AC 2010-1120: REAL-TIME VIDEO TRANSMISSION FROM HIGH ALTITUDE BALLOON: AN INTERDISCIPLINARY SENIOR DESIGN PROJECT

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Abstract

With engineering students facing increasing distractions, it has become more and more challenging to design and create attractive means to recruit and retain them. In the paper we present an interdisciplinary senior design project with collaboration of electrical and mechanical engineering students which attempted to transmit real-time video from a high altitude balloon from 100,000 feet altitude. Through this experience, students have learned principles of integrated engineering technology, and sharpened their skills in cooperative learning, effective learning and team work. The learning outcome of this project was measured by post-course questionnaires, course evaluations and student interviews conducted by the department chair before graduation. All students expressed positive learning experiences after participating in this interdisciplinary project and indicated that the learning outcomes were successfully achieved.

I. Introduction

With engineering students facing increasing distractions, it has become more and more challenging to design and create attractive means to recruit and retain them. This paper reports an interdisciplinary collaborative capstone senior design project for electrical and mechanical engineering students to bring real-time videos from a High Altitude Balloon (HAB) to a ground station. The HAB project has proved to be a unique and exciting tool to attract students from freshmen to seniors to apply their engineering knowledge. At the same time, the HAB system has also become a great vehicle to accommodate scientific research in near space at about 100,000 feet above the ground with a relatively low cost.

The students have designed and implemented a real-time video transmission system to stream live video feeds from the high altitude balloon. With three separate cameras installed in the balloon payload providing different views, students have also designed a micro-controller controlled alternating video from these three video cameras. While the videos captured by all three video cameras are recorded onto a DVR at the same time, only one of the three cameras can be observed from the ground station. With a total payload weight of 6 pounds regulated by the FAA, it is a challenging task for the students to design such a system. Since it is essential for the students to retrieve the payload after every balloon launch, we had designed and implemented accurate localization/tracking and wireless communication systems to track and fox-hunt the balloon earlier. The tracking/communication system weighs about 3 pounds so students need to design and implement the real-time video system in less than 3 pounds including batteries.

Using analog television technologies, the students have designed the circuits, antenna, power amplifiers, and have implemented the system with strict weight and size limits. The system was thoroughly tested in a hostile environment such as extremely low temperatures because the HAB reaches high altitude with temperature as low as -60^{o}C. The experiment has been very successful with real-time video transmissions received from the high altitude balloon for the first time. With this real-time video feed, students are also able to observe many experiments that can be performed in near space.

While working on the HAB project, not only did students get the opportunity to design and implement an exciting project that required knowledge of their discipline, they also had the opportunity to work with others from different disciplines. One essential aspect students learned is effective communication of technical concepts and ideas to students from different departments. In addition, this experience allows students to learn principles of integrated engineering technologies, and nurtures their skills in cooperative learning, team work, and effective planning.

The rest of the paper is organized as follow: Section II briefly introduces the high altitude balloon team and its continuing effort at Wright State University, Section III describes the real time television transmission project design, Section IV covers the launch and result, in Section V we discuss the learning outcome measurement and the student assessment.

II. HAB Team at Wright State University

The high altitude balloon (HAB) project was initiated at Wright State University in the fall of 2005 with funding from the Ohio Space Grant Consortium. The HAB project is an interdisciplinary program which includes a team of Mechanical, Electrical, and Computer Science Engineering students each with their own near space experiments working together to accomplish each other's goals.

The goal each year for the HAB team at Wright State University is to launch each team's main project at the end of the year with smaller test flights earlier in the year. Because of the hours of dedication and preparation, after 14 launches we proudly hold a 100% recovery rate.

A big engineering factor comes into play when designing any experiment which will be sent into near space and that is complying with Federal Aviation Administration (FAA) and Federal Communications Commission (FCC) regulations. FAA part 101 subpart D contains rules and regulations for unmanned free balloons[1]. This subpart has driven the mechanical engineers to design a package which will not only survive sub-zero temperatures and impact forces but also comply with all FAA regulations. One of the restrictive FAA regulations in which we had to design around is the 6 pound weight limit for a single package and 12-pound weight limit for multiple packages. There are also many FCC regulations in which not only the Electrical Engineers have to deal with but also the entire team. Each member of the HAB team is encouraged to get their HAM license in order to operate the equipment the team uses.

The team uses a Micro-Trak 300 which operates on a 2-meter frequency band and uses APRS (Automatic Packet Reporting System) technology to track the speed and location of the balloon at all times. A back-up beacon which transmits Wright State University's call sign through Morse code at a programmable frequency is also implemented as a means to comply with FCC regulations and doubles as a means of tracking the device. There is also a complete backup tracking system which is implemented through the use of a Basic Stamp and a TNC (Threaded Neill-Concelman) connection on a handheld radio. The basic stamp contains a microcontroller in which a loadable program can carry out specific functions and can be used to trigger multiple devices at a certain time or altitude.

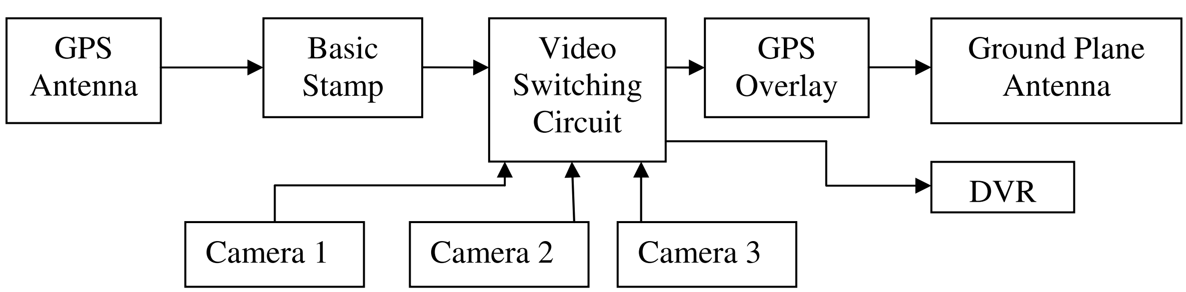
Two environmental elements that we have to deal with when designing for near space experiments are the cold temperatures and the thin atmosphere. Electronics naturally put off a certain amount of heat through the movement of current and are built relying on the air surrounding the component to dissipate the heat. For every 1000 ft elevation above the sea level the air density decreases at a rate of 2.9%-3.0%[2]. So at 80,000 ft above the sea level we can expect the air density to be at 8.7% of the sea level; making the dissipation of heat from the electronic components through convection nearly ineffective. The temperature outside our payload has reached as low as -60˚ C and the temperature is as low as -25˚ C inside the payload. Cold temperatures will severely affect how the electronic components operate and must be kept in mind when designing any project for near space.

III. Project Description

The project was to create a transmission system for an analog video transmission on the UHF 70 cm amateur radio band. An off-the-shelf video transmitter was adapted in conjunction with several versions of a 70 cm ground plane antenna and a video switching circuit in order to produce the desired video transmission. The harsh, near-space environment introduced many problems and engineering walls in which needed to be overcome in order to be successful.

A. Project requirements

The goal for our project was to receive live videos and record videos from three onboard cameras. A video switching circuit attached to the Basic Stamp would alternate between three cameras depending on the altitude. The video switching circuit has four buffered outputs in which one was connected to the video transmitter and another was connected to an onboard DVR. Below 40,000 ft above the sea level there would be a camera pointed straight down. From 40,000 ft to 60,000 ft a camera pointed sideways could capture the horizon. Above 60,000 ft there was a camera to capture the balloon rupturing. Flow Chart 1 shows the operating configuration of the transmission system.



Flow Chart 1

B. Project design

When searching for a video transmitter we kept the FCC, FAA and environmental issues in mind and decided upon a Videolynx VM-70X transmitter. We chose this transmitter due to its light weight, small size, its ability to transmit at a low frequency, lower power consumption, and its ability to operate in low temperatures. Table 1 shows the Videolynx characteristics:

VM-70X Transmitter Characteristics	
Voltage	12V
Current Draw	Max 2.2A
Power	0 to 5W (adjustable)
Frequency	426.25 to 439.25MHz
Size	2.35"W X 2.8"L X 0.75"H
Operating Temperature	-20 to +65 degrees C

Table 1

The transmitter has four adjustable frequencies that can be set by dip-switches. An advantage to this transmitter is that three of the available frequencies can be received by a standard TV set. The frequency can be set to 426.25MHz, 427.25MHz (Channel 58), 434.00MHz (Channel 59), or 439.25MHz (Channel 60); giving us the ability to use the channel with the least interference and a range of frequencies to use when designing an antenna. This transmitter operates on a 70-cm frequency band which requires the user to have their Ham license.

In order to choose which frequency to use we did some calculations for free space path loss (FSPL). According to the following FSPL equation (1), we can see that in order to have the smallest path loss we want the smallest frequency. For this reason we chose the smallest frequency still able to be received on a cable channel (427.25 MHz).

$$FSPL = \left(\frac{4\pi d f}{c}\right)^2 \qquad (1)$$

c: speed of light
d: distance in meters
f: frequency in Hz

In order for us to get a rough estimate of the distance in which we can still receive a signal, we can solve for *d* in equation (2).

d: distance from receiver to transmitter (km)
f: signal frequency in MHz. 427.25

$$FSPL\ (dBm) = 20\log_{10}(d) + 20\log_{10}(f) + 32.44 \qquad (2)$$

$$d = 10^{\left(FSPL - 20\log_{10}(f) - 32.44\right)/20} \qquad (3)$$

From equation (3) we must determine our free space path loss. In order to do this we define a noise floor equal to -69 dBm and since we transmit at 5 W (37 dBm) we know that our free space path loss is equal to 106 dBm. When we plug that into equation (3), we find the distance to be

11.2 km or 6.96 miles. The free space path loss assumes a unity gain for both antennas with no loss in the cables.

C. Heat problem and solution

Because electronics need convection in order not to overheat, we attached a CPU heat sink to the Videolynx transmitter to dissipate the heat through conduction. We also implemented a thermostat (Cantherm R2005025) which would stop the current flow to the transmitter if the temperature would increase above 50˚ C. To prevent the possibility of flying the transmitter and burning it up we created a heat source by combining two 25 Ohm resistors in parallel in order to not only pull the same current as the transmitter but also transfer the same amount of heat as the transmitter (Figure 1). This heat source was then flown in a dedicated flight along with seven temperature sensors in order to record the temperature outside of the package, inside of the package, and two sensors on the CPU heat sink. Chart 2 is a Temperature vs. Time Graph which shows the flight of the balloon. Note that the battery voltage is inverted.

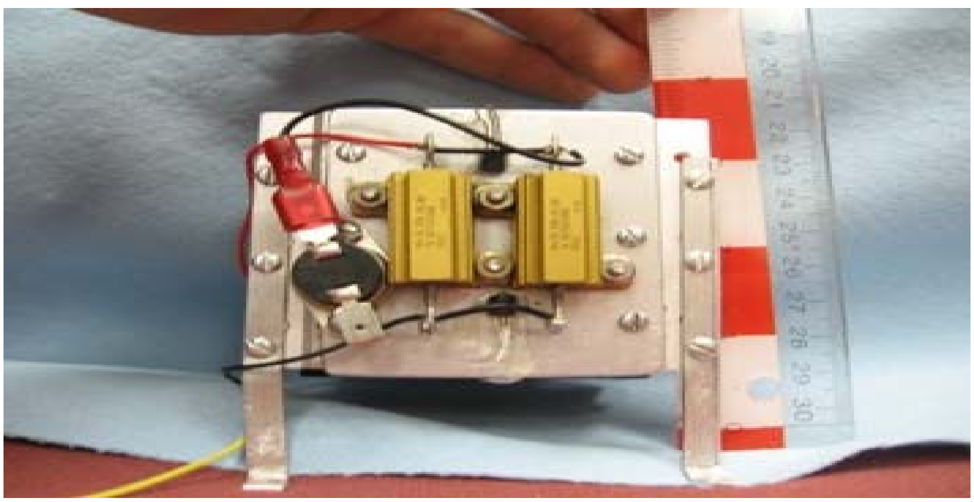


Figure 1

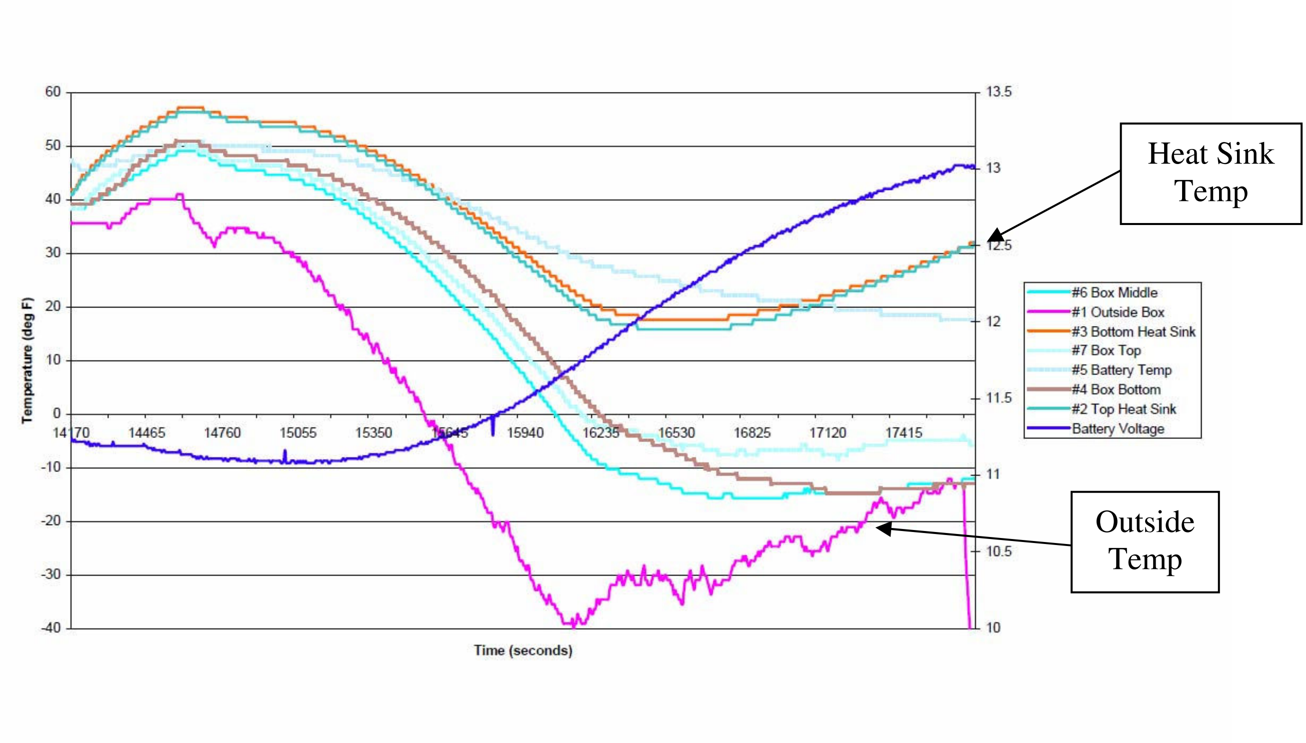


Chart 1.2 Temperature (F) vs Time

As the chart shows the outside temperature of the box reaches temperatures around -40˚F (-40˚C) but the heat sink attached to the thermal load reached a low of 16˚F (-8.8˚C) which is within the limits of our transmitter. The test showed that the transmitter should survive the cold temperatures and the thin atmosphere of a near space environment.

D. Video transmission

In order to accomplish the video switching at the specified altitudes there were several designs which involved relays and integrated chips (IC). We decided that the most reliable and weight efficient system was to create a printed circuit board (PCB) with IC's which would be controlled through the Basic Stamp. The video switching circuit has the ability to power and alternate up to four video cameras. The design also allows up to four video outputs and one auxiliary output (sound). This design was chosen because of the involvement of integrated chips. These IC's are better suited for the environment and has more options for later usage. This design involves 4 integrated chips; two of which act as a mux for four possible camera inputs. A separate IC was controlled through the Basic Stamp and would control which video camera to use. The last chip is a video buffer which can support up to four videos. Figure 2 is the PCB of the video switching circuit.

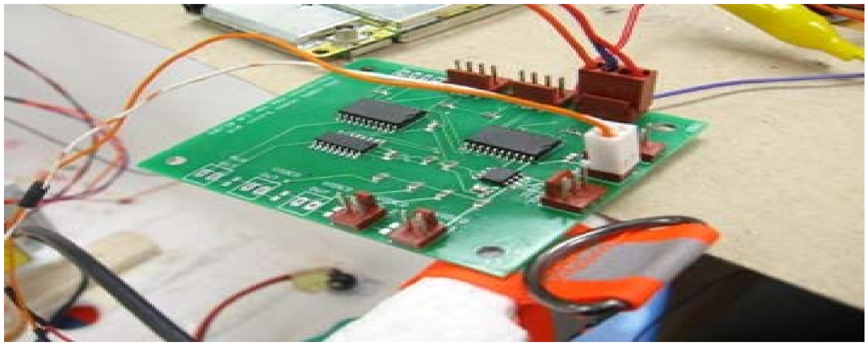


Figure 2 Video Switching Circuit

The FCC regulates that for amateur television transmission the call sign of the transmitting party must be given at least once every ten minutes. In order to accomplish this we purchased a GPS overlay board which was able to display the speed, heading, altitude, time, and our club call sign (W1WSU) on top of our video signal. This not only helped us to comply with FCC regulations but also allowed us to coordinate events which happened in the air with altitude and time information. The GPS overlay board we went with was an OSD-GPS (ID) from Intuitive Circuits LLC (Figure 3). The reason we went with this board is because it has a variable input voltage from 8-14 VDC and could operate down to -10˚ C. We set this board up with a GPS input: NMEA 0183 with a GPGGA sentence to allow the display of altitude.

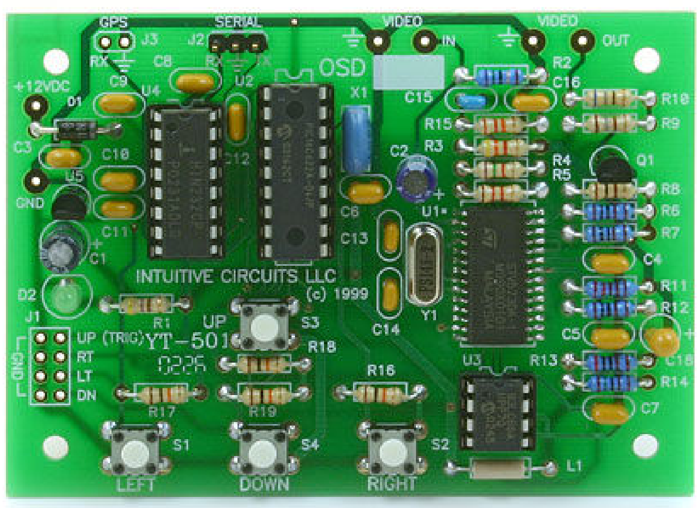


Figure 3 GPS Overlay Board (image provided by www.icircuits.com)

Much of this engineering project was dedicated to the design and development of the transmission part of the live video feed. As described before, one of the advantages of flying the ATV transmitter is the ability to receive the signal over a standard TV set. When discussing options for receiving the video signal we decided upon a USB TV tuner card along with a 70-cm Yagi style antenna. The decision of the USB tuner card for the receiving end of the live video feed was a short term solution until a more reliable stationary antenna could be built on the roof of Wright State University. One of the downfalls of the USB tuner card is its inability to receive a signal with a low signal-to-noise ratio. Future work will be completed to correct for this short coming.

The digital video recorder used for flight, Lawmate PV-500, is only able to record one video input at a time. For our case it recorded the same video which was being transmitted. This was done so if we lost communication between the transmitter and receiver we would still be able to recover video when the package returned from near space. Great video of the balloon can be seen at <http://www.cs.wright.edu/balloon> under the 2008-2009 team. The PV-500 originally was not capable of capturing the whole flight on an SD card because of card capacity and battery life. After we downloaded a new firmware package for the PV-500, we were able to double the size of SD card we were able to use which allowed us to record for the whole flight. We also powered the DVR through an external Li-ion battery which was able to last for much longer than needed.

E. Battery issues

When deciding on a battery to power the transmitter, DVR, GPS overlay board and cameras, we needed something that could survive in the cold temperatures, light in weight, and have enough power to run all of the devices. A rechargeable Li-ion battery topped our list for several reasons. Comparably, Li-ion batteries weigh less than other power equivalent batteries[3]. They also do not suffer from the memory effect as other rechargeable batteries can. The Li-ion battery we chose was an 11.1 V found on all-battery.com which has the following characteristics (Table 2).

11.1V Li-Ion Battery	
Voltage	11.1V
Peak Voltage	12.6V
Weight	12oz
Capacity	4400mAh
Max discharge current	2.5A

Table 2

This battery has a built-in IC to prevent the battery from over charging and provides short circuit protection. The total current drawn from the battery with all devices attached is 1.9 A, which gives the total battery life for in flight to be 2.3 hours. This battery was flown in the flight with the temperature sensors and the thermal simulator. A temperature sensor was attached to the battery and the results can be seen in Chart 2.

F. Microcontroller and antenna

The Basic Stamp and the video switching circuit are what control the altitude based camera switching. The Basic Stamp receives NMEA 0183 GPS data from a Garmin 15L and parses the data to read the altitude. The Basic Stamp then makes a decision based on the altitude reading and enables/disables the appropriate 5 V output. Logic 0 (0 V) and logic 1 (5V) are used by the video switching circuit in order to switch between cameras. Since we used three cameras we used logic 0 0 for the camera below 40,000 ft, logic 0 1 for 40,000 to 60,000 ft, and a logic 1 0 for above 60,000 ft. The logic outputs of the basic stamp were directly fed into the video switching circuit.

The Basic Stamp sends a data packet via a TNC connection through a handheld Kenwood TH-D7A/E. The packet sent contains the package's GPS coordinates, speed, heading, altitude, temperature, and which camera is being used.

After much consideration and several different antenna designs the best performing antenna was a 70-cm ground plane antenna (Figure 4). Each element was made out of a metal coat hanger and the center conductor was a copper wire. The ground plane plate was a small thin plate of metal which held everything together. The reason we went with such expendable items is the ability to quickly rebuild the antenna due to impact force the antenna receives when descending from 80,000 feet.

The antenna was designed and tuned to 427.25 MHz, which is one of the four frequencies in which the ATV transmitter transmits. We attached the antenna above a vehicle in freezing cold temperatures and tested the distance we were able to see a video. With no line of sight we were able to recover the video signal from 3.8 miles away.

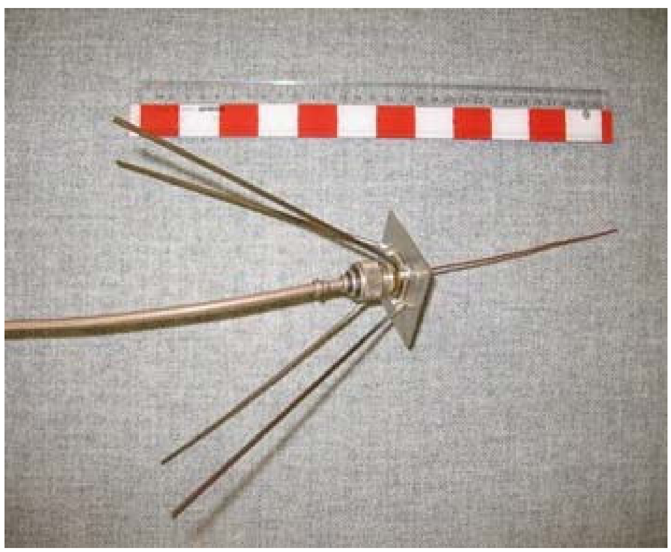


Figure 4

In order to comply with FAA regulations we decided to fly two payloads under one balloon. The top package contained the Basic Stamp and other electrical equipment. The bottom smaller package contained the ATV transmitter, Garmin 15L, GPS overlay board, 11.1 V battery and video switching circuit. Because the Basic Stamp and the video switching circuit were in different packages we had to run the control wires between the packages. The 70-cm ATV antenna and the 2-m APRS antenna were located below the bottom package.

IV. HAB Launch and Results

The flight of the ATV transmission was successful in many aspects and unsuccessful in one part. The unsuccessful part in the experiment had to do with the unsuccessful reception of the video after one minute of launching. We believe this to be a result of the poor performance of the USB TV tuner card along with the receiving antenna. We were not able to securely mount the receiving directional antenna and therefore not able to receive a video signal the entire time. The remainder of the system worked exactly as planned. This was proved through what the PV-500 DVR was able to capture and what we received via the Basic Stamp. On the ascent and descent, the DVR showed successful video switching at 40,000 and 60,000 ft. During the flight the Basic Stamp would send a packet of information once per minute and we noticed the video switching occurred exactly when it was expected. The flight path for the video transmission can be seen in Figure 5.

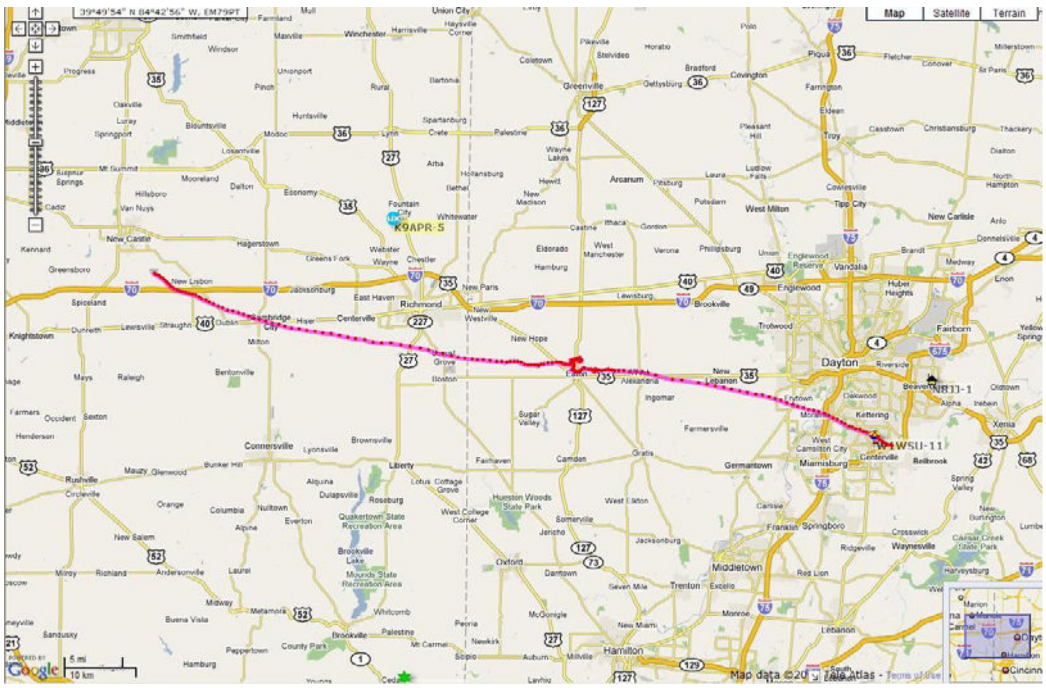


Figure 5 Flight Path of ATV using Google Earth

Future work on the ATV project will consist of designing a better receiving station and the possibility of an ATV downconverter. The downconverter mixes the received signal down to channel 3 or 4 with a 20 to 30 dB gain.

Information about Wright State University's High Altitude Balloon project can be found at <http://www.cs.wright.edu/balloon>.

V. Learning Assessment and Conclusions

While working on this project, students had the opportunity to work with other students from different disciplines such as mechanical engineering and computer engineering. Specifically, an important learning aspect for the students was the effective communication of technical concepts and ideas to peers from different background. During the project, electrical engineering students designed the whole system including circuitry and the triggering mechanisms for different video cameras for the HAB package. This provided a good learning experience to all the participating students. The students were able to communicate and design the system based on various competing constraints such as weight limit, battery power, low temperature operation, power calculation for heating, etc. The most valuable experience students gained from the interdisciplinary project was the development of team work skills required to work in real-world projects, where individual engineers rarely work alone on a project.

The learning outcomes of this project were measured through several means including post-course questionnaires, design documents, midterm reviews, student presentations and question answering sessions for the entire senior design class, course evaluation and final interviews with the chair of the department before the graduation of attending students in this project. Throughout the two-quarter long project, all students learned important lessons that otherwise they would not have the opportunity to learn. Students showed their appreciation of such learning experiences in their feedback to the instructor and senior design project advisors. Specifically, they learned to deal with many mechanical aspects in the project, such as heat transfer calculation, controlling the helium filling speed and amount, reliable and light-weight packaging of the payload, and so on. They also experienced strict real life constraints that they never had the chance to deal with through classroom lectures and laboratories. For instance, the system they designed needed to operate at extremely low temperatures and at very high altitude in near space. Students learned to make performance tradeoffs based on constraints with different priorities. In the course evaluation, students praised this project as "the final piece of the puzzle" that enabled them to integrate the knowledge they had learned from so many engineering courses within one captivating project.

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