Weather Sensor Node Hardware

Author: Conrad Chong

Abstract:
In the Galvin Electricity Initiative, a microgrid is defined as a "small scale version of the central electricity system". Smart microgrids are also referred to as "an ideal way to integrate renewable resources." Renewable energy sources, such as photovoltaic (PV), are intermittent, which raises concern when considering their integration on a large scale. The Renewable Energy and Island Sustainability group (REIS) is proposing the design, implementation, and assessment of a smart microgrid which provides a dynamic energy management plan based on sensing, modeling, and analysis. This project is focused on the development of weather sensor networks, a critical component in the smart microgrid infrastructure.

The student team plans to design the hardware and software for a fourth generation weather sensor network. Verification systems will be implemented on each platform to expedite the fabrication and review process. Once complete, nodes will be placed in various locations throughout the University of Hawaii at Manoa campus. These nodes will measure various types of environmental data, including solar irradiation, temperature, and humidity. The outcome of this project is the production of datasets which can be analyzed to help mitigate the University of Hawai`i at Manoa's dependence on non-renewable energy.

Table of Contents

1 Introduction

The goal of this project is to improve the past design, Apple, the first generation of sensor nodes. Many problems were needed to be addressed. These problems included the accessibility to inside components of the sensor node. The weather seal needed to be broken when the sensor node needed to be reprogrammed. The power consumption of the sensor node also needed to be extended by a significant amount. From testing of Apple, the sensor node would die under long periods without sunlight. The entire sensor node needed to be more efficient to last longer without sunlight. Rapid prototyping also needed to be conducted so a new design for this generation must be used. The solution to this problem included using a more modular design which separates the sensor node into two PCB's. This included the main board which has the microcontroller and transceiver. The other board is the sensor board which contains the various sensors and user interface. The sensor board contains the components needed to be accessed easily for easy programming and debugging. This modular design leads to a faster build time for the sensor node. This report also includes various design decisions used to be more efficient and reduce current draw of the box. This report is organized into three subsystems which will be discussed individually. Section 2 is the main board subsystem which includes the transceiver and microcontroller. Section 3 includes the Sensor Board subsystem which contains all of the sensors and connections for programming and debugging. Section 4 includes the Electrical Power System of the board which include the solar charger and power consumption of the board. Section 5 contains the conclusion.

2 Main Board

The Main Board subsystem is responsible for taking the data coming from the Sensor board and collaborating the data for transmission. The main board includes the following components: the transceiver and the Atmega328p. This subsystem also includes the communication between the transceiver and Atmega328p and between the Sensor board and the Atmega328p. These systems will be discussed in detail for each component of the main board. The components include the communication between transceiver, Xbee, the Atmega328p, and the sensor board which is covered in the sensor board section of the paper and is discussed in 2.1. The design decisions made for the Cranberry design is discussed in 2.2. This section includes the improvements on usage of the microcontroller, the Atmega328p, and the use of smaller components. The future implementations of this particular design are also discussed in 2.3. This section includes the future tests needed to be done for the Cranberry design.

2.1 Communications between Components

One of the obvious communications needed is between Atmega328p and the Xbee. The lines needed are standard UART lines which are connected to the standard UART lines according to the Atmega328p datasheet[4]. Since the Arduino is no longer used, another way of programming is needed. An ISP Programmer (Atmel 6) is used to program the board which requires use of the lines MISO, MOSI, SCK which is SPI communications. From the new changes of Cranberry, all sensors now communicate through I2C for future sensor board designs. Since I2C can support many components, a totally new sensor board may be paired with the main board. This would mean that the main board would be the same, thus making the design modular.

2.2 Design Decisions

Many changes have been made from the last revision, Apple, involving the main board. The main change would be the use of the Atmega328p QFN instead of using the Arduino Uno. The reason for this is since that the Arduino Uno took up too much space. Since one of the goals were to reduce space, the use of QFN chip was to needed to reduce space. Another reason for this change was also since the Arduino drew too much current to fit our design, which is later discussed in detail in the Electrical Power Systems section. Another important implementation is the reduction of clock rate from 16MHz to 8MHz. This will improve the current draw from the Atmega328p. Standard bus lines were also needed to communicate with the sensor board. Other design decisions were to keep all components that needed to be weather sealed on this board. These components included the Xbee and the entire Electrical Power System. From the flaws of the last iterations, the main board was created to be sealed without the degradation from the exposure to the elements.

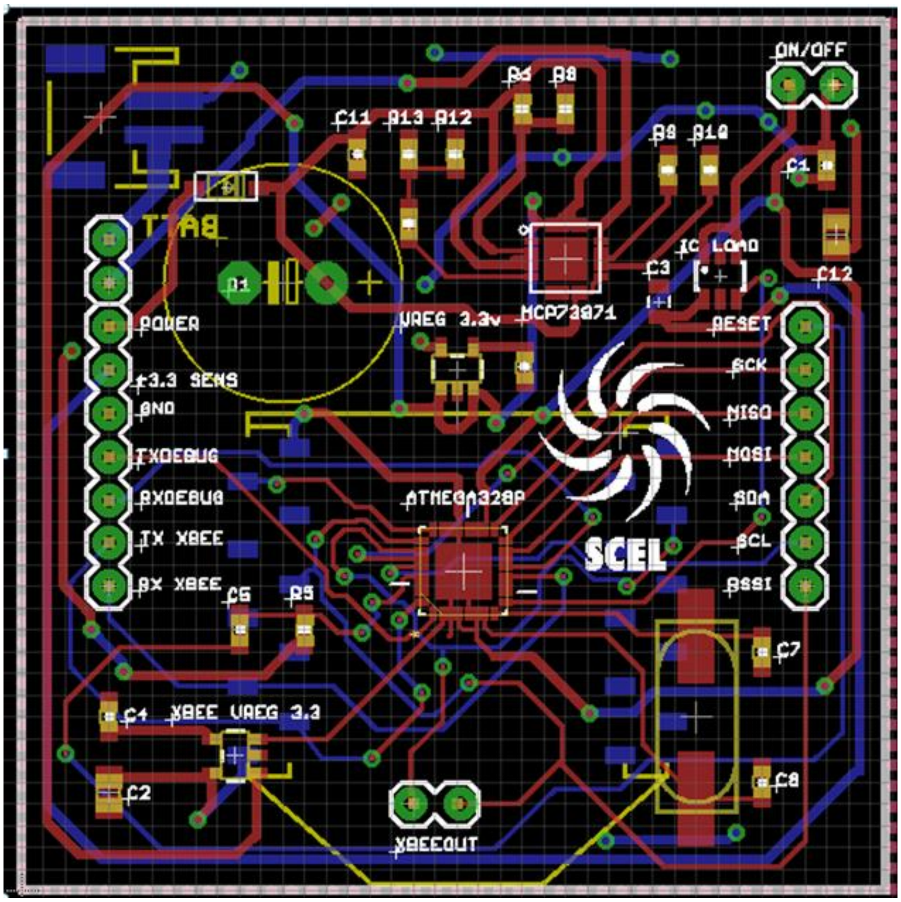


Figure 1 Main Board on EagleCad

2.3 Future Implementations

The future goals of this project include conducting a number tests to confirm resolve of problems of the last design, Apple. Future implementations for this design could be shrinkage of the board to around 1.5’x1.5’ to reduce amount of PCB needed thus reducing cost for manufacturing of many boards which is the main goal of the general scope of the project. From the figure 1 above, one can see that many of the traces can be compressed together for a more sleek design. Also, if the board is reduced in size then the housing can also use less material, which leads to more rapid prototyping since the 3D printer used takes around 9 hours to print the current design for the housing. Testing also can be done so that a better transceiver may be used instead of the Xbee. A longer range transceiver is needed to be researched so that the mesh network can be better implemented. Another test that could be done is to test the mesh network so that the range of the Xbee can be recorded along. The reliability when using a long range transmission is needed to be tested so that loss of data does not occur. Since putting onto various buildings on campus is the recent goal of this project, distances and lines of sight is needed to be calculated so that the mesh network can be implemented to have efficient network of sensor nodes that collect weather data throughout campus. The current design, Cranberry, is also needed to be weather tested so that each node can last throughout the various weather conditions of Manoa. This includes a water tight design to reduce the effect of rusting in the system. These tests and implementations are to be done in the upcoming semester and beyond. As design is improved and debugged, Cranberry is used to replace the previous design, Apple. The improvements should increase the length that the sensor node can last.

3 Sensor Board

The second board is called the sensor board which holds all the sensors and connections to the outside components. These outside components include the solar irradiance sensor and the solar panel. The sensors included in this design are the solar irradiance sensor, humidity sensor, temperature sensor and the barometer (pressure sensor). The design decisions, problems encountered for this PCB and sensors used will be discussed in this section.

3.1 Problems

[5]The main difficulty for this subsystem was making the parts in EagleCad. This included inspecting the datasheet for each component such as the 16bit ADC which has a

MSOP10 footprint that is not currently on the original Eagle library. The datasheet included the measurements for the component. The footprint was made to exact specification so that when soldering the component, the IC will fit and not cause a short. To test each footprint, it was printed to a 1-to-1 scale on paper. The IC was placed and inspected to see that the pad for the component would fit well onto to the board. If the footprint was not correct, it would be readjusted so that it would sit properly onto the board. Once this was tested, a symbol was created such as the one shown below in figure 2. As shown below, all pins are labeled correctly so that, during the schematic process, can be properly connected to the right parts on the board. This included the Ground and Power connections. This process is important so each component may sit properly on the board and make it easier to rapidly prototype each sensor node.

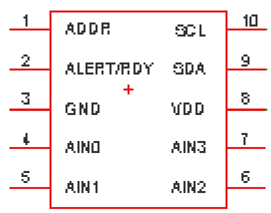


Figure 2 Example of Symbol in EagleCad

3.2 Design Decisions

To move forward with the decision to make this design more modular, the IC's were to be put on the same board away from the main board. The idea of this board was to be able to be replaced without replacing the main board. This board was also designed to transfer readings through purely I2C. The reason for this decision was also for the modularity of the design since the use of the standard bus line allows for a different board to be designed even if the main board is used.

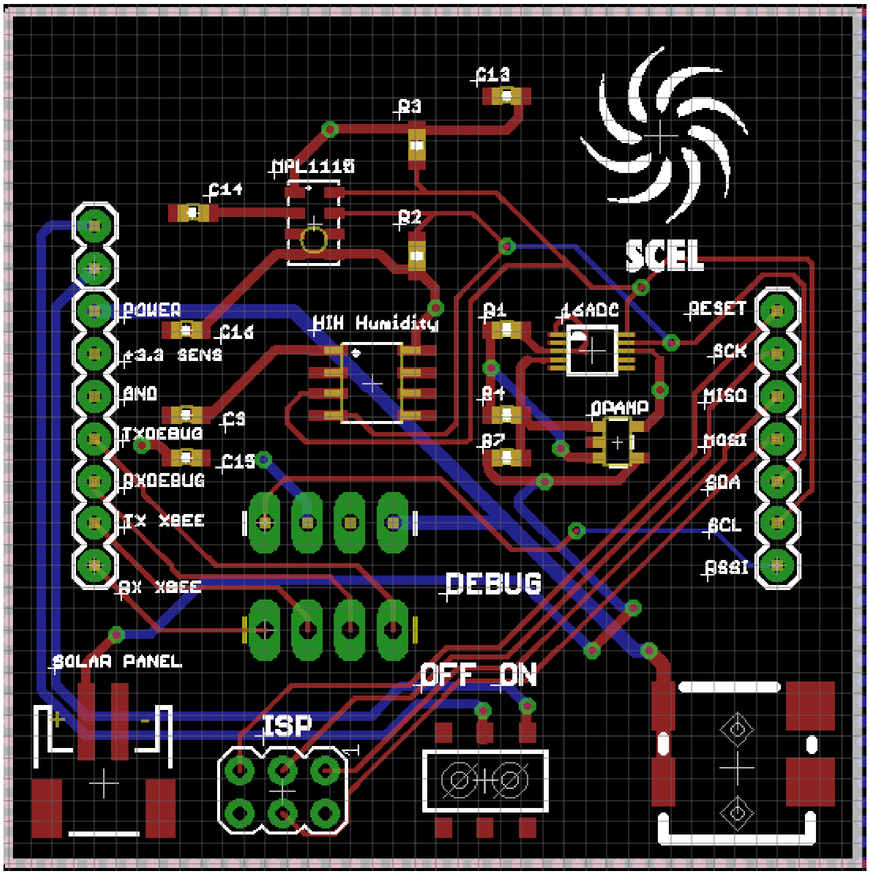
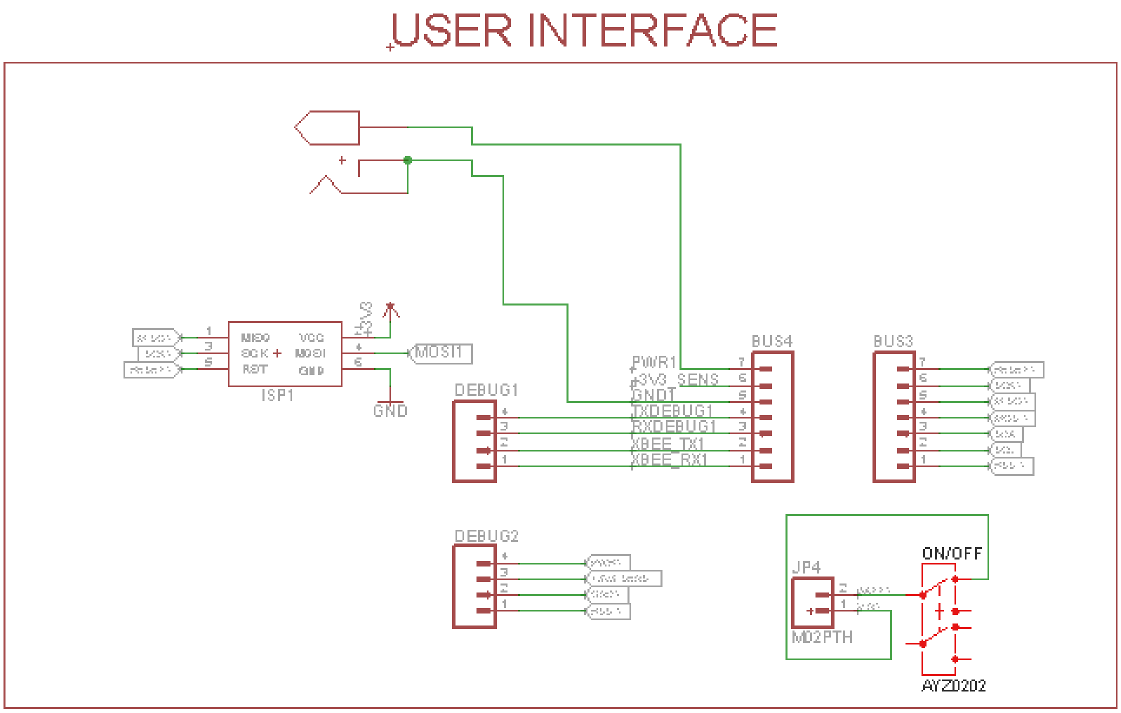


Figure 3 Sensor Board in EagleCad

An important problem needed to be resolved was the accessibility of debug lines for the programmers of the board. Apple was hard to debug since all the programming and debug lines were enclosed into the box. The ability to access these lines in the next revision, Cranberry, was an important design decision. As shown in figure 3, the ISP Programming lines are on the bottom of the board which makes it easy to program the board without taking apart the box. Also, Debug lines are located on this board so that many things may be tested such as the strength of the Xbee and if transmission of a packet is occurring. The solar panel is also connected to this section of the board as the solar panel is connected on the outside of the board. A DCJACK 1.3mm connector is used to easily connect the solar panel. An electromechanical switch is used to turn off the entire sensor module if a hard reset is needed to be done. Since the solar irradiance sensor is the most important, a 2-JST connector is used so that the connector will no wear out or be ripped out from the pad. The solar irradiance sensor is also outside the housing of the sensor node. For easy accessibility, the solar sensor is connected on the bottom half also to ease the connecting and disconnecting of the solar irradiance sensor. As this part of the board is easily accessible from outside of the housing of the sensor module, these decisions will shorten the time to reprogram the sensor module since the sensor node will not be needed to be deconstructed.



3.3 Sensors

The sensors implemented in this design are the solar irradiance, barometer and humidity sensor. In this section, each sensor will be discussed and decision for use of each sensor. As touched upon in the main board section, all of the sensors use the I2C bus for modularity. The sensors used for the board use small packages to fit into the 2’ x 2’ PCB border. The barometer will be first discussed.

The Barometer is an instrument to measure atmospheric pressure used for forecasting. The barometer used an I2C interface which is different from the Barometer from the Apple design. From this sensor, low current consumption is used of 5 uA during active mode. Accuracy of the pressure is +- 1kPa which is good for our applications of this project. Another important factor to this IC is the small form factor which is 2.65mm x 4.65mm. [6] The importance of this is to save space on the board since the board must fit on a 2'x 2' PCB. The schematic for this component is shown below in figure 4.

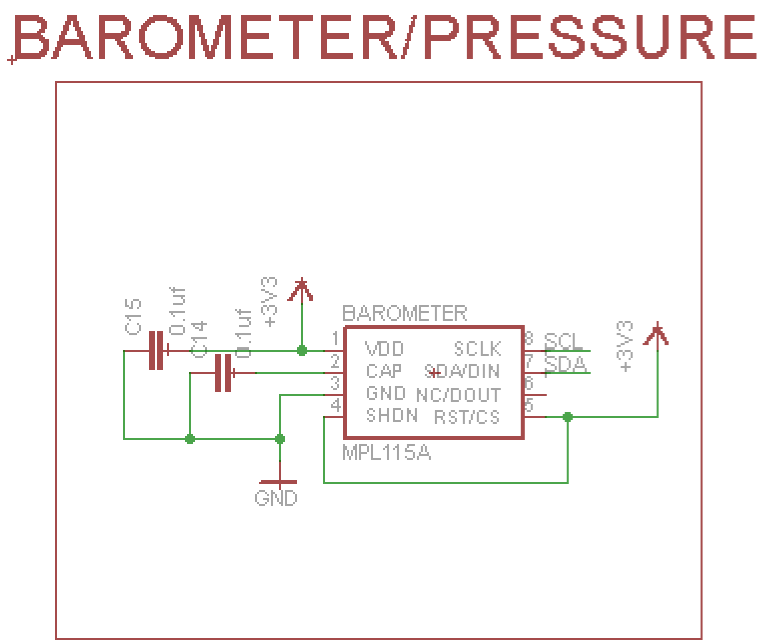


Figure 4 Schematic of Barometer

The HIH Humidity sensor measures both humidity and temperature which reduces the number of traces and components needed for both sensors. [7] The performance include a +- 4.5% RH accuracy which is the humidity performance. This has a good performance for the applications of the project. The temperature sensor part of the IC has a +- 1.0 degree C accuracy. The output for this sensor can be either a digital I2C or SPI. For this application, the I2C bus is used since all the communication between the sensors use that bus as shown below in figure 5. The sensor also had a -40 degree C to 100 degree C operating temperature range which is good for applications as the weather on O'ahu is well within that range. To fit the form factor, the footprint of this component is 4.9mm x 6.0 mm. The schematic is also shown below in figure 5.

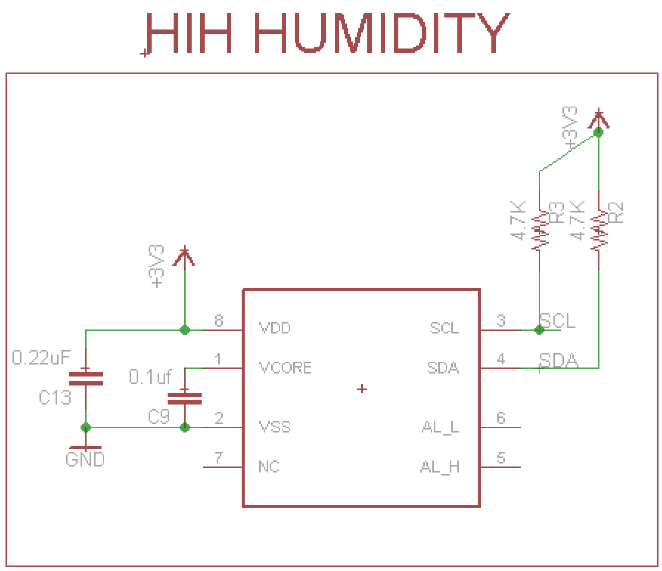


Figure 4 Schematic of Humidity Sensor

The most important sensor is the solar irradiance sensor. Two choices for this sensor are available. These include the apogee or the sensor in which Jesse built. For this design, both sensor may be used by either connecting or not connecting the jumper shown below in figure 5. R7 can be connecting or disconnected depending on which sensor is used. If the jumper is used, the apogee will be used as the non-inverting amplifier will be bypassed. If the jumper is not used the sensor Jesse researched will be used since the output of the sensor must be amplified using a non-inverting amplifier set up also shown below in figure 5. Since both sensors use an analog signal from 0V to 5V, a 16bit ADC is used to convert the analog signal to digital. The schematic for this particular sensor is shown below in figure 5.

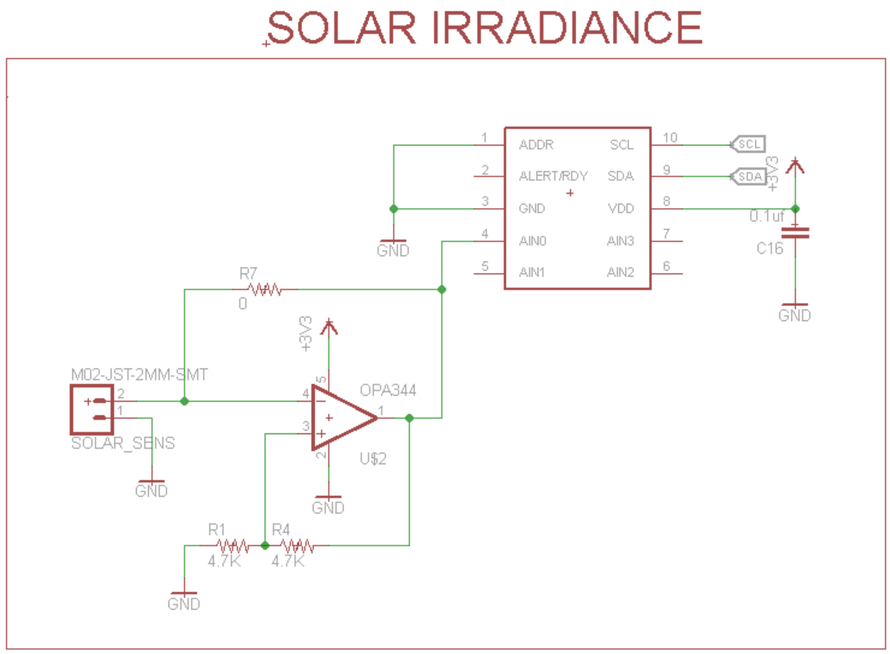


Figure 5 Schematic of Barometer

4 Electrical Power Systems

The Electrical Power Systems subsystem is responsible to distribute sufficient power to all of the electrical components on the weather box. The importance of an efficient power system is important to keep each box running as long as possible while still sending information to the server. The objective for this subsystem is to be capable of lasting at least three days without charging. This means that certain modifications must be made from Apple to reduce current draw of the module to reduce current draw. This includes switching from using an Arduino Uno to using the atmega328p which makes reduces current draw by lowering the required supply voltage from 5V to 3.3V. This will be explained later in this section. The battery was also upgraded from a 6600mAh battery to 15600 mAh battery which increases the time which the module is able to collect and transmit data significantly. The increase in capacity is important since from data from previous iteration, Apple, has shown that the battery charges to max capacity during a sunny day at around noon. This will significantly increase the time a module will be able to collect and transmit data, which results in more accurate data transmitted to server.

4.1 Power Budget

To better implement a more efficient design in this iteration of Cranberry, a new power budget is needed to justify certain power saving decisions. This information justifies what components are needed to turn off under low battery conditions. The data sheets of each component were used to find the average current draw of each component of the Cranberry sensor node. From the power budget calculated below in figure 6, the highest current draw comes from transmission of the Xbee. This gave the idea to be able control the XBee individually since it has a significantly higher current draw than any other component.

Component	HIH Humidity	Barometer	Solar Irradiance	Atmega328p	Xbee
Max Current draw	1uA	5uA	0(self powered)	5mA	215mA

Figure 6 Power Budget

4.2 Voltage Regulation

The change from using 3.3V and 5V supply voltage to strictly 3.3V is implemented in this iteration (Cranberry). Some changes from Apple include more control of the power system through the microcontroller. The same 3.3V regulator is used which has an efficiency of 92%[2]. 2 voltage regulators are used which are used for the Xbee and the rest of module respectively. This decision was made since was made so that the Xbee can easily be turned off from the microcontroller since it draws the most current. An IC-Switch is also used to turn off the sensors for the case the module must save battery from lack of sunlight.

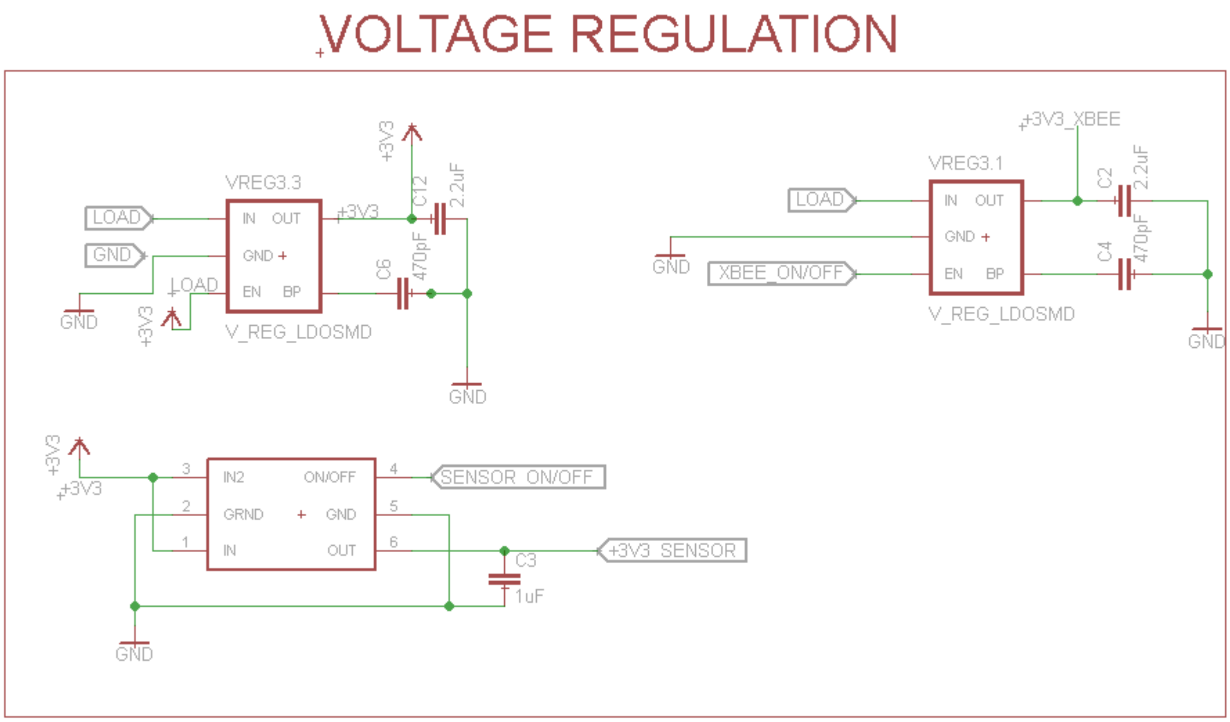


Figure 7 Schematic of Voltage Regulation

4.3 Solar Charger

[1]The design for the solar charger is not a true Max Power Point Tracker (MPPT). The reason for this is noted in this section. The way MPPT works is by tracking the voltage and current to maximize the total power which is the product of the voltage and current. The way MPPT works is to have DC/DC converters but instead a linear converter is used to track the power from the solar panel. This can be described in figure 8 below. The green lines show the I-V curve of the panel for a given light condition. As the amount of sunlight increases, the amount of current drawn is also increases. The red line shows the optimal DC/DC conversion to achieve maximum power.

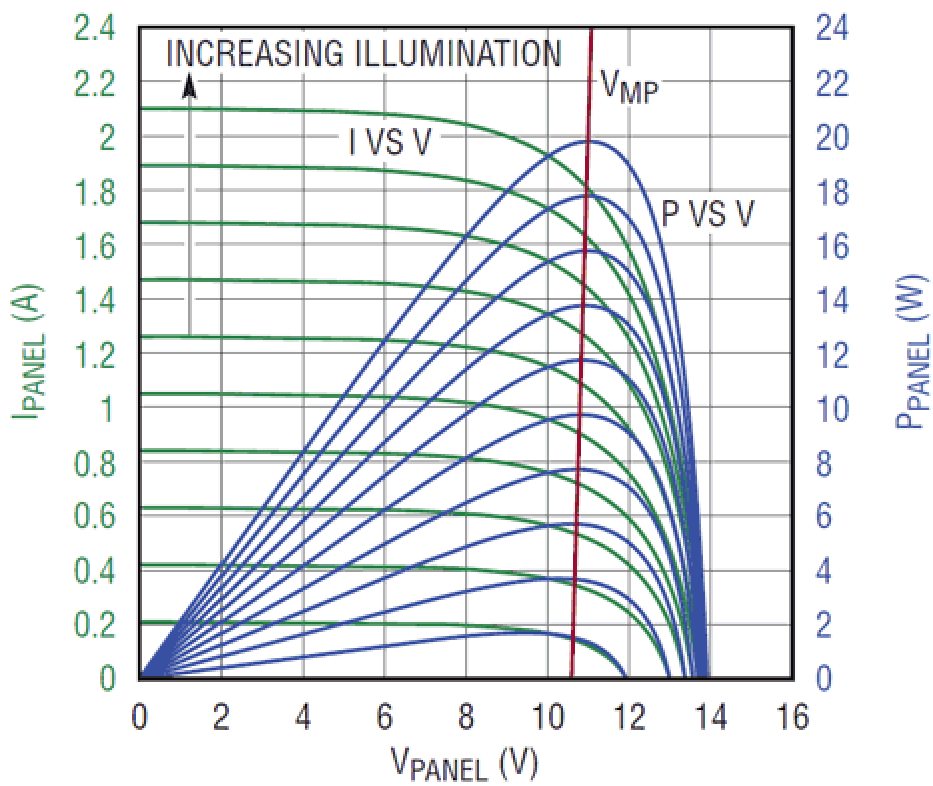


Figure 8 Illustration of Max Power Point Tracking

The reason that this is not implemented is for a few reasons. This includes that the DC/DC converter is expensive and increases the solar charger cost by 2. For the solar panel used which is 6W, the efficiency does not increase by a large enough factor to justify the increase in cost to the overall design. The efficiency increases only by 30%. The cost was better used to increasing the solar panel size from the Apple design. For the implementation of this design, the adafruit solar lipoly charger was referenced. For this we used MCP73871 which uses Voltage Proportional Charge Control (VPCC). This chip sets the battery voltage to 4.5V which is the max amount of voltage the battery we use can take. We also set the max amount of current the battery can take to 1A by setting the resistors shown in figure 9.

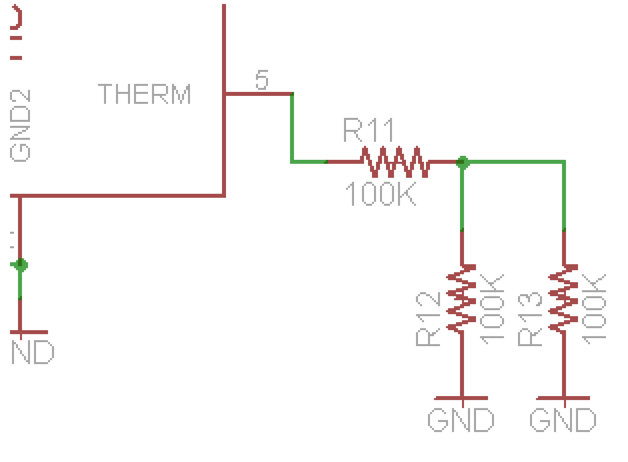


Figure 9 Resistors to Change Max Current

The overall design for this fits the specifications to achieve the max amount of power for the solar panel while maintaining a reasonable amount of cost. The switch from using a breakout board to soldering the individual components reduces cost from $17.50 to $5.64 which is a substantial reduction in cost. A diode is also used to prevent from draining back into the panel. Another reason to implement this design is to save space on the pcb. Since the headers on the breakout board take up room, the implementation of this design saves space. There is a need for small components because of the 2'x2' restriction on each board. A way the design was improved was the use of 0603 footprint compared to the 0805 footprint for various capacitors. The use of headers were also reduced to save space on the Cranberry design.

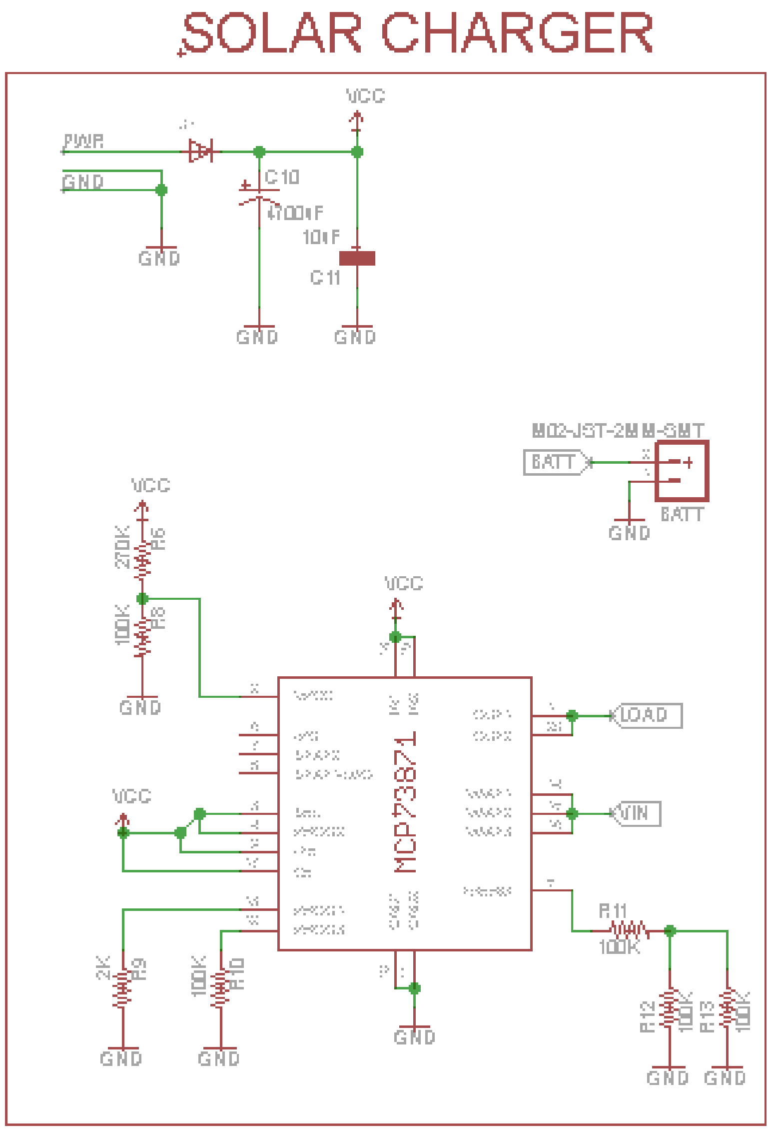


Figure 10 Solar Charging Circuit

4.4 Design

The main focus for the design of the Electrical Power System was to be as efficient as possible. This included the use of many different components to prolong the lifespan of the sensor node. One of these components was the use of another voltage regulator for the Xbee. The transceiver is the main current draw component of 200mA during transmission. If the sensor node must save power due to lack of sunlight, then the microcontroller is able to turn of the Xbee completely which would extend the life of the box until the solar panel is able to charge the circuit again. Also, the inclusion of an IC-switch to turn off the entire sensor board by using the Atmega328p was an important option to also extend the life of the battery. Turning off the sensor board and the Xbee will save power, since the only component powered is the Atmega328p. These power system design components will enable the sensor node to last through days without sunlight. The lifespan of the node was an important goal of this revision. The changes included the following: use of 3.3V exclusively, voltage regulator for Xbee, and ability to turn off sensor for power saving.

Another important focus of this design was the ability to save space. The design of the Electrical Power System also solved this problem. The use of through hole components were kept to a minimum. Surface mount components allow for a more compact design. The adafruit solar charger breakout used in previous designs was implemented into the design. The conversion of using the breakout board saved space since the use of unnecessary headers were excluded from the design.

4.5 Testing

One of the main problems of the last design, Apple, was that the board was not able to last without sunlight. To quantify this problem, we had power testing done in the lab. Estimates of the improvements of the new sensor node, Cranberry were also necessary to have an idea of how long the node will last over a long term of gathering data. Power testing was done through using a current test done in the lab. The purpose of this test is to simulate the current drain done on the battery. This test simulates the case that the node is not charging to find out how long the battery will last. In figure 11. shown below we can see that the board will last around 3.8 days without using the sleep feature of the sensor node. If the sensor node is below a certain threshold, it will go into a power save mode which would increase the lifespan of the sensor node significantly. This test was done with the lower capacity battery of 6600mAh. If the higher capacity battery is used, the sensor node should last much longer since the capacity of the battery is 15600mAh. Shown below in figure 11, the old revision, Apple, is able to last around short of one whole day without sunlight which caused the problem the sensor node running out of battery. This test concludes that with the power saving features of the new revision, Cranberry, will last a significant longer time without going into power saving mode. From this graph, one can see that the box should be able to last at least 457% longer from the changes implemented in the new design. This test is an insight into how long the battery should last without sunlight under the new design of Cranberry.

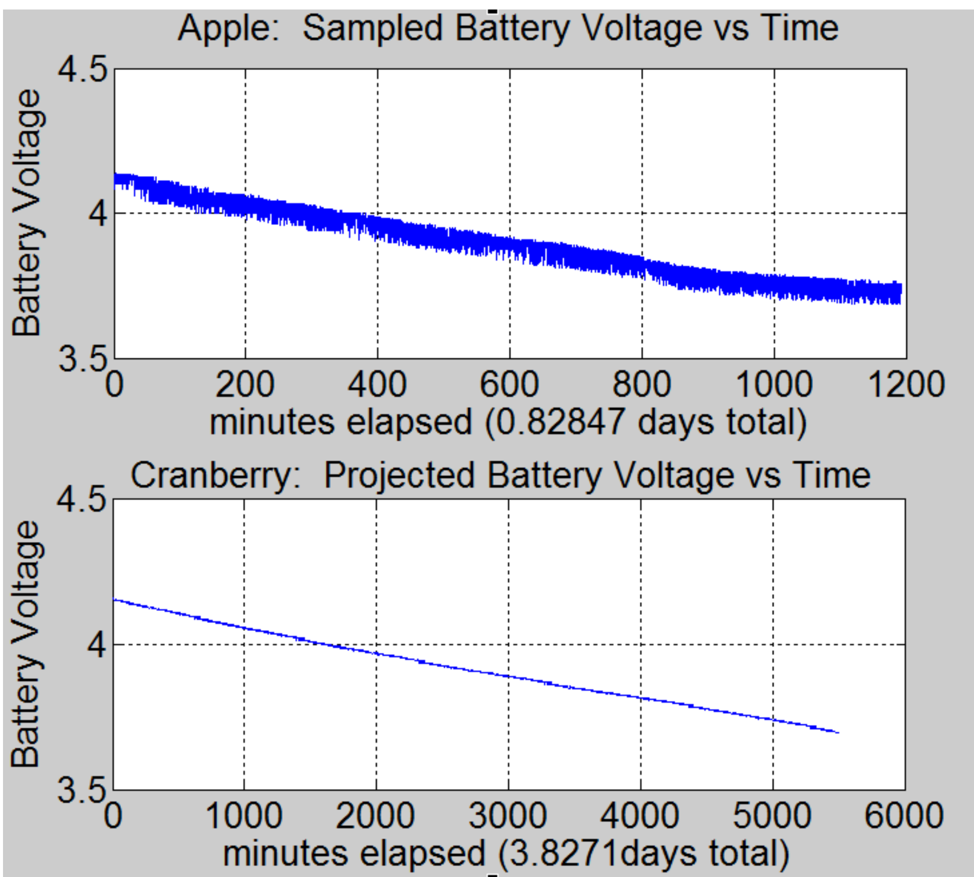


Figure 11 Projected Battery Voltage vs Time

4.6 Future Implementations

For future implementations of this node, some changes could be made to improve up time of each box. This includes using a dc-dc converter in replacement of a voltage regulator. This would increase the 92% efficiency to around 94%[3]. This would be important to the sensor module since the constant save of power would lead to more up time of the module. Another possibility would be a larger solar panel. This would increase the rate in which the node charges in limited sunlight. These changes would be important to longevity of the node. The reason why each node must last for a sustained amount of time is for two reasons. One is the goal of this project to have many nodes across campus. Some rooftops may have a hard time accessing for security reasons. The node must last through days without sunlight or risk losing all data from that area.

5 Conclusion

The new generation of sensor nodes improve on many of the aspects the previous. This includes the use of more efficient components which reduce the current draw by a significant amount. This design is modular which makes it easier to test each subsystem individually. Also because of the modular design, the main board or sensor board can be developed individually by the use of the standard bus line. Also many of the components needed to be accessed easily or now accessible on the sensor board. This design improved on many flaws that Apple had with efficiency and accessibility. Overall, this improved on the design which led to more compact and modular design.

References

1. “USB, DC & Solar Lipoly Charger” Adafruit 2011, <https://learn.adafruit.com/usb-dc-and-solar-lipoly-charger/design-notes>
2. “MIC5219” Micrel 2010, <http://www.digikey.com/product-detail/en/MIC5219-3.3YM5%20TR/576-1281-1-ND/771902>
3. “LTC1174” Linear Technology, < http://www.linear.com/product/LTC1174>
4. “Atmel 8bit AVR Microcontroller” Atmel, <http://www.atmel.com/images/atmel-8271-8-bit-avr-microcontroller-atmega48a-48pa-88a-88pa-168a-168pa-328-328p_datasheet.pdf>
5. “Lecture 8 – Eagle:Schematics” Sparkfun June 2008, <https://www.sparkfun.com/tutorials/108>
6. “MPL115A2” Freescale, <http://www.freescale.com/files/sensors/doc/data_sheet/MPL115A2.pdf>
7. “Honeywell Sensing Humidicon” Honeywell, < http://sensing.honeywell.com/honeywell-sensing-humidicon-hih6000-series-product-sheet-009073-6-enq.pdf>