Cheap, Open Source and Retrievable Radiosonde

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1. Introduction

1.1 Objective

The objective of this project is to design additional features for a radiosonde and to provide a reproducible, open source design. Radiosondes are launched in over 92 different locations across the United States twice a day, 365 days a year and cost nearly $300 each. Unfortunately, currently these instruments provide no way of being recovered or tracked after their launch, although the device remains operable.

We aim to design a radiosonde with a tracking functionality. For this purpose, we will track it with GPS and the radiosonde launchers will receive GPS coordinates from the device so that the radiosonde may be tracked down to within 15 meters of its actual location. In addition to this, we will add visual and audio aids to help locate the device once it has landed to further narrow down its location that can be triggered remotely.

1.2 Background

Radiosondes are instruments commonly known as “weather balloons”. These instruments are used as in-situ devices to sense and transmit information on pressure, temperature, wind at different altitudes in the atmosphere. This data is used to produce a weather “sounding” which helps forecasters and atmospheric scientists understand the daily weather, the fluid dynamics and thermodynamics of the lower layer of the atmosphere known as the troposphere.

The radiosondes are launched near the surface on meteorological helium balloons. These helium balloons rise up in the troposphere until the height of the tropopause (12 km altitude). Around this height, the pressure inside the balloon is greater than the external pressure and the balloon bursts. The radiosonde descends back to the ground. The radiosondes that land back on the ground may land in areas where they may be retrievable or not. Currently, landed radiosondes found by people are either sold on online websites or put in museums -- the device remains operational, however it is rarely, if ever, used again.

Radiosondes are launched in 92 different locations in the United States. The density of this radiosonde network is limited by the high cost associated with each launch (upwards of $300 each). The current launch-sites do not cover all locations. For example, for Champaign, IL, the closest launch-site is in Lincoln, IL. If this network were denser, the resolution of temperature, pressure and wind data provided to forecasters would increase. Forecasters would be able to make more accurate and timely weather forecasts. This would have a great impact on the prediction of severe weather that could prevent major economic damages as well as the loss of life and overall better and timely preparedness to severe weather disasters that have in previous times resulted in economic losses in the U.S. to the order of millions of dollars.

In addition to this, radiosondes are made of complex design circuitry that is proprietary to the manufacturers of the instrument. If the instrument design were made open source, scientists could use this in-situ instrument to sense and study different variables in the atmosphere and conduct customizable experiments. For example, PM2.5 or carbon-dioxide sensors may be used on the radiosonde to monitor air quality and air-borne particles in the troposphere.

1.3 High-level requirements

1. The radiosonde should feature a GPS tracking device that can provide GPS coordinates with an accuracy of 15 ± 2.5 meters to locate the device.

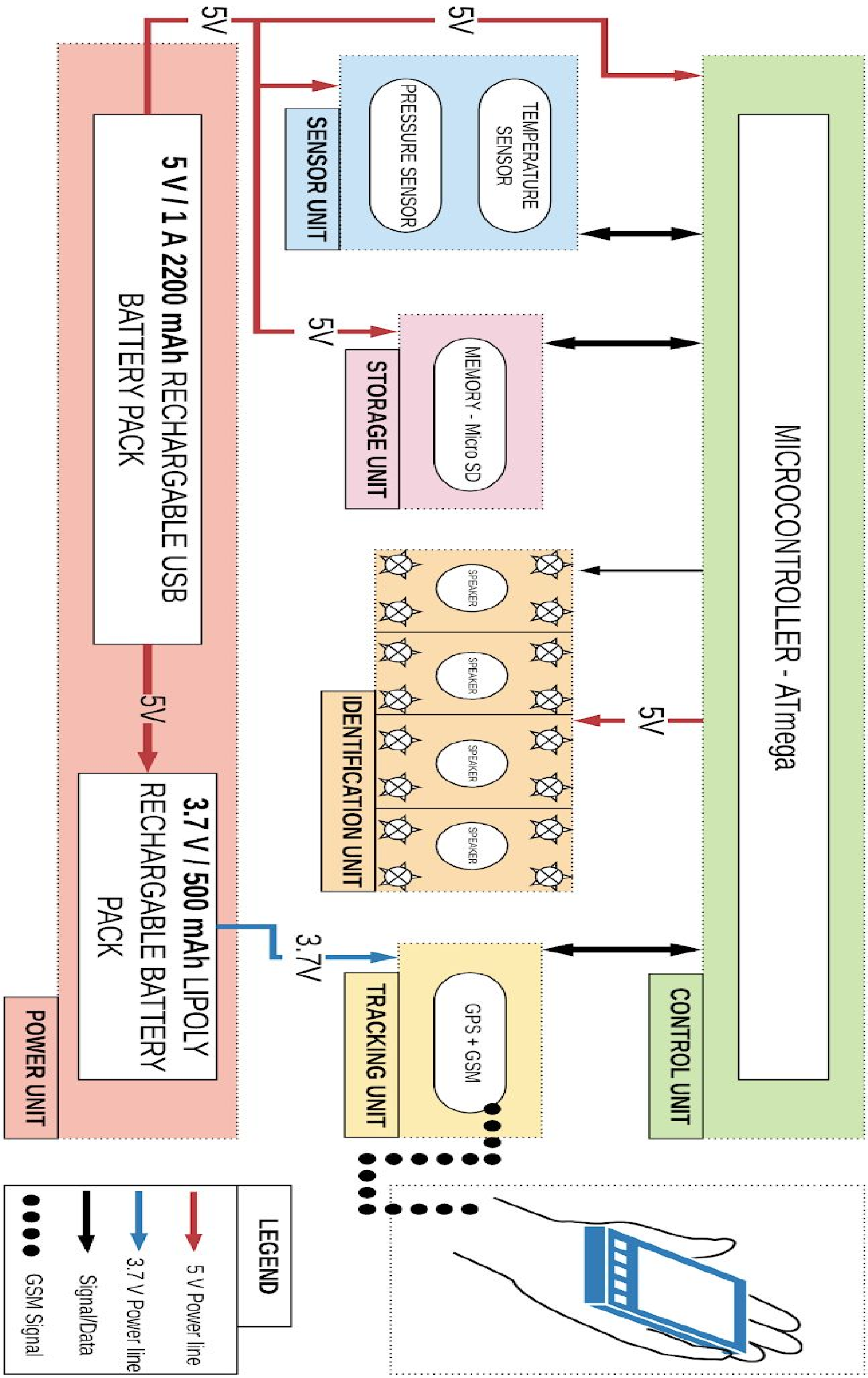
2. The radiosonde should feature additional tracking aids (audio and visual) that help narrow down the location of the device within the specified radial range of error which is 15 ± 2.5 meters. These tracking aids must be triggered remotely.

3. The radiosonde should feature sensors that can measure data with a 15% accuracy, the sensors should measure data that radiosondes would typically be able to measure as in-situ experiment instruments (such as pressure, temperature).

2. Design

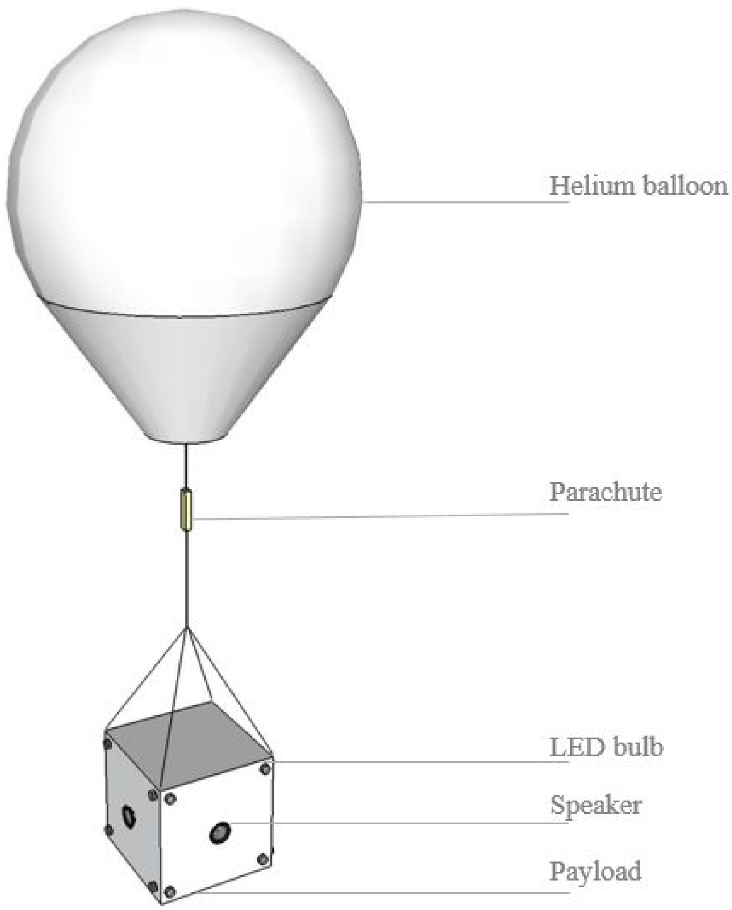
2.1 Block diagram

The overall design comprises of six modular units - Power, Control, Sensor, Tracking, Storage, and Identification. The Power Unit supplies the desired voltages to each of the other five modules. The Control Unit relays data to and from the Sensor, Storage, Tracking, and Identification units. The Sensor Unit houses the Temperature and Pressure sensors which gather the required data that our radiosonde is trying to capture. The Storage Unit stores data collected in the Sensor Unit for the user to access when the sonde is retrieved. The Tracking Unit allows us to locate the sonde through its GPS+GSM module. Lastly, the Identification Unit is our audio-visual module that helps the user find the sonde once close enough. The figure on the following page is a high level block diagram of our design.


MICROCONTROLLER - ATmega
CONTROL UNIT
TEMPERATURE SENSOR
PRESSURE SENSOR
SENSOR UNIT
MEMORY - Micro SD
STORAGE UNIT
SPEAKER
SPEAKER
SPEAKER
SPEAKER
IDENTIFICATION UNIT
GPS + GSM
TRACKING UNIT
5 V / 1 A 2200 mAh RECHARGABLE USB BATTERY PACK
3.7 V / 500 mAh LIPOLY RECHARGABLE BATTERY PACK
POWER UNIT
5V
5V
5V
5V
5V
3.7V
LEGEND
5 V Power line
3.7 V Power line
Signal/Data
GSM Signal

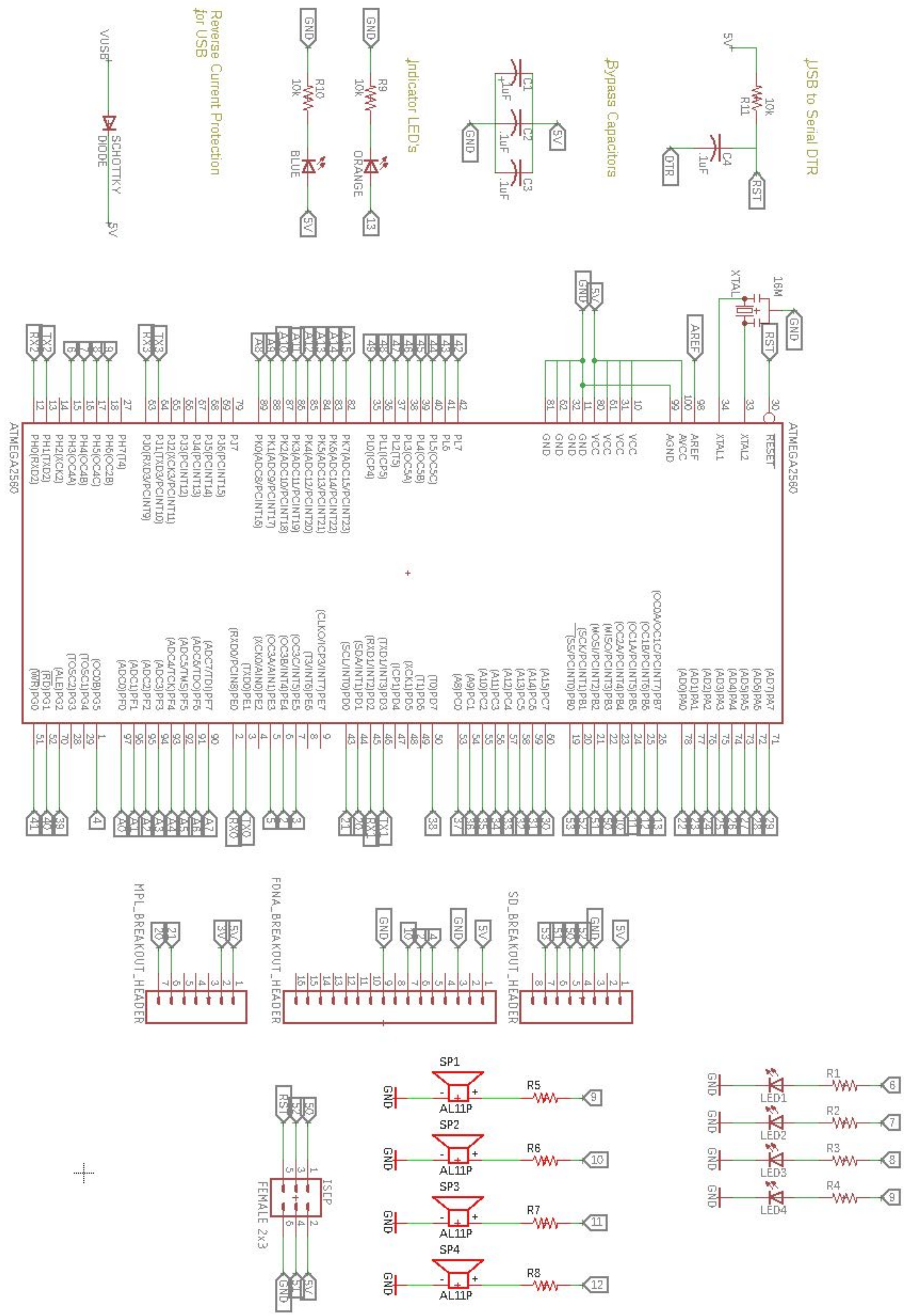
2.2 Physical design

Our sensors and components will all be housed in a styrofoam payload box that has speakers and LEDs on the external faces. Each face has four LEDs (one for each corner) and a small speaker in the middle. The payload will be tied to a Helium balloon and allowed to ascend into the atmosphere for data collection. Tethered in between the balloon and the payload is a parachute which will serve to retard the payload's descent rate and ensure safe landing.



2.3 Block design

Following is an overall circuit schematic of our design. The sections following it (2.3.1 - 2.3.6) will individually explore the design and functionality of each of our six modular units.


USB to Serial DTR
Bypass Capacitors
Indicator LED's
Reverse Current Protection for USB
SCHOTTKY DIODE
ATMEGA2560
MPL_BREAKOUT_HEADER
FONA_BREAKOUT_HEADER
SD_BREAKOUT_HEADER
ISCP
FEMALE 2x3

2.3.1 Control Unit

Functional Overview:
The control unit is comprised of a microcontroller and its supporting components. We will be using the ATMega2560 chip for this project. We have chosen this chip due to its large number of pins as well as its ability to serialy communicated with multiple devices at the same time. The control unit will be responsible for controlling all all of the other modules. It will read in data from the sensor module, write data to the memory module, control the identification module, and send and receive messages from the communication module.

It will accomplish these functions using its pins to directly power the identification module and use various communication protocols to communicate to the sensor, tracking, and memory modules. The microcontroller will use I2C protocol to communicate with the sensor module. The microcontroller will use hardware serial or software serial in conjunction with a UART to interface with the tracking module. The microcontroller will also use SPI to interface with the memory module. In addition the microcontroller will directly control the identification unit using its digital pins.

Requirements & Verifications:

Control Unit (ATmega Microcontroller)		
#	**Requirements**	**Verification**
1	Communicates with the Tracking Unit (GPS+GSM unit) via UART module	The microcontroller will read GPS data from the Tracking Unit and display it on the computer.
2	Communicates with the Storage Unit (SD Card) via I2C protocol	Write dummy values onto the SD card using the microcontroller and check the number of data points and accuracy using an external SD card reader.
3	The microcontroller should trigger the LEDs and Speakers	LED lights must start flashing and speakers must turn ON

2.3.2 Tracking Unit

Functional Overview:
The tracking unit is comprised of a combined GPS and GSM module. The GPS component acquires the GPS location of the device and the GSM component relays that information back to the user. Additionally, the GSM unit receives a trigger signal to turn on the Identification Unit, which it then passes off to the microcontroller.

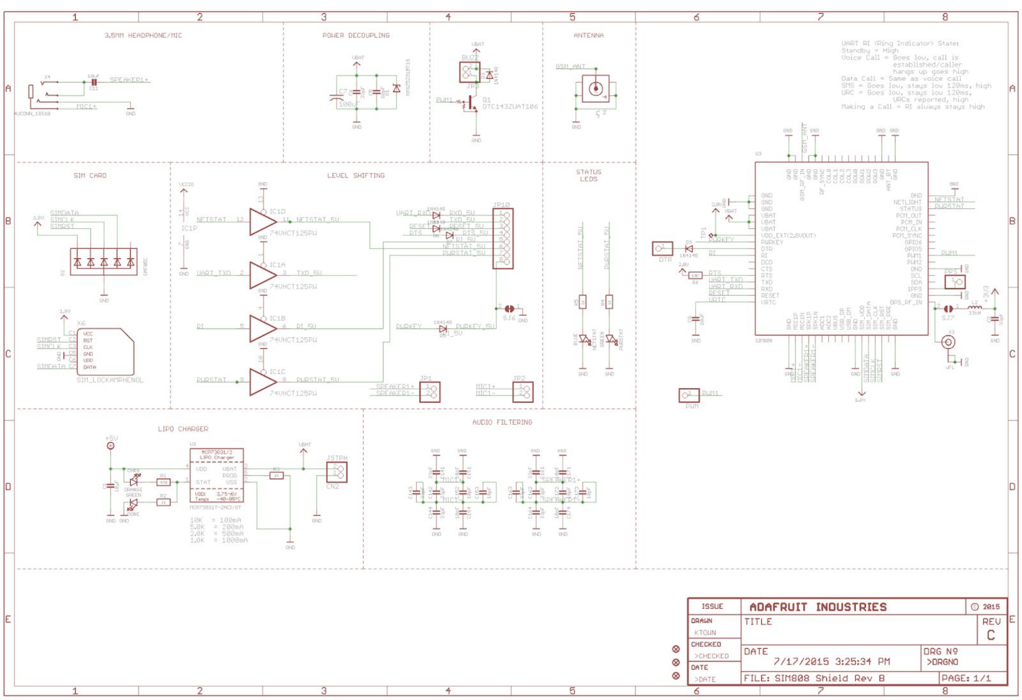
The unit will be comprised of a combined GPS and GSM module in the form of an off the shelf breakout board. It will in addition consist of two different antennas for receiving GPS signals and transmitting and receiving GSM signals. The tracking unit will also require a dedicated battery capable due to current spikes and large power consumption. As the tracking unit communicates using GSM it will only be able to send and receive data when close to the ground. This however is not a problem as we will only need to receive its location and send commands once it has landed.

The GPS will be able to provide a location within 15 ± 2.5 meters once it has landed. Furthermore, the GSM module will be able to be able to send and receive data, once landed, allowing us to receive its location and trigger the identification unit.

Requirements & Verification:

Tracking Unit (GPS+GSM unit)		
#	**Requirements**	**Verification**
1	The unit should indicate location to an accuracy of within 15 ± 2.5 meters measured as a radial-distance from the instrument.	Simulate a tracking test by randomly placing our radiosonde at known locations and measure the distance between our GPS coordinates and its actual location and accuracy in readings. 5 tests will be conducted.
2	The unit should send GPS coordinates from the module to the user via the GSM module	Verify that the received data values are valid and accurate GPS coordinates.
3	The unit should receive the command to trigger LEDs and speakers	The microcontroller will indicate the receipt of trigger signal.

Circuit Schematic:



[3] GPS and GSM Unit Schematic

2.3.3 Power Unit

Functional Overview:
The power unit will be made up of two off the shelf batteries. One of these batteries will be a Lipoly battery used exclusively for the tacking unit. This battery will be directly connected the the module and will not require any other regulation due to existing current and voltage regulation in the board. The second battery will be usb charger module. This will provide five volts for the rest of the device to use. This is possible because all components of our device can accept a five volt power input as they voltage regulating capabilities if necessary. Thus our device will be power off two stable and rechargeable batteries.

Requirements & Verification:

Power Unit		
#	**Requirements**	**Verification**
1	The power unit must provide a voltage of 5.0 ± 0.5 V dc to the Control Unit	Use voltage probe and Oscilloscope to view the ripple across the voltage supplied
2	The power unit must provide a voltage of 5.0 ± 0.5 V dc to the Sensor Unit	Use voltage probe and Oscilloscope to view the ripple across the voltage supplied
3	The power unit must provide a voltage of 5.0 ± 0.5 V dc to the Storage Unit	Use voltage probe and Oscilloscope to view the ripple across the voltage supplied
4	The power unit must provide a voltage of 3.7 ± 0.6 V dc to the Tracking Unit	Use voltage probe and Oscilloscope to view the ripple across the voltage supplied

2.3.4 Sensor Unit

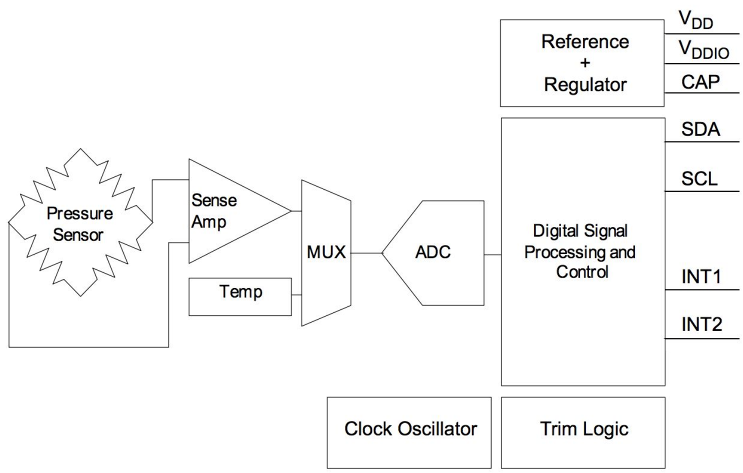
Functional Overview:
The sensor unit contains temperature and pressure. These will allow the unit to collect necessary and typical radiosonde data. These sensors are located on one physical chip which is placed on a breakout board. This module communicates using I2C communication protocol. These sensors will be able to make five measurements per minute. Furthermore, the temperature and pressure sensors will be accurate within ± 4℃ and ± 10 millibar respectively. The sensor module will be placed such that it can freely measure both the temperature and pressure without the interference from the enclosure.

Requirements & Verification:

Sensor Unit		
#	**Requirements**	**Verification**
Temperature Sensor		

1	The temperature sensor should accurately read temperature to ± 4℃	Verify that data is within accuracy as compared to local temperature readings for Champaign, IL, provided by Weather.com.
2	The sensors should collect temperature readings at a rate of 5 samples/minute	Analysis of total flight time and the number of samples collected should be in accordance with the data sampling rate.
Pressure Sensor		
1	The pressure sensor should accurately read pressure to ± 10 millibar	Verify that data is within accuracy as compared to local pressure readings, surface readings from a barometer.
2	The sensors should collect pressure readings at a rate of 5 samples/minute	Analysis of total flight time and the number of samples collected should be in accordance with the data sampling rate.

Circuit Schematic:



[1] Sensor unit schematic

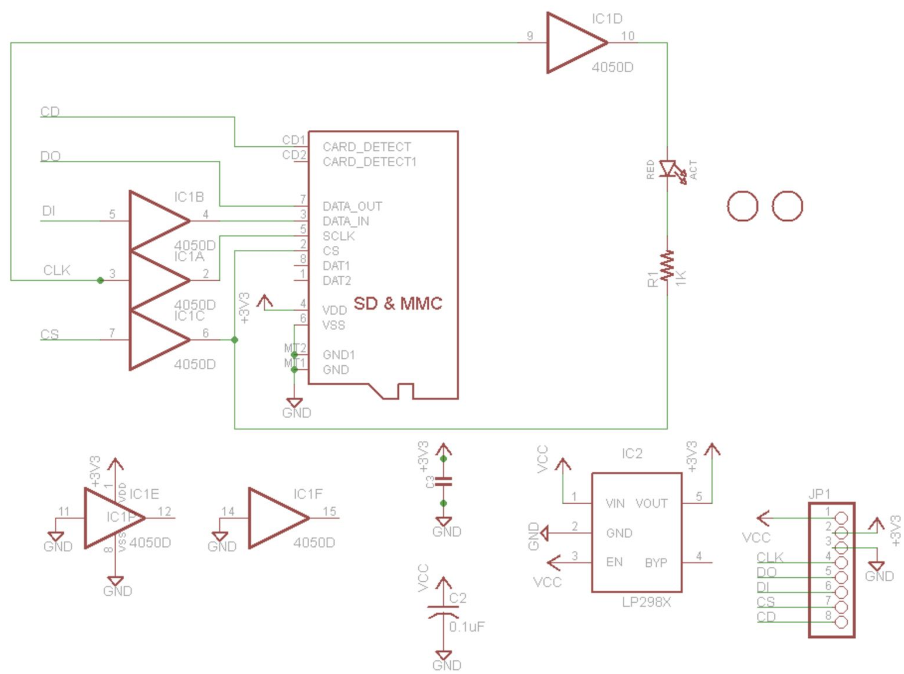
2.3.5 Storage Unit

Functional Overview:
The purpose of the storage unit is to store important data retrieved from the sensors locally. The data will be stored on an SD card, which can be removed and read from without the radiosonde itself. This is helpful not only for testing but also for data collection.
The storage unit will be big enough to store data of four sensors at their refresh rate during the entire flight. The SD card will will be contained on a breakout board which will be directly connected to the control unit. The storage unit will communicate to the control unit over hardware SPI allowing for a stable and fast reading and writing.

Requirements & Verification:

Storage Unit (SD Card)		
#	**Requirements**	**Verification**
1	Store all the data from the sensors without any data loss	Cross check the number of data points collected with the sampling rate of each sensor and the overall flight time.

Circuit Schematic:



[2] Storage Unit Schematic

2.3.6 Identification Unit

Functional Overview:
The identification unit includes a speakers and a LEDs. The purpose of this unit is to add in location of the unit when in close proximity. The unit will receive a command from the control unit to emit a loud noise and a bright light. The LEDs and speakers will be located on four sides of the radiosonde so that light and sound will be projected in all directions. These devices will be directly powered from the control unit unless additional power is needed. If the control unit is unable to provide enough power to ensure identification then simple amps will be used to increase speaker volume and LED brightness where needed.

Requirements & Verification:

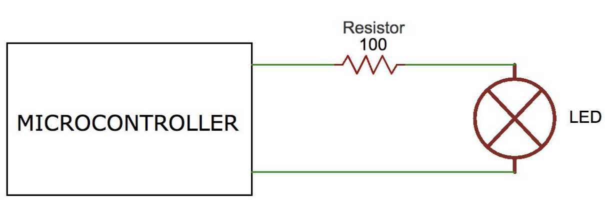
Identification Unit

#	**Requirements**	**Verification**
	Speaker	
1	The speaker on the radiosonde should be audible at the location provided by the GPS module.	Test the radiosonde at varying distances between 0-15 meters from the GPS coordinates provided by the module and test the audibility levels of the sound emitted from the speaker by a simple "audible" or "inaudible" to human ear test.
2	Each of the four speakers should be programmed to beep/tweet at a 0.5 Hz frequency to be identifiable by the human ear.	30 ± 5 beeps per minute, from each speaker, can be counted to check for the frequency of the sound output.
	LED Lights	
1	Each of the sixteen LEDs should be programmed to flash at a 0.5 Hz frequency to be identifiable by the human eye.	30 ± 5 blinks per minute, on each LED, can be counted to check for the frequency of the blinking.

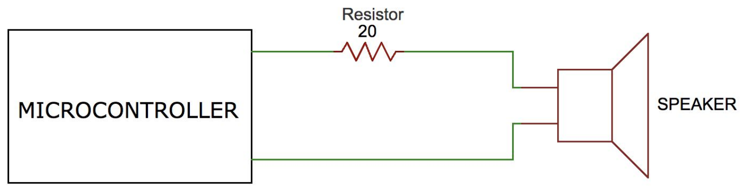
Calculations:

LED	Speaker
Optimal forward voltage = 3.0 V	Optimal input power = 0.25 W
Optimal forward current = 20 mA	Current through 8 ohm speaker = $\sqrt{\frac{0.25\,W}{8\,\Omega}}$ = 0.177 A
Resistance required = $\frac{(5\,V - 3\,V)}{20\,mA} \approx$ **100 Ω**	Voltage across 8 ohm speaker = 0.177 A x 8 Ω = 1.414 V
	Resistance required = $\frac{(5\,V - 1.414\,V)}{0.177\,A} \approx$ **20 Ω**

Circuit Schematics:
1. LED Circuit:



2. Speaker Circuit:



2.4 Tolerance analysis

Through discussions with your TA, identify a critical requirement to explore in great detail. Your analysis of that component will prove that your implementation will meet that requirement. See the Tolerance Analysis guide for further guidance.

3. Cost and Schedule

3.1 Cost analysis

LABOR:
Total Salary = ($/hour) x 2.5 x hours to complete

	Hourly Rate	Hours per week	Weeks to complete	Total Salary
Khushboo Jain	$30/hour	40	15	$45,000
Lake Boddicker	$30/hour	40	15	$45,000
Raunak Barnwal	$30/hour	40	15	$45,000
Total				$135,000

PARTS:

	Description	Manufacturer	Part #	Qty	Cost / unit	Total Cost
USB Battery pack	This is a 5 V / 1 A 2200 mAh rechargeable USB battery pack	PKCELL	5V/1A 2200 mAh USB	1	$14.95	$14.95
Sensor Module	This is a low-cost sensor for barometric pressure and temperature	Freescale Semiconductor	MPL3115A2	1	$9.95	$9.95
GPS + GSM Unit	This is a cellular and GPS tracking module in one. It is capable of location - tracking, voice, & text	Adafruit	FONA 808 Shield	1	$49.95	$49.95
Passive GSM Antenna	This is a tiny antenna (15 mm in length) that will provide a 1 dBi gain	Adafruit	Passive GSM Antenna uFL	1	$3.95	$3.95
Lipoly Battery	This is a small 3.7 V 500 mAh Rechargeable battery	Adafruit	Lipoly/LiIon Battery - 3.7 V 500 mAh	1	$7.95	$7.95
Quad -	This slim, extremely	Adafruit	Quad-Band	1	$2.95	$2.95

Band Antenna	sensitive, antenna boosts the GSM signal to 3 dBi		Antenna - 3dBi uFL			
Micro - controller	This microcontroller is capable of running programed code and interfacing with external devices	Microchip	ATmega2560	1	$14.22	$14.22
SD Card Reader	This is an SD card read / write board	Adafruit	MicroSD card breakout board	1	$7.50	$7.50
LED	Super bright, low wattage, white LEDs	FRE China International	FLR-50T04-HW7	25 pack	$0.278	$6.95
Speaker	Low wattage 1" diameter 8 ohm speaker cone		M2850-8B-0L03R	4	$1.50	$6.00
Total						$124.37

Total cost of project = Total Labor + Total Parts = $135,000 + $124.37 = $135,124.37

3.2 Schedule

Week	Khushboo Jain	Lake Boddicker	Raunak Barnwal
02/18 - 02/24	- Further exploration of ethical and safety considerations of our project. - Oversee the formulation of the design document.	- Finalise circuit schematics for the overall design. - Layout the functional overview of each module for design document.	- Design the power unit and incorporate feedback from MDR into block diagram for design document. - Conduct cost analysis of our project.
02/25 - 03/03	- Submit part order requests and apply to the Leung fund for additional funding	- Begin designing PCB with allowance for feedback from design review	- Assist in the PCB design and compile presentation and documents for review
03/04 - 03/10	- Work on soldering assignment - Run tests on all the ordered components as they come in	- Work on soldering assignment - Finalise PCB design prior to placing PCBway orders	- Work on soldering assignment - Build test circuit for power unit on proto board before PCB order
03/11 - 03/17	- Test all the ordered	- Beginning testing SD	- Finalise power unit

	components to ensure they function as expected and if they need to be replaced	card read/write functionality - Review PCB order and get the order approved in the audit	design and get PCB order approved in the audit - Run tests on lithium battery
03/18 - 03/24	Spring Break		
03/25 - 03/31	- Begin building the physical unit of the sonde - Make incisions for speakers, LEDs, and sensors as needed	- Build and program the microcontroller - Unit test each component and interface through the microcontroller	- Build and test the power unit - Unit test power and voltage to each module of our design
04/01 - 04/07	- Run unit tests on modules in the styrofoam enclosure	- Test and debug circuit with all the parts assembled	- Test and debug circuit with emphasis on power consumption
04/08 - 04/14	- Begin testing our project through trial launches verifying tolerances	- Begin testing our project through trial launches verifying tolerances	- Begin testing our project through trial launches verifying tolerances
04/15 - 04/21	- Make any required changes to physical design based on tests from previous week - Prepare for mock demo with TA	- Make any required changes and calibrate microcontroller based on tests from previous week - Prepare for mock demo with TA	- Make any required changes to power unit and lines based on tests from previous week - Prepare for mock demo with TA
04/22 - 04/28	- Work on final presentation and incorporate feedback from mock presentation	- Work on final presentation and incorporate feedback from mock presentation	- Work on final presentation and incorporate feedback from mock presentation
04/29 - 05/05	- Prepare final paper and fulfill all logistical needs prior to course wind down	- Prepare final paper and fulfill all logistical needs prior to course wind down	- Prepare final paper and fulfill all logistical needs prior to course wind down

4. Discussion of Ethics and Safety

Our project is by and large benign, however there are some safety concerns related to releasing a high-altitude balloon. Such an object can interfere or damage aircraft that happen to be in the same area as the weather balloon. There exist a number of regulations that need to be followed. This includes a Notice to Airmen (NOTAM) [4] that needs to be filed before launching the device with a helium balloon.

For the purposes of our verification, the device may be tethered with string (nylon) and stores all observation data on an internal SD card module, therefore the device poses little threat and is a non-aerial, tethered launch device. If the radiosonde is launched untethered, safety and precaution is advised to developers for aerial devices. In addition to this, if the radiosonde transmits at radio frequency, additional care must be taken to abide by the FCC rules on power and RF transmission [5].

Our design requires the use of a lithium ion battery. Leakage or venting of Li-ion cells will release flammable vapors. Therefore, extra care and precaution is taken while handling as well as designing the implementation of these batteries.

This project is built for the purposes of scientific research and use. We abide by all IEEE code of ethics in completing this project [6].

5. Citations

[1] Adafruit Learning System, "Xtrinsic MPL3115A2 I2C Precision Altimeter," MPL3115A2 datasheet, Dec. 2013. https://cdn-shop.adafruit.com/datasheets/1893_datasheet.pdf

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[4] "Prohibitions, Restrictions and Notices." *FAA seal*, 14 Feb. 2018, www.faa.gov/air_traffic/publications/us_restrictions/

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