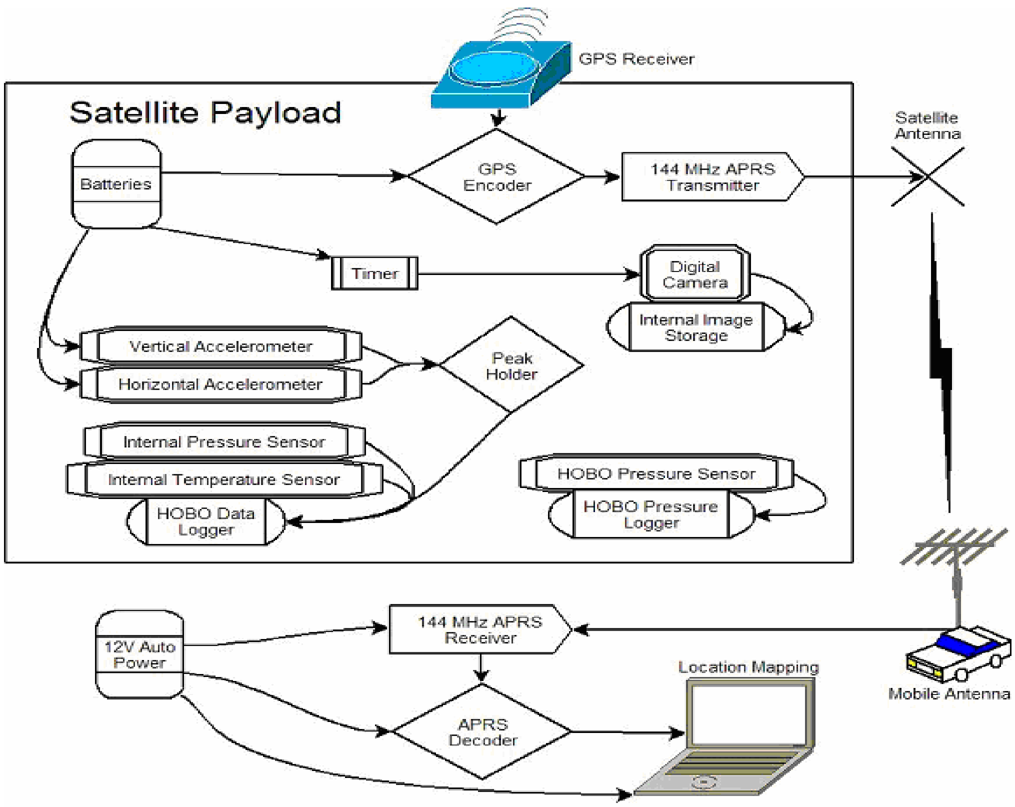

Figure 1.3: System Block Diagram

The sensor subsystem will include a thermometer to measure internal and external temperature variations, a pressure sensor, a relative humidity sensor, and accelerometers to measure the G forces. All the sensor output data will be stored on 2 HOBO data loggers. The imagery subsystem will consist of a digital camera with high image quality and an image capture controller. The tracking subsystem will be based on a GPS to provide the system with it is positioning and a GPS data logger to store and analyze the data. Finally, the power subsystem will be based on rechargeable lithium ion battery cells. This system is outlined in figure 1.3.

Section
2

Latest Results

Testing and Analysis

Failed Launch
Unfortunately the scheduled balloon flight on 4/22/06 was canceled due to a balloon failure at launch. On the drive back from Maricopa City to Flagstaff, a complete functionality test was run to prove that each subsystem met its requirements. The individual subsystem results from this test and previous tests are mentioned below.

Digital Imaging Subsystem Results
Approximately 458 pictures were taken over a 2-hour period. Around the 2-hour mark an error occurred on the camera causing it to shut down. Initial thoughts on the problem suggest that the error was caused by the digital camera's inability to store more than 1 GB of data. A solution to this problem would be to reduce the number of pictures taken by the camera every minute. Currently the camera records an image every 15 seconds. It is recommended rather to record an image every 30 seconds to ensure that the camera can take pictures over a required 3-hour period.

Wireless GPS Telemetry Subsystem Results
The Wireless GPS Telemetry subsystem worked successfully. A teammate in a separate vehicle was able to track our vehicle's location throughout the entire trip. The mapping results of this test are shown below in figure 2.1.

Figure 2.1: GPS location map in South Phoenix

This particular image shows the route from Maricopa City to Southern Phoenix. The KE7HHX labels are Rob Hough's radio call sign. Each point shows are vehicles location at 1 minute intervals.

Sensors Subsystem Results

The temperature, vertical accelerometer, and horizontal accelerometer sensors all worked successfully. These results from the temperature sensor and horizontal accelerometer are shown below in figures 2.2-a.

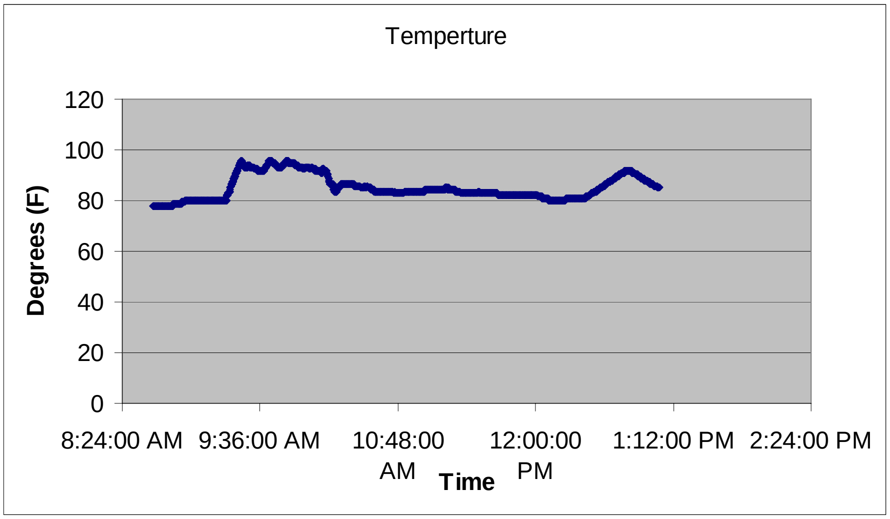

Figure 2.2-a: Temperature sensor test data downloaded from the HOBO data logger

The high temperatures reported by the temperature sensor are due to the warm temperatures found in the back of our rental vehicle. The temperature sensor was able to successfully turn on at the correct time as well as store data well over the needed time period. The accelerometer circuit was able to detect the G-forces exerted on the satellite during out test. The G-forces values were successfully stored and then downloaded off the HOBO data logger. The data were then plotted in excel to be analyzed as shown in figure 2.2-b.

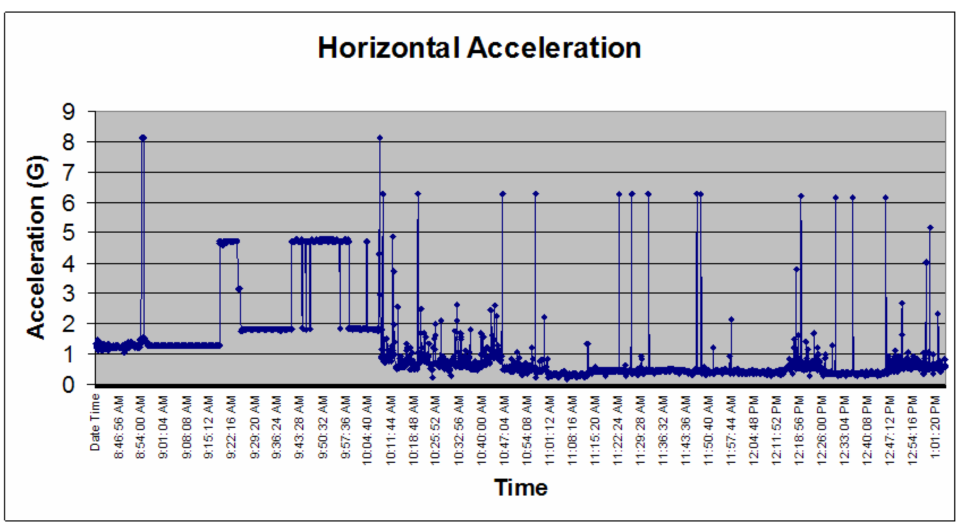

Figure 2.2-b: Horizontal acceleration test data downloaded from the HOBO data logger

Payload Package subsystem Results
The temperatures reported on the car ride back to Flagstaff were too warm to test the insulation used on the package. A future balloon flight is essential to ensure its success.

In the mean time a thermal test was run between polyethylene foam and spray in foam. The test showed that the spray in foam did a better job of insulating the package than the polyethylene foam. Unfortunately the spray in foam was almost twice as heavy as the polyethylene so it could be used. After some consideration the team decided that the best solution to the package would be to use a hybrid of both polyethylene and spray in foam. This gave the best weight to insulation ratio for the package.

Section 3

Accomplishments

Design Performance Vs. Requirements

The CAPHAB satellite payload has met all the notable requirements observable to-date. Operation in the actual launch environment temperature is the only variable that has not been tested. The other requirements have been achieved and verified. Table 3.1 below lists the most important requirements specifications and the achieved results.

Requirement	Specification	Acheived
Size of the container	12'' x 12'' x 12''	6.5'' x 6.5'' x 6.5''
Weight of the container	2-3 pounds	2.9 pounds
Operation Temp. Range	Down to -40° F	unknown
Battery Life	3 Hours	4+ hours
Pressure Range	0-1 Bar	0-1 Bar
Images/Minute	1	2
Image Resolution	3 MP	5 MP
Budget	$2,400	$1,900
Image Storage	>180 Images	458
Ready-By Date	April 29 (June 3)	22-Apr
Altitude Range	0-100,000'	0-Technical limits (>100k')
Data Correlation	<10 mins	<1 second

Table 3.1 : Requirements Vs. Acheived

Final Requirements

1. Mechanical

The satellite will contain all relevant components in a container that satisfies the size and weight requirements. The container should be able to facilitate a non-abrasive tether through the center mass of the container. The payload should be able to withstand the shocks, vibrations and temperatures incurred during the flight and landing.

Requirement	Specification
Size of the container	1 cubic foot (1ftx1ftx1ft
Weight of the container	2-3 pounds
The temperature range that the container should withstand	-80° to 90° F

Table 3.2: Mechanical Specifications

2. Electrical

The electrical system will consists of a digital imager, temperature sensors, pressure sensor, and tracking device. Each data device must be able to record data for the entire flight. The images and atmospheric data must be correlated with altitude and geographic location as well as time. All electrical devices should be easily interfaced with a personal computer to retrieve logged data after the satellite's recovery.

Requirement	Specification
Power	Minimum Battery life of 3 hours
Devices operation specs	Temperature range between -80° and 90° F
	Pressure range between 0 and 1 bar
Digital imager	Obtain a resolution of 3-5 Mega-pixels
	Capture an image each one minute
	A storage capacity of at least 1 GB (>180 images)
Temperature Sensor range	-80° to 90° F
Pressure Sensor range	0 to 1 bar
Tracking device altitude range	0 to 100,000 ft
Accuracy	Data correlation error between devices of < 10 minutes

Table 3.3: Electrical Specifications

3. Documentation

The documentation requirements consist of biweekly reports and a final document. The specifications of each report are illustrated in Table 3.4.

Requirement	Specification
Biweekly reports	What happened since last report
	Major Milestones for the next two week
	Critical problems
Final documentation	Design & detail descriptions of each sub-system
	Well recorded to facilitate repairs

Table 3.4: Documentation Specifications

4. Testing

The satellite test will occur during the second one-third of the spring semester. The satellite will undergo a payload operation test, a battery life test, a durability test, a camera functionality test, and a data logging test for each of the sensors. The specification of each test is described in Table 3.5.

Requirement	Specification
Testing period	Completed during the second one-third of the spring semester
Payload operation test	Simulate operation under high and low temperature
Battery test	Battery operation for at least 3 hours
Durability test	Simulate payload under vibration and shock
Camera functionality test	Appropriate correlation between timing and image capturing (i.e. 1 image per 1 minute)
	Enough memory space to capture > 180 images
Data loggers	Test storage of sensors data outputs

Table 3.5: Test specifications

5. General

General requirements and specifications such as project budget, payload launch location as well as payload launch and recovery date are illustrated in Table 3.6.

Requirement	Specification
Project budget	Payload should cost < $2400
Payload launch location	Maricopa City, AZ
Payload launch and recovery Date	Late April (28-29 April)

Table 3.6: General specifications

Section 4 Design Process Details

The first step in any design process is meeting with the client to discover and understand the needs of the client. Thus the first step Team CapHAB took in the design process was to meet with Dr. Lutz to discover what he desired from this project. The needs of the client were then translated into a specification sheet that could be utilized throughout the project to verify that the project was indeed on-task.

After the client needs were fully understood, the next step was to divide the system into separate subsystems that could be researched, designed, and built by individual team members. Furthermore assigning individual responsibility to subsystems ensures that each subsystem will be kept on-track throughout the entire design. Thus the project was divided into several subsystems. The entire team discussed the subsystem partitioning before the system was finally divided into five subsystems. These subsystems included: sensors, digital imaging, location tracking, satellite structure, and power.

The next few weeks were spent researching solutions to each individual subsystem. This portion of the design process tends to be fairly iterative. For example, a group member may spend several hours researching a solution to the subsystem. Then the following day the group member may present the solution to the team. If the solution is not quite the optimal solution, then the member would go back to researching until finally an optimal solution is met. One solution of interest is for the tracking subsystem. It was found that there are pieces of hardware that are capable of logging the output of specific GPS units. This data could then be extracted after the flight and the entire flight could be mapped using commercial or open-source software. The team discussed this solution and ultimately decided that it would be more interesting and useful to be capable of tracking the payload throughout the flight. Further it is important to track the payload throughout the flight in order to successfully recover the payload. Thus wireless transmission functionality was added to the payload tracking subsystem.

Once the team had researched and formulated optimal solutions, the solutions were then documented into a subsystem design proposal. The respective costs of each of these subsystems and their components were included in this proposal, which was then sent to our project sponsor in order to obtain approval to order the parts and build the subsystems. Any desired changes should then be incorporated into the project. Fortunately for Team CapHAB, our project sponsor accepted our proposal and therefore did not ask the team to change any of the subsystems.

The next phase of the project is perhaps one of the most pleasurable. Upon receiving approval of our design from Dr. Lutz, Team CapHAB purchased the components necessary to begin assembling the individual subsystems. After building the subsystems, each individual system should be tested to verify that the design operates correctly. If necessary the design should be modified. One example of how this affected Team CapHAB would be when the team realized that the mapping software accepted a different type of input than we were ready to provide it. The team decided that the solution to this problem was to find a separate piece of software. After verifying correct operation it is important to verify that the solution meets the specifications that the client provided. If the subsystem is found to not be in spec, then modifications would be necessary. One problem that Team CapHAB encountered was that the Terminal Node Controller for the wireless subsystem was not responding to any computer configuration. The problem persisted on two separate computers. Finally it was found that the USB to serial adapter that was being used was faulty. The team convened to discuss the problem and it was decided that the team would seek out a laptop that had a serial port built-in. A laptop with a serial port was procured and the problem was solved.

Finally after each subsystem has been assembled and tested, it is time to put the individual subsystems together to form the complete system. It is necessary after the entire system is assembled to verify that the system functions correctly. If there are problems, then it will be necessary to fix or modify the design of the subsystem or system. Team CapHAB found that the GPS receiver did not receive a signal when placed inside the payload. Upon creating several solutions, Team CapHAB found that the easiest and most reasonable solution would be to secure the GPS receiver to the outside of the payload package.

A great deal of difficulty was encountered throughout the design and implementation of this project. Several examples of these difficulties were documented above. Every single problem that was encountered during this project was successfully solved. Each member of Team CapHAB gained a great deal of knowledge through the problem solving and teamwork involved in troubleshooting and solving the problems encountered throughout the project. One type of knowledge gained during the project was the ability to be tolerant of others when difficulties were encountered. It can be quite stressful working with a subsystem that is malfunctioning. As a result, sometimes team members were less than cordial with one another. This, however, is not a professional way to conduct one's self. After discussing this issue, the team began working towards having tolerance during these stressful periods. Thus the team gained valuable experience in being professional during stressful periods of time. Another example of knowledge gained through this project is the ability to properly manage a subsystem time schedule. Each portion of the project must always be kept on time in order to keep the entire project on time. By systematically approaching every difficulty encountered for throughout the project, Team CapHAB was able to successfully solve the problem and gain valuable career knowledge.

Section 5

Budget and Time

Budget Summary

Itemized Budget Breakdown

Items	Expense Amount
Timer kit, perf bd., 2m ohm, 9v caps	$8.25
Foil, 9v bat, tubing/nuts, elec tape	$17.66
CR2 battery, 12 v batteries	$13.27
Canon Elph Camera, film	$57.39
HOBO's, probe, software	$407.00
Wire, 5w 4ohm resistor, SPST switches	$47.65
Memory Card	$84.47
Digital Camera & Battery	$241.92
Accelerometer	$29.76
Conn PLCC Socket	$18.60
Socket Adptr., Accelerometer Dual Axis	$30.00
Kantronics +	$77.00
GPS Unit	$157.63
(Sun Will Tech)	$14.66
RCEPP2	$10.55
Digikey	$21.62
Lithium Batteries	$42.46
Yaesu VX	$354.85
Memory Card - Fry's Electronics	$108.09
M2 Antenna kit	$98.91
Microphone Adaptor	$18.56
Total	**$1,860.30**
Remaining Budget	**$539.70**

Table 5.1: Itemized Budget Breakdown

Subsystem Budget Breakdown

Subsystems	Expense Amount
Imaging	$491.87
Sensors	$506.98
Wireless	$732.16
Package	$17.66
Batteries	$55.73
Misc.	$55.90
Total	$1,860.30

Time Spent

The time spent on the project was broken up into the four following sections: research and requirements, design proposal, detailed design, and integration and testing.

Project Area	**Time Spent in Weeks (40 hour blocks)**
Research and Requirements:	3.2
Design Proposal:	4.2
Detailed Design:	4.4
Integration and Testing:	6.4
Total 40 hour Weeks	18.2

Table 5.3 : Man-Weeks Per Design Phase

The fall project phases consisted of the requirements and research phase, and the design proposal phase.

- Requirements and Research
    - Met with Sponsor
    - Developed Specific Project Requirements For Each Subsystem – Imaging, Sensors, Packaging, Tracking
    - Investigated Partial Solutions
- Design Proposal
    - Researched Specific Solution
    - Built Simple Payload - Practiced Launch
    - Verified of Design with Sponsor

The spring project phases consisted of the detailed design phase, and the integration and testing phase.

- Detailed Design
    - Determined Specific Subsystem Specifications
    - Added Wireless Transmission Requirements
    - Delivered Schematics and Circuit Diagrams
    - Ordered Subsystem Parts
    - Created Web Page
- Integration and Testing
    - Modified Detailed Designs
    - Built Second Satellite Package
    - Completed Each Subsystem
    - Attended Launch
    - Will Retry Launch

Section 6

Design Details

Telemetry System Block Diagrams

6.1 Telemetry Ground Station

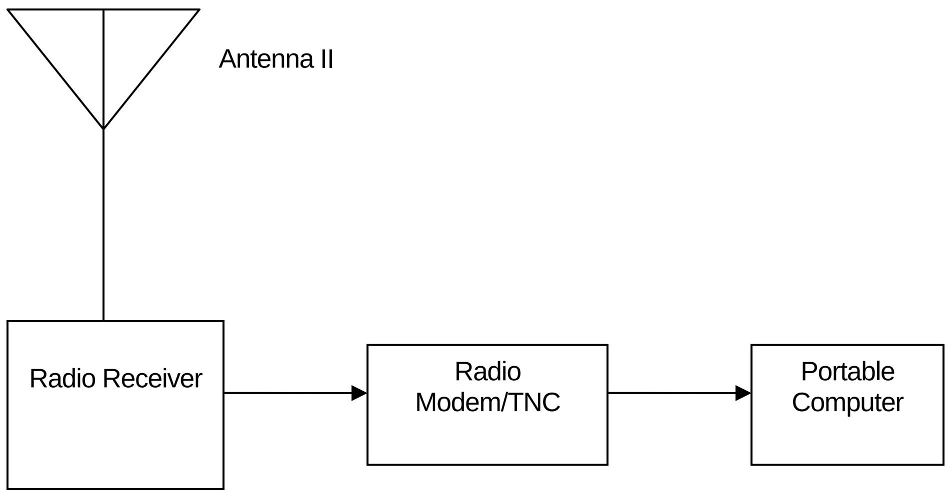

Figure 6.1-a: Telemetry ground station design diagram

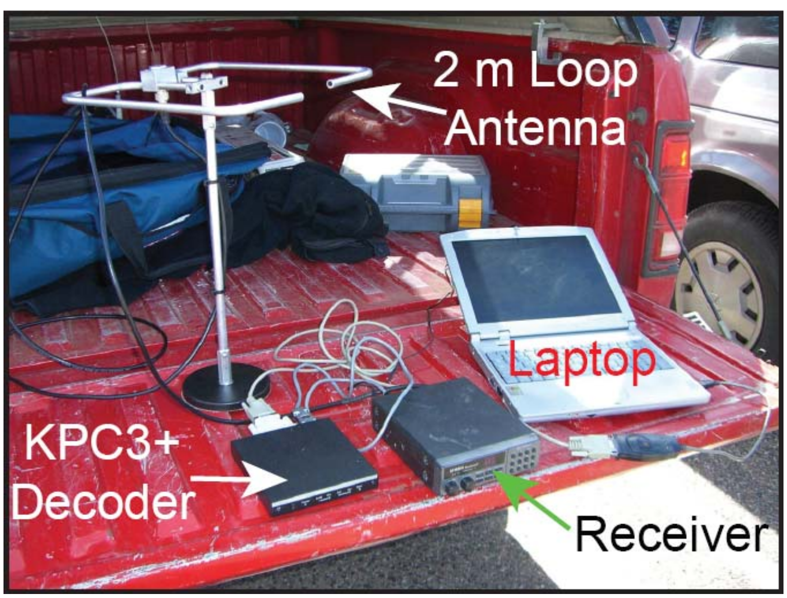

Figure 6.1-b: Telemetry ground station system

6.2 Satellite Telemetry Subsystem

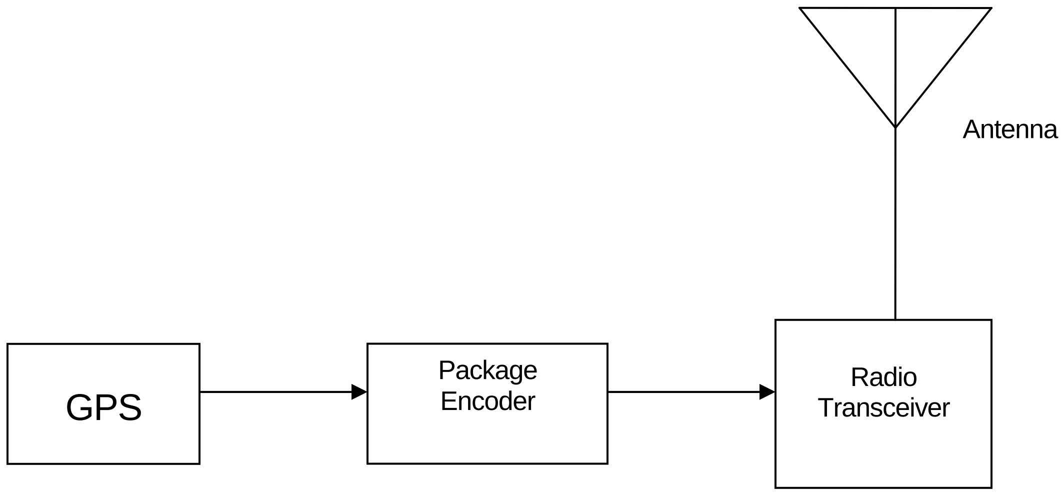

Figure 6.2-a: Onboard of the satellite telemetry design diagram

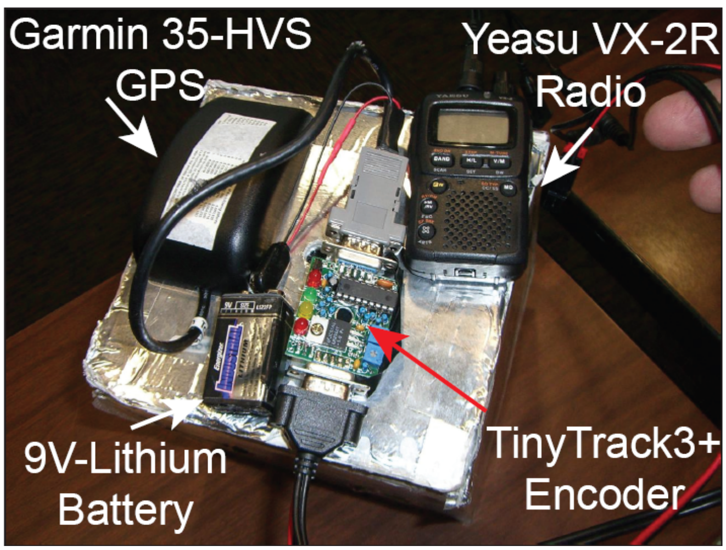

Figure 6.2-b: Onboard of the satellite telemetry subsystem

7. **Transmitter Antenna**

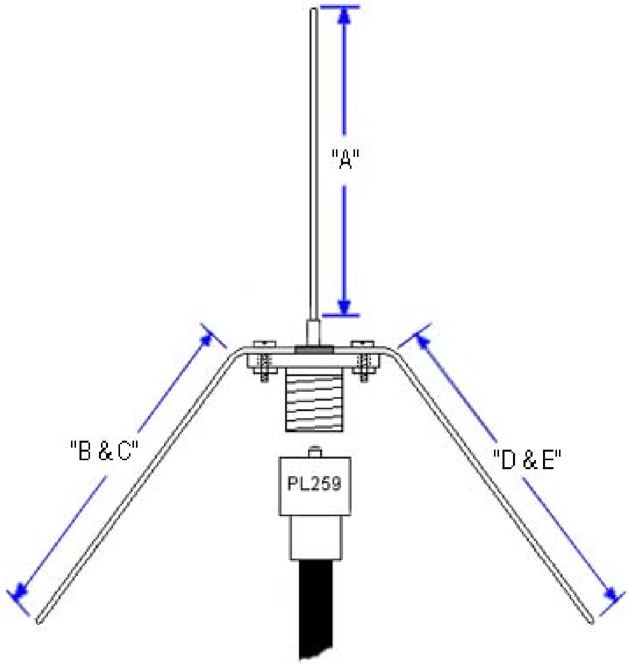

Figure 6.3 : ½ Wave ground plane transmitter antennas tuned at the 2-m Band

8. **M2 2 Meter Square loop Receiver Antenna**

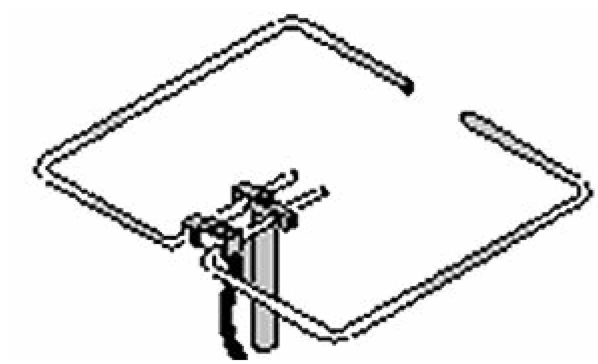

Figure 6.4: M2 2 meter Ho Loop receiver antenna

6.3 Component Brands of Telemetry System

Components	Brand
Global Positioning System	Garmin GPS 35-LVS
Terminal Node Controller/coder	Kantronics KPC-3+
Package Encoder	TinyTrak3Plus
Radio Transmitter	Yaesu's VX-2R
Radio Transceiver	Uniden Bearcat
Antenna I	¼ wave ground plane
Antenna II	2 Meter square loop

Table 6.1: Components brand used on team CAPHAB's telemetry system

Satellite Package Detail

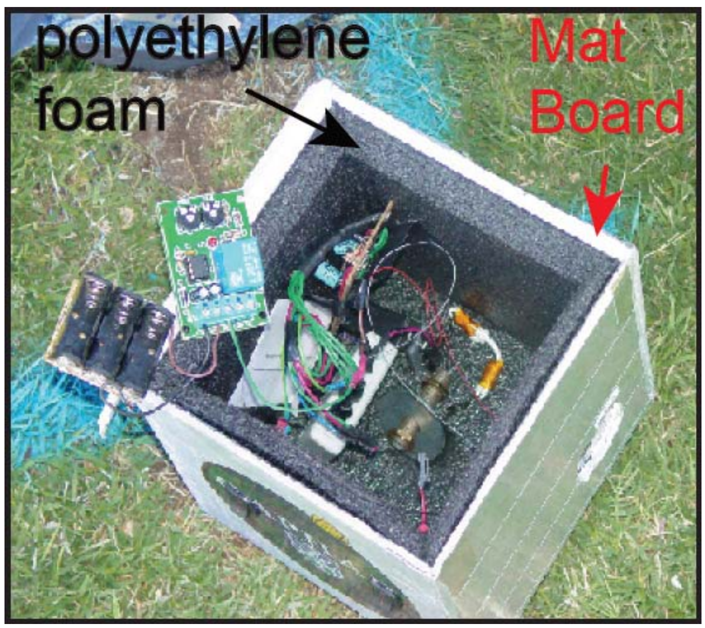

Figure 6.5: Team CAPHAB Payload with the Mat Board and the Polyethylene foam

Accelerometer Circuit Design

The accelerometer sensor design illustrated in figure 6.6 consists of the following components:

1. One ST Microelectronics 3-Axis accelerometer, 24SOIC Mount
2. Two 100 uF capacitors
3. Two op-amps
4. Two 8 pin chip mounts (for op amps and 555)
5. Resistors, 2x15K, 2x290K and 4x100K
6. One 555 timer
7. One 2''x3'' PC board for mounting
8. Two 1N914 diodes
9. Two 2N4401 NPN Transistors
10. Two 1/8" mono jacks
11. One 9V Source

Note: The parts listed above are for a complete two axis setup. To make a two axis peak holder, simply use the listed parts and duplicate the circuit below.

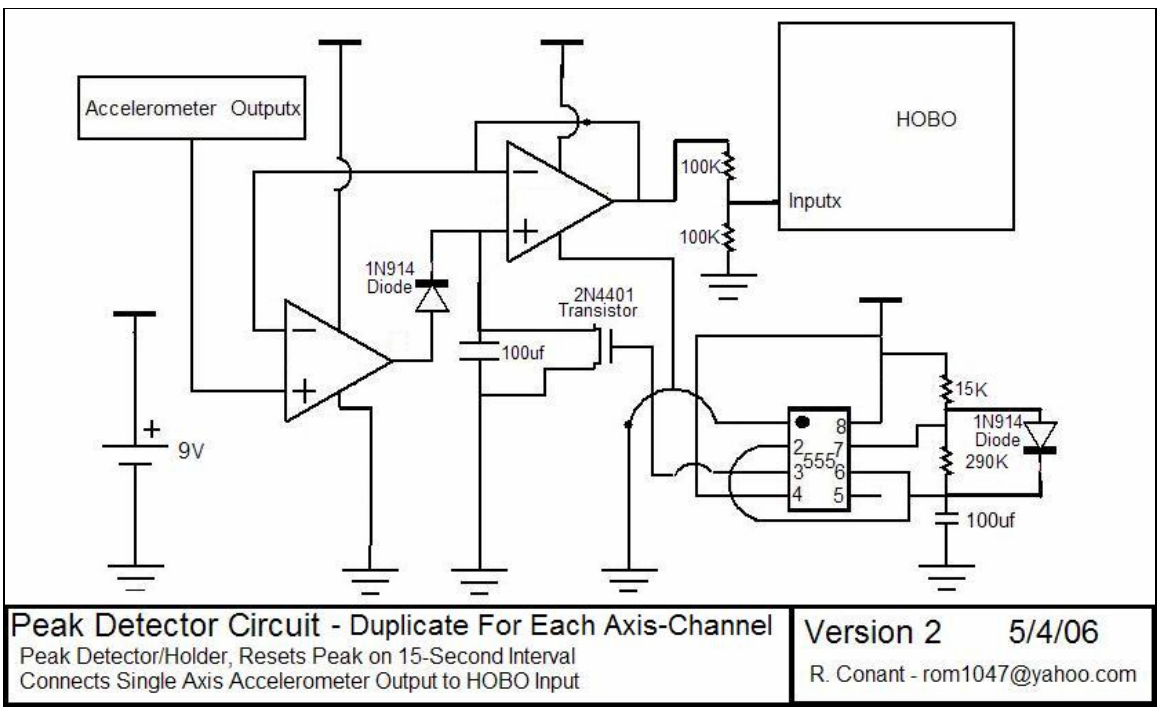

Figure 6.6: X-Axis Accelerometer sensor circuit design including the peak detector and the 555 timer

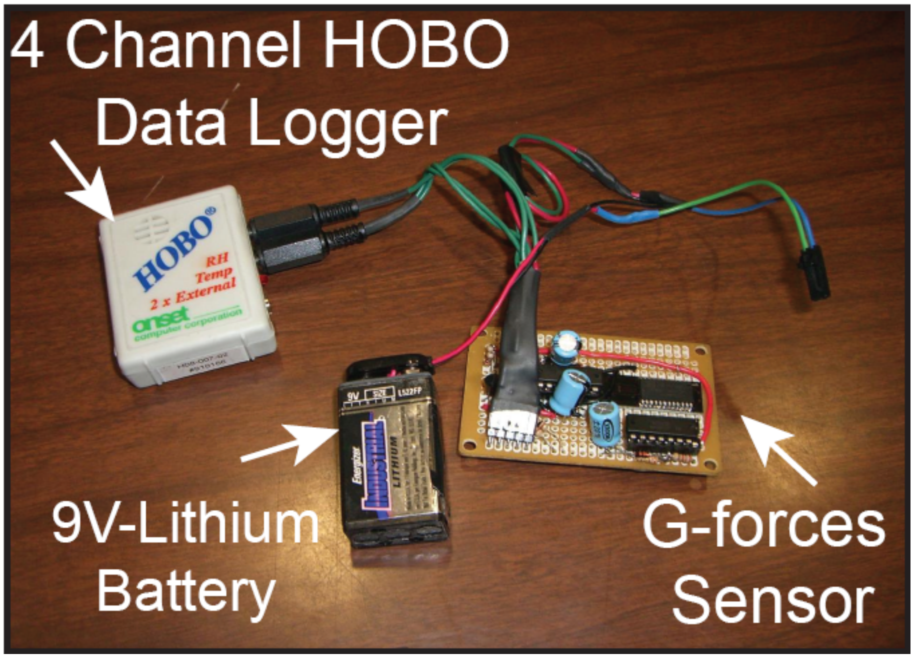

Figure 6.7: Accelerometer sensor circuit board, 9-V power supply, and the data logger

Final Schedule

Fall 2005

a. Phase I (first 1/3 of semester)
    Project and Team decided (9/22/2005)

b. Phase II (second 1/3 of semester)
    Status Report and Presentation (11/10/2005)

c. Phase III (final 1/3 of semester)
    Design Proposal Documentation (12/01/2005)
    Design Proposal Presentation (12/08/2005)

Spring 2006

a. Phase I (first 1/3 of semester)
    Finalized design documentation (1/17/2006 - 2/23/2006)
    Conducted design reviews (2/10/2006 - 3/23/2006)

b. Phase II (second 1/3 of semester)
    Implemented the design and built the payload (2/23/2006 - 4/3/2006)
    Payload underwent extensive pre-flight testing (4/17/2006 - 4/21/2006)

c. Phase III (final 1/3 of semester)
    Failed launch of payload in central Arizona (4/22/2006)
    Full test of each subsystem preformed (4/22/2006)
    Final Capstone Presentation and Poster Session (4/28/2006)
    Space Grant Undergraduate Research Symposium (4/29/2006)
    Final Documentation (5/05/2006)
    Re-Launch of payload down in central Arizona (6/03/2006)

Section
7

Presentation

A copy of our Capstone presentation is included here.