Solar Panel Monitor System

Group 2

Benjamin Brindle
Devin McLean
Robert Parish

Table of Contents

Section 1: Definition

Executive Summary

Solar Arrays, a heated topic in the energy industry, have many applications as the price per watt has come to a more reasonable level. Power companies and residential homes have become increasingly more interested in installing photovoltaic arrays as a way to become more carbon neutral or "Green". Though they have their advantages, they also have some short falls. As the technology is now becoming more affordable, the use of these has become more widespread; and with use the problems have become apparent. One of the major problems is knowing when a singular solar cell or photovoltaic cell has stopped functioning, which sometimes greatly affects the output of the array. Monitoring each string of cells would be a great way to solve this problem.

We propose building a portable wireless solar power monitoring system with remote capabilities. The main objective is to produce a solar power station that collects and stores energy for its own use and powers any microcontroller needed for monitoring, while still producing energy for other uses. It needs to run autonomously but still have the infrastructure to be monitored and controlled remotely in real time, when necessary. A prototype of this nature would consist of one solar array and a least one microcontroller. Ideally, we would employ a wireless protocol to monitor/control remotely any and all aspects of the devices. As large arrays have hundreds of panels, a wired solution would be messy and time consuming. The uses for this device could be adapted for large and/or small arrays. Applications for data retrieval will also be necessary.

This requires a two part solution, a small device to be attached to each solar panel string and a base station to receive communications from the small devices.

The requirements for the small device would be to: only use small amount of power from a singular string of solar panels, store enough power to power the device for a limited time if one of the panels fail, transmit some sort of signal wirelessly to the base station, and be inexpensive and mass producible. These small devices would be placed on every solar panel string so that large array setups are inexpensive and mass producible.

The base station would ideally be placed with the power management system for the array. The requirements for it would be: store enough energy to be monitor 24 hours a day (even when it is dark), have some kind of connection to a network (private network or the Internet), serve data in a form that can be viewed via any device with a web browser, receive data from the small devices and interpret it to meaningful data. It would need a more powerful wireless system as the small devices will not be able to transmit large distances.

Motivation

Our Senior Design group consists of three students: Robbie Parrish (EE), Benjamin Brindle (EE), and Devin McLean (CpE). The group formed on the first day of class and made the commitment to try and find a sponsor to pick up the financial burden associated with Senior Design.   It was then that QuickBeam Energy made their power point presentation and we decided to pursue their offer. Ben had experience with solar panels as a hobbyist and we felt we were well suited to tackle their project.

The primary motivating factor for the project came directly from the QuickBeam Energy. Their business model is focused around the deployment and maintenance of customized solar panels at multiple locations around Florida.   The dynamic nature of solar panels often requires specific solutions per customer in order to achieve the best possible through-put of solar energy.   These specific solutions cause a rather large portion of QuickBeam Energy's capital to be invested into the design and outfitting of solar arrays.

One of the ideas they had for reducing cost and increasing productivity was to create a monitoring system that could be easily installed along with the solar panels that could remotely monitor the entire array. This would effectively reduce their need to regularly check on the output of their panels. This frees up employees to do other jobs, and helps QuickBeam management deploy their employee's more effectively.

This would provide QuickBeam Energy with several benefits:

- A marketable way to monitor their solar arrays from any location.
- Gives their customers the satisfaction of seeing the power they are saving from their home computer.
- Gives them the ability to troubleshoot their solar panels, more specifically the ability to narrow down the location of the panels that are not performing correctly.
- Allows QuickBeam to do their own market research to see which panels are performing better.
- Allows QuickBeam the data to assess the life-cycle of their solar panels and make future decision of the purchase of panels.
- Free up regular maintenance personnel to do other jobs.
- Allows QuickBeam to quickly assess the personnel and equipment needed to commit to fix a solar array.
- By using UCF, QuickBeam effectively eliminates any cost of labor in the creation of this device.
- QuickBeam is given the opportunity to look at possible job applicants based on the success of the project and the quality of work done.

Solar Generation vs. Central Generation

Why would the choice of solar over a form of centralized generation (coal or nuclear)? There are a multitude of reasons that would be beneficial over paying a utility company for power. With residential home installations of solar power generation becoming more and more popular knowing the pros and cons of having a solar installation over having using power from the utility company.

Local (PV or distributed generation)
- Increased cost over utility power
  - About $.40- $.60 per KWH
  - Increased control over your power generation and consumption
- Size is all dependant on cost of solar cells
  - Price of the panels are about 50-60% of the cost of an entire Solar power generation system
- Types of Cells
  - Multi crystalline
    - Maximum efficiency of ~30%
    - Costs as low as $2.00 per Watt
  - Mono crystalline
    - Maximum efficiency of ~30%
    - Costs as Low as $2.00 per Watt
  - Thin Film
    - Cheaper than other types
    - Lower efficiency ~10%
    - Cost are on average lower than Mono or Multi
    - Costs as Low as $1.70
- Average cost nationwide is $4.31 per Watt.
- Generates during peak usage times.
- Lowers the projected peak of Utility power generation capability.
- Solar industry is projecting to be cost effective the price for the entire system needs to be below $1.50 or $2.00 per Watt of generation power.
- Increased interest and increased competition has lowered average cost ~$.50 in the last 3 years.

Centralized (grid or Utility power)
- Decreased cost
  - About $.10- $.20 per KWH depending on your utility and taxes needed
  - Zero control over what power is generated and how it is distributed
- No Large start up cost
- Utility companies must build infrastructure and generation for peak capacity
- Leads to wasted money on about the capacity needed which is only used for about 40% of the day/year

Environmental Factors

Not only are there cost and control benefits for a solar installation, but there are environmental factors that can be considered compared to conventional power generation. As well as the offset compared to the environmental factors of a Car.

- o Generated offsets per KWatt generated
  - o Up to 16kg NOX Nitros oxide
  - o Up to 9 kg SOC Sulfurous oxide
  - o 600-2300kg CO2 carbon dioxide
- o Above is about as much as an average car

The table 1 below depicts the generated amount of each of the labeled gases. This is from a variety of generating sources primarily used in the United States.

Energy Source	SOx (gSOx/kWh)	NOx (gNOx/kWh)	C in CO2 (gC/kWh)	C in CO2 from non-generating portion of fuel cycle * (gC/kWh)
Coal	3.400	1.8	322.8	50.0
Oil	1.700	0.88	258.5	50.0
Natural Gas	0.001	0.9	178.0	30.0
Nuclear	0.030	0.003	7.8	7.8
Photovoltaics	0.020	0.007	5.3	5.3

Table1: Gases from different Power Sources

The average home will require a 2.5 KW system to satisfy most needs of its power needs. And a 2.5 kW system will also take about 400 square feet, which some of the requirements for size are also dependant on the size of the size of best panel for price and efficiency. With interests in cost savings control and access, and environmental aspects, there has recently been a lot of interest in legislation to help the industry along. After many of the rolling black outs in the late 90s the western United States has had a great push for helping the industry take off.

"As we meet tonight, many citizens are struggling with the high cost of energy. We have a serious energy problem that demands a national energy policy…. The [western United States] is confronting a major energy shortage that has resulted in high prices and uncertainty. I have asked federal agencies to work with California officials to help speed construction of new energy sources. And I have directed [the] Vice President, Commerce Secretary, Energy Secretary, and other senior members of my administration to develop a national energy policy…. Our energy demand outstrips our supply. We can produce more energy at home while protecting our environment, and we must. We can produce more electricity to meet demand, and we must. We can promote alternative energy sources and

conservation, and we must. America must become more energy independent, and we will."
— President George W. Bush, February 27, 2001

Objectives

There are two key elements to the project, the solar device and the base station. Within these two elements there are several objectives that both must meet in order to satisfy our sponsors.

1. The device must be mass producible with primarily Commercial off the Shelf (COTS)
2. The device must be easily installable, requiring only minimal understanding of its workings to properly use and maintain.
3. The devices must be able to work under outdoor conditions; this can include high or low temperatures and varying degrees of humidity.
4. The two devices must communicate to each other via wireless connection that can operate at distances of up to, but not limited, 500 feet.

Several Objectives exist for each individual device as well.

Base Station

The base station general high level requirements are the following: The base station shall output the data of the solar panels in a meaningful and easy to understand way. The base station is constrained the size of the junction box, while this is not a major limiting factor it should be easily mountable inside the junction box. The base station shall operate at all times day/night and can pull from an outside power source. The base station is NOT responsible for providing internet connection, but must have the proper protocols to connect to the internet.

Solar Device

The solar devices general high level requirements are the following: The Solar Device will have to be self-sufficient in terms of its power--it should be able to pull from the solar array. This is a considerable problem considering the high voltage the device will be under. The size of the Solar Device should be as small as possible and be mountable to the underside of the solar array. The device will have to have fully functional wireless capabilities and able to connect to the base station. The Solar Device will have the ability to track the voltage and current being outputted by the solar array and transmit the data wirelessly. The Solar Device must have a long life span, because it will not easy to replace or maintain.

Specifications

These specifications were derived from several meetings with our primary sponsor, QuickBeam energies. While these are estimated values some careful thought was made to select these values. The sponsors more or less had very few 'specific' requirements so these are primarily self imposed and are due to change as complications arise, but we are shooting for these values.

Solar String Specifications

The solar device specifications were driven by the need to make the device portable, easy to install, but the primary motivation for the solar device was to make the device self-sufficient. These portable and be able to survive the following specifications:

- Antenna ability to transmit 500 feet
- Low cost components less than $50 for prototyping
- Must be able to tolerate all environment conditions -10C to +70C
- Must be able to use power from Solar String DC volts from 6-600V
- Store enough power for more than 24 hours
- Last as long as the life of the solar panel approximately 20-30 years
- Sense voltages from 6-600 volts Dc
- The string device will update no frequently than every 1 minute and no longer than 15 minutes.

Base Station Specifications

The Base Station specifications were created to allow flexibility in the design and are meant to be fairly vague. The BaseStation is not meant to fulfill the entire specific.

- Battery system with 12 volt out put
- RS232 or USB data output of at least 1GB
- Local Storage For at least 24 hours
- Networkable
    - RJ45
    - 802.11

Requirements

Solar String Requirements

- Low power microprocessor with wireless capabilities
- Power system to charge a storage device (battery)
- Sense the power output of the String
- Located within transmit distance of base station
- Weatherproof containment- be able to fit inside a preexisting junction box

- One device per panel
  - Unique ID number

Base Station Requirements

- Base station located within transmit distance of solar device
- Website that updates when data becomes available
- Maintains data logs, stores and analyzes trends (offsite?)
- User interface for remote control of power station?
- Uses email or text message alerts for emergencies, i.e. Panel failure?
- Power management to allow for 24/7 data collection If need for large arrays multiple base stations mesh networked
  - Data base would automatically remove redundant ID #
  - Only one database needed
- Weather proof enclosure for microprocessor and electrical storage

Roles & Responsibilities

Division of Labor

Like any successful group, whether it is business, engineering, or a senior design project, the proper division of labor is paramount and organizational skills must be well understood and documented. Our group composition consists of three members, two electrical engineers and one computer engineer; with this in mind, Figure 1 was created to show how the project was going to be divided. Each member was responsible for his individual tasks as well as to let the group know any important details that could affect other group member's tasks. Ultimately it is a project of collaboration, we are all working together to the same goal and we all share details of our individual tasks with one another on a weekly basis. This chart is merely the specialties each member is expected to achieve at the end of the 1st semester, so when the prototyping begins and a question comes up; the group will know who to turn to for the answer.

Ben's primary responsibility for the definition section of the paper is the specs and requirements. This is an extremely important part of the paper as it drives much of the research. What Ben basically did was taking the needs from Quick Beam energies and converts them to the numbers and requirements that the device would have to be for both the base station and the solar device. Ben was also responsible for finding a solution to the power problem inherent to solar device; he was also responsible for figuring out the interface between the solar device and the String. Ben is responsible for the designing of the solar device and its interface with the string. He is also charged with finding the appropriate sensors to monitor the strings power output.

Robbie's primary responsibility for the definition section of the paper was the motivation,

goals, and objectives. These sections define in more detail what the project is supposed to do, what was the reason the project was conceived in the first place, and how the group is going to get to its objectives. The objectives portion is nearly as important as the specs because it shows the group members the guidelines to follow in their research and what exactly the sponsors need from the device. Robbie was responsible for the over coercion of the architecture, the construction and research of similar projects, and how to come up with test procedures to find and test the readiness of the devices.

Devin was in charge of the Project Budgeting and Financing Goals for both devices. He maintains a spreadsheet that covers our expenses and projected expenses that will be provided for the document. Devin is also responsible for the research of the base stations components, including router and all devices included inside the base station. He is also responsible for designing the base station and its wireless component for both the base station and the solar device.

Roles and Responsibilities for Senior Design I Paper
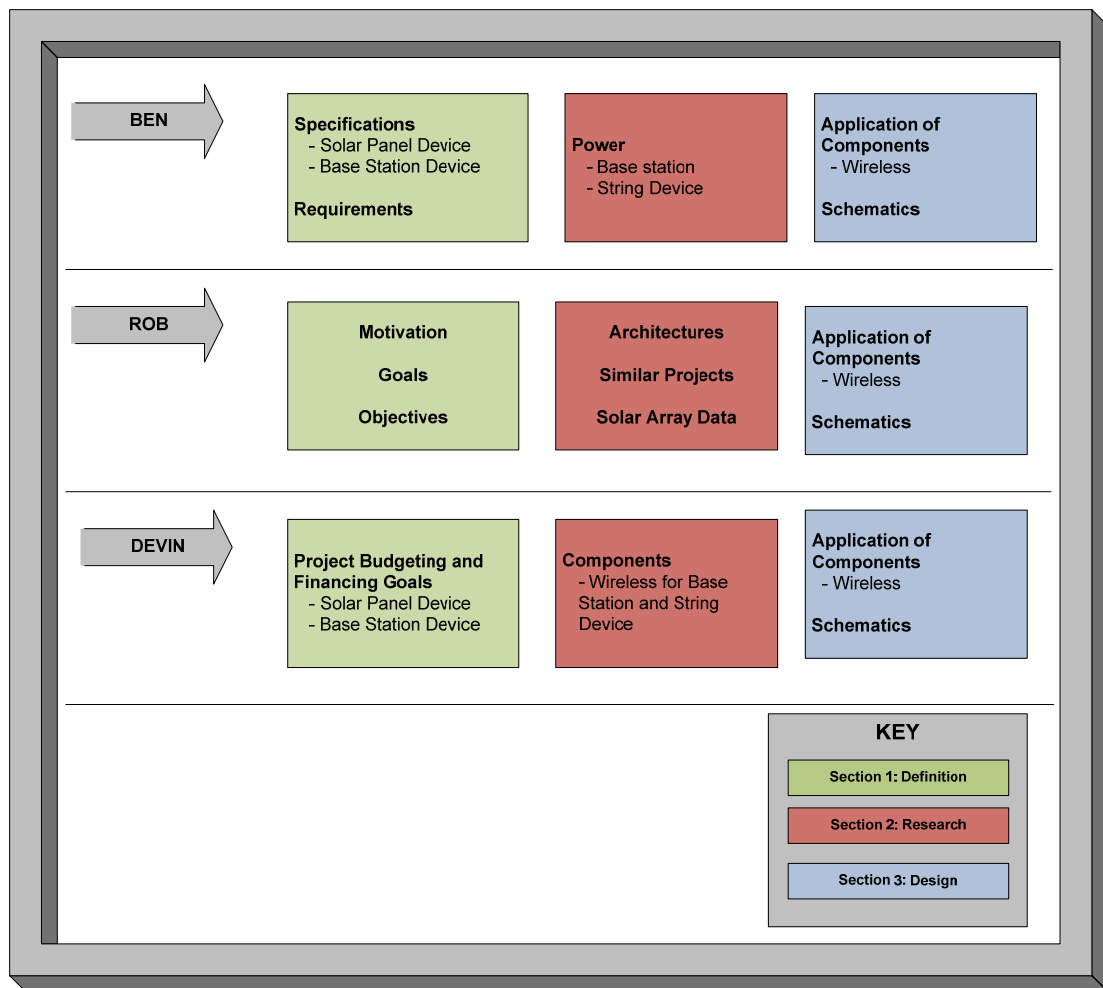
Figure 1 –Roles and Responsibilities

Code and Lead Design Breakdown

Figure 2 is a continuation of the roles and responsibilities Figure 1. It also goes into more depth of how the paper will be managed and the breakdown of who will be responsible for coding. The group agreed upon agreed on these division of labor on the [date] for the Senior Design I.

The coding will primary takes part during the second semester and will be discussing in more detail in each research section. However, since there are especially three sections to the project: The Website, Base Station, Solar Array Device, it was deemed appropriate that we divvy up the coding for each device. This decision was mainly done because there may be different languages used for each device. All of the group members also showed a desire to become more proficient in coding by the end of the senior design class.

Ben was responsible for the coding of the microcontroller which will be for the solar device. The specifics on this will be discussed in more detail in the research portion of the document. Ben was the lead designer of the solar device and responsible for all interoperability issues. This basically represents the need to have someone take charge of making the devices communicate with each other. Designing each device independently of each other has the inherent danger of the devices not being able to easily communicate with each other. By signaling that each member is responsible for this from the beginning we reduce this risk by designing with communication at the forefront of our minds.

Figure 2 - Code and Management Divisions

Project Block Diagram

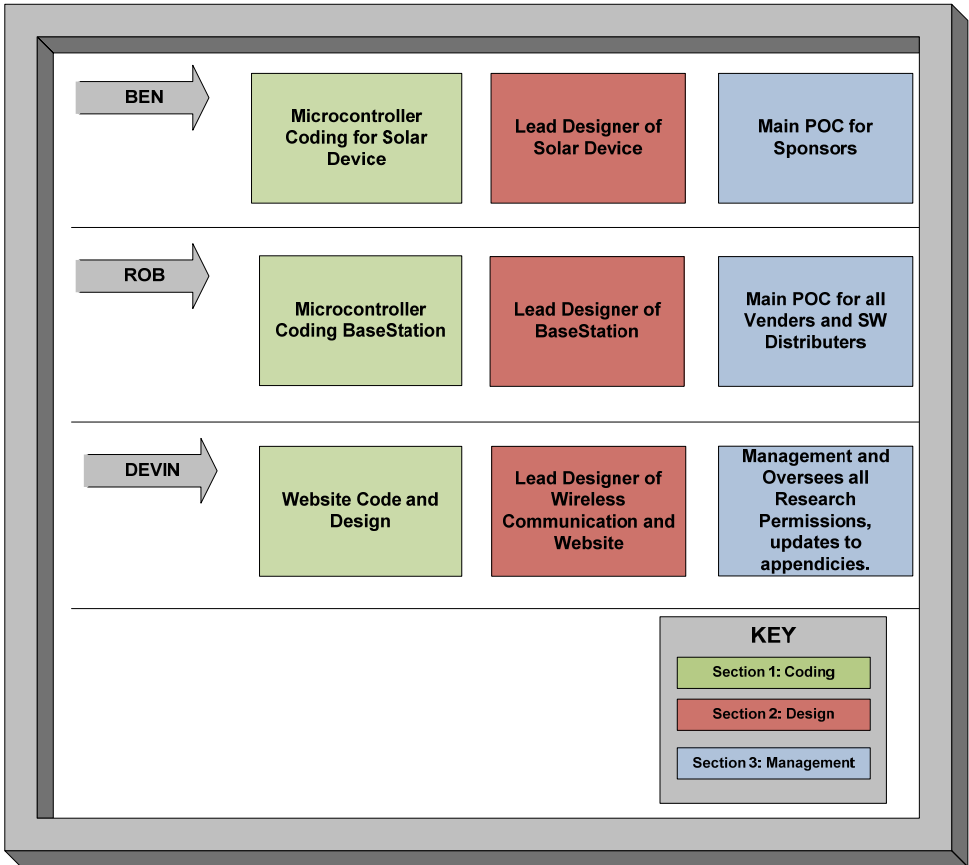Figure 3 is a high level representation of our entire project; it is on a component level and shows the two major portions of our project, the Base Station and the Solar Cell Device. These two items make up the entire Solar Panel Monitoring Station.

Solar Panel Flow Chart

September, 25th

Solar Panel Monitoring Station

Base Station

Solar Cell Device

Base Station
- Block Status: Research
- Input: Wireless Signal from Solar Monitoring Devices
- Output: Status of Cells, Webpage

Wireless Connectivity / Remote Capabilities
- Block Status: Research
- Input/Output: Talking between the Systems.

Solar Cell Microcontroller
- Block Status: Research
- Input: Solar Panel Signal from some Analog Monitoring Device.
- Output: Status of Cell to Solar Station.

Data Storage/ Management
- Block Status: Design
- Input: Data from the Solar Cell Devices (are they functioning)
- Output: Solar Cell/Panel Status to webpage, or other monitoring software.

Router / Wireless Signal
- Block Status: Research
- Input: Input from Multiple Solar Cell Devices, must be able to sync them, and be low power design.
- Output: Signal to the Base Station

Battery System
- Block Status: To be Acquired
- Input: Solar Power from Solar Cells
- Output: Powering the Microcontrollers and Wireless Device.

WebService
- Block Status: Design
- Input: Data from Data Storage Device
- Output: Onto website the status of the Panels (cross talk?)

Wireless Device for Solar Cell Device and Base Station
- Block Status: Research
- Input: Signals from Wireless Device
- Output: Wireless Signal

Monitoring System
- Block Status: Research
- Input: Power Signal from Solar Panel
- Output: A Go/No Go response to microcontroller
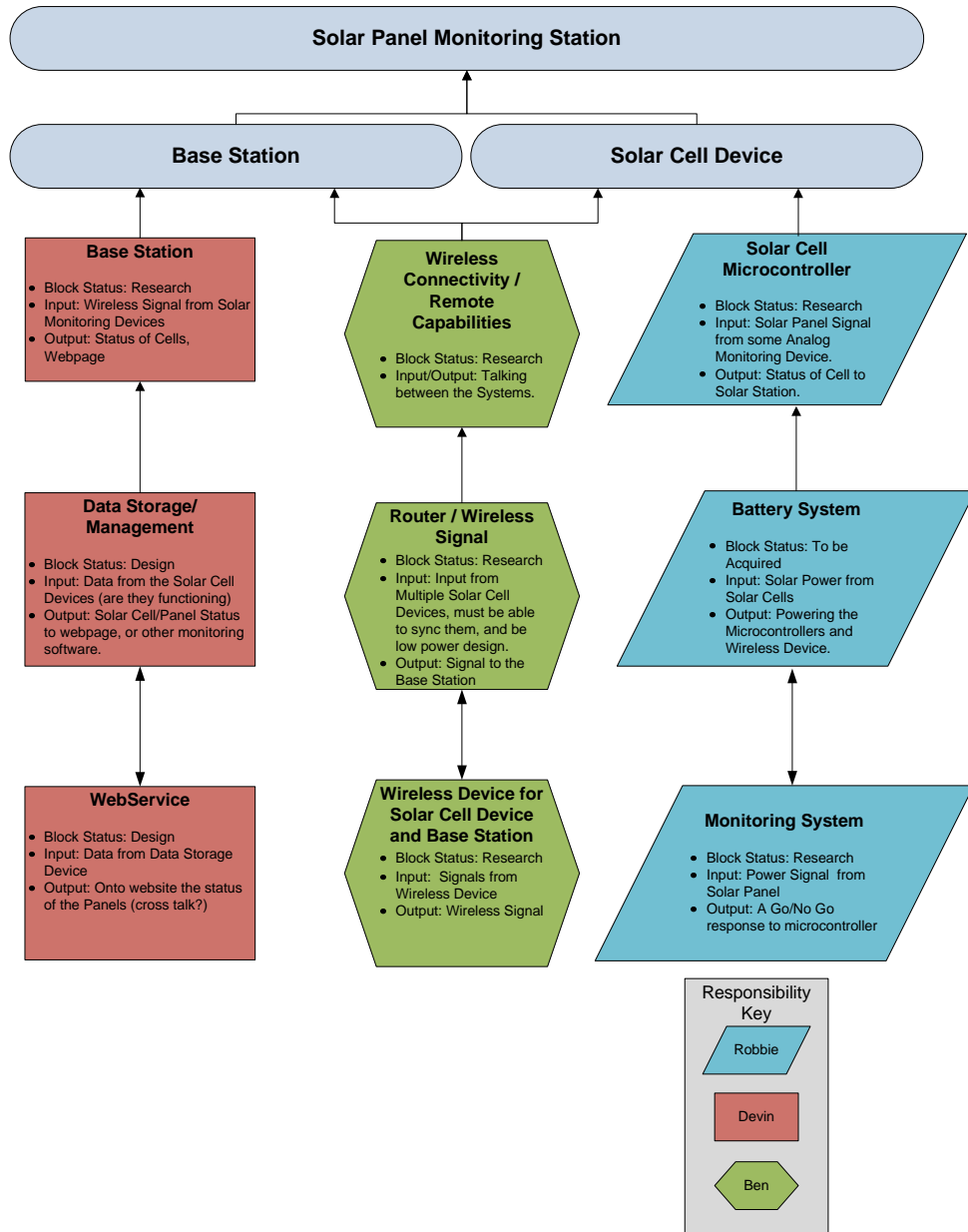
Responsibility Key

Robbie

Devin

Ben

Page 1

Figure 3 - Project Block Diagram

Time Lines

The Group has agreed to meet each week after class on Monday to discuss any findings as well as to meet with our sponsors on any milestone decisions. All dates of import will be shown on this Figure 4. This is one of the primary tools used to access the timely completion of our goals and objectives.

The group decided in the first 'kick-off' meeting to establish certain milestones for our group. These milestones would help us in several ways. Firstly, it would give us some concrete dates to have our work finished by. Thanks to Dr. Richie's advice about not writing your paper all in the last weekend we thought that also having a relative page count would help us progress at a reasonable rate so we do not suffer a schedule 'creep' like so many other project do. After looking at other group members projects and seeing the general layout of their papers and the percentages each section takes up in each paper the following guidelines were set.

- Document Summery 10.3.2009: This is essentially our executive summery and contains all of the components that the executive summery is supposed to have. While revision of this document is necessary before turning it in, it was written with the intent to be incorporated directly into the senior design paper. Approximate page count: 5 pages.

- Preliminary Research 10.19.2009: A little over two weeks later the group has done some basic research and has been able to narrow down the topics that paper will be covering, no writing is actually done, but brainstorming, looking at different solutions to the problem, and general research. Approximate page count: 15 pages. The reason it is so small is because a lot of this research is essentially useless and does not affect our final project, but was looked at and disregarded for a specific reason. This section will be added to in milestone B.

- Milestone B: Research Completed: This is a big milestone for the group. On average most senior design projects have about 70% of their paper done in the research portion. I think this is largely due to the need to find and disseminate the knowledge and it is also the easiest thing to write about since the prototype has not been built yet. This milestone should be the largest page count to date, approximate page count: 45 pages. Which are 15 pages from each group member on their various topics. While this is perhaps a 'hopeful' thinking objective to meet, since it is half way through the semester, having half the paper done seems appropriate.

- Review Preliminary Design Work: We have begun design on all of the various parts of the project and need to convene with each member and work on interoperability among devices, and to simple get a pulse for the group and make sure the integrity of the project is on target. Creep-age should be looked at in the

paper and each member self-evaluates his progress. This is a wakeup call, one month to go before due date.

- Milestone C: Design Completed, Paper Rough Draft Completed: Design is decided on and the writing should be completed for all parts of the project. The page count should be near the 90 mark, review of material, checking of grammar and proof reading will be taking during the next two weeks to ensure a solid paper is turned in. Page count: approximately 90 pages.

- Paper printed and Bound: The group decides who will be responsible for the printing and binding of the project. We will all go to turn in the paper just to be safe, but one member is responsible for organizing this effort. The decision on what kind of bindings and all last minute changes are finished. The group will split the funds necessary to print and bind.

Milestone Timeline

	12.1.2009 Milestone C: Design Completed, Paper Rough Draft Completed

9.26.2009
Milestone A: Project Decided Upon

10.19.2009
Preliminary Research Completed

12.13.2009
Get Paper Printed and Bound

10.1.2009   11.1.2009   12.1.2009

9/18/2009

10.3.2009
Document Summery Complete.

11.14.2009
Review Preliminary Design Work

12/14/2009

12.14.2009
Paper Due

11.1.2009
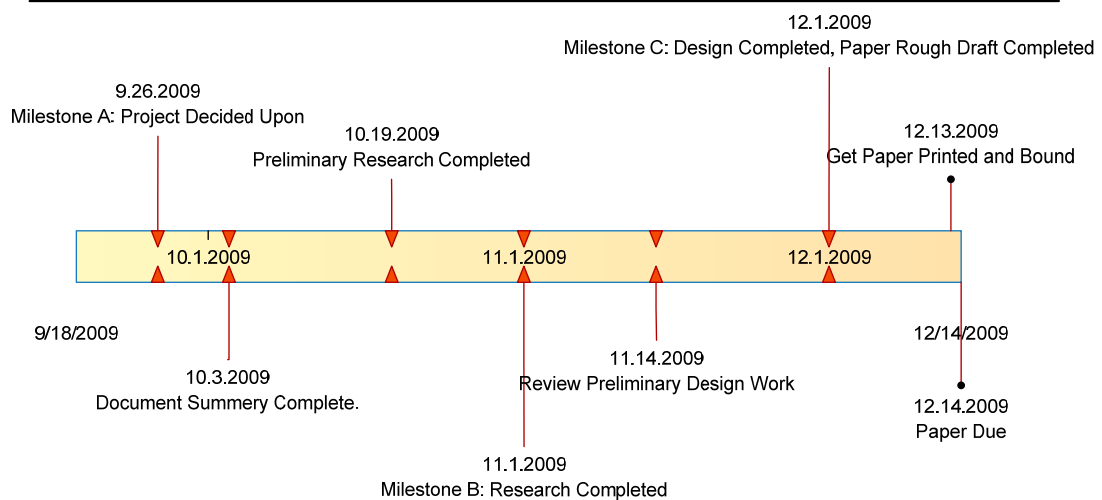Milestone B: Research Completed

Figure 4 – Milestone Timeline

The next chart has two entry types. The first, and most numerous, is a group meeting which consists of all three members of the group meeting either after class or on a conference call (typically Skype). These meetings form the backbone of how our group connects with one another; it is both a social event, progress report of the efforts going on

Page 13

at the time, and a forum in which to discuss concerns or problems members encounter during their research. The meetings range from an hour to an all day event, while they illustrate the major meetings our group has, they by no means reflect the numerous e-mails, phone calls, and conversations held outside of the group meetings. We are a true 'group' in the since that we work as a team on every level of the project.

The other entry type is a meeting with our sponsors, which we plan to conduct before each milestone. These meetings are the formal discuses between our group and our sponsors at Quick Beam energy. During the course of the meeting we discuses our progress as well as any concerns that our sponsors having regarding the project. These meetings often give us great insight into the requirements they have for our project and help us evolve our design to better meet the needs that our sponsors have. Figure 5 shows the dates of these two entry types.
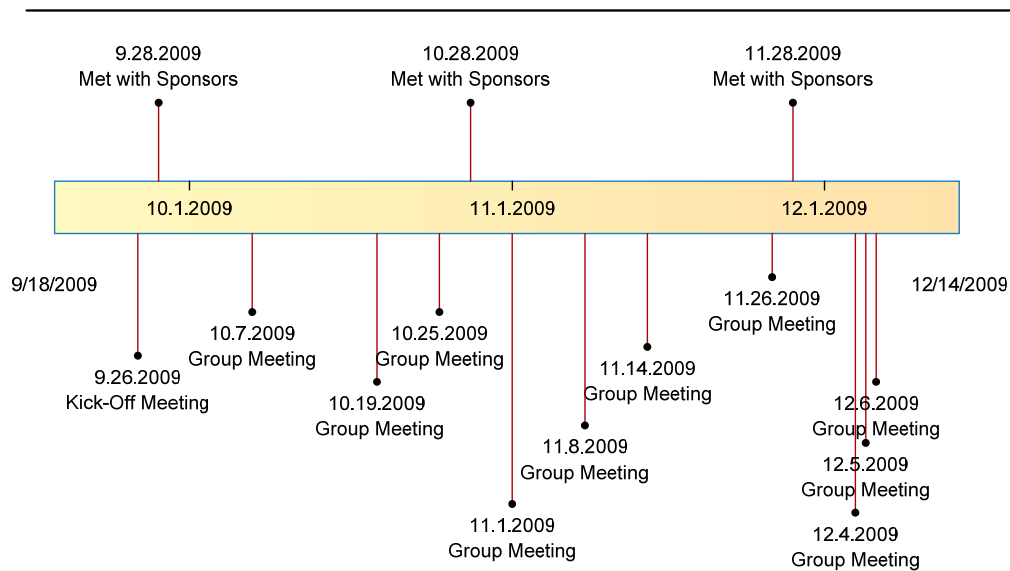
GroupMeeting Timeline

Figure 5 – Group Meetings Timeline

Project Budgeting and Financing Goals

The solicitor of this project, and therefore the persons liable for project expenses, is QuickBeam Energy. Below is table 2 that outlines the potential devices and their estimated costs. This is for a potential installation estimated to be a useable size. For our prototype we will likely only have one solar panel to test our concept.

QuickBeam Energy will be supplying our group a budget of $500. Nearly half of the components initially planned for our prototype are already in possession. For example, group member Benjamin Brindle owns the base station device. Also, a college colleague will be providing us with the Explorer 16 development board for interfacing the wireless module. Below is a table with components that we will need and not need with their advertised prices. If an item is marked as costing $0, it means that it is provided in kit or is provided by a group member. After analysis of the budget, items that we need for our project, we will be well below the supplied $500 from our sponsor.

Item Name	Item Part Number	Item Price
ZeroG 802.11 Development Kit for Explorer 16	AC164136	$189.99
ZeroG PICtail Plus Daughter Board	AC164136-2	$0.00
ZeroG Wireless Module with PCB Antenna	ZG2100MC	$0.00
ZeroG Wireless Module, external antenna	ZG2101MC	$0.00
Antenna Kit for ZG2101M module	N/A	$0.00
Asus WL-520GU Wireless Router	N82E16833320023	$0.00
9dB Antenna	N/A	$0.00
LM5116 synchronous buck controller	LM5116	$10.00
Explorer 16 PIC Board	N/A	$0.00
Explorer 16 Power Supply	N/A	$0.00
Current Transducer FHS 40-P/SP600	FHS 40-P	$1.39

Table2: Budget

Section 2: Research

Research Methods

The initial kick off meeting was a brain storming session on how we would try and meet our sponsor's requirements. The team brainstormed numerous ideas for how to tackle the project. A strategy was concluded, and it involved posing cogent and relevant questions that we felt at the time needed to be answered for the group to have a good understanding Solar Panels, Wireless devices, and possible power solutions to the large voltages the device would have to monitor. Of course, as the research process got more involved, so did the list of questions we sought to answer.

Books, Websites & Relevant Works

The primary research tool was the internet, which we complemented with several of our text books and relevant works form the library. One good thing the initial process of "Googling" was provide a few actually good resources. They were few and far between, but there were some. Among the truly useful resources was http://www.solarhome.org. This website served as the very basis for getting a clear understanding of how solar systems work. Utilizing this resource helped the team immensely in answering some of the core question posed during the brain storm session about solar energy and how the systems were organized. The website essentially served to give us a very high-level overview of what solar energy was and how it was managed in practical applications.
Another resource that was stumbled upon during the course of surfing the web USB The Basics of 802.11 Wireless LANs, a book by Frank M. Groom. This resource as the name suggests completely detailed all the intricacies that go into the design and build of a wireless device. The very volume of this book, 170 plus pages, required that the team divide up the responsibility of understanding the material. Upon examining the text, it was decided that the key concept that we needed to understand for this project were the following; Wireless Fundamentals, Wireless Transfers, Wireless Protocols.
We then chose among ourselves to specialize in our individual unique areas of interest. More interested in the Power Electronics side of the project, Ben volunteered focusing on the power aspect of the project, and in addition to the previous chapters also read up on Managing Power, Testing and Debugging, and the Electrical Interface. Being a computer engineer, Devin focused on the microcontroller and the programming aspects required of it. As such he also read Matching a Driver to a Device, Detecting Devices, Human Interface Devices: Using Control and Interrupt Transfers, Human Interface Devices: Reports, Human Interface Devices: Host Application, and Signals and Encoding.

Expert, Faculty and Colleagues Resources

Once again, another excellent resource stumbled on the internet was the availability of several wireless forums online. These forums provide a watering hole for wireless enthusiast and beginners alike to gather round and exchange ideas about the fascinating world of wireless technology. Our project team precociously registered on the online forum for and asked questions about our project. Not surprising, we received good feedback from the forum, and insight into issues we had not originally thought about.

After getting past the initial concern expressed by the said employer on the challenge the project posed for us, he gave the team some good advice as to what areas to look at and focus on for the project. Also, he provided the team with other useful resources including other experts in the field to get the team adequately situated.

Finally, the guidance of the project advisor, Dr. Samuel Richie was instrumental in helping us directly understand what sort of challenges we were facing with the implementation of the project. Dr Richie also provided a rigorous timing scheme which undoubtedly helped keep the team on track in implementing this design.

Figure 6 shows the divisions of research done. This is obviously estimation, but is very close to where the research came from. As it can be seen in the graph the vast majority of our research was done online, and very little was done with text or from professional help. I think if we looked at the average engineer that their methods of research would not be to dissimilar from this figure.
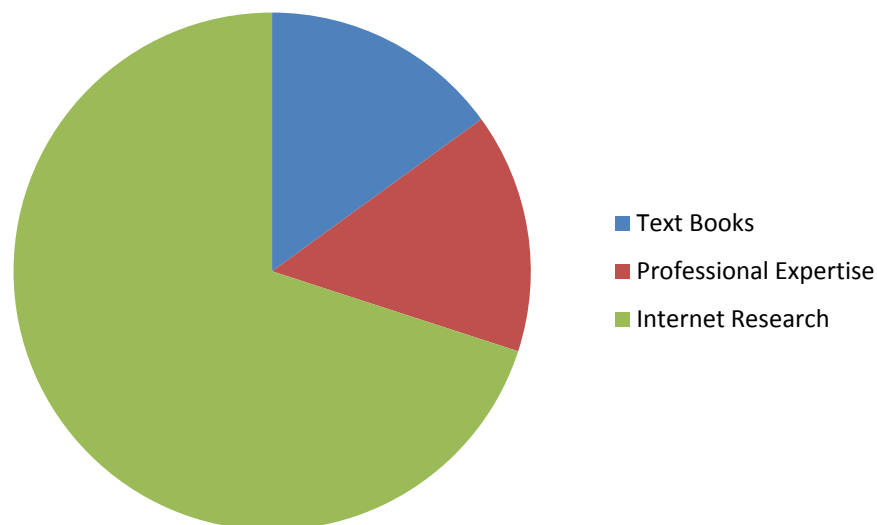

Figure 6 – Research Method Distribution

Solar Panels

The design of our project is largely limited by, and driven by the current solar power standards that exist in today's market. Often solar energy panels are placed in very inaccessible locations so they can achieve the largest amount of efficiency, this can be easily illustrated by simply looking outside at the Engineering Building 1 Solar Array on the 'North' side facing Harris Engineering Center. We had the opportunity as a group to see these solar panels first hand.

The main objectives of the trip was to get a feel for the dimensions of the enclosure box, the material used for the enclosure box, and to really put into our minds eye what these solar panel arrays look like. What we saw was impressive. But it also raised a very valid point made by our sponsors; that one of the main benefits to a wireless monitoring system is its ease of install and eliminates the need to run wires all over the solar array. Considering the Solar Array at UCF is about 5 stores off the ground, mounted about 4 feet from the edge of the roof, the group was thoroughly convinced of our sponsors rational. As you can see in Figure 7 it would be both time consuming and presumably dangerous to run a wired monitoring system across a solar array. Also, by comparison, the Solar Array at UCF is nearly a 10th of the size of some of the panels fielded by QuickBeam Energies.

Figure 7 – Solar Panel Outside UCF Engineering Building

One of the major design considerations for the Base Station was the size and layout of the Enclosure case used to house the power inverters and other electronics for the solar array. One of our main concerns was whether or not a metal enclosure case was going to be used, because it would require us to boost our wireless signal. Also if the enclosure case was too small It would limit the size of the router we would be able to use. While we did not get a chance to open the enclosure case for the UCF solar array (for obvious reasons), it did lay to rest some of those concerns. Figure 8 shows the two enclosure cases on the UCF solar array. They are both hardened plastic and are approximately 3 ¼ feet by 2 ½ feet by ¾ a foot. They are both under a protective overhang which should help with some of the severe weather and also shades them for most of the day. Since our electronics need to have a very high temperature range this was a good sign. Our sponsors confirmed that it is common practice is to 'shade' the enclosure boxes as much as possible, this is partly to due to debris protection from hurricanes and severe storms and partly to keep the electronics away from those extreme temperatures.

Our Sponsors confirmed that most enclosure boxes use a hardened plastic or ballistic nylon casing, but that some older models could use Metal enclosures. For the design of the prototype a plastic enclosure case will be considered, and we are assumed to have plenty of room for any router and electronics inside the enclosure box.
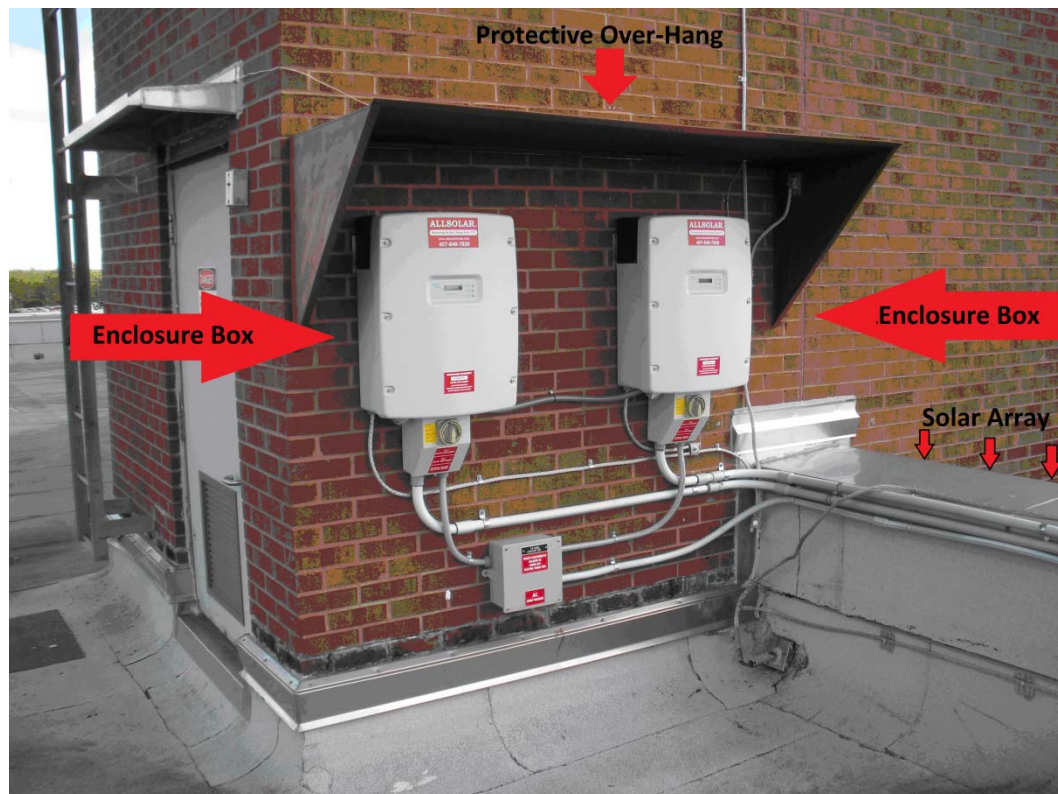

Figure 8 – Junction and Inverter Boxes of Solar Panels on Engineering Building

A key note should be made. While our project is called Solar Panel Monitor System, and

we have a Solar Device component, we ourselves are not doing anything with the solar energy. The only time we even touch the power network is to read the voltage/current on the line, and to charge our battery. Our project goals exist, however, due to some of the very important limiting factors mentioned above, i.e., difficult to install, dangerous environment for construction, large areas to cover with wires. These reasons created a *need* for the project we are pursuing, and have lead to some very interesting research and unique engineering solutions.

Battery Charger

The battery charger is a part of the solar device and its main function will be to power the solar device during hours of limited or no solar activity. The charger has given the group an interesting and challenging design problem. Foremost among them, How do you pull energy from a load that can reach levels of 600 volts into a small rechargeable battery without destroying it, as well as destroying the battery charger circuit? This problem will be more thoroughly discussed in the design and prototype sections, I mention it only because it has driven the research of the battery and battery charger circuit a great deal. Other considerations do exist however. The battery charger must take into account its need to be rechargeable. The device is going to be located in some very hard to reach locations and therefore having to change the battery out every other week, or even every other month, would not meet the design specifications of our sponsors. That design spec is; that the charger unit should be as low maintenance as possible and have as long as a life-span as feasible given the limited amount of time to do trade-studies and our limited expertise in the area. Several rechargeable battery types were researched and will be discussed with further detail below.

Another consideration for research of the battery charger is its size and its volatility in extreme conditions. The solar device is going to need to be a small device that can attach to the strings that run off of solar panels; this limits the use of several larger battery types that could have possible handled the 600 volt load, but is a very important requirement. It also means that using battery cells in a package would not be feasible since most come in relatively large packaging. Ultimately the size should be something akin to a highlighter or pen in length and no thicker than inch to an inch ½ in diameter.

Many batteries can decompose over extended periods of time, destroying the circuits and eventually our solar device project. In general, it is advisable if a battery is not exposed to 110 degrees Fahrenheit conditions, or 100% humidity, or freezing temperatures. The solar device does not have this luxury and so its battery does not have this luxury. No battery exists that will be able to fulfill all of these requirements perfectly, but the 'best' possible choice will be found with the research.

A review of the requirements driving the battery and battery charger circuit are:

- Remain small in size to fulfill the sponsor requirement for portability.

- Be rechargeable to fulfill the sponsor's requirements for longevity of the device and to ensure low maintenance.
- Be able to keep the device active during hours of no solar activity and during hours of limited or partial solar activity.
- The battery needs to robust enough to survive extreme weather conditions.
- The battery needs to have a long life span, having the largest amount of recharge cycles possible.

Rechargeable vs. Alkaline Batteries

One of the communalities between the rechargeable batteries is their reduced voltage rating when compared to similar sized alkaline metal batteries. Rechargeable batteries have a voltage rating of approximately 1.2 volts and the alkaline metal batteries have a voltage rating at approximately 1.5 volts. This is not really a disadvantage for our solar device since all of the parts we will be using in the solar device will have very low draws and should not require even 1.2 Volts to function properly. Rechargeable batteries also have a problem with 'self-discharging,' meaning that they lose their charge much quicker if they are not being used or charged. They lose on average 10-25% of their charge over a month if they are not used. While this does not affect our use of the device, in terms of storage or buying in bulk, it should be a consideration for our sponsors with the plan on deploying the solar device with this type of battery.

Another common disadvantage to rechargeable batteries is their capacity. The capacity of Alkaline batteries are roughly 2400 mAh, where as the average rechargeable is in the range of 500 – 1300 mAh. This capacity difference may be a large factor after during the prototype stage to see if we need a battery that requires more charge capacity. A battery with 1300 mAh that can be recharged on a daily basis should, by our estimates, be enough to maintain the solar device during the hours of little or no solar activity. The size difference between the rechargeable and alkaline batteries is negligible, as the capacity goes up so does its size. Both batteries seem to come in the size that our project requires. Overall, the rechargeable seems to be the better choice simply because it will allow us to meet more requirements than alkaline batteries will. The follow is a the breakdown of the research done on the various rechargeable batteries and there pros and cons as they pertain to the solar device.

The three most common types of rechargeable batteries are:

- Nickel Cadmium Battery
- Nickel-Metal Hydride Battery
- Lithium-Ion Battery
- Lead Acid Battery

Also some notable battery types that are not as common:
- Litium Sulfur Battery
- LiPO4 Battery
- Rechargeable Alkaline batteries

The figure 9 below shows the watt hours. We basically want the highest rated Watt hour battery.
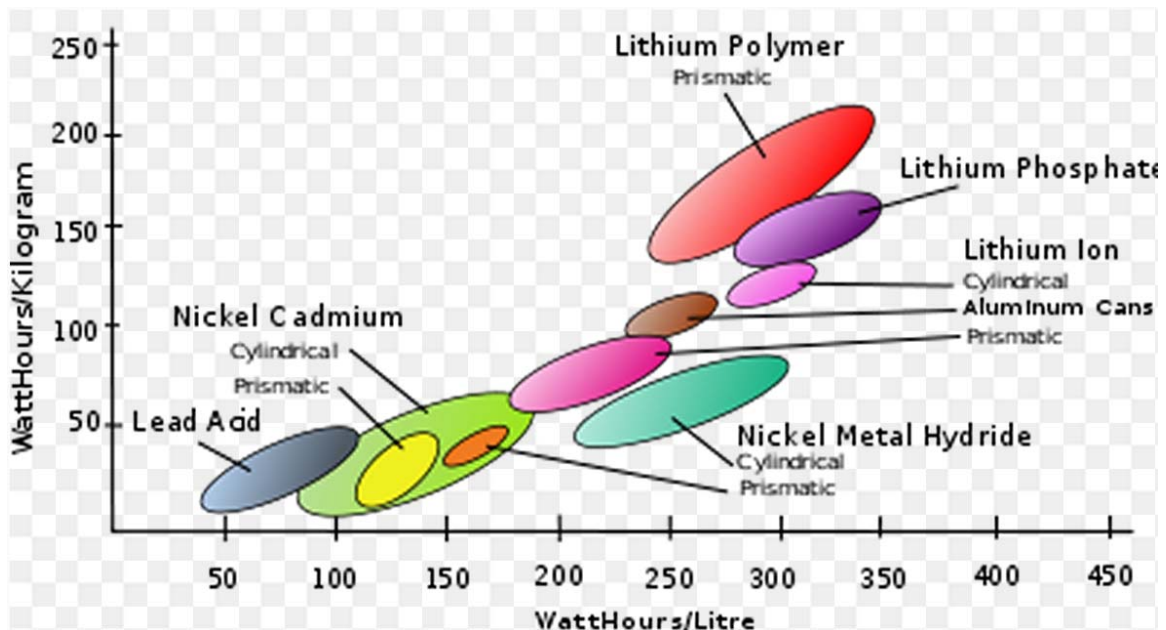

Figure 9 - Power of Batteries (Reprinting Permission Requested)

Nickel Cadmium Battery

Nickel Cadmium batteries or NiCd, use a nickel oxide hydroxide and metallic cadmium as its electrodes. This gives it several advantages in regards to the solar device and its requirements. First, it is very difficult to damage when compared to other batteries. This fact alone makes it a likely candidate since there are so few batteries than can handle the extreme stresses that the solar device will have to handle. Another advantage is that NiCd batteries typically have larger number of charge/discharge cycles than other rechargeable batteries.   However this advantage is crippled by the fact that NiCd batteries don't last very long before needing a recharge. NiCd batteries also have toxic metals inside of them, so while they are more versatile as a whole, if they DO in fact break then it could damage the solar panels themselves. These toxins also mean that they

are not safe to throw away. This could have implications to our sponsors if they have to manage a large quantity of the devices in the field. It is also somewhat counterproductive in their field, since solar energy is in essence trying to save the environment, to use devices that essentially harm it. You also cannot over charge NiCd batteries, while we can certainly design a battery charger circuit to stop charging when the battery is at a reasonable level if we do happen to miss judge the threshold, or if we overcharge the battery by too much, it could destroy the battery entirely. This would be catastrophic for our sponsors. Overall NiCd batteries are more than probably not a good choice for our solar device.

Nickel-Metal Hydride Battery:
NiMH's have much higher capacity than NiCd's.

NiMH's have replaced NiCads as the rechargeable battery of choice, because they have a higher capacity than NiCads and don't have the special disposal requirements that NiCads do. Unlike NiCads, NiMH's contain no toxic metals and have no special disposal requirements, so when they won't hold a charge any more you can throw them away.

Unlike alkaline's which lose their voltage steadily, NiMH batteries maintain most of their voltage over the whole charge and then suddenly plummet, as shown in the graphs below. For this reason many electronic devices that tell you how much battery life is left have a hard time reporting an accurate level for NiMH's. The voltage is very similar for both a fully-charged battery and a nearly-spent battery. Some devices (like my GPS wristwatch) let you specify in the setup menu whether you're using NiMH or alkaline, so they can try to be more accurate with the battery-remaining indicator.

Lithium-Ion Battery

Lithium-Ion batteries, also referred to as Li-ion batteries, are another type of rechargeable battery we considered for the solar device. They have a change/discharge efficiency of about 85%; they last for up to a year and a half and have a cycle durability of up to 1200 cycles. The voltage on these batteries is also slightly higher than the NiMH batters rated at 3.6 volts.

Figure 10 - Lithium Battery Size Comparison (Reprinting Permission Requested)

Disadvantages

Lithium-ion batteries can be formed into a wide variety of shapes and sizes so as to efficiently fill available space in the devices they power.

Lithium-ion batteries are lighter than other energy-equivalent secondary batteries—often much lighter. A key advantage of using lithium-ion chemistry is the high open circuit voltage that can be obtained in comparison to aqueous batteries (such as lead acid, nickel-metal hydride and nickel-cadmium).

Lithium-ion batteries do not suffer from the memory effect. They also have a self-discharge rate of approximately 5-10% per month, compared with over 30% per month in common nickel metal hydride batteries, approx. 1.25% per month for Low Self-Discharge NiMH batteries and 10% per month in nickel-cadmium batteries. According to one manufacturer, Li-ion cells (and, accordingly, "dumb" Li-ion batteries) do not have any self-discharge in the usual meaning of this word. What looks like a self-discharge in these batteries is a permanent loss of capacity (see below). On the other hand, "smart" Li-ion batteries do self-discharge, mainly due to the small constant drain of the built-in voltage monitoring circuit.

Disadvantages of Traditional Li-ion Technology

Shelf life

A disadvantage of lithium-ion cells lies in their relatively poor **cycle life**: upon every (re)charge, deposits form inside the electrolyte that inhibits lithium ion transport, resulting in the capacity of the cell to diminish. The increase in internal resistance affects

the cell's ability to deliver current, thus the problem is more pronounced in high-current than low-current applications. The increasing capacity hit means that a full charge in an older battery will not last as long as one in a new battery (although the charging time required decreases proportionally, as well).

Also, high charge levels and elevated temperatures (whether resulting from charging or being ambient) hasten permanent capacity loss for lithium-ion batteries. The heat generated during a charge cycle is caused by the traditional carbon anode, which has been replaced with good results by lithium-titanate. Lithium-titanate has been experimentally shown to drastically reduce the degenerative effects associated with charging, including expansion and other factors. See "Improvements of lithium-ion technology" below.

At a 100% charge level, a typical Li-ion laptop battery that is full most of the time at 25 °C or 77 °F will irreversibly lose approximately 20% capacity per year. However, a battery in a poorly ventilated laptop may be subject to a prolonged exposure to much higher temperatures, which will significantly shorten its life. Different storage temperatures produce different loss results: 6% loss at 0 °C (32 °F), 20% at 25 °C (77 °F), and 35% at 40 °C (104 °F). When stored at 40%–60% charge level, the capacity loss is reduced to 2%, 4%, 15% at 0, 25 and 40 degrees Celsius respectively.

Internal resistance

The internal resistance of lithium-ion batteries is high compared to other rechargeable chemistries such as nickel-metal hydride and nickel-cadmium. It increases with both cycling and chronological age. Rising internal resistance causes the voltage at the terminals to drop under load, reducing the maximum current that can be drawn from them. Eventually they reach a point at which the battery can no longer operate the equipment it is installed in for an adequate period.

High drain applications such as power tools may require the battery to be able to supply a current that would drain the battery in 1/15 hour if sustained; e.g. 22.5 A for a battery with a capacity of 1.5 A·h). Lower-power devices such as MP3 players, on the other hand, may draw low enough current to run for 10 hours on a charge (e.g. 150 mA for a battery with a capacity of 1500 mA·h). With similar battery technology, the MP3 player's battery will effectively last much longer, since it can tolerate a much higher internal resistance. To power larger devices, such as electric cars, it is much more efficient to connect many smaller batteries in a parallel circuit rather than using a single large battery.

Safety requirements

Li-ion batteries are not as durable as nickel metal hydride or nickel-cadmium designs[j] and can be extremely dangerous if mistreated. They may explode if overheated or if charged to an excessively high voltage. Furthermore, they may be irreversibly damaged if discharged *below* a certain voltage. To reduce these risks, lithium-ion batteries generally contain a small circuit that shuts down the battery when it is discharged below about 3 V or charged above about 4.2 V. In normal use, the battery is

therefore prevented from being deeply discharged. When stored for long periods, however, the small current drawn by the protection circuitry may drain the battery below the protection circuit's lower limit, in which case normal chargers are unable to recharge the battery. More sophisticated battery analyzers can recharge deeply discharged cells by slow-charging them.

Other safety features are also required for commercial lithium-ion batteries:

- shut-down separator (for over-temperature),
- tear-away tab (for internal pressure),
- vent (pressure relief), and
- Thermal interrupt (over-current/overcharging).

Microcontrollers

The primary integrating component for both the solar device and the base station will be a microcontroller. The wireless solution required by QuickBeam Energy is a consideration the microcontroller. Before a microcontroller can be chosen all options must be looked at. This section describes the research conducted to find the most appropriate microcontroller given the set of requirements. *NOTE* this section is not yet completed and permission for each of the diagrams needs to be given. The following is some of the questions that need to be answered:

- What brand of Microcontroller does the group feel comfortable programming in?
- What are the available interrupts?
- What size and footprints are available?
    - Is it surface mounted/through-hole?
    - What are the dimensions constrain, height?
- What type, if any, of Analog to digital converters or digital to analog converters will be needed?
- Will the microcontroller be able to perform thoroughly through times where no solar power is provided?
- What kind of memory is required/preferred?
    - ROM
    - EPROM
    - EEPROM
    - Flash Memory
- What peripherals come with the microcontroller?
    - Timers
    - Watchdog
    - Converters
- Does any development tool exist for the Microcontroller?
    - What is the group preference?

- What language does the group prefer?
  - Does the architecture of the microcontroller fit into the overall architecture?
  - What is the optimum cost for the microcontroller?
  - What are the required Voltage and Current requirements?
  - What frequency is needed for the microprocessor?
  - What additional features are offered within the microprocessor family?

Possible Wireless Solution with a Microcontroller

The BS1-IC or BASIC Stamp I could be a good possible solution for a microcontroller. This would be an inexpensive solution to the Solar Panel Device; the version shown below is a transmitter with the BS1-IC Pin Diagram. A basic layout would require the use of a data pin (pin 7) as well as a small antenna; this would allow us to get up to 400 feet of transmitted data. Four hundred feet is well beyond what we are project to prototype towards, so the BS1-IC could potentially be a cheap and cost effective way to create the Solar Array Device.
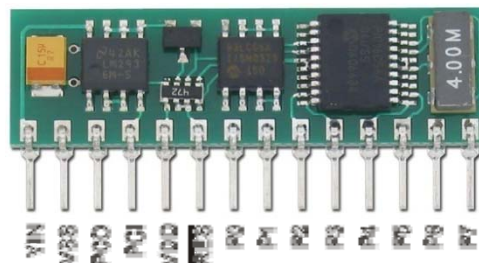

Figure 11 - Pin Layout of BSI-IC (Reprinting Permission Requested)

The major short coming of this device is its lack of available options. It's somewhat outdated device and has a very short life span; it would not meet the rugged environmental testing the solar panel device is going to have to go through.

Microchip PIC

During the hardware research phase of this project, the design team was confronted with the need to determine the nature of the processing unit to be used in the device. One of the devices that the design team considered was the PIC family of general purpose, high performance 16-bit DSP specific PIC microcontrollers from Microchip. A member of the design group had some limited experience with Microchip 8-bit offerings so extensive

research was made into the capabilities of both the PIC24F and the PIC microcontroller families. The design group also consulted the Microchip Advanced Part Selector available from the Microchip website on the front page. The criteria that were input for the selection of this chip model was a limit on the number of physical pins were limited to a quantity between 6 and 40. This decision was made to increase the likelihood of finding a microcontroller with a package type suitable to both surface mounting, as well as use in a breadboard for prototyping purposes. The PIC that was selected for further consideration came in a 28 pin DIP package as well as QFN and SOIC packages. The variety of packages available means that during both the prototype and actual construction phases of the project, the design team would have flexibility in both circuit design and board layout. **PIC33** (Condensed specifications)
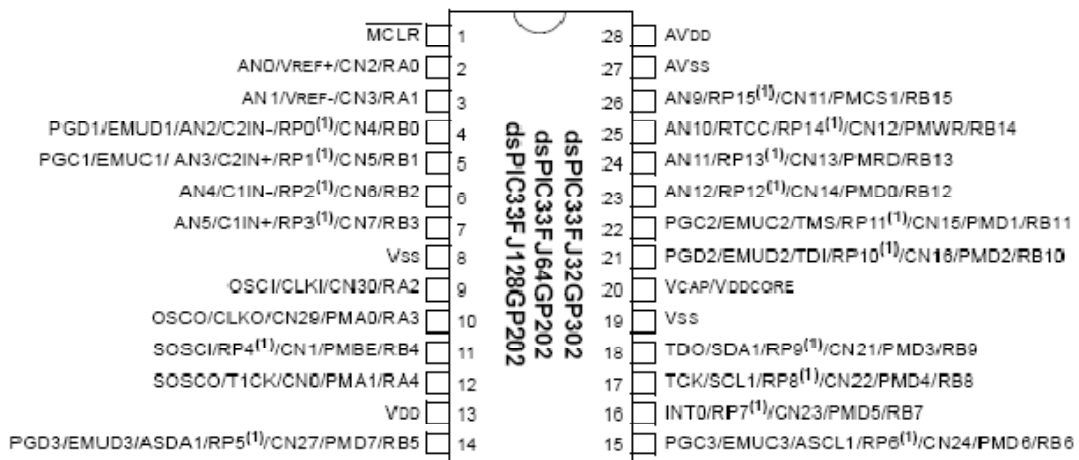

Figure 12 - Pin layout for 28 pin SOIC package PIC33 (Reprinting Permission Requested)

The most important aspect of the PIC33 is the dual 32-bit digital timers, as well as the very high processing rate 40 Million Instructions per Second shown in Figure 18: Condensed specification for the PIC33 microprocessor from Microchip. The importance of the 32-bit timers is that the timers can be used by the device as well as well as by the transmission sources as a clock to count absolute time. It is possible using different mathematical methods for position finding based on known distances or time of arrival calculations to utilize absolute time to simplify the computation. The lack of a dedicated floating point unit for this chip implies that the design team would need to implement in software either a reproduction of a functional floating point system, most likely based on the current IEEE standard, or relegate the computation to use fixed point numbers which could place a relative maximum on the values used in our computations. The limitation to either improvised floating point, or fixed point notation weighed heavily against this unit in the decision making process because the numerical methods that would be implemented in the system software rely on a highly accurate underlying number system

in order to properly converge to the correct solution. Also, by virtue of the hardware not including a floating point unit, it is unlikely that the hardware would have built in support for basic mathematical functions like the square root, transcendental and trigonometric functions in the standard library (or ideally with hardware acceleration).

In Figure 28: Pin layout for 28 pin SOIC package PIC33 (Permission Pending), some very important aspects of the PIC33 are exposed in the 28-pin SOIC package will be subsequently explained. The PIC33 offers a parallel data bus that is exposed through pins labeled with labels beginning with "PM". This is a multiplexed parallel data bus that allows several input devices to write into the memory of the chip. Critical to the design phase are the JTAG (IEEE 1149.1) interface header pins that are exposed and labeled with labels that begin with "T". JTAG is a standard microcontroller programming interface that allows interoperability between various host programming systems and the microcontroller. The actual update of the chip EEPROM would be done either through the JTAG interface or a more specialized EEPROM programmer tool. In the case of this device, the design team would construct a JTAG cable and interface it to a PC running a version of Microsoft Windows that is compatible with the programming tools provided by Microchip. There are also several commercial vendors that provide JTAG programming hardware that supports a wide variety of JTAG interface types.

PIC33 (Permission Pending) provides sufficient memory for the purposes of the design team, as the principle space requirement will be the application code itself which should not exceed these parameters. The onboard storage of 43k words of data on this 16bit processor implies that there are 86kB of storage available in the EEPROM. The onboard storage can be extended via a variety of interfaces with several available NAND based Flash chips from Microchip sized up to a megabit. This extensibility more than assures that the eventual software package should be capable of being fit into the confines of this chip. A more critical component of the system is the 16K ram capability. Depending on the size of the application, buffer sizes may have to be reduced in order to perform the required memory mapped IO configurations to interface to the signal capture and analysis hardware. It should also be noted that a critical factor in the eventual selection of the FPGA board was the inability of this chip to perform rapid shifts of binary strings in excess of 128 bits. The specialized DSP module is capable of extended bit shift operations at a very high rate of speed, but the design group determined that a 32bit processor or at the very least a more optimized parallel pipeline would be needed to sufficiently process the incoming data from the sensor array for the device to be accurate to specification.

The final decision on the dsPIC33FJ128GP802 came down to its competitiveness in signal processing against a proper FPGA board that was also geared towards digital signal processing; the design team favored the FPGA board over the PIC33 for a number of reasons that may not be clearly discerned from the above so they are summarized as follows. The FPGA offers an order of magnitude more active RAM and extremely easily upgrades when it comes to permanent storage as compared to the addition of one or more chips to an already crowded board for the PIC33. The PIC33 offered a choice between an

assembly language interface and a c language interface for applications programming while the FPGA offered both of the previous options as well as an optional VHDL / Verilog interface along with extensive software, code examples and documentation to go along with it. Most members of the design team have experience writing Verilog code for nontrivial processing tasks.

Microchip PIC32 Series Microprocessor

We also evaluated the Microchip PIC32MX3 series of 32-bit microprocessors for fulfilling the processing unit requirement from the product specifications. This chip was selected due to the upwards compatibility between it and the dsPIC33 16-bit processor. The tool chain that is provided by Microchip for software and hardware development on the dsPIC33 series of DSU has as a feature, a capability to generate code that is compatible with the PIC32 series of 32-bit Microcontrollers. The PIC32 offers a significant increase in functionality over the dsPIC33 and the other offerings from Microchip. This chip was evaluated following the evaluation of the PIC33 microcontroller to overcome its perceived shortcomings in the areas of Direct Memory Access, Interrupt Handling, and Millions of Instructions per Second. A brief summary of the functionality of the PIC32 follows in a table. The data was taken from the PIC32 datasheet provided by the Microchip Corporation:

1) High-Performance 32-bit RISC CPU
   i.   MIPS32® M4K™ 32-bit Core with 5-Stage Pipeline
   ii.   80 MHz Maximum Frequency
  iii.   1.56 DMIPS/MHz (Dhrystone 2.1) Performance at 0 Wait State Flash Access
   iv.   Single-Cycle Multiply and High-Performance
   v.   Divide Unit
   vi.   MIPS16e™ Mode for Up to 40% Smaller Code Size
  vii.   User and Kernel Modes to Enable Robust
 viii.   Embedded System
   ix.   Two Sets of 32 Core Register Files (32-bit) to Reduce Interrupt Latency
   x.   Prefetch Cache Module to Speed Execution from Flash

2) Microcontroller Features
   i.   Operating Voltage Range of 2.3V to 3.6V
   ii.   32K to 512K Flash Memory (plus an additional 12KB of Boot Flash)
  iii.   8K to 32K SRAM Memory
   iv.   Pin-Compatible with Most PIC24/dsPIC® Devices
   v.   Multiple Power Management Modes
   vi.   Multiple Interrupt Vectors with Individually
  vii.   Programmable Priority
 viii.   Fail-Safe Clock Monitor Mode
   ix.   Configurable Watchdog Timer with On-Chip

    x.   Low-Power RC Oscillator for Reliable Operation

3) Peripheral Features
    i.   Atomic SET, CLEAR and INVERT Operation on Select Peripheral Registers
    ii.   Up to 4-Channel Hardware DMA Controller with Automatic Data Size Detection
    iii.   USB 2.0 Compliant Full Speed Device and On-The-Go (OTG) Controller
    iv.   USB has a Dedicated DMA Channel
    v.   10 MHz to 40 MHz Crystal Oscillator
    vi.   Internal 8 MHz and 32 kHz Oscillators
    vii.   Separate PLLs for CPU and USB Clocks
    viii.   Two I2C™ Modules
    ix.   Two UART Modules with:
          a. RS-232, RS-485 and LIN 1.2 support
          b. IrDA® with On-Chip Hardware Encoder and Decoder
    x.   Parallel Master and Slave Port (PMP/PSP) with 8-bit and 16-bit Data and Up to 16 Address Lines
    xi.   Hardware Real-Time Clock/Calendar (RTCC)
    xii.   Five 16-bit Timers/Counters (two 16-bit pairs combine to create two 32-bit timers)
    xiii.   Five Capture Inputs
    xiv.   Five Compare/PWM Outputs
    xv.   Five External Interrupt Pins
    xvi.   High-Speed I/O Pins Capable of Toggling at Up to 80 MHz
    xvii.   High-Current Sink/Source (18 mA/18 mA) on All I/O Pins
    xviii.   Configurable Open-Drain Output on Digital I/O Pins

4) Debug Features

    i.   Two Programming and Debugging Interfaces:
    ii.   2-Wire Interface with Unintrusive Access and
    iii.   Real-time Data Exchange with Application 4-wire MIPS Standard Enhanced JTAG interface
    iv.   Unintrusive Hardware-Based Instruction Trace
    v.   IEEE Std 1149.2 Compatible (JTAG) Boundary Scan

5) Analog Features
    i.   Up to 16-Channel 10-bit Analog-to-Digital Converter:
    ii.   500 ksps Conversion Rate
    iii.   Conversion Available During Sleep, Idle
    iv.   Two Analog Comparators
    v.   5.5V Tolerant Input Pins (digital pins only)

The PIC32 offers a multistage pipelined 32-bit processor which is a massive improvement over the unpipelined architecture of the PIC33. One of the most important features of the PIC32 is the fast response times of the IO pins. The IO pin requirement is

directly proportional to how fast the device will eventually be able to update. A number of interrupts will need to be triggered for each measurement from each transmission source. Obviously, the latch time for the IO pins will occupy a considerable portion of the time spent queuing input from the receiver array. The PIC32 also contains a four port DMA bus that can allow each receiver unit to write its output directly into the memory of the microprocessor without the use of programmed IO. An additional feature that will be useful is the presence of 5 16-bit timers. Two of these timers can be used together to form a 32-bit real-time counter. As one of our design iterations calls for broadcasting Time of Arrival signal information as part of the transmission pattern, it would be very useful for the processor to be able to accurately measure and count time. The PIC32 also has 512kB of NAND flash memory and 32kB of internal random access memory. Additional features from the summarized feature list that are important to the success of our design include the double set of 32 32-bit registers that are designed to reduce the latency of interrupts by providing a separate subset of registers with which to process interrupt service routines. A low latency, pre-emptable software solution will be required for the needed processing to be done in a timely fashion. To this end, the following block diagram concerns the DMA input systems for the PIC32 and the discussion that follows will explain the importance of the design of this input system to the project.

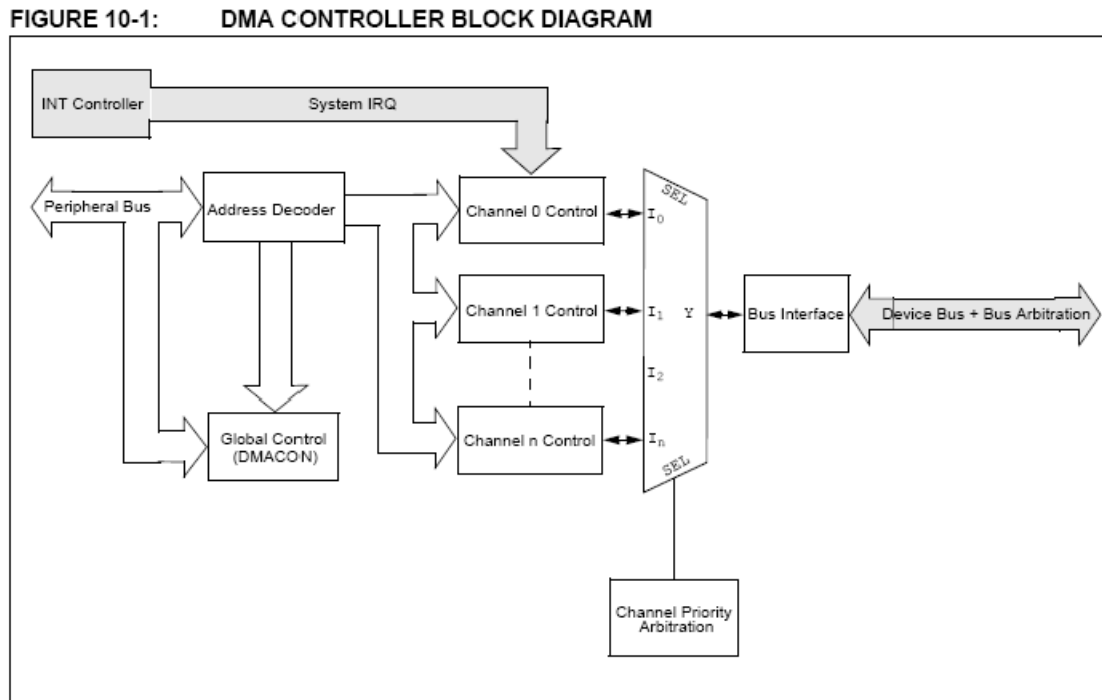FIGURE 10-1:   DMA CONTROLLER BLOCK DIAGRAM

Figure 13 – DMA Controller Block Diagram

The DMA controller described in Figure 12: DMA controller block diagram (permission pending) provides a simple way for the receiver devices to interact with the processor in a controlled manner without requiring the use of Programmed IO or Interrupt Driven IO. Removing the constraint on the processing unit of stopping and waiting or preempting the current running operations to handle the constant stream of input from the receivers will

serve to greatly improve both the cache coherency and pipeline efficiency for the PIC32. Obviously, the implementation of a DMA bus will add complexity to the system but a properly designed DMA bus will provide immense benefits to the overall system performance characteristics. Instead of the entire fetch/execution cycle being brought to a halt every time a piece of data is received and processed by the receivers, the receivers can instead lock the DMA bus and proceed to transfer the required information directly into the memory of the PIC32 for later processing without disruption. DMA has obvious advantages over both Programmed IO and Interrupt Driven IO, especially on a pipelined processor such as the PIC32. Despite the extremely fast clock speed, a critical issue in both the hardware selection process and later on during the software design process will be to avoid data and branch hazards in our code while also attempting to keep the pipeline from stalling. Unlike a more sophisticated 32-bit processor offering from Intel or AMD, our processor will not be clocked at several billion cycles per second: every cycle of the PIC32 must be made to count towards our design goals. It will be the full time job of one or more of our design team members to keep the pipeline from stalling and to maintain as much as possible the cache coherency of our eventual software package.
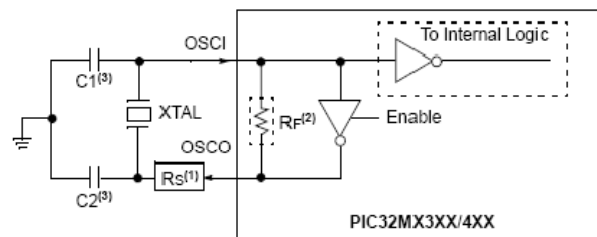
Note 1: A series resistor, Rs, may be required for AT strip cut crystals.
2: The internal feedback resistor, RF, is typically in the range of 2 to 10 MΩ.
3: Refer to the "PIC32MX Family Reference Manual" (DS61132) for help determining the best oscillator components.

Figure 14 - Crystal Oscillator Schematic (Reprinting Permission Requested)

A critical portion of any design including the PIC32 must be the crystal oscillator that will be used to drive it. The manufacturer provided reference manual contains an electrical schematic shown in Figure 14: Crystal oscillator schematic (permission pending) for hooking up a temperature corrected crystal oscillator to the PIC32 in order to assure that its internal clock circuits run in an accurate fashion. Proper construction of the oscillator circuit is an absolutely pivotal part of the device design.

The PIC32 was originally considered as a drop-in replacement for the dsPIC33 in case a pipeline processor with a larger word size was determined to be required by the software design. The design team discounted the use of the PIC32 microprocessor in favor of a more polished FPGA solution from another manufacturer. As was highlighted in Figure 21: Crystal oscillator schematic (permission pending), the design team was concerned with the requirement to drive the PIC32 internal clock circuitry with an accurate input signal. This need for accuracy in the internal clock signal arises from the possibility of

doing time of arrival calculations and the need for both transmitter and device clocks to be synchronized.

MC9S0QE Microcontroller

The MC9S0QE microcontroller is very robust microcontroller, its target applications include:

- Measurement equipment
- Gas, Water and heater meters
- Security Cameras
- Digital Cameras

Below is the 64 pin layout of the MC9S08 configuration.

Figure 15 - Chip - (Reprinting Permission Requested)

The device is perhaps more powerful than necessary to complete the basic tasks required for our device. Yet the power consumption of this microcontroller is very minimal for the feature it provides. Some of the key power saving feature are:

- Two ultra-low power stop modes, running with a voltage supply of 1.8 to 3.6 volts.
- Ultra-low power wait mode, this will allow the running of our applications in a reduced power state which would extend our battery life. This would be particularly useful during the night time hours.
- The chip also allows us to take full advantage of its programming, with up to 128 KB of On-Chip Memory.
- For 1 chip the price is 4.21 dollars at Digi-Key Corporation.

The MC9S0QE also would meet the temperature requirements, handling temperature ranges of -40 degrees Celsius to +85 degrees Celsius.

Since our project requires us to store and transmit data, the peripherals inside the MC9S0QE could greatly simplify our design. With Analog Digital Converters and Serial Communication Interfaces, the transfer of data to and from the base station could be achieved with multiple solutions. The basic premise of researching the microcontroller is that we do not want to be bottlenecked in our design from the constraints of this part. Microcontrollers a fairly cheap, and run on very little power, getting a slightly more power microcontroller than necessary for prototyping may be in the best interest of the group.

The follow is the Block Diagram for the S08QE128 from Energy Efficient Solutions. Figure 16 below shows all of the necessary outputs as required by this project, including things like an onboard voltage regulator so we will not need to give it a specific voltage but a range as will as 2 SPI ports allowing us to interface more than one device at a time.
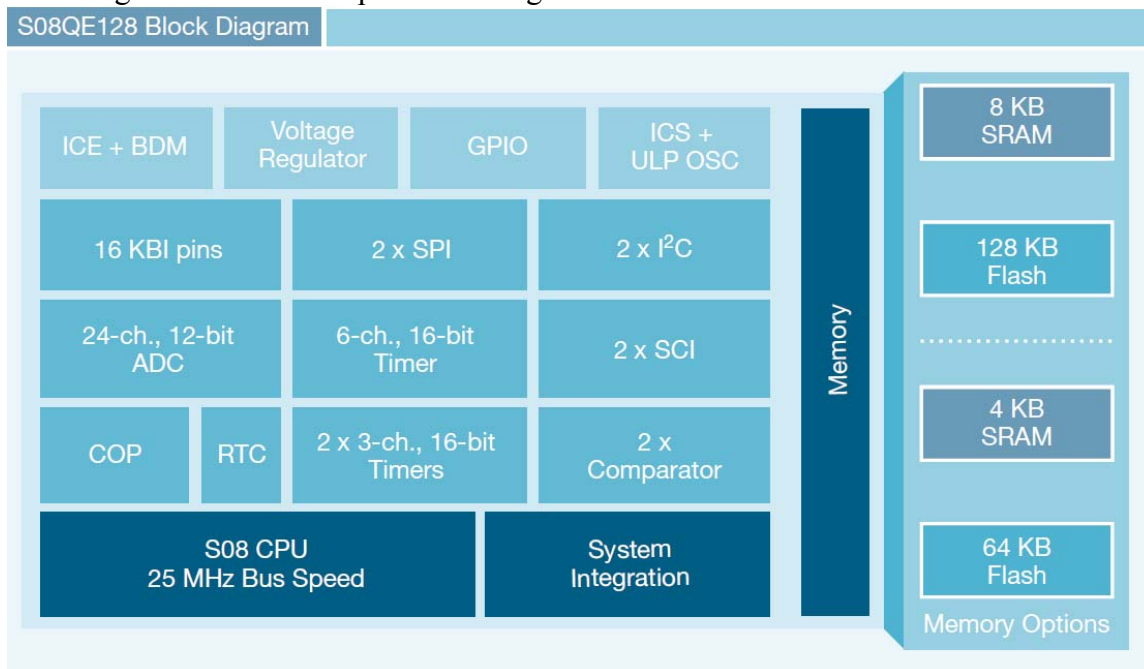
Figure 16 - S08QE128 Block Diagram (Reprinting Permission Requested)

MSP430 Microcontroller

The single greatest thing with choosing to use the MSP430 would be the support and wealth of information to help us programming and come up with a design. Texas instruments has spent a great deal of money to support this family of microcontrollers and our project could do well by choosing to use that information to guide us in our programming. This is also a very affordable solution, only 8.75 per chip at Digi-Key Cooperation. Below is a 48-pin diagram or a standard MSP430.
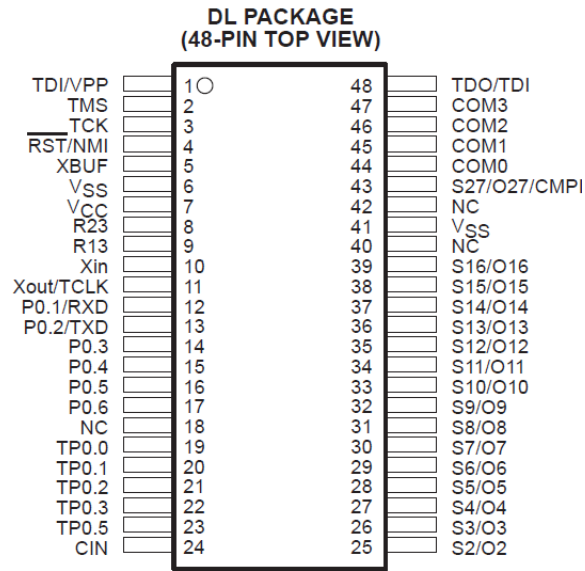
DL PACKAGE
(48-PIN TOP VIEW)

TDI/VPP	1	48	TDO/TDI
TMS	2	47	COM3
TCK	3	46	COM2
RST/NMI	4	45	COM1
XBUF	5	44	COM0
V$_{SS}$	6	43	S27/O27/CMPI
V$_{CC}$	7	42	NC
R23	8	41	V$_{SS}$
R13	9	40	NC
Xin	10	39	S16/O16
Xout/TCLK	11	38	S15/O15
P0.1/RXD	12	37	S14/O14
P0.2/TXD	13	36	S13/O13
P0.3	14	35	S12/O12
P0.4	15	34	S11/O11
P0.5	16	33	S10/O10
P0.6	17	32	S9/O9
NC	18	31	S8/O8
TP0.0	19	30	S7/O7
TP0.1	20	29	S6/O6
TP0.2	21	28	S5/O5
TP0.3	22	27	S4/O4
TP0.5	23	26	S3/O3
CIN	24	25	S2/O2

Figure 17 - MSP430 Pin Layout (Reprinting Permission Requested)

A list of some of the applicable features the MSP430 could bring to our project:
- Low Supply voltage Range 2.5v – 5.5v (This is ideal for us because the solar panel device is pulling power from the panels, the power the voltage the better).
- Ultra Low-Power Consumption
- Five Power saving Modes/Standby Modes (great for operation during night hours)
- Quick Wakeup time (6microseconds)
- A/D Converter
- EPROM versions of MSP430 chips for the use in prototyping **this could be very good since none of us have much experience in programming microcontrollers.
- Can be battery operated.
- Time Tested and a market standard for excellence, which will resonate with our sponsors.
- Fulfills all temperature requirements.
- Through Documentation *31 page data sheet.
- Example Schematics.
- Active Forum community if we have any questions.

Microcontrollers:

Indeed there are several dozen microcontroller architectures and vendors * Wikipedia
- 68HC11
- 8051
- ARM

- STMicroelectronics STM8S
- Atmel AVR
- Freescale ColdFire
- Hitachi H8
- MIPS
- PIC
- MSP430

The world of microcontrollers have a diverse market and trying to find the right microcontroller could be as easy as saying 'we want what works' or as time consuming as 'we what the best bit.' The overall architecture of the project is to be cost efficient and to be building the solar device with the intention of going into low-rate production. With this architecture in mind more specific solution may be required for the final design. Needless to say, a great deal more research is necessary to come to any meaningful conclusions.

The basic qualities we are looking for in a microcontroller are the following:
- Perform within a wide spectrum of temperatures and humidity's.
- Be low maintenance and have a long off-the-shelf life span.
- Have embedded wireless functionality.
- Have low power consumptions
- Have a strong community to pull from in the form of example code and tutorials.

Base Station

Firmware

The DD-WRT firmware offers several ways to obtain access to its configurations to make changes. The primary way is by logging into the router via its web interface (typically by pointing the router to the default gateway IP address: 192.168.1.1). Here, the default password can be changed. This is a mandatory step since in the future the router will be configured to allow remote connections from outside the LAN, and intruders may stumble across the router and make malicious changes. An image of the web interface is shown below. It shows the many different configuration tabs for the DDR-WRT firmware compared to the standard firmware provided by the factory.

Figure 18 - DD-WRT Web Interface - Reprinting Permission Requested

The second most popular way to make changes to the router is by logging into it through a command line. This can be done either by Telnet or SSH. The username to obtain access to the firmware's command line is "root" and the password is the password that is set within the web interface (described in the preceding paragraph). Telnet is enabled by default and SSH must be enabled via the web interface. Telnet and SSH are very similar to each other. Telnet was developed in 1969 and is a network protocol that provides bidirectional interactive communications between a client and server. The client in this case would be us configuring the DD-WRT firmware the server will be the router that has the DD-WRT firmware installed. The telnet protocol is a very old and unsecure protocol to use. Although the nature of our project is not sensitive or proprietary, the medium of communication is not that crucial. SSH is the predecessor of telnet. It was designed to replace telnet and provide a more secure medium to transmit the data between the client and server via encryption.

SSH must be enabled through the firmware's web interface. There are two ways to configure how a user logs into the router via SSH: username/password or clients whose public keys are manually entered into the web interface. The public key method would provide additional security because only the client and server would have the public keys; however, it's more a hassle. Therefore, the likely way that we will do it is via username and password.

In order to enable SSH via the web interface, we must navigate to the Administration tab. Under the Services sub-tab, there is a checkbox labeled "Enable SSHd" within the Secure Shell section. In order to use the username/password scheme, the checkbox labeled "Password Login" must be enabled. If the public key method is used, the public key must be copied and pasted into the "Authorized Key" box within the same section.

Telnet is a standard program that comes with Linux and Windows, and therefore a

download will not be needed in order to access the router. A program that can connect to a server with SSH on the other hand will need to be downloaded. There are several programs that can handle this. The one likely to be used within our project is Putty. Putty is a free SSH client created by Simon Tatham and distributed under the MIT license.

Web Server

One of the great features of the DD-WRT firmware is that its web server can be customized. The firmware runs a small web server that is used by an admin to configure the router for use. It can be customized to serve pages to the outside world. This is needed in order to display and serve the solar panel string's information. The firmware must be configured to allow such a web server to run, and thus would be best before being deployed out into the field. There are several tools that are needed in order to log into the router and configure its web server.

First of all, telnet or Secure Shell (SSH) must be enabled on the DD-WRT run router. This can be done via the web interface of DD-WRT. Then, a telnet or SSH client must be used to gain access to the router to manipulate its configuration to allow the web server to be accessed from outside the LAN. Then, the files that want to be hosted on the web server must be sent over the SSH connection. After this is done, the SSH or telnet connection the router can be closed. The web server must then be stopped and restarted via the web configuration module of DD-WRT. Under the Administration and then Diagnostics page, press "Run." Enter the following lines into the command box:

```
killall httpd
cd /www
httpd -p 81 -h /www
cd /jffs
httpd -h /jffs
/usr/sbin/iptables -I INPUT 1 -p tcp --dport 80 -j logaccept
```

If the web server ever needs to be shut down, the following command can be used:

```
kill `cat /tmp/var/run/httpd.pid`
```

With the opening of the router to the outside world via a web server comes potential security risks. Security risks involved in doing this must be researched, analyzed, and mitigated in order to ensure that the integrity of the system is not compromised. Uptime and stability is one thing that the solar panel monitoring device as a whole must incorporate (the solar panels themselves have a ~20-50 year warranty for example). The potential security risks involved in implementing a web server to the outside world is outlined in the section below.

Security Risks

Opening a web server to the outside world opens the base station to potential security hazards. The base station must be able to withstand these security hazards in order to preserve the integrity of the system—the system must not falter under such conditions introduced by the vulnerabilities of a web server. In this section, the potential security risk of having an open web server to the public world will be researched, analyzed, and attempted to be mitigated for future implementation.

First of all, web servers are one of the number one launch platforms for new malware and spam attacks on the internet today. They are being scanned for by malicious programs and people in order to exploit to launch attacks. The scanning of web servers is nearly automated by programs scanning the entire global Internet Protocol (IP) address map. Therefore, the likelihood of our base station's web server being found is highly likely. The type of web server at first is unknown, but the base station must be able to withstand the initial scan and intrusion attempt.

One way of mitigating such an attack is to block all traffic to the base station except those IP addresses approved. The ASUS WL-520gU router supports because it runs on Linux kernel and supports iptables, which is seen when setting up the web server on the DD-WRT custom firmware. Iptables can be used to restrict the incoming traffic to the port used for the web server. However, this also introduces some flaws in the project's design. The solar panel string will not be able to be monitored from anywhere in the world. Instead, it will only be able to be monitored from an already known IP address. In addition, IP addresses are usually not static and therefore change every so often. This will eventually lead to no one being able to access the web server to view the solar panel information. Therefore, the iptables method of restricting traffic to the web server is invalid. If one did persist on having the iptables method of restricting connecting parties, the following command can be issued within the command line:

```
iptables -I INPUT -p tcp -s <remote_location_ip> --dport 80 -j
ACCEPT
```

A secondary method of protecting the web server on the base station is to introduce a complex password. This keeps the web server in the open so that anyone can view the solar panel information if they have the correct access—and therefore the permission of the owner. The DD-WRT firmware by default has an administration section on its web server to configure the features of the router and firmware. The base station portion of the project can be hosted within this section to ensure that a password must be entered each time a new visitor arrives to the web server. The password must be complex, however, to mitigate brute force attacks. If an attacker were to get access to the router configuration, the base station could be rendered useless and data from the solar panels

would be lost until the issue is corrected.

In addition to the security risks involved in running a web server on the public internet domain, having SSH or Telnet enabled on the router presents a whole series of problems as well. Similar to web server sniffers, there are programs out there that try to scan servers on the internet that run SSH. When a server is found, they will try to brute force the password until they obtain access. The most common way they determine whether or not a server has SSH running on it is by scanning the default SSH port, 22. Therefore, a random non-standard port should be used (i.e. 4678). This is most important since most our router will be exposed to the outside world.

Data Handling

The main purpose of the base station is to receive the data transmitted wirelessly from the string device and then format in such a way that it is presented to a remote user via a web server. This section will describe how the data is collected, manipulated, and displayed upon the web server. Scripts will have to be run on the router. Therefore, different scripting languages supported by the router will be looked at. Also, the different formats of displaying web pages will be analyzed as well.

Scripting

The ASUS WL-520gU router runs on a simplified version of Linux. Therefore, it supports several scripting languages, including two shell scripting languages: ash and bash. The Linux also supports a slim down version of CGI. The scripting languages will aid in the automation required in analyzing the data received from the string device. Also, the scripts will be responsible for formatting the received data and creating a presentable web page to broadcast to the world over the router's web server.

Shell Scripts

This section will briefly describe the two shell scripting languages supported by the router's Linux operating system.

Bourne Shell

The Bourne shell scripting language is the primary shell language of the router. The Almquist shell is a clone of the Bourne shell. According to Wikipedia, the Bourne shell, or sh, was the default Unix shell of Unix Version 7, and replaced the Thompson shell,

whose executable file had the same name, sh. It was developed by Stephen Bourne, of AT&T Bell Laboratories, and was released in 1977 in the Version 7 Unix release distributed to colleges and universities. It remains a popular default shell for Unix accounts. The binary program of the Bourne shell or a compatible program is located at /bin/sh on most UNIX systems, and is still the default shell for the root superuser on many current UNIX implementations.

A benefit to using the DD-WRT firmware with the ASUS WL-520gU router is that DD-WRT can interpret shell scripts as CGI scripts and display the content to a web page. The shell scripts can also be used to automate the web server. The below snippet is from a shell script that will enable the web server when it is requested from the internet. The author of the script has been e-mailed seeking permissions for reprinting.

```sh
#!/bin/sh

INTERVAL=5
NUMP=3
OLD=""
WOL=/usr/sbin/wol
TARGET=192.168.1.100
MAC=00:00:00:00:00:00
logfile="/tmp/www/wol.log"

while sleep $INTERVAL
do
NEW=`cat /var/log/messages | grep ACCEPT | grep "DST=$TARGET" |
grep "DPT=80" | tail -1 | awk '{print $3}'`
SRC=`cat /var/log/messages | grep ACCEPT | grep "DST=$TARGET" |
grep "DPT=80" | tail -1 | awk '{print $10}' | sed -e "s/SRC=//g"`
LINE=`cat /var/log/messages | grep ACCEPT | grep "DST=$TARGET" |
grep "DPT=80" | tail -1 `
if [ "$NEW" != "" -a "$NEW" != "$OLD" ]; then
echo "$SRC $LINE"  >> $logfile
RET=`ping -c $NUMP $TARGET 2> /dev/null | awk '/packets received/
{print $4}'`
if [ "$RET" -ne "$NUMP" ]; then
  echo "$SRC causes WOL at" `date`  >> $logfile
  $WOL -i 192.168.1.255 -p 7 $MAC  >> $logfile
  sleep 5
fi
OLD=$NEW
fi
done
```

HyperText Markup Language

HyperText Markup Language, most commonly known as HTML, is the dominant markup language for web pages. It creates structured documents—interpreted by web browsers—by denoting structural semantics for headings and paragraphs. It was initially

developed by Berners-Lee in 1991. Since its release, there has been seven major releases and updates to the HTML markup language. There are many scripting languages that people program in where the end result is a web page displayed via a web server. These scripts, when executed, generate the necessary HTML code to display the web page properly.

Components

Wireless

The primary motivating factor behind QuickBeam Energy's proposal for this project is its wireless capability. In the past, sensor networks were built using wires, which quickly became more of a hassle than relief. Some solar arrays may have sensors on each solar panel to track whether or not it is online. Each sensor would be attached to a power source and a base station—for reading its online signal—via wires. The massive amount of wires contributes to greater complexity when maintaining and installing solar panels. The goal is to relieve this cumbersome requirement of wires and install more simple sensors via wireless technology. This section will describe what research went into the various different types of wireless technologies when designing this project.

There are several wireless communication technologies that meet the requirements of our project: radio frequency, Wi-Fi, Bluetooth, and Zigbee. Each of these types of communication channels have been researched thoroughly in order to determine the one that would fit our specifications the best. Before a decision can be met, several aspects of each technology must be analyzed:

1. What is the optimal range of the wireless technology?
2. What kind of interference is the wireless technology prone to?
3. What is the cost of implementing the technology?
   a. How much does each chip cost?
   b. Do we need a transceiver or just a transmitter?
   c. How much does it cost for a device that the wireless technology will interface to?
4. How much power input does the wireless technology require?
5. Will the wireless technology be able to perform thoroughly through times where no solar power is provided?
6. Does the wireless technology require an antenna?
   a. If so, where will the antenna be placed/mounted?
   b. How much would an external antenna cost?
   c. What range benefits do each antenna provide?
7. What is the bandwidth of the wireless technology?
8. How will the information be transmitted?
   a. Does it need to obtain an IP address?

　　　　　　　　i. If so, will it need to be preconfigured?
　　　　　　　　ii. If so, will it obtain one automatically via a DHCP server?
　　　　　　b. Will the data be encrypted?
　　9. Will the sensor need confirmation that data was received?
　　10. If so, what is the best way to acknowledge reception?
　　11. How often will the data be transmitted to the base station?
　　12. Will each sensor have a unique identifier?
　　　　　　a. If so, how will the particular wireless technology handle a unique identifier (i.e. MAC address)
　　　　　　　　i. If no MAC address, will it be hard coded?
　　13. If there needs to be predefined information for each sensor, how will it be stored?
　　14. How do we receive the information from the voltage and current sensors and transmit the data to the base station?

802.11 - Wi-Fi

The IEEE 802.11 (Wireless Local Area Network) protocol is the most widely used computer related wireless communication technique. The term Wi-Fi® is a registered trademark of the Wi-Fi Alliance®. The protocol has been in constant development and streamlining since its release in 1999. Because of this wide range of use, the availability of buying such Wi-Fi microchips for embedded devices is very high and feasible.

Before we can determine if Wi-Fi is the way to go, we must first analyze the capabilities of Wi-Fi and see if it will meet the requirements of our project. The range of typical Wi-Fi configurations meets our requirement. The first IEEE 802.11a was released with an optimal range of 50 feet. However, this range can be amply boosted with the use of an external antenna.

ZeroG Wireless (http://www.zerogwireless.com) has a product that meets the requirements of our project. They have a subset of chips called the ZG2100 class, which is available in two forms. One chip, the ZG2100M, contains an on-board PCB antenna. The second chip, the ZG2101M, is used with an external antenna for extended range. Depending on the base station's wireless range, an external antenna may or may not be needed. Below are brief specifications for the two chips, as advertised by ZeroG Wireless.

- Wireless Standard: IEEE 802.11b
- Data Rate: 1 & 2 Mbps
- Wireless Security: WEP, WPA-Personal, WPA2-Personal
- Host Interface: SPI
- Supply Voltage: 2.7V – 3.6V
- Operating Temperature: 0 – 70 Degrees Celsius
- Module Dimensions: 21mm x 31 mm x 3.7 mm

- Certifications and Compliance: FCC, IC, ETSI, Japan, Wi-Fi, CE, RoHS

Below are two block diagrams of the ZeroG wireless modules. The first block diagram is a bubble block diagram listing the different modules per chip, and the second block diagram is a functional block diagram.

ZG2100M/ZG2101M Block Diagram

RF Filters	PCB antenna (ZG2100M only)	1.8V Regulator
2.4GHz Radio	IEEE 802.11 LCC 802.11 MAC 802.11B Protocol	AES, TKIP Hardware Accelerator
SRAM		
ROM	Power Management	SPI

Figure 19 - ZeroG Wireless Diagram - Reprinting Permission Obtained 11/12/2009
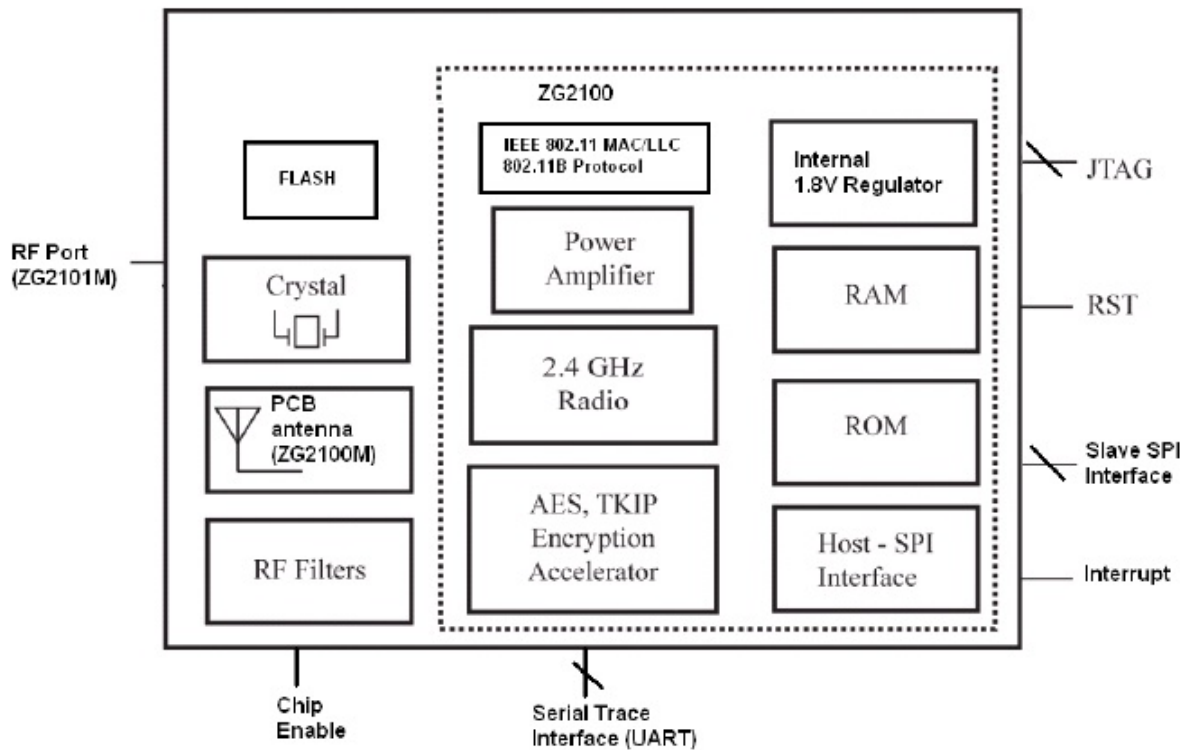
Figure 20 - ZG2100M/ZG2101M Functional Block Diagram - Reprinting Permission Obtained 11/12/2009

ZeroG Wireless marketing angle is: low design effort, low power consumption, low system requirements, and low system cost. Some key features of the ZG2100M and ZG2101M will be outlined here. The chips come with an on-chip serialized MAC address. This is a benefit because it reduces processing power on addressing each transmission. The modules come with a suite of API calls, which makes programming, interfacing, and performing complex tasks much easier. The chips are both capable of running at very low power levels. Normal operation requires 2.7V to 3.6V, and each chip can go into sleep or hibernation mode requiring 250μA and 0.1μA respectively. Sleep and hibernation may be required in order to save battery life in between communication streams when solar power is not provided. The power sequence for these three power stats (on, sleep, and hibernate) is below.

	VDD33	VDD18	CE_N	Circuitry
OFF	0V	0V	0V	Power disconnected to ZG2100
HIBERNATE	3.3V		3.3V	All internal circuitries are OFF
SLEEP	3.3V		0V	Reference clock and internal bias circuitry are ON
RX ON	3.3V		0V	Receive circuits are ON
TX ON	3.3V		0V	Transmit circuits are ON
STANDBY				Transition State Only

Figure 21 - ZG2100M/ZG2101M Input Power Chart - Reprinting Permission Obtained 11/12/2009
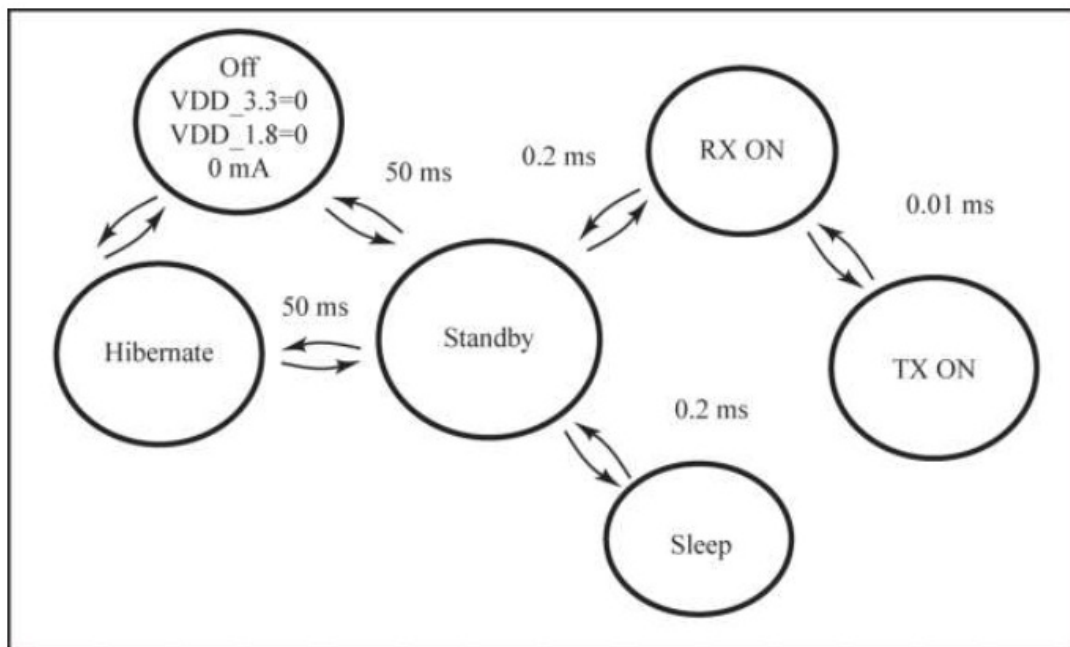
Figure 22 - ZG2100M/ZG2101M Power Sequence Diagram - Reprinting Permission Obtained 11/12/2009

The normal operating conditions is 25° C with 3.3V supplied to the VD33 pin. The maximum storing temperature is 125° C and the minimum -40°C. The maximum voltage to the VDD33 is 4.2V. The table below shows the power consumption under the normal operating conditions:

Power Conservation Modes	Min	Typ	Max	Unit
Hibernate, CE_N=3.3v		0.1		uA
Sleep		250		uA
Standby (transitional power state)		10		mA
Core Supply	Min	Typ	Max	Unit
Rx On, Receive Irx, -83dBm		85		mA
Tx On, Transmit Itx, +0dBm		165		mA
Tx On, Transmit Itx, +10dBm		230		mA

Figure 23 - ZG2100M/ZG2101M Power Consumption - Reprinting Permission Obtained 11/12/2009

The ability to use an external antenna makes this set of chips very appealing. The distance between a solar panel's junction box and the base station for the solar panel can vary depending on the location. However, the prototype will require a range of 50 feet, and therefore an external antenna will be needed. The interfacing board must supply a crystal for the reference clock. The modules both support 1 Mbps & 2 Mbps of data streaming with the 802.11b protocol. They also have hardware support for AES, TKIP, and RC4 encryption (WEP, WPA, and WPA2). The RF component of the chips comes with all required parts: crystal oscillator, bypass and bias passives, and an antenna (only ZG2100M). The chips are controllable via an 8 or 16-bit processor. They are interfaced with Serial Peripheral Interface (SPI) with an interrupt for operation. The chips support RS232 for debugging. The chip is manufactured on a Flame Retardant 4 (FR4) Printed Circuit Board (PCB) with components only on the top side. The chip is connected to a PCB as a surface mount component with flat pack connections on both sides (36 total).

Below is a diagram showing where to place the antenna in the ZG2101M chip:
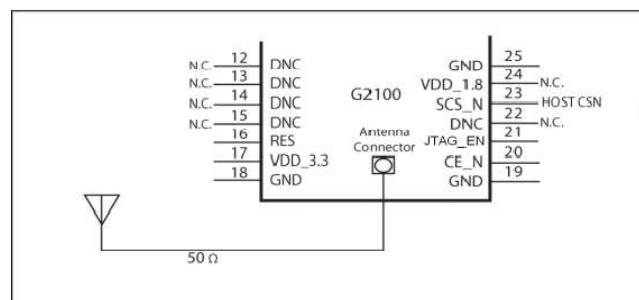
Figure 24 - ZG2101M Antenna Placement - Reprinting Permission Obtained 11/12/2009

Below is a figure showing the different PIN functions of the ZeroG wireless module. The wireless module will most likely be interfaced to a PICtail daughter board and then connected to an Explorer 16 board. Therefore, the function of each pin is a good thing to know considering the pins will be plugged into a development kit. ZeroG provides code that will use some of these pin's for its demonstrations. The development kit's demonstrations are forecasted to be tested in order to become familiar with the board.

Pins	Name	Internal	Required Bias	Description
1	GND			Ground
2	VDD18			See below
3	JTAG_TDO	H		JTAG data out
4	JTAG_TCK		Constant drive	JTAG Clock in
5	JTAG_TMS	H		JTAG Mode in
6	JTAG_TDI	H		JTAG data in
7	RST_N		Constant drive	Chip reset in
8	DNC			Do Not Connect
9	JTAG_RST_N		Constant drive	JTAG Reset in, pulling this pin low will keep JTAG idle (reset)
10	GND			Ground
11	VDD18			See below
12	DNC			Do Not Connect
13	DNC			Do Not Connect
14	DNC			Do Not Connect
15	DNC			Do Not Connect
16	RES		Pull-down	FLASH Write Protect. See below.
17	VDD33			3.3V Power
18	GND			Ground
19	GND			Ground
20	CE_N			Chip enable in
21	JTAG_EN	L		JTAG Enable in, this pin needs to be high for Boundary Scan use
22	DNC			Do Not Connect
23	SCS_N		Constant drive	Serial chip select from host (input)
24	VDD18			See below
25	GND			Ground
26	UART_RX	H		Debug Serial in
27	UART_TX			Debug Serial out
28	GND			Ground
29	VDD33			3.3V Power
30	GND			Ground
31	VDD18			See below
32	SDO			Serial data out to host
33	INT_NX		Pull-up	Interrupt to host (output)
34	SCK		Constant drive	Serial clock in from host
35	SDI		Constant drive	Serial data in from host
36	GND			Ground

Figure 25 - ZG2100M/ZG2101M Pin-Out and Function - Reprinting Permission Obtained 11/12/2009

The dimensions of the two chips are illustrated below in the two figures. The first figure shows the dimensions and layout of the ZG2100M chip, while the second figure illustrates the dimensions of the ZG2101M chip with external antenna support.
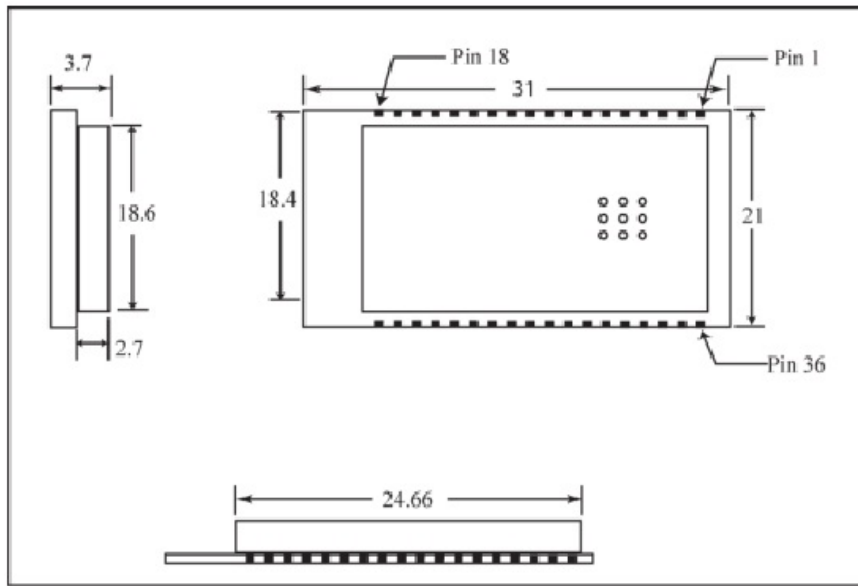
Figure 26 - ZG2100M Module Drawing - Reprinting Permission Obtained 11/12/2009
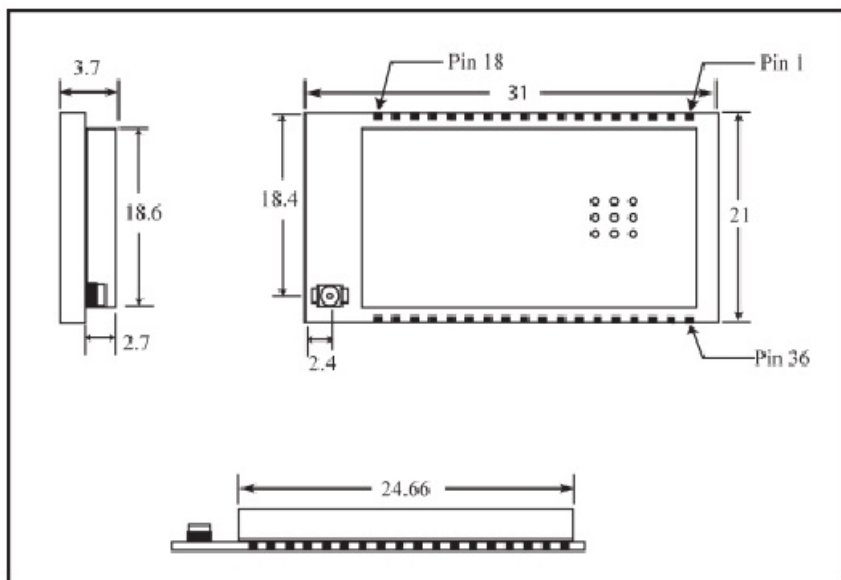
Figure 27 - ZG2101M Module Drawing - Reprinting Permission Obtained 11/12/2009

The chips have several constraints when being interfaced. There are four keep away areas of the chip to maintain optimal performance. Also, if the ZG2100M chip with the onboard PCB antenna is used, the enclosure for the sensor and base station should not be metallic or metalized plastic. Such enclosures will impede the antenna's ability. Below is a picture showing the stay away areas of the chips:
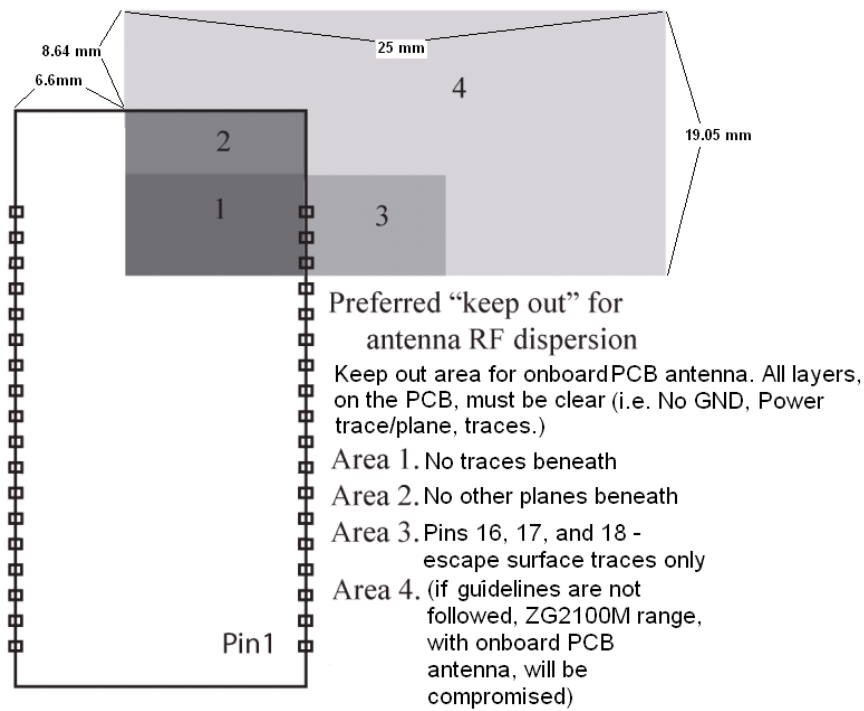
Figure 28 - ZG2100/ZG2101M Keep Away Areas - Reprinting Permission Obtained 11/12/2009

Below is a schematic of the chip and the electrical connections for each pin:
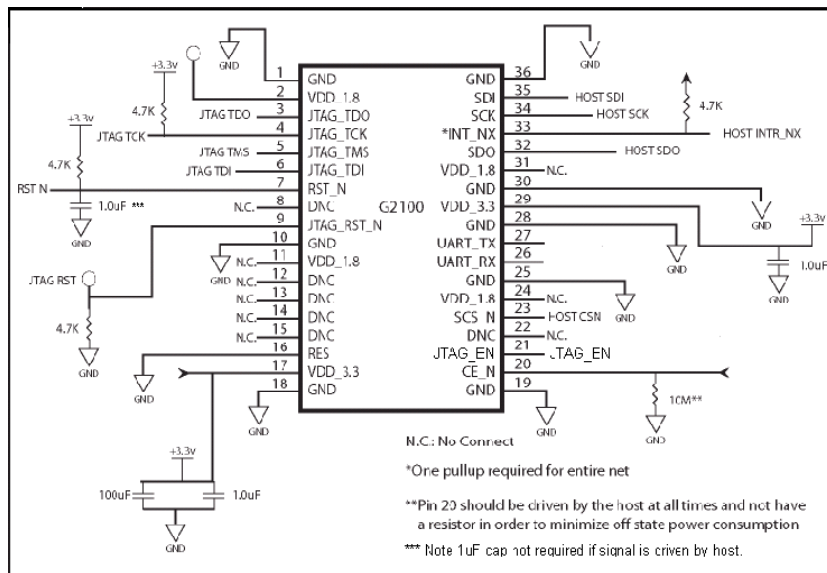
Figure 29 - ZG2100M/ZG2101M Module Use Schematic - Reprinting Permission Obtained 11/12/2009

Interfacing

The ZG2100/ZG2101 chips can be interfaced to almost any 8, 16, and 32-bit microcontroller unit. While researching for this project, a good microcontroller must be selected for use with the wireless component. Robbie did the microcontroller research, and it can be found in the previous section. However, this section will describe a little further about how to interact with the ZG2100 module chips regardless of the host microcontroller.

Power

String Device

The key to the research for this device has been surrounded by the fact that we have a large DC voltage coming in from the solar panel string. The voltage range from 6-600 volts is a very large voltage to deal with. The first part is to find a way to detect that voltage and current to accurately transmit this data, after all that is the whole intent of this project. The second part will be to turn that voltage range into a constant voltage for the purpose of storing that voltage in a battery.

The voltage and current sensing can be done in a few ways. In the power industry, they use devices that step down the voltage to measurable ranges. They use transformers to step down voltages to detect them in ranges that are safer and more manageable to measure. Our nation's power grid is AC power; because of this the transformers cannot be used for our application. So in order to detect the voltages we need to construct a voltage dividing circuit for an integrated device to detect the range necessary for this application. In conjunction with a shunt resistor a device that can measure voltage across that resistor will tell us all we need to know about the power profile of the solar string.
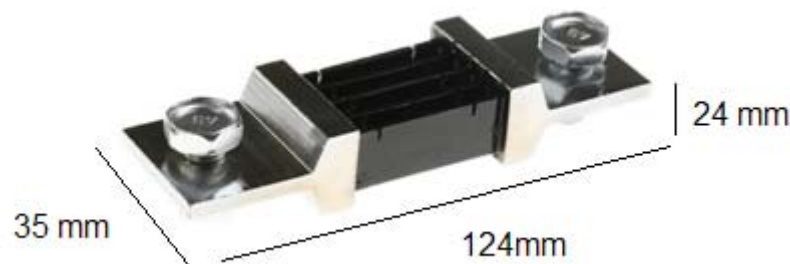
Figure 30 - Shunt Resistor Dimensions

There is another device that is used for higher current detection. Hall Effect sensors use the surrounding magnetic field associated with flowing current to send the correct data. The device that we have selected for use is the LEM FHS 40-P/SP600. This device detects from 0 to 100 Amps. It will require a placement on the Bus bar of the string

junction box, as indicated in the figure bellow. It will also have the option depending on the layout of the junction box to be mounted near a wire and be able to detect the current as well, as depicted in the Figure 32 and Figure 33 bellow, depending on how the sensor is mounted.
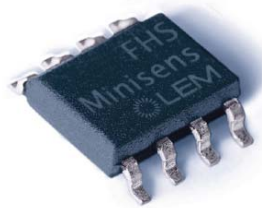
Figure 31 - LEM FHS 40-P/SP600 (Reprinting Permission Requested)
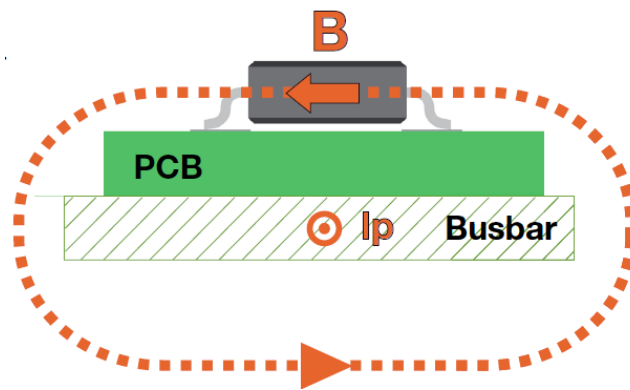
Figure 32 - Placement of the LEM FHS 40-P/SP600 (Reprinting Permission Requested)
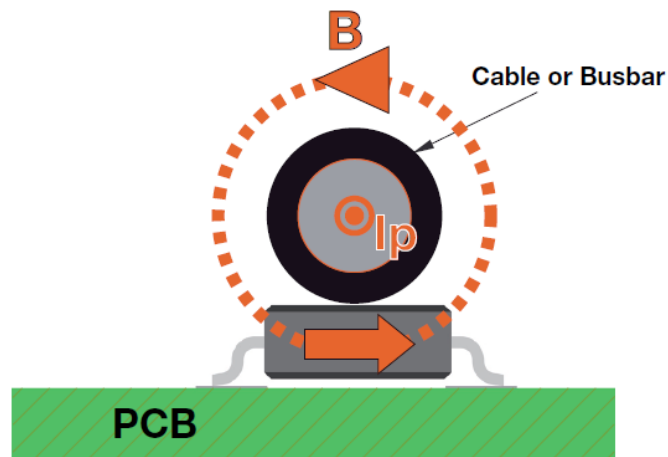
Figure 33 - Placement of the LEM FHS 40-P/SP600 on Bus bar of solar string

(Reprinting Permission Requested)

The only down side to using a device such as the LEM FHS 40-P/SP600 is the variability of the sensitivity depending on the distance from the conductor carrying the current we want to measure as depicted in the graph below. We have determined that the distances and level of sensitivity at those distances will be expectable for this application.

Sensitivity function of distance
(thin and long conductor)
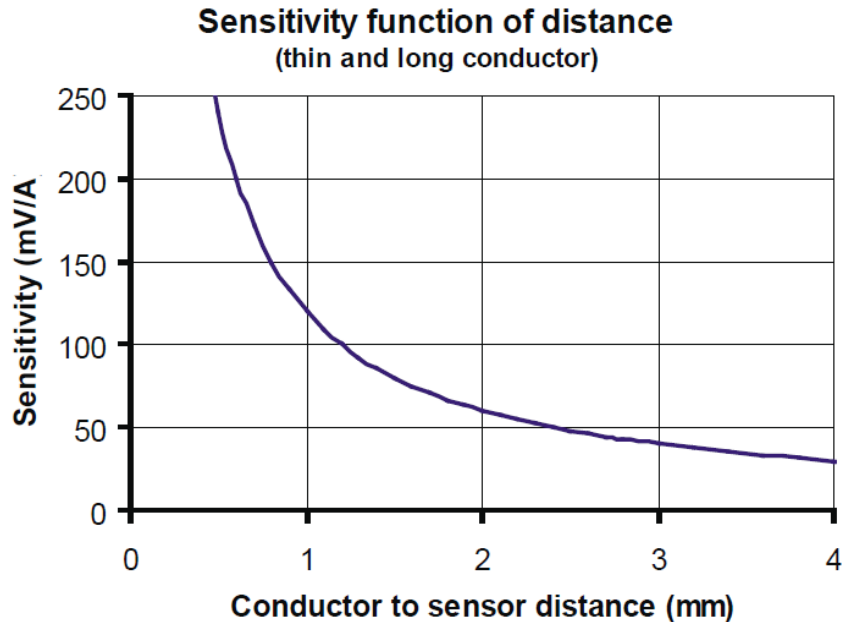
Figure 34 - Graph depicting the Sensitivity to Distance of the LEM FHS 40-P/SP600 (Reprinting Permission Requested)

There are a few applications that are used to convert DC to different DC voltages. Shunt Regulators are constructed from a type of diode and series resistors. This type of devices has several drawbacks. They provide no constant voltage output, as they act as a voltage divider using ohms law to lower the voltage. This means that the input voltage proportional to the output voltage. It also requires that we know the exact resistance of the load which we do not know. The main problem is efficiency as resistors dissipate most of that power as heat.

The next option for DC to DC conversion is linear regulators. These devices are centered around the use of transistors to create a clean stable power output. They can be found as integrated circuits which is helpful to this application. As before with the shunt regulator, this device is also using resistance in series with the load which can decrease efficiency. Also the ability of these devices to have clean power is not necessary to charge a battery. If we were powering an analog device directly it might be necessary because dirty DC power could affect the results. These devices can also be only found for low voltage applications, which rule them out completely because we need to regulate a relatively high DC voltage.

This leaves only one more DC to DC converter. Switching regulators work similar to how a linear regulator functions. For one exception, the principle of how they function is in its

name it uses a transistor to switch on and off a series element. This stabilizes the voltage by charging an inductor or capacitor bank, switches the input off, discharges the inductors or capacitors and the cycle starts over again. This creates less power loss than the first two applications because they are not always putting elements in series as they are switching on and off. The most important part as to why this is a good choice for our devices is that is extensible for voltage ranges closer to what is required. Like linear regulators the operational device of switching regulators is contained in an integrated circuit. But they have external elements that are required that can be quite large as large value inductors and capacitors are needed to charged by the input. Also they have one other advantage to linear regulators, they are capable of raising a lower input voltage to a higher regulated voltage, which for our application is useful because we only have a limited time to charge our battery due to the nature of solar power.

In review we have chosen to use a switching regulator to convert of Solar String power into a regulated power source for our device. But unfortunately we have a small problem with the Switching regulator. The largest voltage range we could find was the LM5116 which has an operational input voltage range from 4.5 volts to 100 volts which is only 1/6th the voltage we might expect to have. So another solution must be added to get the needed range.

There are many ways to control how much voltage gets to the regulator. We have found that a network of MOSFET devices controlled by a digital device can control how much voltage gets to our regulator. In order to do this we need MOSFET devices that can handle 100 volt switching, and put them in series up to our expected maximum of 600 volts. These devices need to be controlled by a device that knows what the input voltage is. This we are already doing as stated in the beginning of this subsection, so we will adapt a digital controller to activate opto-couplers to turn on the MOSFETs. The main reason opto-couplers should be used is if on MOSFET is if one fails it will isolate it from the rest of the devices, if not input voltage and current could get into our digital system which doesn't need to be stated, would be bad, as it will possibly destroy all of the MOSFETs that otherwise would still be functioning.

Base Station

As the base station will be located inside the utility housing we are given the assumption by QuickBeam Energy is that there will be a 120 VAC outlet located by the also assumed internet connection.

To allow for use even when there is an outage, we will make use of a consumer UPS which will supply all the power needed for at least 24 hour if not more for data collection and continuing connection to all of the string devices.

Similar Projects

This section shows the projects that are similar to ours. As engineers we are told to learn from others, to find the right and easy solution, and to not 're-invent' the wheel. A lot of these doctrines that the engineering program has instilled in us are displayed by using the similar projects from other senior design groups. Not only have they embarked on the same task as having to write a paper to the same level of professionalism desired by us, but they have already done the research we ourselves are conducting. These projects are often an incredible wealth of information, from deciding on what sections we should write about, to looking at other group's research on microcontrollers. Below are some of the more key note projects that our group looked and decided to show in our similar projects portion of the document.

The Wee Wireless USB

This group, which during the fall 2007 semester completed their senior design I paper, it was a three person group and helped us with our formatting as well as with several of our research topics. The following is a paraphrasing of their executive summary:

"The Wee USB Wireless is a reliable, inexpensive, handy wireless USB device with a seamless interface that can be used to wirelessly transmit data, with minimum errors, between a computer and a USB peripheral. This is accomplished by two modules, of our design, which will wirelessly transmit data. The wireless transceiver will convert data coming from the microcontroller into a signal to be sent between the modules. The microcontroller will also be programmed to coordinate data in both directions – from the pc and to the pc."

Much of the research done in this paper that pertained to the wireless functionality of the USB was helpful in the design of our project. Also the PC peripheral device they use is not that different from the base station that we will be using for our solar device.

AIMS

This project was an Automatic Irrigation Management System or AIMS. It had a controller that managed a lawns sprinkler system and monitored the moisture, rain and temperature and fluid levels with sensors. The project helped us decide on some of the sensors types that existed and provided valuable feedback in how to write the paper, the paper was well organized and had some sections that we had not thought to include in our paper. It also had an interface with a touch screen LCD screen that could be a possible addition to our current project for the solar device. The project also shares the same ideals of the 'green' movement and we deemed it appropriate to mention.

RFID Inventory Project

This project control system was the main point of interest for our group, they had a keep track of the several data types and they method of transferring data back-and forth was of particular interest during our research. The follow is a selected excerpt from their executive summary:

"The RFID Inventory Project is a real-time inventory control system for industrial and construction equipment dealerships to keep track of extra attachment parts and equipment that are easily lost or stolen. It keeps a reliable count of each part on the dealership lot and then sends the changes, or delta, to the business system interface. There are two ways to keep track of units on a lot and to display the units on a universally accessible website: First, put a gate in-place where units are read in and out. Second, no gates are used and units are monitored in a section of the lot. The second method is preferred but a gate-style RFID system may be added to monitoring the lot to enhance security. Any combination of solutions is feasible. A web interface gives dealership owners one place to go to in order to see where their equipment is at any given time, from anywhere in the world. The interface contains data from not only those units on the lot, but data from other areas as well. For example, the sponsor has a relationship with QUALCOMM, a GPS tracker for rental equipment. It would be valuable in the response back from the business system to include this extra data. The website shows what is currently in the yard, and in addition, can display other unit data from another source."

Power Monitoring System

Our project deals with the monitoring and recording of data over a solar panel, this project had a similar idea with their power monitoring system. They utilized the data collected to provide the power consumption with graphs and helped integrate the findings, this has helped our web design brain storm and will perhaps lead him to new ideas on how to change the website to be more user friendly. The following is a selected excerpt from their executive summary:

"With the world changing at a very fast pace, the way of living is changing at that same pace. With the emergence of new developed countries, the birth of technology in several third world countries, energy has become more and more indispensable to a larger part of the world. Hence we have witnessed lately the sudden increase in the price of oil due to more significant demands in the world. In this same state mind, we have seen a movement lately in research trying to find alternative measure to create energy. Also due to the fact of global warming we feel that as humans we need to reduce significantly our energy consummation. This is therefore the reason why we building the power monitor system.

Our goal is to design and construct an inexpensive Power Monitor system that would provide the functionality of screening the power consumed by 120 Volt, 60 Hz household loads. It will also provide additional information including RMS values of current and voltage and the active power consumed by the appliances. Applications for this device can be easily extended to household and commercial use. The device will employ Current and Voltage transformers to obtain RMS current and voltage values. The data obtained from these sensors will be processed to find the required parameters."

Radar Interface Design Project

The Radar interface design project gave the group a great deal of insight into the construction and uses of how to build a circuit board from scratch. The space constraints seen in their project are not dissimilar from ours; we will be looking at this groups work for a great deal of our PCB design and prototyping.

"The project is for the Joint Air to Ground Missile (JAGM) program. JAGM needs a next generation power supply for the transceiver of this missile. The circuit board must convert the power source voltage and convert it to multiple voltages for the transceiver. The circuit board must also have a timing control unit that will do power up sequence and power down sequence, as well as monitoring the temperature. Timing signals are expected to be highly accurate and reliable. One of the main challenges of this particular project is the limited circuit board space and limited airflow in the system. This is a particular challenge because there must be low heat dissipation from the board. Low heat parts and proper package will have to be considered. Electromagnetic interference (EMI) must be kept to a minimum to insure optimal performance of missile guidance and tracking systems. The power supply needs to be clean, contiguous, and responsive."

The Green Box

Another 'green' project, this time dealing with a home power box. This project implemented in how to store the energy was unique and lead the group to new design considerations. The following is an excerpt from there executive summery.

"The Green Box was a system intended to make green energy more practical for use in the average home. Consumers were then able to create an entire alternative energy system with The Green Box, even with minimal knowledge of electrical engineering. The project strived to allow for the easy connection of up to 3 types of energy producing devices that included wind, solar, human or any other type of "green" power in any configuration. The system also stored any energy generated and provided familiar interfaces to the consumer that allowed for easy and practical use of the power."

Solar Array Data

This section is to be filled with data from an actual solar array system that is functional, the problem with most installations that they don't have any data collection or it is not available to the public. So there has been an effort made to find projects that have data that is accessible to use for use in our research

The best place that we have found to find data about live solar installations is from municipal power companies or co-op utility company. These types of companies for the most part have an agenda that includes making sure that the citizens they serve have access to the information of what is being contributed. Below is the home page for a co-op installation in the Florida Keys called the Florida Keys Electric Cooperative Association. They allow for their data to be put onto an interface on the internet.
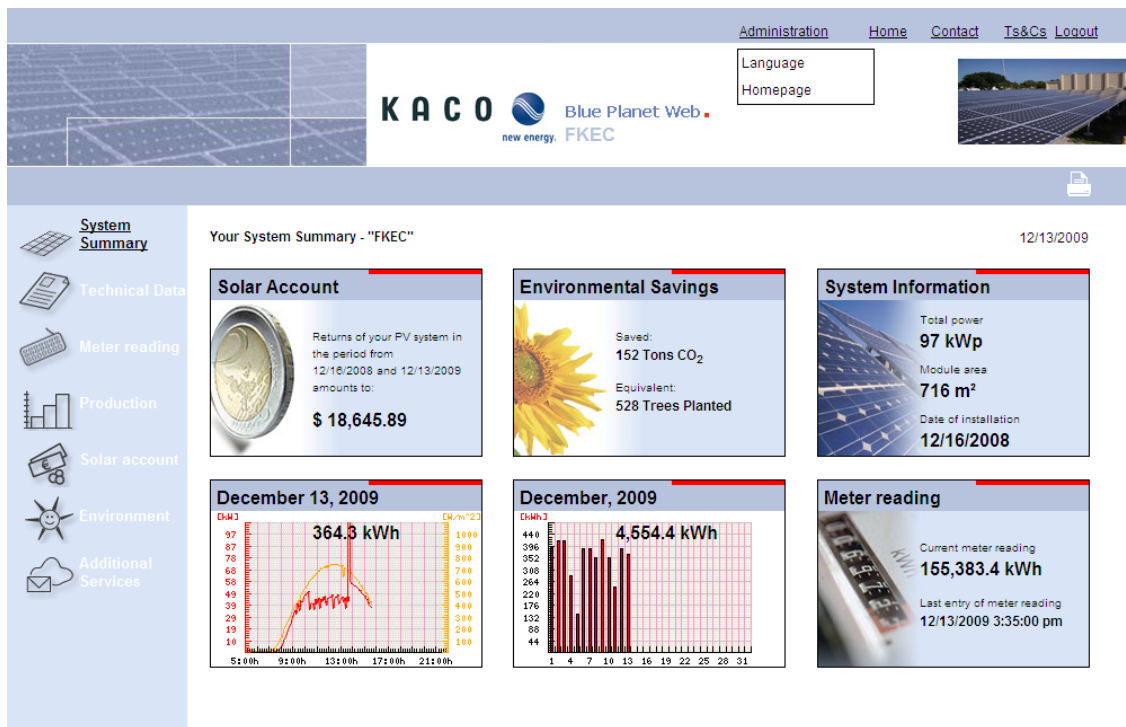
Figure 35 – Homepage for Cooperative Program's Power Data (Permission Not Required)

This shows the current data for the month of December which can go into more detail. This data will be very useful for determining what we should expect from our prototype aspect as it should correlate extremely well to what is available to us on this site.

The data that we are most interested in is the daily generation in Watts as this will be similar to what we will need to display for monitoring purposes. The graph below indicates that the power generation peaks at certain parts of the day as well as showing

variations in the output over the day as relating to cloud cover and other variables that will cause variances in the power output of the solar array as well (red line shows KW)

Figure 36 – Kilowatt vs. Hours and Irradiance vs. Hours (Permission Not Required)

This graph also indicates another piece of data that might be useful for determining how much power can be expected from solar arrays in different geographical locations. So knowing the Irradiance would be a useful thing to compare against the over power output.

Section 3: Design

Design Architecture

Figure 37 below shows the high level design architecture. It shows the basic components that the group will be designing and interfacing and how it all comes together as a product. The arrows show dependencies and the general flow of data in the project.
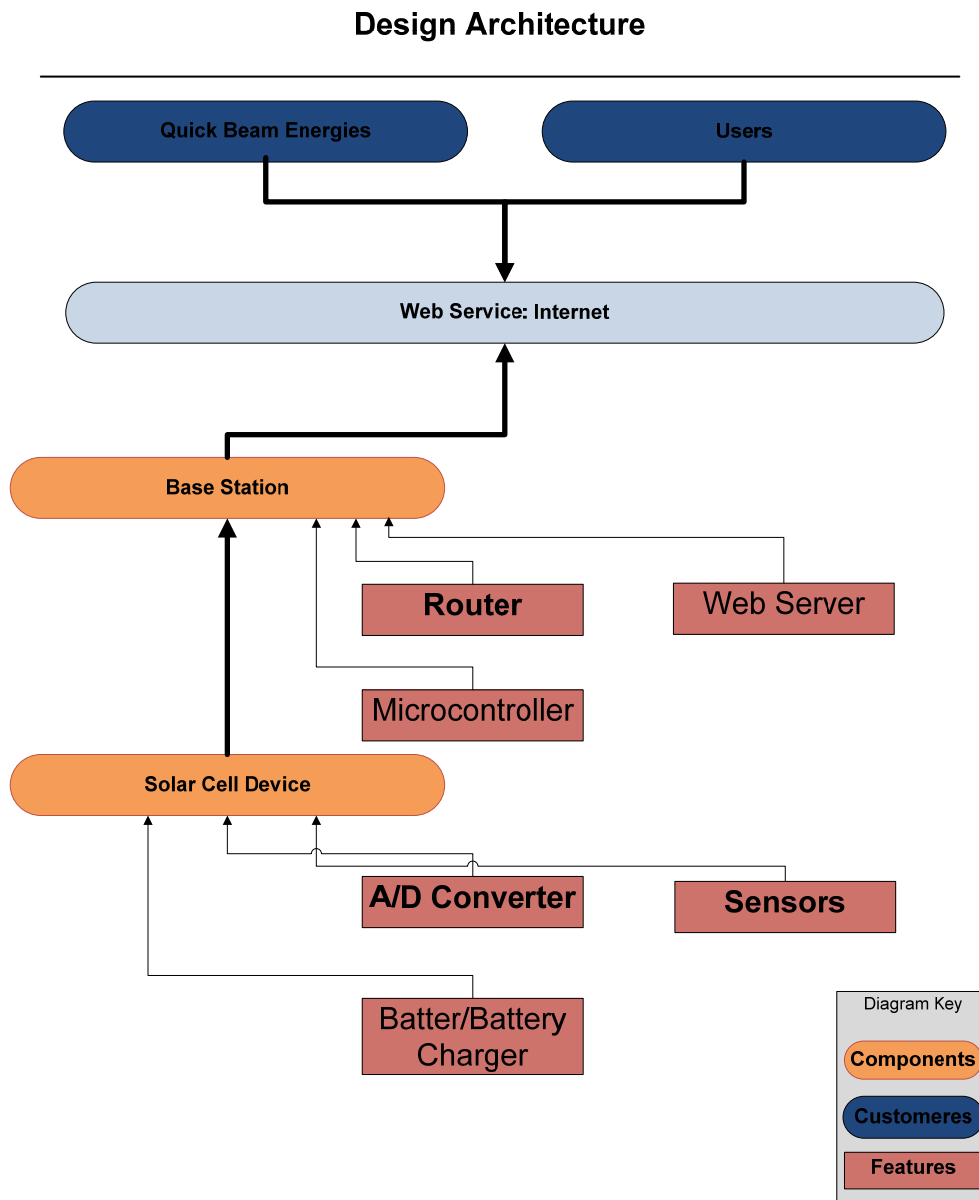
Figure 37 –Design Diagram

Schematics

This section will be used on how we are indicating and calculating all of the needed parts and values of parts for this installation. The string device will have a two part approach, it will have an analog or power electronic side and it will have a digital electronic side. We will keep these separate for a few reason. Ground planes can be very easily polluted by digital and analog devices due to noise. Often times one ground plane will not act as a ground plane for the other, which could result in unexpected values or worse yet damage to components on either the analog or digital side. We will start on the analog portion of the board as it will be the most complicated. We will need to make a PCB and layout for this board. Before we do that we need to how many device components will be needed to fit on this PCB.

As detail in the spec sheet on LM5116 is in the Appendix which will contain all the details on how the selection of what materials are need and at what values. The part that we are most interested in is controlling the output voltage to the range that we need. There are two resistors as indicated in the diagram below that put the voltage at the value that we need for the battery charger to function (circled in Red.) Diagram from LM5116 spec sheet layout for 5 volt output operation. With values of Rfb1 being 1.21k ohms and Rfb2 being 3.74k ohms.

Figure 38 - Diagram from the LM5116 spec sheet (Reprinted with permission pending National Semiconductor)

The following equation is needed to change the values of these resistors to have a different output voltage over what is given in the spec sheet.

$$\frac{R_{FB2}}{R_{FB1}} = \frac{V_{OUT}}{1.215V} - 1$$

Figure 39 - Equation from the LM5116 spec sheet (Reprinted with permission pending National Semiconductor)

So picking a output voltage of 12 volts would change the values needed for Rfb1 and Rfb2 such that it gives us the voltage required. This will allow us to pick any battery charging system and only need to change a few resistor values depending on what voltage is needed.

The battery charging system will be constructed of a comparator that will check the voltage of the battery to make sure the battery has the correct voltage and does not have any over voltage conditions as well. This will be done with a LM350 voltage regulator and an LM471 comparator, for testing purposes only.
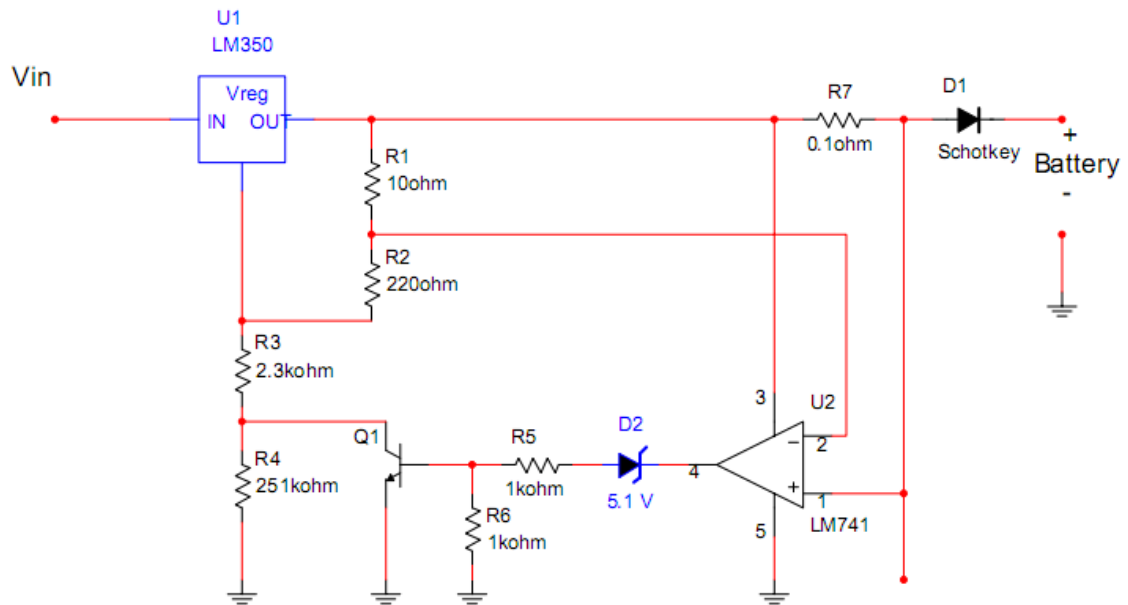
Figure 40 – Multisim Drawing of Battery Maintainer

Depending on the efficiency and losses due to the second regulator we may not use the LM350 but the proof of concept is the same. With this schematic this demonstrates that a voltage regulator and comparator can be used to charge a battery and maintain the battery without running into overcharging or other harmful conditions.
The next part of the analog part of the sensor which is the center part of this project, it is

the part that senses the current going on the DC lines from the solar string. Without knowing how this product interfaces it would be useless to us. The part that necessary is the pins that are need to go from this device to the A to D convertor on the Explorer 16 development board. The pins indicated are circled in Red.
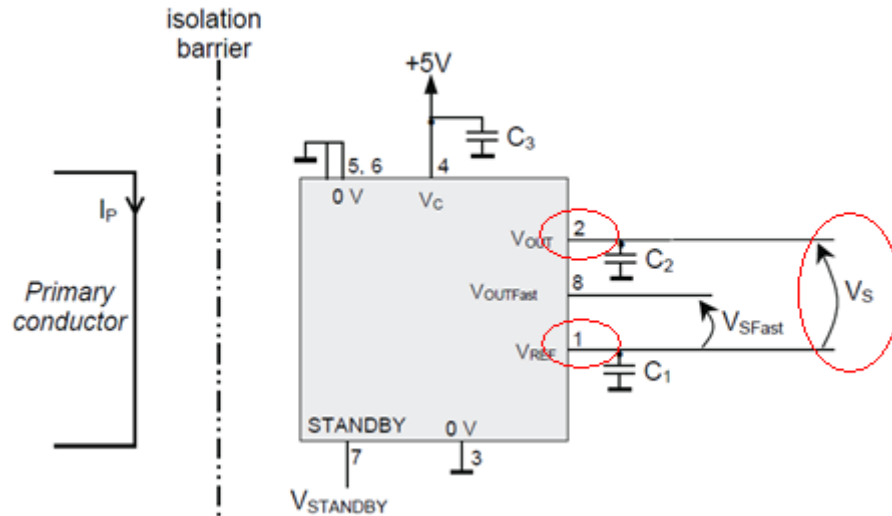
Figure 41 - Connection Schematic for LEM FHS 40-P/SP600 with C1=C3 = 47 nF C2=4.7nF

(Reprinting Permission Requested)

Base Station

The base station is the device that will be receiving all of the transmitted data from the solar panel string device. It will be responsible for analyzing the data and outputting it in an easily readable and sensible fashion. The analyzed data will be able to be viewed through the base station's web server. The base station will be connected to the internet via an Ethernet cable. Therefore, the solar panel string can be monitored from miles away from an office.

The device that will be used as a base station is the ASUS WL-520gU router. This router is capable of supporting customized firmware. With custom firmware, one can control the way the router behaves and also take advantage of the features of the router that are usually unused. For example, with custom firmware, one can use the router to host a web server to the outside world versus just the Local Area Network (LAN). This is the plan with the WL-520gU. We need to utilize it as a web server to host the information received from the string device.

The router's dimensions are small, and therefore will be more than an acceptable base station. In addition to its size, the router comes standard with two external antennas. This will make up for the lack of range within the string device. The Asus router comes with a Wide Area Network (WAN) port on the back of it. This will be used to connect to

the outside world via an Ethernet cable. With outside connectivity, one can monitor the solar panel string from a remote location. This is one of the primary goals of this project (remote monitoring). The router of choice is depicted below in the figure. Its dimensions are listed. The unit weights 0.82 lbs.

Figure 42 - ASUS WL-520gU Router Dimensions - Reprinting Permission Requested

Range Boosting

The range of the base station will be improved via an external antenna. This will make up for the lack of reception accompanied by the string device. The string device will have a printed circuit board antenna; therefore, its range will be significantly shorter than that of the base station. The base station's range will be boosted via a 9dB external antenna. This antenna is not stock with the router. Group member Benjamin Brindle has both the router and the external 9dB antenna, which makes the cost of the base station and router virtually free.

Custom Firmware

The custom firmware that will be used for the base station in this project is DD-WRT. We will install the firmware via the Asus Recovery Utility, which is provided on Asus's

website at the following URL: http://dlsvr03.asus.com/pub/ASUS/wireless/WL-500g-03/Eng_1380.zip. The correct version of DD-WRT must be installed. The correct version of DD-WRT will be obtained at the DD-WRT website. The version that will be installed at the writing of this paper is version v24-sp2. The following is a list of steps that must be followed in order to install the new custom firmware is taken from the DD-WRT website:

1. Remove the power connector of the WL series router.
2. While holding the reset button, plug the power connector back in. (WL500gP - button labeled "restore")
3. When the power LED flashes, release the reset button. The router is now in recovery mode.
4. You need to manually set the address of your Pc Network LAN card to 192.168.1.10 and subnet mask 255.255.255.0
5. Use the Asus recovery utility to upload the DD-WRT mini-asus.trx file.
6. After the upgrade the Utility will ask for a router reboot. Give it about a minute to be on the safe side before removing the power. Once plugged back in, you should be able to access the web interface.
7. DO NOT use Firefox for upgrading builds! Use Internet Explorer!!!!
8. Type 192.168.1.1 into your browser and set your username as root and pick a password.
9. Navigate to Administration->Firmware Upgrade and upload either the recommended build provided on the main page of the site, or another of your choice.

Now that the custom firmware is installed onto the router, it must be configured to properly work to the base station's specifications. The specifications and requirements of the project call for the base station to be able to display the data over the internet via a web page. Also, the router must be able to receive the solar panel device's information via an easy means. In the following sections, these topics will be discussed.

Web Server

As described in the Section 2, the base station accompanied by the DD-WRT firmware has the ability to act as a web server to the LAN and/or outside world. We will be configuring the DD-WRT firmware to allow outside connections—that is, outside of the local area network. This section will describe how the DD-WRT firmware is configured to permit such a web server to run properly.

First, we will move the firmware's web admin pages to port 81. Then, we will start a new web server at port 80 for the outside world. The initial pages for the base station's display will need to be uploaded to the router via SSH to the /jffs folder. Then, we will navigate to the Administration tab and Commands sub-tab. Here, we can enter shell commands that will be issued on the router's Linux command prompt. The command that we will enter into this command field will stop the current web portal and restart it

on port 81. Then, it will start another web server running from the /jffs folder. Finally, it will open up port 80 to the outside world so that this web server can be accessed from outside of the local area network.

Below is the command that must be entered to do the above stated. Also below is a screen shot of the command field box seen from the web administrator portal.
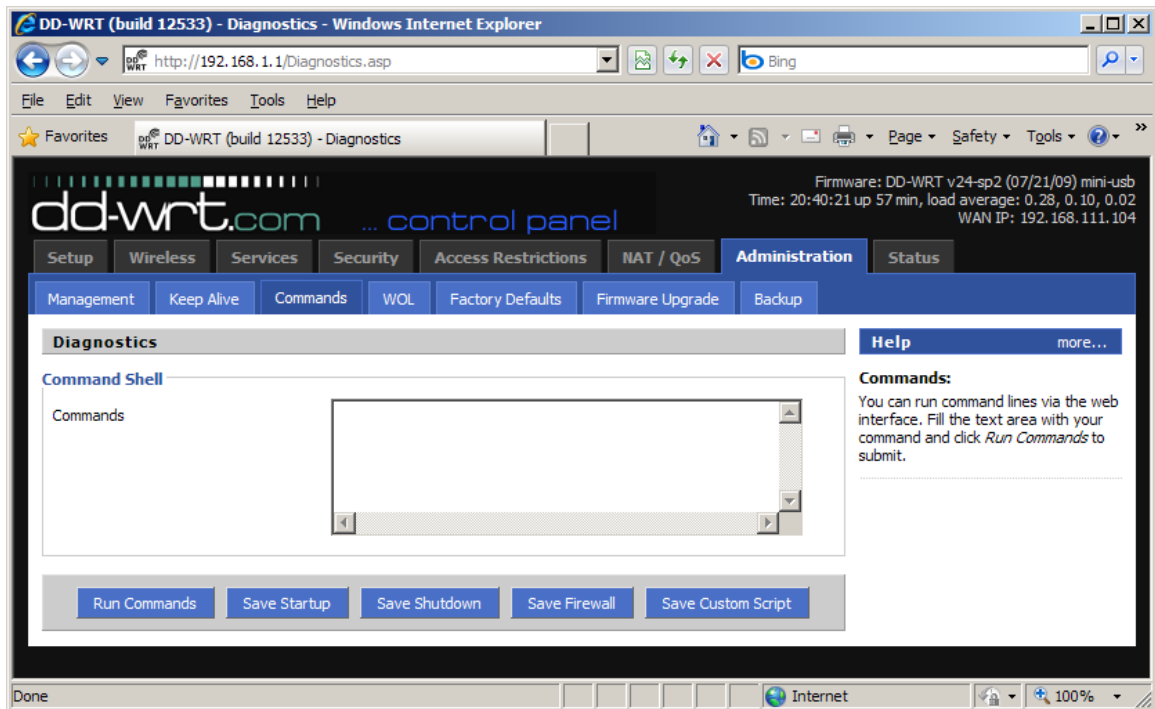
Figure 43 – DD-WRT Command Shell (Reprinting Permission Requested)

```
killall httpd
cd /www
httpd -p 81 -h /www
cd /jffs
httpd -h /jffs
/usr/sbin/iptables -I INPUT 1 -p tcp --dport 80 -j logaccept
```

Now that the web server is open, the method that the base station receives the data from the string device and how it is processed to be viewed from the outside world will be discussed below.

Data Handling

The main purpose of the base station is to receive the data transmitted wirelessly from the string device and then format it in such a way that it is presented to a remote user via a web server. This section will describe how the data is collected, manipulated, and displayed upon the web server. Scripts will have to be run on the router. Therefore,

different scripting languages supported by the router will be looked at. Also, the different formats of displaying web pages will be analyzed as well.

Incoming Data

The DD-WRT firmware supports the telnet protocol. This protocol is very easy to emulate and implement. Therefore, this will be the method used to transmit data from the string device to the base station. Telnet is simply a pure text client/server connection on port 23. This is the medium that the solar panel device will transmit the data.

Files will be created on the router over telnet via the command "cat." This command will append contents to a file or create a new file with new contents. This will be received from the string device between every 1 minute and 15 minutes. The base station will have to continually loop looking for new files or new contents to output to the web server. The command issued to the router from the string device will be "cat >> filename." After issuing that command over telnet, the string device will then begin to transmit the file's contents. When it is done filling the file with the data, it will end the command by issuing the command Ctrl+D over telnet. Below is a screen shot of what a terminal to the DD-WRT firmware looks like:
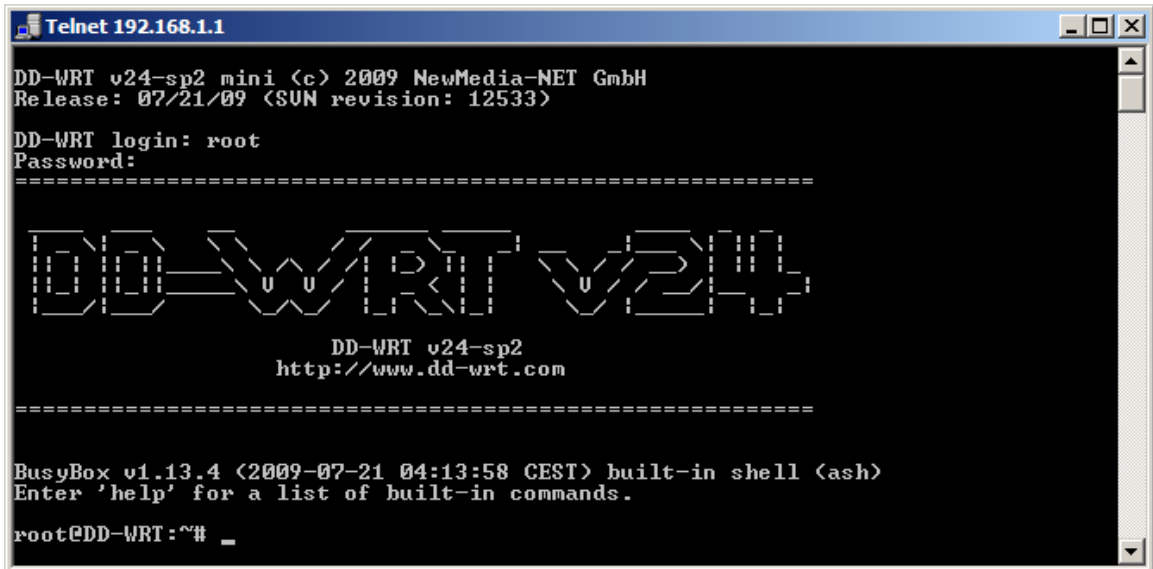
Figure 44 – DD-WRT Root Shell Command Prompt – (No Permission Required)

The string device will have to issue the change directory (cd) command several times to get to the mounted file system that is described below. The anticipated directory will files will be stored is: /mnt/usb/data/.

Data Storage

The Asus WL-520GU router supports USB flash drives. Therefore, flash drives can be mounted as a file system on the router to expand its storage capacity. This will be used to store the data received from the string device. This is a necessity because the router comes standard with only 16Mb of RAM. Below is a picture showing where the USB flash drive will be installed onto the base station.

Figure 45 – Asus WL-520GU USB Installation (No Permission Required)

Once the USB flash drive is installed onto the physical router, the DD-WRT firmware must be configured to recognize it as a file system. This will be done via the web portal configuration. Under the Services tab, navigate to the USB sub-tab. There, enable the radio box labeled "USB Storage Support." New options will appear where the "FAT File System Support" will be checked. Below is a screen shot depicting these aforementioned instructions:
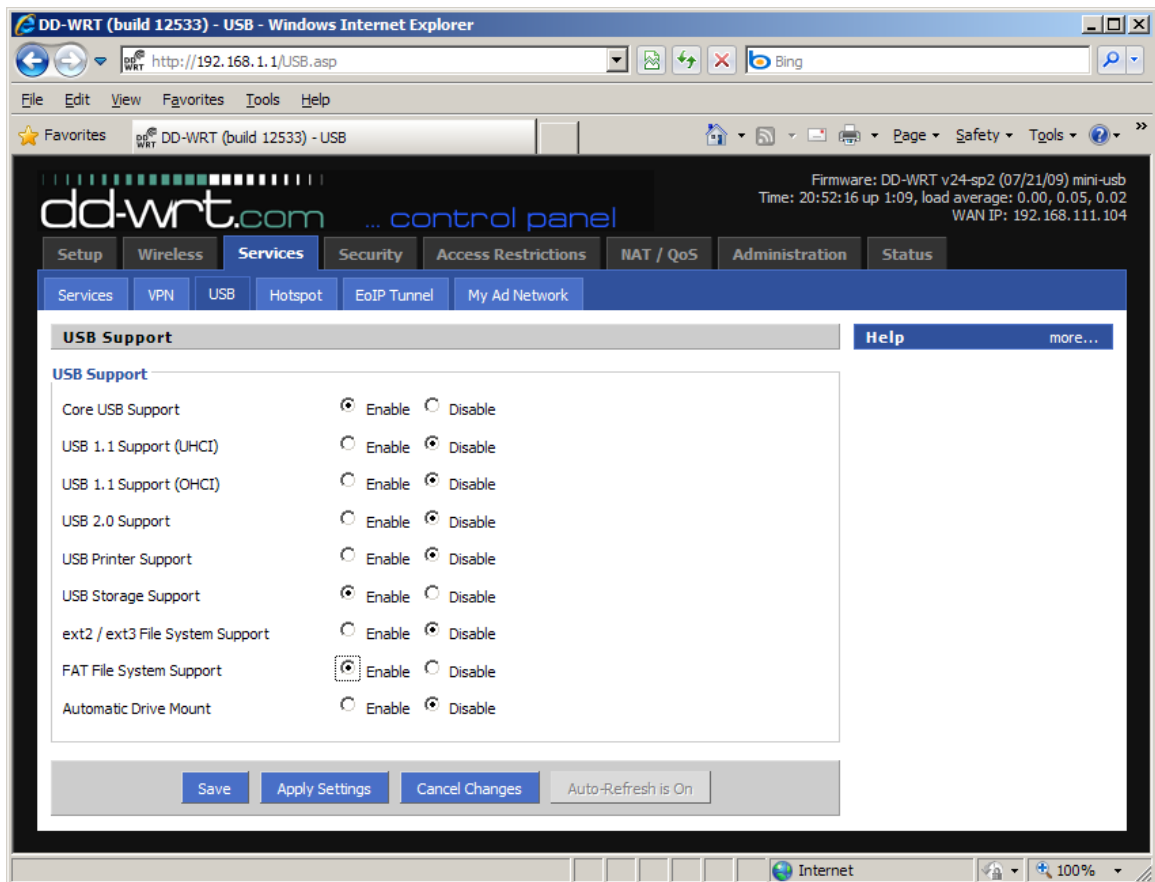
Figure 46 – Expanding Storage Capacity via USB Flash Drive (Reprinting Permission Requested)

Data Output

The router will be responsible for outputting the data received from the string device to the web server. The router will need a shell script that will interpret and manipulate the data received over telnet and output it to a HTML page for viewing. The shell script will be written in the Bourne/Ash shell scripting language. It will indefinitely loop, locating files in the designated storage folder (anticipated to be /mnt/usb/data/), and then analyzing these files. The files will contain a timestamp of the transmission along with the current reading of the solar panel string. Therefore, the file contents will look like the following interpretation:

```
2010-03-20 23:22:45 3
```

This represents the time of March 20th, 2010, at 45 seconds past 11:22PM. The next number, 3, represents the amperage reading of the solar string panel. This number will then be used to calculate the voltage of the solar panel string. Since the resistance of the buck-boost converter is known, the voltage can be calculated using Ohm's Law, V=I*R.

This information will then be stored onto an HTML page. The HTML directory that the

Page 70

web server is fed from will be /jffs/. It is planned to be able to display in a spreadsheet fashion with the readings and times lined up. The implementation of graphs is proposed, but the limits of the router base station could hinder these plans.

String Device

The design of the string device will be one of the most challenging parts of this project. It will be the section of the project that requires the most design and research because it encapsulates most of the components. The components included in the string device include: the wireless communication module including its microcontroller, the voltage and current measurement devices, an analog to digital converter for each voltage and current reader, a charge controller, a battery, and a buck-boost DC-DC converter. The design of each of these components can be found in their respective subsections of Section 3, but this subsection will detail how the components will be put together to complete the solar panel string device.

Wireless Component

The wireless component for the string device is the ZeroG Wireless ZG2100M module. It is described above in the research section. The module will be controlled and interfaced with a PIC-microcontroller-based development kit from Microchip Direct. The part number is AC164136 – ZeroG 802.11 Development Kit for Explorer 16. The description of the development kit is described by the manufacture as: "The ZeroG 802.11 Development Kit for Explorer 16 demonstrates 802.11 connectivity via the ZeroG ZG2100M PICtail board for the PIC-microcontroller-based Explorer 16 Development Board. This kit includes a wireless router, a ZeroG PICtail Board, and a pre-programmed PIM with Microchips free TCP/IP stack and radio driver. The development kit provides everything the user needs to begin development of an 802.11 network. Explorer 16 development board and power supply not included. www.zerogwireless.com. Also note that the router is only for 110V operation." Below is a picture of what is included in the development kit:

Figure 47 – Microchip Direct Development Kit (Reprinting Permission Requested)

Explorer 16 Board

The ZeroG wireless module is connected to the microcontroller via a PICtail Plus Daughter Board. Its purpose is to make the interfacing to the microcontroller printed circuit board easier. Also included in the development kit is prewritten code to drive the wireless TCP/IP functionality. Something that is not included in this development kit is a PIC Explorer 16 board. This will be provided by a fellow colleague. Figure 3 shows the ZeroG PICtail that will plug into either the PICtail Plus (Explorer 16) using the card edge connector or the PICtail slot (PICDEM.net 2) using the pin header on the development board. Because the two development boards operate at different voltages, the end user will need to set the jumper JP3 on the ZeroG PICtail correctly for the setup that is being used. Below is also a bulleted list of procedures to follow when installing the PICtail to the development board:

1. Connect the RJ11 cable (grey phone cable) to the RJ11 port on the development board to the ICD.
2. Connect the serial cable to the serial port (UART port) of the development board and to the serial port (COM port) on the PC. (Typically, the default port on the PC is COM 1, but this default number may differ from PC to PC.) This is only required if you want to monitor the debug messages coming from the PICtail. Please see Serial Monitor Setup for more information on setting up the serial connection correctly.
3. Connect the USB cable from the ICD to the PC.
4. Power on the router, and connect the PC to the router with an Ethernet cable. If a wireless laptop (or PC) is being used, then associate the computer with the correct SSID of the wireless access point.
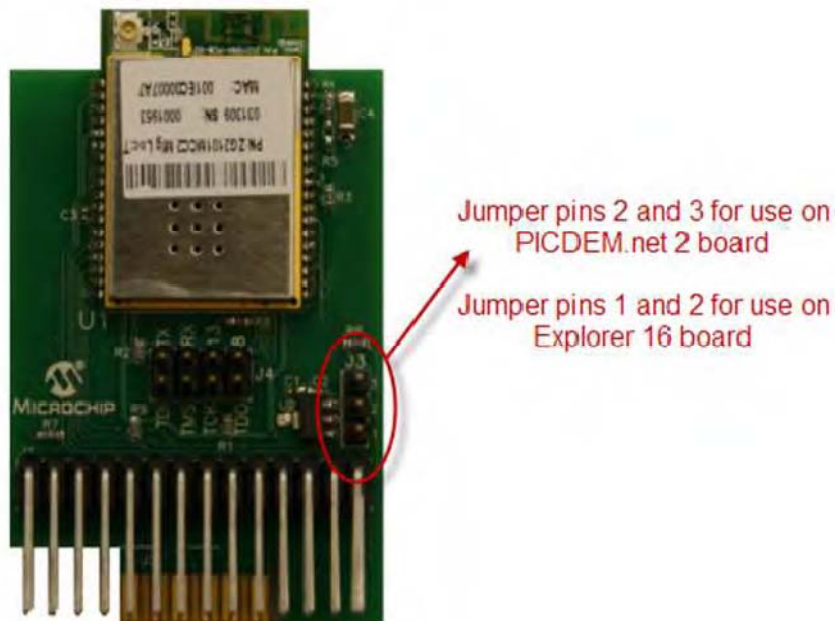
Jumper pins 2 and 3 for use on PICDEM.net 2 board

Jumper pins 1 and 2 for use on Explorer 16 board

Software Installation

After the Explorer 16 board is installed, software must be installed in order to configure the microchip and wireless module. The software required to install includes the Microchip MPLAB integrated development environment v8.40 or later, Microchip MPLAB C compiler, Microchip in-circuit debugger (ICD 2 or ICD 3) driver, and the Microchip TCP/IP stack installer (which contains the ZeroG Wi-Fi driver). The software listed is provided free by Microchip and is distributed on ZeroG's website and Microchip's website.

The last part of the software, the TCP/IP stack installer is the last stage before interfacing with the functionality of the Wi-Fi module is achieved. The installer by default will install the stack code, driver, documentation, and demo project files in the directory C:\Mirochip Solutions. Depending on the development board used, the HardwareProfile.h file must be changed to match the configuration of which slot the PICtail is plugged into. Figure 43 shows the location of the changes needed:
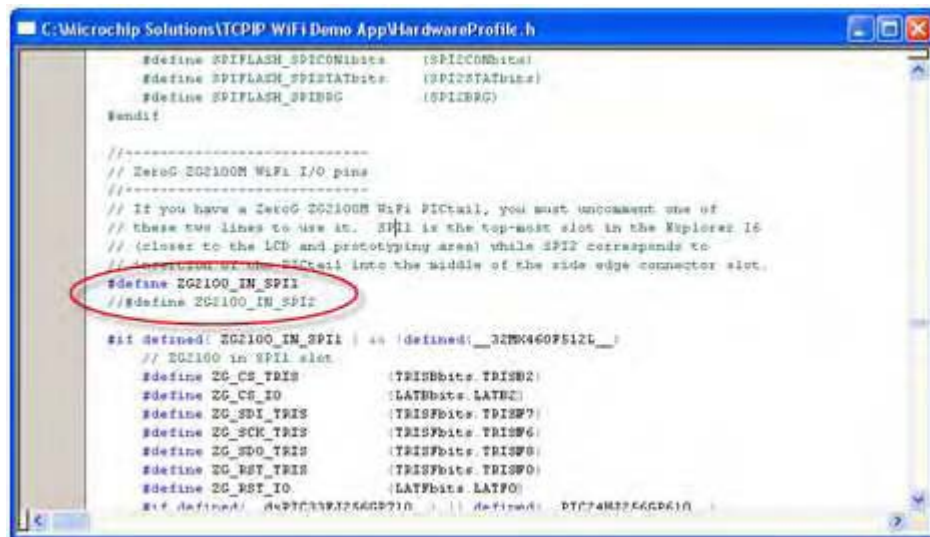
Figure 49 –HardwareProfile.h SPI Options (Reprinting Permission Obtained)

For the Explorer 16 board, if you are using the PIC24FJ128GA010, we will use either ZG2100_IN_SPI1 or ZG2100_IN_SPI2, so long as it matches the location that the PICtail is plugged into the card edge connector. If you are using the dsPIC33FJ256GP710, currently, this PIM will only work when ZG2100_IN_SPI2 is defined and the PICtail is plugged into the middle card edge socket.

There are two main files that contain most of the compile-time options for the wireless module, TCPIPConfig.h and HTTP2.h. The TCPIPConfig.h file contains the variables to make the wireless module establish a wireless connection with an access point and the

HTTP2.h file contains configuration variables to host a HTTP server. Both of these files can be viewed from within MPLAB IDE, by using the file navigator. Note that HTTP2.h is located under Header Files/TCPIP Stack. The SSID of the router that the string device will be connecting to is declared under the variable MY_DEFAULT_SSID_NAME in TCPIPConfig.h. In order to have the string device obtain a static IP address from the router, a couple of tasks must be done. First, we will need to comment out some lines in TCPIPConfig.h that tells the wireless module to use DHCP. This involves commenting on the definition #define STACK_USE_DHCP_CLIENT, which is shown below:

Figure 50 –Disabling DHCP on Wireless Module (Reprinting Permission Obtained)

Then, the IP address that the wireless module will try to register must be defined along with the subnet mask. The subnet mask must meet the router's subnet mask as well. In the screen shot below, the wireless module will try to obtain an IP address of 192.168.1.77 with a subnet mask of 255.255.255.0.

Figure 51 – Assigning Static IP (Reprinting Permission Obtained)

In addition, the MAC address must be defined in the same header file. This is defined in 6 different variables, each containing the hex digit. The MAC address for the wireless module is predefined by the factory and is provided by ZeroG. Below is a screen shot of configuring the TCPIPConfig.h header to reflect the predefined MAC address:

Figure 52 – Defining the MAC Address (Reprinting Permission Obtained)

Since the wireless access points are broadcasted over a certain Wi-Fi channel, the wireless module's TCPIPConfig file must reflect the appropriate possible channel list. This is mainly to ensure that data is transmitted consistently without interference. The possible channel list is stored in the variable MY_DEFAULT_CHANNEL_SCAN_LIST. Below is a screen shot showing where this is stored in the file. In the screen shot, the channel 1, 6, and 11 are in the list.

Figure 53 –Defining the Channel List (Reprinting Permission Obtained)

One method talked about for transmitting data to and from the string device to and from the base station is by having a web server on both the string device and base station. That way, the base station or the string device can store data and transmit it by the means of a web server. The development kit comes with code to host a web server. The server is configured through the HTTP2.h header file. The port of the web server is defined in this file. This is a port that we will consider changing due to security concerns outlined in the research section. The port is stored in the variable HTTP_PORT. A screen shot below shows where to make these changes to the port:

Figure 54 – Wireless Module HTTP Server (Reprinting Permission Obtained)

Section 4: Prototype

Vendors

The vendors used in this project have a special bearing to our sponsors. Since they are a part of a green industry they have a mandate to use companies and products only from companies that also have similar dispositions towards having a greener environment. While most companies do indeed have some sort of 'green' mission it was requested by our sponsors to mention which venders we use a brief disposition of that vender's disposition.

Asus

ASUS or ASUSTek Computer Incorporated is a Taiwan based multinational cooperation which produces motherboards, graphics cards, sound cards, optical disc drivers, PDSs, computer monitors, laptops, servers, networking products, mobile phones, computer cases, computer components, and computer cooling systems. It considered one of the top 10 global brands by info Tech magazine. It has a Net income of 21 billion dollars and has approximately 100,000 employees. In 2007 ASUS did some restructuring and split into three distinct operational units, ASUS, Pegatron and Unihan, the other two brands focusing on the Asian markets. In 2000, Asus officially launched Green ASUS, a companywide sustainable computing initiate to overseen by an aspiring comminute that is trying to make ASUS more environmentally friendly. Green Asus restricts 37 hazardous substances, and is a leader in the PC recycling industry from its launch of its 'PC recycling for a Brighter Future' program. In 2006, ASUS obtained IECQ (IEC Quality Assessment System for Electronic Components) HSPM (Hazardous Substance Process Management) certification for its headquarters and for all of its manufacturing sites. Without a doubt ASUS is a 'green' company and strives to make its electronics in the most environmental safe possible way. This is in line with our sponsor's mission statement and is considered a good vender to use.

Microchip

Microchip Technology is an American manufacture based out of Arizona. It is a manufacturer of microcontrollers, memory and analog semiconductors. Microchip has approximately 5000 employees and products include Serial EEPROM devices, Serial SRAM devices, Pic32, Pic 24, and dsPic microchips. Their Pic devices are ideal for any battery powered or power constrained applications, which is why the vender appealed to our project. Microchip also has several Environment Health and Safety Certifications and is a partner in the Sony Green Partner and Samsung Electronics Eco-Partner. You can see their certificates and safety polices at http://www.microchip.com/stellent/.

Z-G Wireless

ZG Wireless is a nonprofit, enthusiastic movement being driven by a computer of people who are interested in new technology. We were considering this vender based on their free software solution to a wireless system. Since they are essentially a free enterprise they

National Semiconductor

National Semiconductor is a California based manufacture of power management circuits, display drivers, audio and operation amplifiers, and communication interface products and data conversion solutions. They also deal with wireless handsets and a variety of broad electronics markets. Last year the company did 332 million in net income. National Semiconductors also has a national Solar Magic Technology program that is aimed at maximizing solar panels efficiently. Their panels can recoup up to 71 percent of the power lost, dramatically improving the economics in shaded and other real-world conditions. Between this and their safety and environmental section on their website, this vender is very good selection for our sponsors to use within our solar device.

Texas instrument

Texas Instruments or TI is an American company based from Dallas Texas. TI is the no 4 manufacture of semiconductors worldwide, and is the No. 2 supplier of ship for cellular handset and No. 1 producer of digital signals processors. They had a registered net income of 1.92 billion dollars and have over 25,000 employees. Texas Instrument has had large contributions to having a Lead Free manufacture in all of its devices. They also take great care in the electronic disposal of their manufacturing sites making them one of the largest and greenest manufacturers.

Eagle Electronics Inc

Eagle Electronics Inc is a PCB manufacture with up to 12 layer boards. They are privately owned and are based out of Schamburg Illinois. They are going to be our PCB fabricator for Senior Design II. They follow all quality control systems dictated by the state and are ISO certified since 1996.

PCB Design

This project is going to require that we design and make or order a custom PCB layout. This will require some research on what PCBs are made of, and what the average cost of an ordered PCB will be. First printed circuit boards are needed to put a more permanent solution rather than using a protoboard, everything is soldered onto the board to be in a low profile manner making it able to be enclosed in a case and protect it from the elements. Because boards can be complicated they are often printed in a form that will

allow small traces to be made out of small amounts of conductive materials. PCB are made from an insulator and a conductive material. In hobby type environment, PCBs are made from copper clad fiberglass boards that a printed trace layout is pressed onto the copper surface. Then etched off by some type of strong acid, this process can be harmful and may etch more or less copper than you want. There are many types of techniques for lithography of PCBs which is nicely detailed in this table from Solarbotics.net author Eric Seale July 29, 2003.

Resist Mask Creation Method	Price	Process Complexity	Results
Ink pen / transfer material	Very low	Simple, but time-consuming.	Functional, if not (in general) particularly aesthetic. Difficult to get accurate hole alignment for ICs, sometimes difficult to get traces that reliably survive etching.
"Press-N-Peel" sheets	Medium recurring cost ($1.50 US per sheet of PNP film)	Medium complexity, but few manual steps; manual "touchup" of resist areas often required	Good, but you must be obsessive about cleaning your board (and keeping your PNP film clean), and vigilant about checking / "touching up" traces before etching the board
"Toner Transfer Paper"	Medium recurring cost ($3.00 US per sheet of paper; in bulk, cost can be as low as $2.00 per sheet)	Medium complexity, but few manual steps	I have yet to test this method yet.
Clay-coated paper	Low (a few cents per page of paper, plus etchant)	Medium complexity, but few manual steps; manual "touchup" of traces sometimes required	A bit less detailed than "Press-N-Peel" (based solely on description, I have yet to find paper that works)

Figure 55 From Solarbotics.net About PCB lithography techniques

This very nicely lays out the differences between the lithography techniques, and will greatly help us chose what technique to do.

There is software that is free on the internet that helps you design a PCB. Eagle PCB design by Cadsoft Computer, is a free tool for use in designing PCBs, which is available to run on a multitude of operating system platforms including Windows XP and Vista as

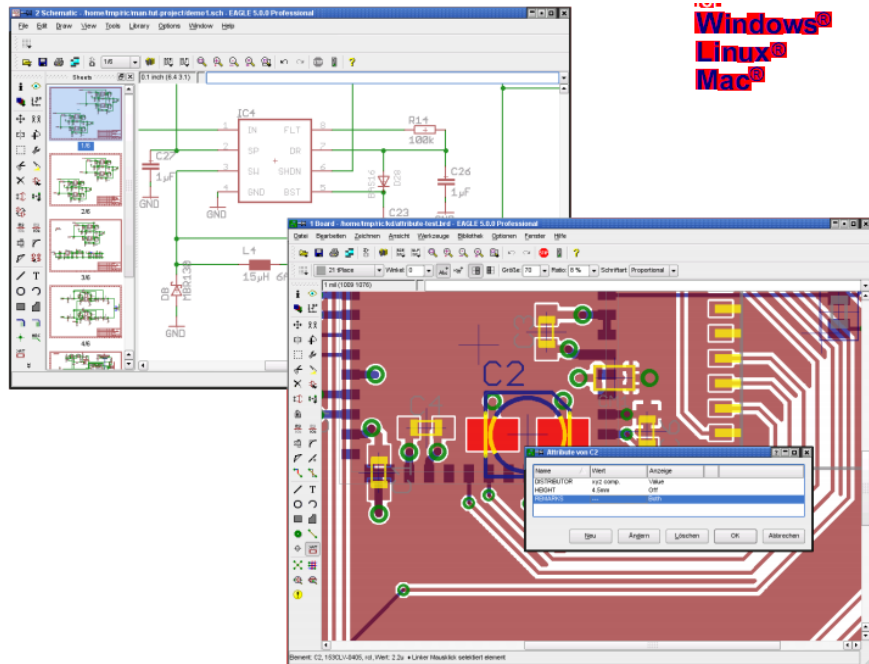well as Linux distros such as Ubuntu as well as Mac OS X.

Figure 56 From manual for Eagle PCB design tool

We will also explore the option of purchasing a professionally made PCB as it will be a quick and easy solution and look extremely professional. I will focus one of many vendors of PCBs. I will take a look at ExpressPCB, at their website expresspcb.com. Their home page basically explains all that is needed to know about them without looking too much further.

There prices start at $51 dollars and they have Design software for use with their ordering system with should aid us in making a PCB that is ready for production with little or no problems.

Base Station

The base station is the device that receives data from the solar panel sensor and outputs it to a webpage. The base station is composed of an Asus WL-520GU router. It is connected to a D-Link ANT24-0700 2.4GHz 7-dBi Omni-directional antenna for additional range. The antenna boosts the base station's transmitting power to approximately 25.5 dB. The router is operated by DD-WRT, which is a highly customizable Linux based open source firmware. The next figure illustrates the base station connected to its antenna.

Figure 57 – Base Station

Since the base station is a router, the solar panel device connects to the base station's Wireless Local Area Network (WLAN). While connected to the WLAN, the solar panel device establishes a telnet connection to the DD-WRT's telnet server. Throughout the entire time that the solar panel device is powered on, the base station receives new data every 15 seconds through the telnet connection. The figure below illustrates the telnet console for the DD-WRT firmware.

Figure 58 – Base Station's Telnet Server

Page 81

The base station has the capability to store up to 2GB worth of solar panel device data. Each data insertion consists of four separate entries of 13 bytes of time, current, voltage, and power. Each data insertion consists of four separate entries of 13 bytes of time, current, voltage, and power. Each data set is sent to the base station every 15 seconds. Below are calculations made to determine that the base station can hold 119 days worth of data:

$$\frac{13\ bytes}{entry} * \frac{4\ entries}{insertion} * \frac{4\ insertions}{minute} * \frac{3600\ minutes}{hour} = 731.25\ kB\ every\ hour$$

$$\frac{13\ bytes}{entry} * \frac{4\ entries}{insertion} * \frac{4\ insertions}{minute} = 208\ bytes\ every\ minute$$

The data received by the base station is handled by both parties. First, the solar panel device inserts the time, current, voltage, and power data into log files via telnet commands. Second, the base station uses a shell script to convert the data into a webpage. This shell script is executed every 15 seconds via a telnet command from the solar panel device. Below is the shell script file:

```
root@DD-WRT:~# /bin/sh/solar.sh
Shell script execution:
rm index.htm
more v.txt >> index.htm  more h >> index.htm
more p >> index.htm      more t.txt >> index.htm
more p.txt >> index.htm  more c >> index.htm
more f >> index.htm      more c.txt >> index.htm
```

The preloaded templates combined create the following HTML:

```
<!DOCTYPE    html    PUBLIC    "-//W3C//DTD    XHTML    1.0    Transitional//EN"
"http://www.w3.org/TR/xhtml1/DTD/xhtml1-transitional.dtd">
<html xmlns="http://www.w3.org/1999/xhtml"><head>
<meta http-equiv="Content-Type" content="text/html; charset=utf-8" /><title>Solar
Panel Monitor System</title>
<style type="text/css">body { font-family: Georgia; color: black;}div { font-
family: "Courier New", Courier, monospace; }
div#wrapper{width:800px;margin:                                              0
auto;}.box{float:left;display:inline;width:144px;margin:0 20px 0 0;}
.boxEnd{float:left;display:inline;width:144px;margin:0;}</style></head><body><h1>S
olar Panel Monitor System</h1><br />
The solar panel monitor system measures the current and voltage of the solar panel
to accurately keep track of the solar panel's power output.
<br /><br />Below is the solar panel monitoring data:
<br /><br /><div id="wrapper"><div class="box">
Time:<br /></div><div class="box">Current (A):<br /></div>
<div  class="box">Voltage  (V):<br  /></div><div  class="boxEnd">Power  (W):<br
/></div>
<div style="clear:both"></div></div><br /><br /><hr />
<img    src="logo_UCF.gif"    />                   <img
src="logo_quickbeam.jpg" /></body></html>
```

Page 82

The webpage can be accessed by going to the base station's IP address. The output of the webpage looks like the figure below.
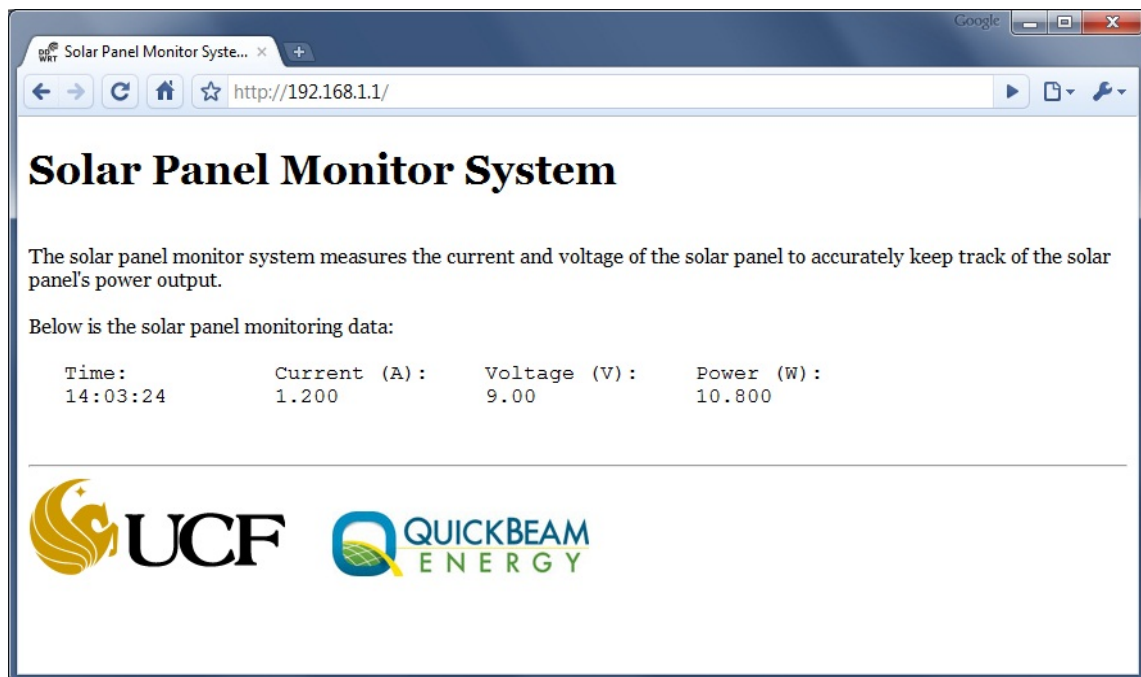

Figure 59 – Base Station's Output

Solar Panel Device

Explorer 16 Development Board

The solar panel device microcontroller is responsible for reading data from the current sensor, transmitting the data to the base station wirelessly. The Explorer 16 Development Board, which comes with the PIC24FJ128GA010 microcontroller from Microchip, is used to perform these tasks. This setup was chosen for the following features:

- External 5V/ground supply for current sensor
- Easy to interface with microcontroller's pins
- SPI interfacing for wireless module
- C compiler
- Analog to Digital Converter
- 16 MIPS

The solar panel device reads the current sensor's measurement as an analog signal. The PIC24 uses its third analog to digital conversion channel to convert the analog signal to a digital and numerical value.

Once connected to the base station's WLAN, the solar panel device will establish a telnet connection. It will transmit the current sensor's data and other calculations every 15 seconds. An example telnet command: echo "11.321
" >> c.txt. The echo command copies the text within the double quotations to the screen, and the >> command takes the copied text from the screen and appends it to the filename that follows.

Below is a picture of the Solar Panel Device's Explorer 16 Board with attached ZG2100 module and current sensor.
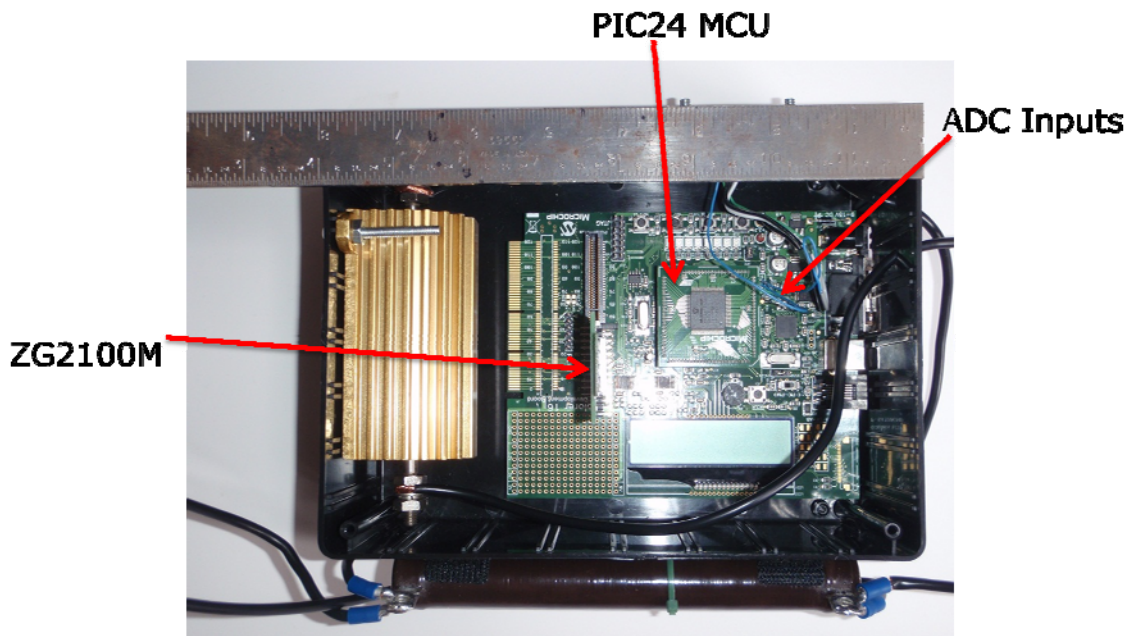

Figure 60 – Solar Panel Device

Buck Switching Regulator

The over end selection for the buck convertor was limited due to constraints need for the design as well as the process of implementing the design. The change from a Buck-Boost regulator to just a Buck regulator stems from the fact that the Buck Boost combination lends itself to more complexity and even more limit to the type of regulator used. The overall prototype construction lent to the selection of a different chip then originally intended. The original chip, the lm5116 was intended for this use but was too difficult to implement as it was a surface mount part. The figure bellow shows our attempt at mounting the chip to prototype via a breadboard.
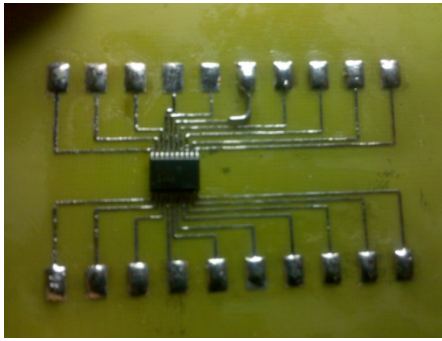
Figure 61 – Breakout Board for IC

This attempt ultimately failed due to the small nature of the chip with 20 pins. After some research we decided to move to a Buck regulator. This research led us to the LM 2575 HV adjustable Buck switching regulator. This device had a lesser range than the originally specified 100 V, but is expectable due to the fact that this device will need a voltage divider regardless of the operational range of the Buck. This part is also a T0-220 package type with a 5 pin, as in the figure below. The through hole design allows us to very easily prototype and construct a final board.
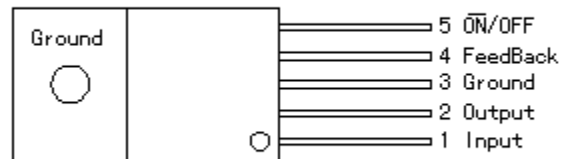

Figure 62 – Pin Out for LM2575

The design of the rest of the circuit is an adaptation from the LM 2575 HV datasheet. The adjustable component is controlled by the resistor network with the 50K potentiometer that feeds into the reference/ feedback pin. The original design only required one LC component off of the output to level and de ripple the output of the chip. We felt that that output was too unstable i.e. it had too much fluctuation in the output. Since we needed a stable voltage for the battery charger we decided to add another filter component to the design adding another inductor and capacitor. This got us to the required stable voltage. The figure below is the simulation of the end resulting design.
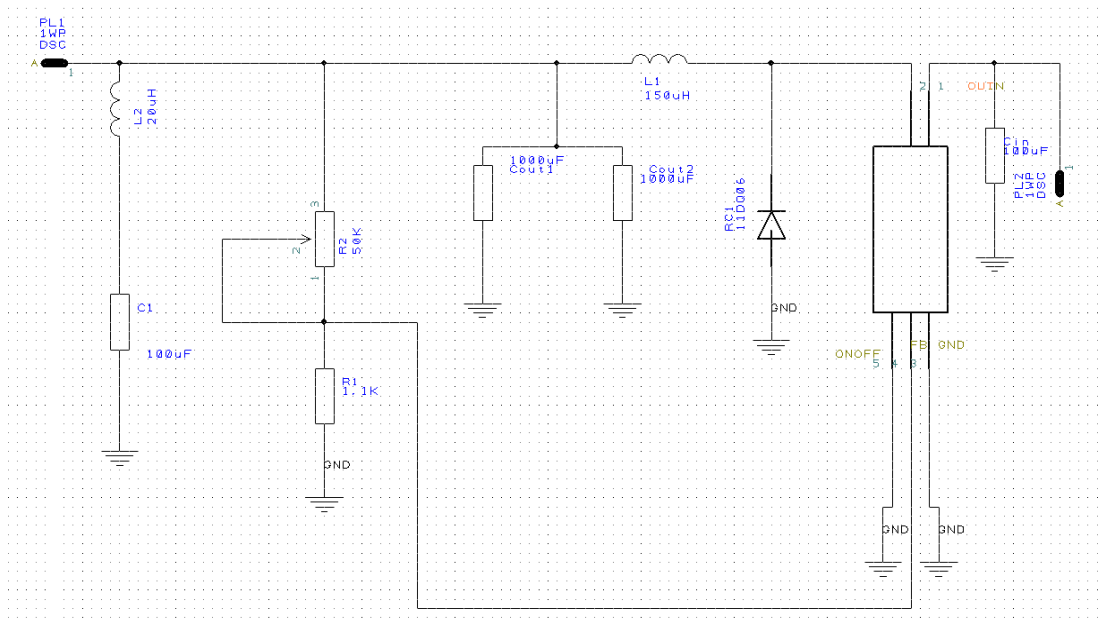
Figure 63 – Simulation of Buck Circuit

The prototype needed to be on a board that was more than a bread board. To complete this task we had a few options available to us, regardless of the method chosen we need to design a PCB layout board. This was accomplished by using PCB artist, the software needed to be used if we were going to send out to 4PCB for manufacture. This was an advantage because if we had chosen to send this design out, but because of the simplicity of this layout we decided to etch the board ourselves. The figure below shows the PCB layout as used (without Ground plane for visibility).
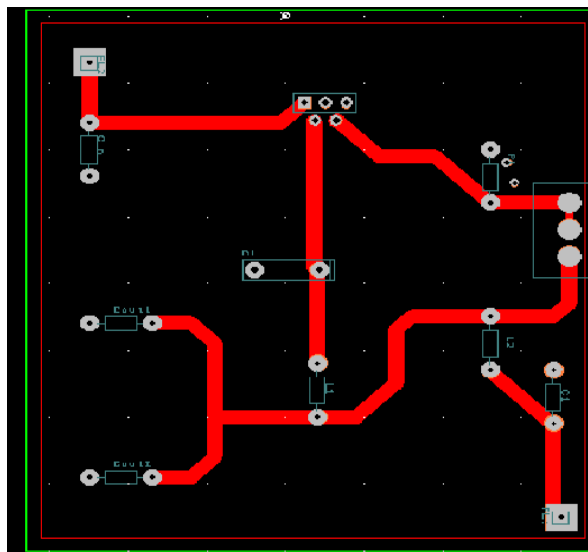

Figure 64 – PCB Design for Buck Circuit

Page 86

The resulting board was then tined by soldering the entire surface of the copper, this prevents the copper from corroding. This also gives a better platform to solder onto when adding the parts. The resulting board is depicted in the board below showing a final dimension of 4.5 inches square.
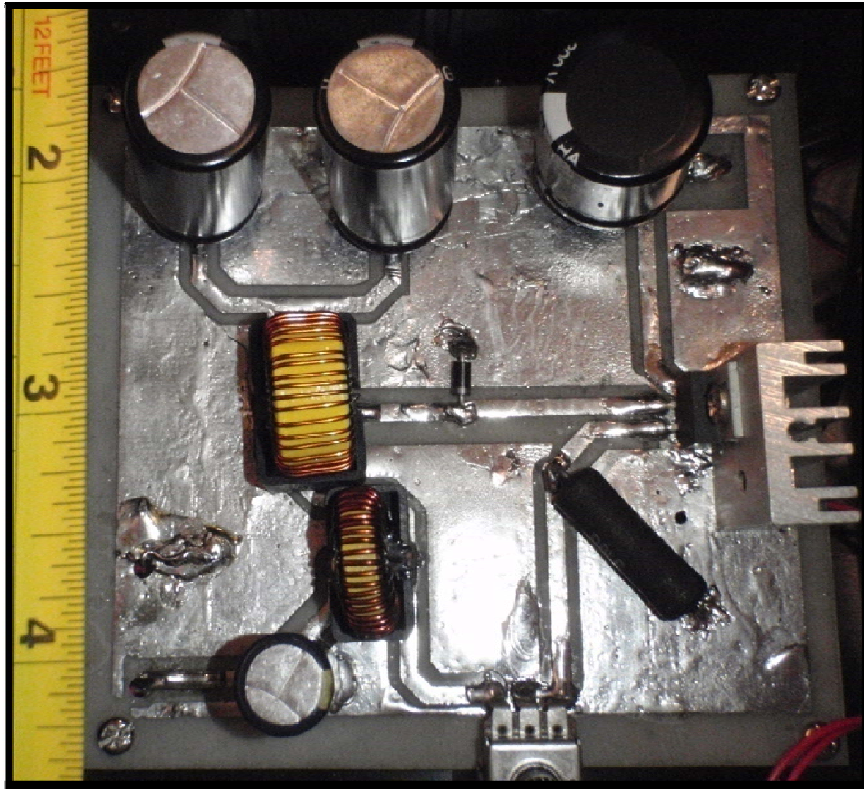

Figure 65 – Buck Circuit Finalized

Battery Charge Controller

The Battery Charge Controller has been designed as a dependable workhorse to charge and hold our 12 Volt lead acid batteries at its peak level, insuring a long life and maximum performance. The charging procedure used when working with a flooded 'wet' cell battery or one of the newer VRLA (Valve Regulated Lead Acid – 'Gel' or 'AGM') batteries is the same. The battery being charged will automatically set the Battery Charge Controller in one of two charging modes upon hookup. The circuit design takes into account the battery's current SOC (State Of Charge) and adjusts the terminal voltage at switch accordingly. The main charging circuit is very simple because as we discussed

before, the concept of lead acid batteries has been around for centuries The real secret to correctly charging a lead acid battery system is to use a temperature compensated voltage source that automatically varies its output in accordance with the batteries SOC. 'Frying' our battery occurs when the charging unit fails to sense that the electro-chemical rejuvenation (or charging) process has slowed to the point that the higher voltage charging mode should end. Continual high voltage charging will decrease the overall life of the battery.   We designed the following Battery Charge Controller as against the spec provided to us by Quick Beam Energies, the schematic is shown in figure 1.
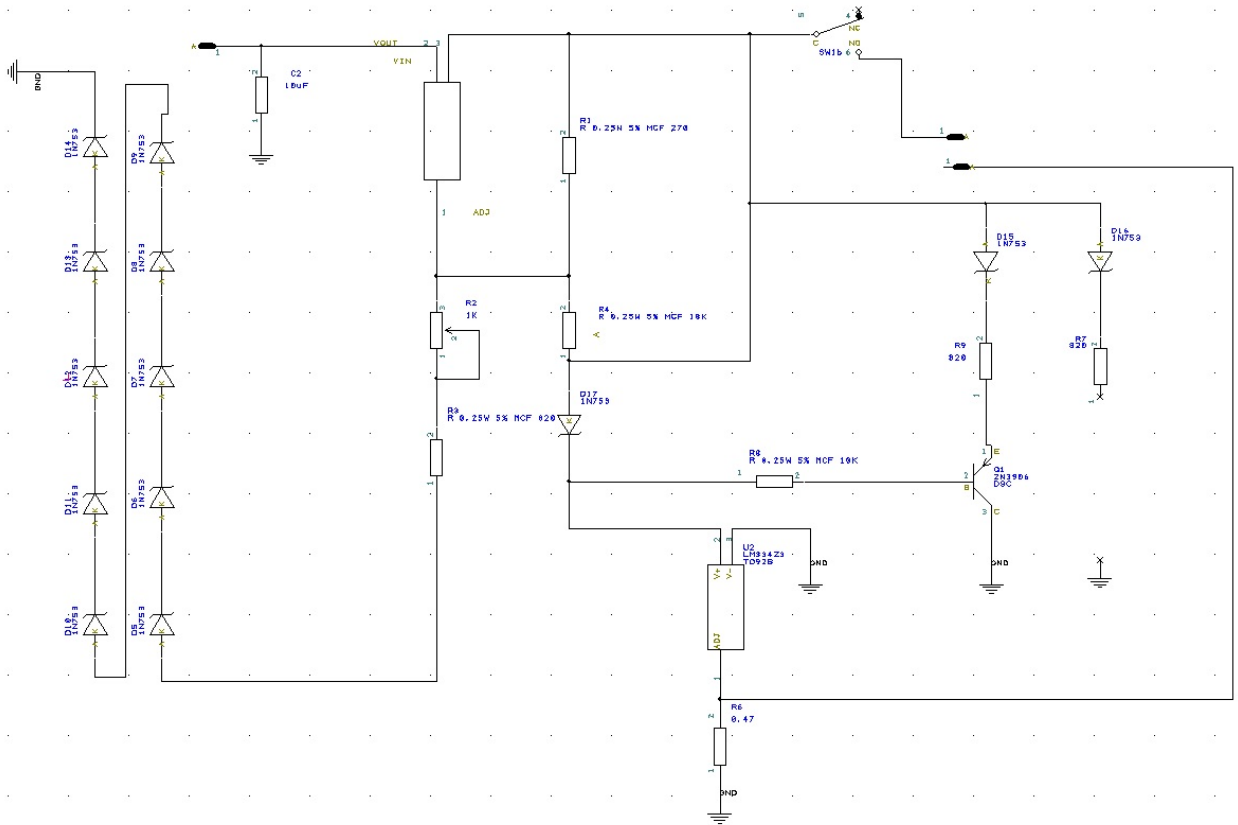

Figure 1: Battery Charge Controller Schematic Capture

Our group used PCBArtist, a free piece of software available online and used to manufacture PCBs.   The schematic shown in above was done in PCB artiest.   The layout and routes can be seen below in figure 2.
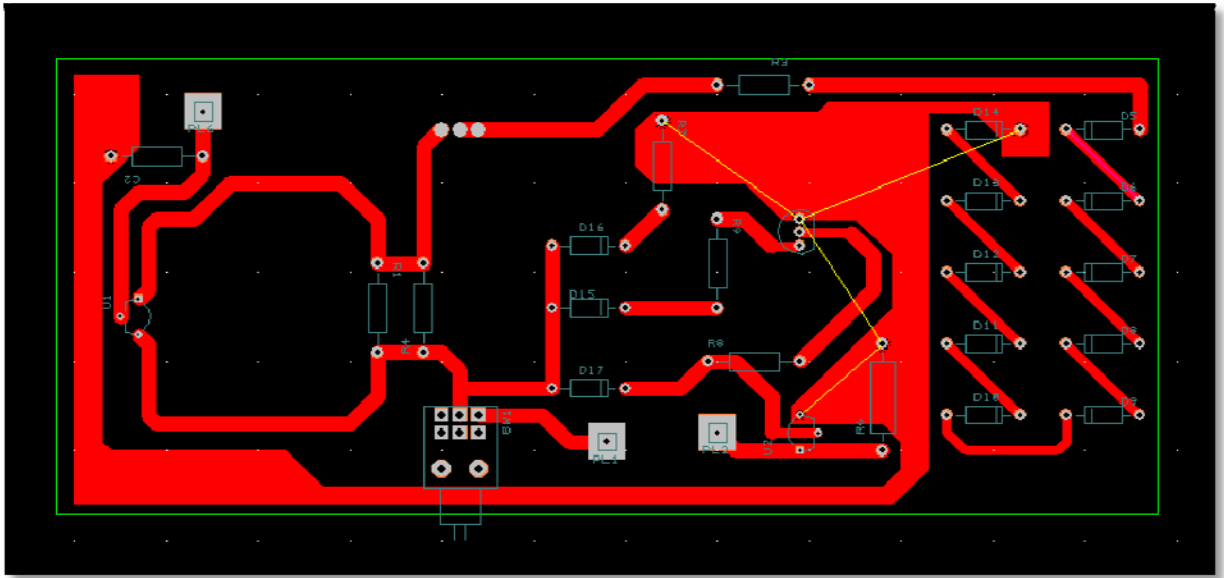
Figure 2: Battery Charge Controller PCB Layout

To save money on design as well as to ease troubleshooting, we decided to etch our own boards using a homemade acid from pool cleaner and hydrogen peroxide. This decision was made upon realizing that our initial board layouts may not be very effective, and turnaround from 4pcb, while fast, is somewhat expensive after the initial purchases. Luckily we had a very good system to acid etch these boards, a process that we refined over the course of the semester. Below in figure 3 is our finished, acid etched, battery charge controller.
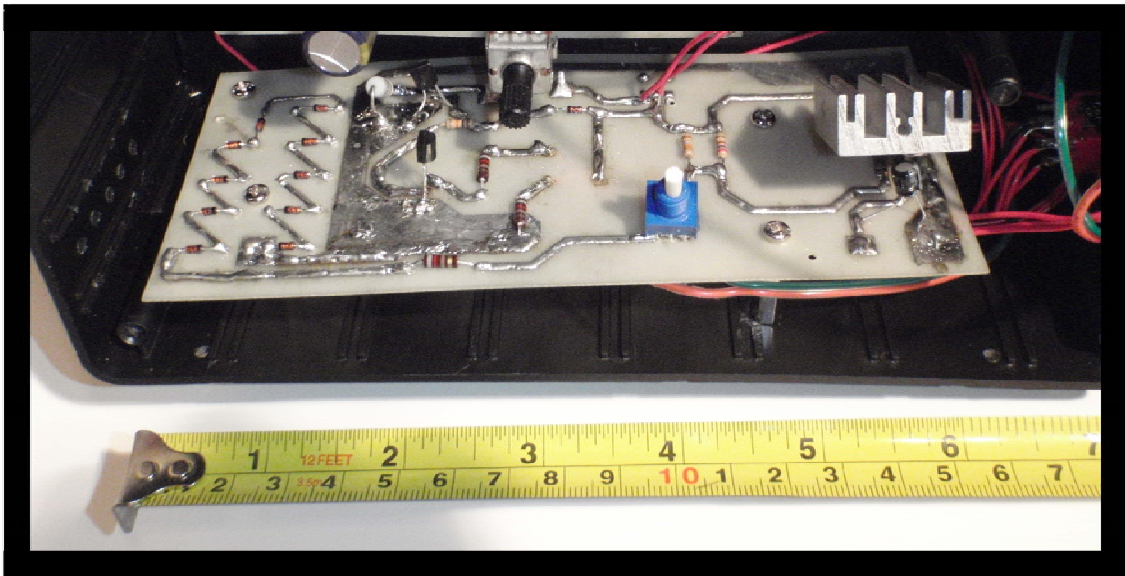

Figure 3: Completed Battery Charge Controller

Let's take a closer look at the Battery Charge Controller schematic and see what's

happening. The power supply inlet for the Battery Charge Controller is the switch. The input voltage is immediately presented to a filtering capacitor C1 to reduce the voltage ripple. Using a bridge configuration on the voltage input allows the user more options to power their Battery charge controller. The use of a 20 VDC (positive tip) power supply will do nicely with any 12 Volt lead acid battery. Varying our power supplies current capacity will allow us to charge any type of lead acid battery without a problem. Most of the standard cells require a charging current of 650mA or greater. For these systems a 14 VAC (2 Amps or so) transformer will work very well. In our application is to charge very small capacity batteries with a maximum charge current of only a few hundred milliamps, using a 14 VAC @ 500mA 'wall wart' supply or a current limited bench-top power supply set for 20 VDC will avoid excessive current draw that could damage a heavily discharged battery. Internal heating from excessive charge current will also degrade our overall battery life.

The LM317 is a voltage regulator that provides the precision terminal voltage we need to charge the lead acid cells. Unlike a standard voltage regulator that is designed for a fixed level output, LM317 lends itself well as a variable voltage source. With a maximum current source capability of about 1.3 amps, LM317 gives the user the flexibility to charge even very large capacity batteries. The other support components on the board help LM317 to know when to adjust its output voltage up or down to ensure the proper charging rate of the battery. These other components are grouped into two major sections, the SOC feedback loop and the ambient temperature compensation used during the 'Float' mode after the battery has been fully charged. The SOC feedback loop consists mainly of LM334 and R6 together to form a low voltage comparator in conjunction with R1 and R4 to set the range of the charging voltage. Here's how the loop functions. Assume for starters that the battery under charge, or BUC, is discharged and drawing enough current to set the Battery Charge Controller in charge mode. After the current drawn by the battery drops below a certain point, the need for 'high' voltage charging has ended. LM334 monitors the voltage drop across R6 to determine when to switch LM317's output at switch from 14.4V ('Charge' mode) to 13.4V ('Float' mode). As the battery comes to a full charge, the charging current it draws drops below about 150mA. The voltage across R6 (0.47 ohms) will then fall below 0.07V thanks to Ohm's Law, V=IxR. This trigger point causes the V+ pin (LM334:1) to toggle from its 'Charging' mode 'high' value of about 12.8V to a charged 'Float' mode 'low' value of about 0.7V. When V+ (LM334:1) toggles low, R4 is switched into the reference feedback circuit of LM317 causing its output voltage drop back to 13.4V. The 'Charged' LED (D15) is turned on when the Base-Emitter junction of 221334 Transistor is thus forward biased indicating that the battery is charged and is being 'topped-off' by the 'Float' mode operation. Now that the battery is charged, the ambient temperature compensation circuit comes into play. The effects of this circuit, formed by R2, R3 and diodes D5 to D14, are used only during the 'Float' mode operation to adjust the terminal voltage in accordance with the ambient temperature. If the temperature is not factored in, we would run the risk of over-charging the battery when it's hot or under-charging the battery when it's cold. Taking advantage of the thermal characteristics of a PN diode ($\Delta 2.2$mV/°C), the diode matrix (D5 to D14) raises or lowers the reference terminal of LM317 by 22mV (10 x

2.2mV/°C) for every 1°C change. This is just the right negative temperature compensation we needed to properly charge our lead acid batteries! At the start of the charge cycle, we'll notice that the heat sink used with LM317 can get very warm if we are charging a large capacity battery. The fact that the temperature sensor matrix is on the same circuit board and in the same case will not negatively affect the compensation network because there will be very little dissipated heat by the board components once the unit switches into 'Float' mode. The drop in charge current drawn by the battery is so low by the time 'Float' mode is entered, the air cavity around the temperature sensor diodes will re-acclimate to the surrounding ambient temperature.

Figure 4 shows the layout for the LT1510, which was one of the other battery charge controller types that we tried before going with our own design.
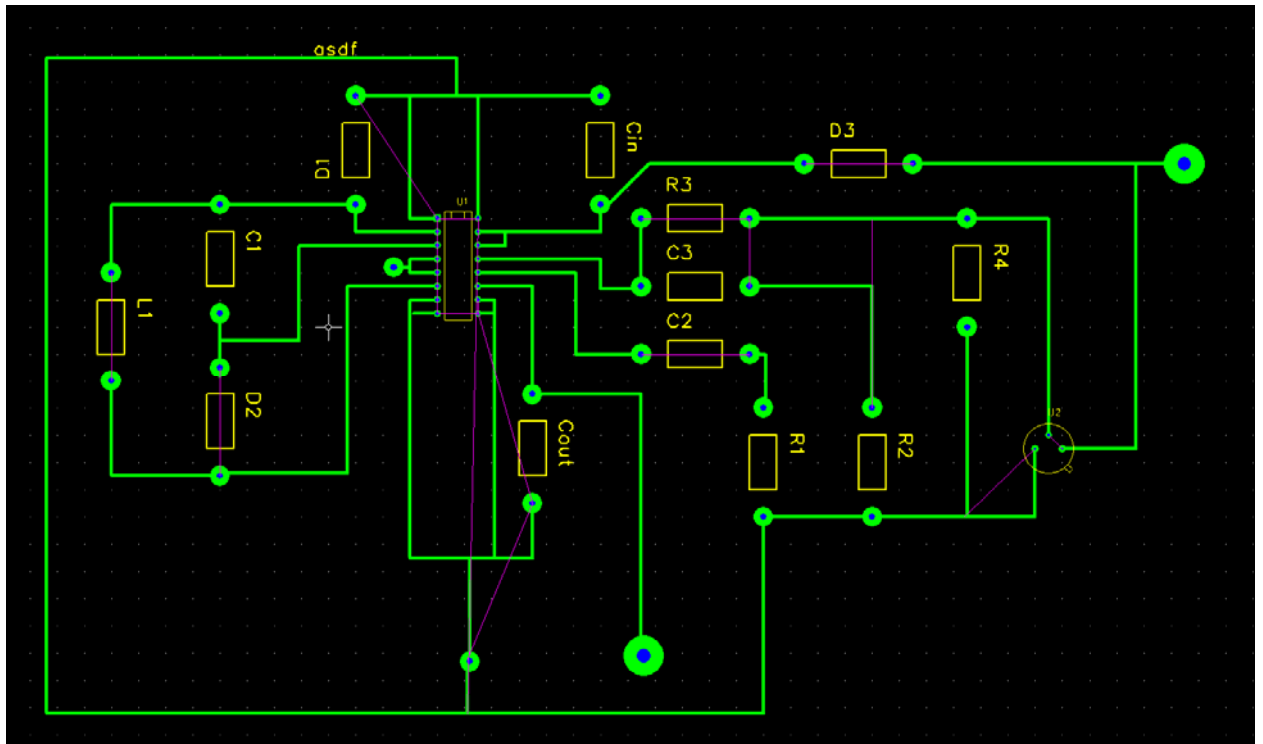

Figure 66 - LT1510 PCB layout

Section 5: Testing

Wireless Communication

The wireless communication between the solar panel device and base station was tested by observation. A telnet session could be made to the base station to observe the solar panel device sending data to the log files. Also, a serial cable could be connected to the Explorer 16 Development Board to catch real time information that was programmed into the device for debugging purposes. Changes to the code were made when problems were encountered.

Battery Charge Controller

When we designed the battery charge controller we placed two LED lights into the circuit. These were to add an aesthetic look to the circuit as well as to provide testing feedback. These LEDS were one of the primary tests we used to see if the battery charger was working. The first LED was a power led, and was placed in on the main output line. If there was power feeding into the LM317, then the power led would be on. The second LED was on the ouput line. If the battery was fully charged, then the circuit would change to a float setting, which would then turn this LED on.

Our initial build of the circuit had a problem with the ground plan that was giving us some major difficulties. Only the power LED would turn on and we had to troulbeshoot the battery charge contorller circuit. We knew from scematic capture tools what the voltages should be across certain components and tested those componets until it was discurved that we hada potential difference among some of our group plains that was not allowing the circuit to go into its float mode. We redesigned the PCB layout of the circuit to compensate for this issue, and the LEDs began to work as intended.

We used a volt meter to test across the LM317 and acorss the potentiometer, we needed a 13.7 volts across the battery to charge it. When the battery reached approximatly 13.5 volts, the charge contorller would then go into a float mode that would charge the battery at a slower rate to make sure overchage did not occur. The potentiometer aloud the circuit to go from approximatly 20 volts to 5 volts, this aloud us to pick froma wide range of batteries.

We had to be especially careful with it came to the temperature as the current died off at 150 degrees C. We tested the circuit at room temperature, and never had the oppourtunity to test this extreme value, but we are confident that the chip will withstand the temperatures.
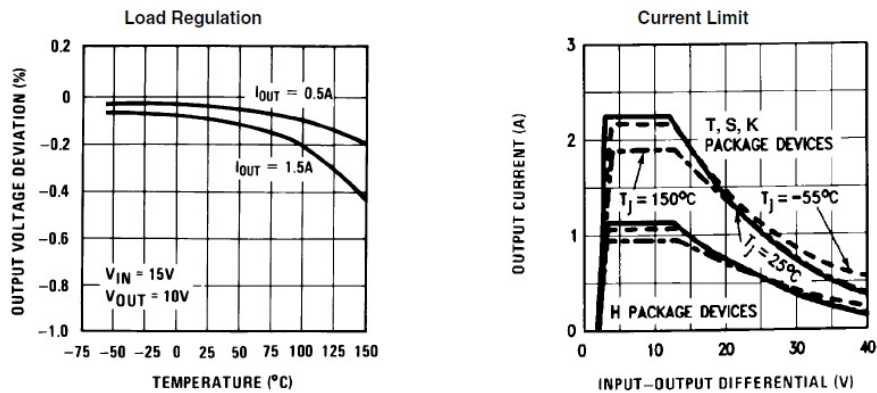
Figure 67 - Load Regulation and Current Limit of the LM317

Test Procedures

The test procedures are basically broken into five parts. The first is the collection of data points from our sample solar panels.   Figure 59 shows the block diagram for the solar panels that will be tested. A standard amp meter and volt meter will be used to measure the two values then recorded in a excel table shown in Figure 58.   The solar panel connectors have a power collector which will be the source we monitor for our 'dry' test run. The 'dry' test run is to get a baseline for the solar panels that our sponsors are given to us and to check to make sure they work.

Solar Data Spreadsheet						
Entry Number	Current	Voltage	Energy Stored	Solar Activity	Time	Time Interval
1	15A	500 V	40 watt	Sunny	9:00	1 hour
2	15A	400 V	80 watts	Sunny	10:00	2 hour
3	12A	300 V	120 watts	Partly Cloudy	11:00	3 hour
4	12A	300 V	150 watts	Partly Cloudy	12:00	4 hour
5	12A	300 V	170 watts	Partly Cloudy	13:00	5 hour
6	12A	300 V	190 watts	Partly Cloudy	14:00	6 hour
7	12A	300 V	200 watts	Partly Cloudy	15:00	7 hour
8	0A	0 V	200 watts	Raining	16:00	8 hour
9	0A	0 V	200 watts	Raining	17:00	9 hour

Figure 68 - Sample Data Sheet for testing just the Solar Panels

One of the major problems our project has had to deal with is the need to adjust our device to handle the 600 volt spikes that solar devices have at the beginning of solar activity during the day. This very sharp spike during the first hour when solar activity will be measured several times during the second semester when we acquire the solar panels. At the end of this testing we will be able to confirm that any future problems with readings are not a product of the solar panels but rather our device.   It will also give us a baseline in which to check to see how much power our solar device is taking from the total output of the panel. The group has voted begin this testing early in the morning, since it will take up a good portion of the day to complete Each member will do the test once and we will average the data to get our 'baseline' results.   One of the members of the group will be monitoring the panels real time and recording the data points in a excel spreadsheet. The time intervals will be initially be very short intervals, about 1 data point per minute, but as the solar panel becomes steadily active the voltage/current should steady out. Some of the things to be incorporated with each data point is the time of day, the overcast or solar panel coverage (cloudy, no overcast, etc.). This data will be used to determine the maximum and minimum values that the device needs to operate on, as well as to have valid, first hand data points of some solar panels.   This data will also be compared with to the solar panels with the device and without the device. The excel spreadsheet is shown in figure 58.

As any good engineer knows, troubleshooting can be one of the most difficult and time consuming portions of any project. The necessity to have a clear, concise, and very through test procedure can mitigate some of the risk of building the prototype. AT the very least it will help narrow down the problems to certain regions of the device. One of the design considerations when we did the design was separating the analog devices from the digital devices. This will be a great help to us when we begin to troubleshoot later in the second semester. The two devices will be tested individually. So when one of the devices is checked out, we can be reasonability sure that it is not a problem.
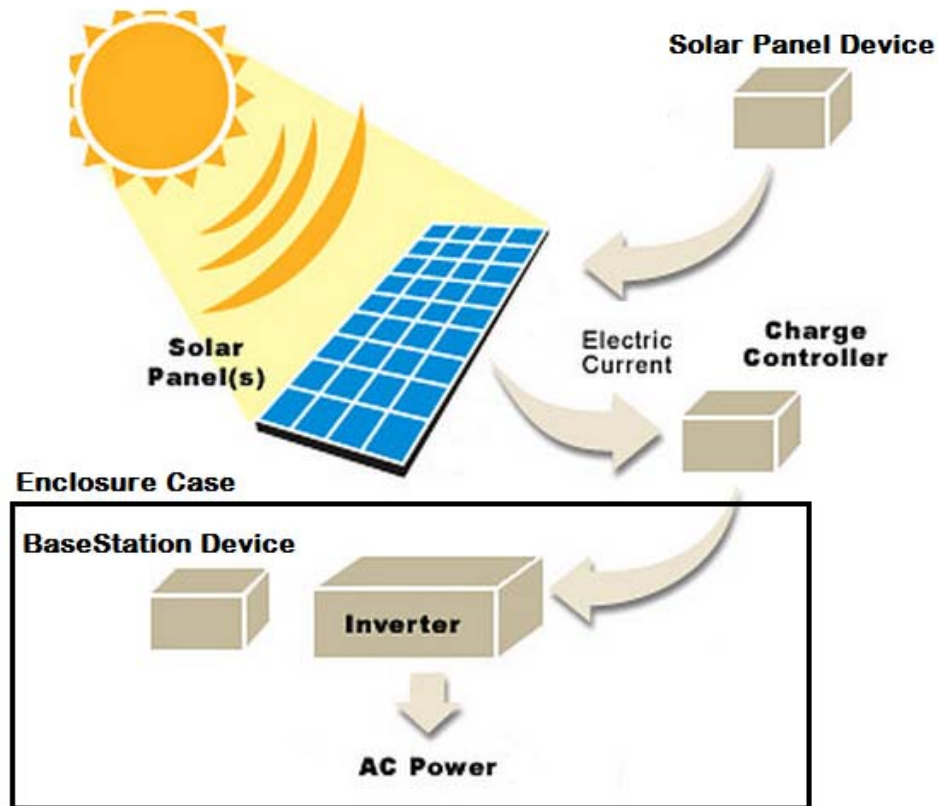
Figure 69 - Solar Device Test Block Diagram

The second set of testing will be connecting the device up to the sample solar panels. The device should be securely mounted onto a pole or other stationary object that will serve as our base station box.   The same spreadsheet as used in Figure 57 will be used to monitor the progress of the panels, periodic monitoring of the device online will also be tested at 10 min intervals (preferably the same intervals as the solar panels being checked. This will allow us to see if the sensors are noticing a full range of power thought-out the day.

The following is the risk assessment that the group has discussed at several of the meetings as well as some of the mitigating measure we are implying reduce the risk of them occurring.

1. Data recorded by the solar device does not match the data from the dry run of the solar panels and the amp/volt meter.
   a. Sensors are broken

b. The logic inside the base station is not reading the data correctly
c. The A/D converter is not properly working
d. The device is burned out from a overload
e. Solar panels are not producing the same amount of amps/volts that they did in the dry run
   i. Weather
   ii. Panels Broken
   iii. Human Error in recording
   iv. Location of solar device is changed.
f. Wireless is transmitting incorrect data
g. Spreadsheet in Excel is not working properly
h. The code is not managing the data correctly.

There is no easy way to trouble shoot this problem, it has so many different angles and is considered by the group to be the biggest risk to the project. If we cannot accurately record the data then our project is pretty much useless. Each of these problems can be addressed however, and by understanding the depth and different possibilities of the errors involved it will be easier to test.

First and foremost, we need checking to see if the data matches would be the first test to see if this is even an issue. Table 60 below shows the format in which we will be recording the data with some sample figures to lock in the format that the group will be using to record.

Solar Data Spreadsheet /w Device					
Entry Number	Time	Time Interval	Solar Device Current	Solar Device Voltage	Solar Device Green/Red
1	9:00	1 hour	15A	500 V	Green
2	10:00	2 hour	15A	400 V	Green
5	13:00	2 hour	12A	300 V	Green
8	16:00	3 hour	0A	0 V	Red
9	17:00	1 hour	0A	0 V	Red

Figure 70 –Solar Data Spreadsheet

If the tables do not match up then we can more than likely rule out the panels themselves since we tested them earlier, thought if all other routes have been checked then double checking the panels may be necessary. Check to see if the sensors are functioning by putting the device directly to an oscilloscope and see if it is acquiring any readings. This would be the best way to test the sensors. This will also be the way we test the sensors

before we solder them onto the solar device. We can test the logic by simple changing the logic inside the code and seeing if it affects the data, and double checking our logic to make sure that the data is being correctly received from the transmitter end.

2. The base station does not receive any data from the solar device

    a. The transmitter is broken

    b. The transmitter is out of range of the Base Station

    c. Base Station router is not receiving data

    d. The solar device and the base station are receiving and transmitting, but the data is not getting carried over from the solar device

    e. Coding is not correct and it appears that no data is being received

        i. Base station code

        ii. Solar device code

        iii. Web page code

The group has identified this as our second biggest risk for the prototype. The first test to troubleshooting this portion is to check the solar device and make sure that the data is being recorded. If the problem
The testing will need to confirm that the wireless device and base station are community cited properly. With Excel Spreadsheet feature, this will all be uploaded to the webpage which should be monitor able from any internet device with a flash plug-in. he first set will be comprised of using just a regular power supply to test the ranges of the device, this will check the device at key voltages below in the table.
The second set of testing will be connecting the device up to the sample solar panels. The device should be securely mounted onto a pole or other stationary object that will serve as our base station box.   The same spreadsheet as used in Figure 58 will be used to monitor the progress of the panels, periodic monitoring of the device online will also be tested at 10 min intervals (preferably the same intervals as the solar panels being checked. This will allow us to see if the sensors are noticing a full range of power thought-out the day.

These procedures are likely to change as the device matures in design and changes are made thought-out the second semester of senior design, but for a preliminary idea these are the procedures we plan on using to test/monitor/and collect data for the solar device and base station. Some testing material that we need to review is how to check the microcontroller and its flags, if the microcontroller is not tested properly then the entire device will not work properly. Reference the Microcontroller User manuals is a great and the base station connectivity need to be checked. The oscilloscope user manuals are also a necessary thing, as the UCF labs have notoriety for having some older equipment. This

equipment could be as much a liability as a source to rely on. The first set will be comprised of using just a regular power supply to test the ranges of the device; this will check the device at key voltages below

Test Areas that still need to be considered by which the design of the project has not progress to involve the following:

1. Logic testing of the PCB board
2. A longevity test for the battery
3. Testing the Charge Controller
4. Testing the Code for the Microcontroller in Base Station and Solar Device
5. Testing the Strings on the solar panel
6. Testing router
   a. Range of wireless signal

Equipment

In order to test our devices we will need some test and construction equipment. Some of the device will be available to use in the senior design lab.

- Oscilloscope: This will allow us to see a wave form of how analog devices are acting in relation to their source. This will be useful when constructing the regulators because we will need to determine if the current and voltage stored in the capacitor and inductor elements is up to the voltage and current that we require.
- DC power supplies: Until we have worked out and perfected the voltage regulators we will still need to test and construct anything relating to the digital side of the device. Also these will be useful in test other parts of the analog system including but not limited to the charging system for the battery and any other regulators that may be need for the rest of the power system.
- Protoboards: These will be useful for doing a preliminary layout and proof of concept design of our electronics.
- High Current Ammeter: This will allow us to safely measure high currents without causing damage to our device or the meter itself. Most meters are limited to a certain current by a fuse, so it may be necessary to have a high current detector without being limited by a resistor.
- High DC voltage meter: This will be useful in measuring the voltage not only from our power supplies but the outputs of sensors and leads for troubleshooting.
- Alligator clamps and wires: These will be need for prototyping before we have a PCB and soldered together components
- ESD cable: Many of the components that we have including both analog and digital are often times extremely sensitive to electro static discharge so we will need to take measures
- Safety equipment: As we will likely be dealing with high voltages and high

currents we will need protective clothing and tools so we may test our device without and harm to ourselves or anyone else in the lab.

- Various R C and L values: components are added as need so we will need a variety of these to be able to accomadate any change in our design.
- Digital logic testers: This will be used to determine logic levels on any of our digital devices will be need to trouble shoot problems we may have with these components.
- Computer simulation: This will be used as a preliminary tool before we start physically building anything. This will make us be able to know how a circuit should behave before we build it.

Environment

The environment for the majority of this project will be inside the Senior Design lab. Be due to the nature of this project we will need to see other locations for test of our final prototype.

The nature of the location will have to be as follows, as these requirements are necessary for effectively testing our device.

- Location outside
  - o Must be in an unobstructed sun light area
  - o No possible interference from trees or other overhanging materials
  - o Must have a safe location to be undercover in inclimate weather
  - o Must have a mounting location for solar panels
- Possible testing at an operational solar generation station

Final Specifications and Requirements

Solar Panel Device

The following specifications are the final list of all things accomplished by our prototype device solar string device. This is an adaptation of the original list of specifications given to us in the first semester. This list has been done for a variety of reasons including but not limited to: Change in requirements by sponsor, limit in technology, economical part acquisition and final implementation.

- Antenna ability to transmit minimum of $1/10^{th}$ of a mile
- Low cost components less than $150 for prototyping
- Must be able to tolerate all environment conditions -10C to +70C
- Must be able to adaptable for using power from Solar String DC volts from 180-480V
- Store enough power for more than 24 hours

- Last as long as the life of the solar panel approximately 20-30 years
- Sense current ranging from 1-70 Amps

The following requirements are the final list that have come from the requirements given to us at the beginning of senior design. These requirements have only changed with the specifications.

- Low power microprocessor with wireless capabilities
- Power system to charge a storage device (battery)
- Sense the power output of the String
- Located within transmit distance of base station
- Weatherproof containment- be able to fit inside a preexisting junction box
- One device for maximum of 6 solar strings

Base Station

The following specifications are the final list of all things accomplished by our prototype device, basestation device. This is an adaptation of the original list of specifications given to us in the first semester. This list has been done for a variety of reasons including but not limited to: Change in requirements by sponsor, limit in technology, economical part acquisition and final implementation.

- Battery system with 12 volt out put
- USB data storage
- Local Storage For at least 1 month
- Networkable
    - RJ45
    - 802.11

The following requirements are the final list that have come from the requirements given to us at the beginning of senior design. These requirements have only changed with the specifications.

- Base station located within transmit distance of solar device
- Website that updates when data becomes available
- Maintains data logs, stores and connects to offsite
- User interface for remote monitoring of power station
- Power management to allow for 24/7 data collection If needed for large arrays multiple base stations mesh networked to provide further wireless coverage
- Weather proof enclosure for microprocessor and electrical storage

Section 6: User Manual

To use the Solar Panel Monitoring system on need to situated in an appropriate location. The location must be equipped with an enclosure that will contain the microprocessor and the power electronics and battery. The power electronics must be connected in parallel to the solar string. To energize the battery charger circuit the switch on the enclosure must be turned on. A red LED will light up indicating power. The second LED will only light when the Battery has been fully charged or in float mode.
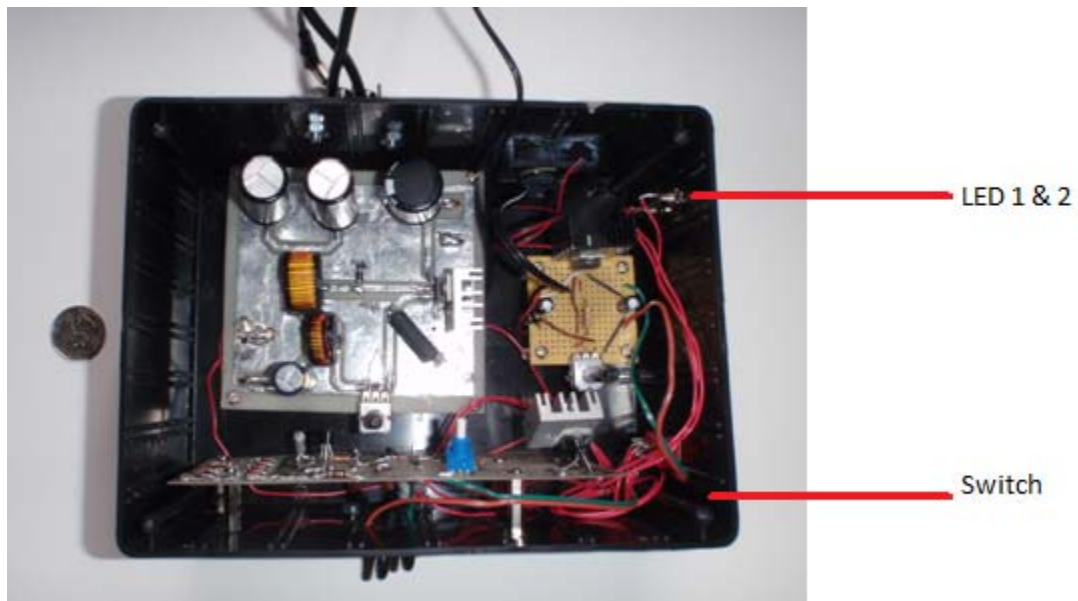

Figure 71 – Buck Converter and Battery Charger

Once battery is connected to the charger, the microcontroller will automatically boot. The boot process includes activating the wireless module and acquiring an IP address. This concludes the User required action for the Solar Device.

The User will then only need to go to the Basestation's IP address. This will show them the website that shows a list of the current and past data. To be updated a refresh is needed. The figure below depicts an example of this website. This website can be easily linked to a company website without difficulty. The Basestation is also capable of being attached to a VPN allowing for encrypted viewing of this data.

Figure 72 – Solar Panel Device Explorer 16 Board

To activate the base station, the user is only required to connect the power and Ethernet connectivity, and place the antenna in a location that will maximize its range and sensitivity.
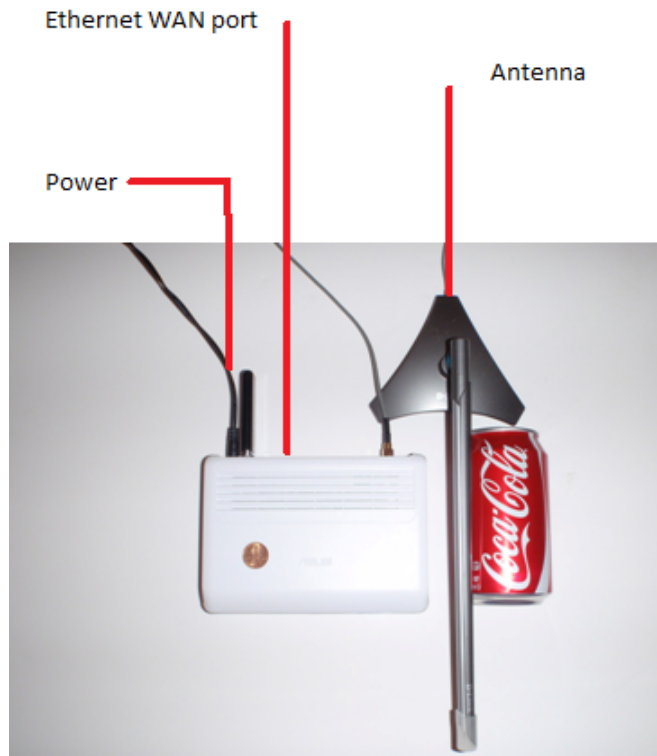

Figure 73 – Base Station

Section 7: Administrative Content

Timeline

Below is the timeline of our senior design project. It illustrates the progress that we made throughout the two semesters that senior design spans. The most notable progressions are the design and construction of the project, illustrated at the borders between the two semesters.

Figure 74 – Project Timeline

Work Distribution

Below is the work distribution of our senior design project. The project was evenly divided and completed, allotting 33.33% of the project to each group member. Ben's primary responsibility was the power regulation from the solar panels. Robbie's primary responsibility was the power regulation from Ben's part to the solar panel device. Finally, Devin's primary responsibility was programming the microcontroller and base station to work properly with every part.
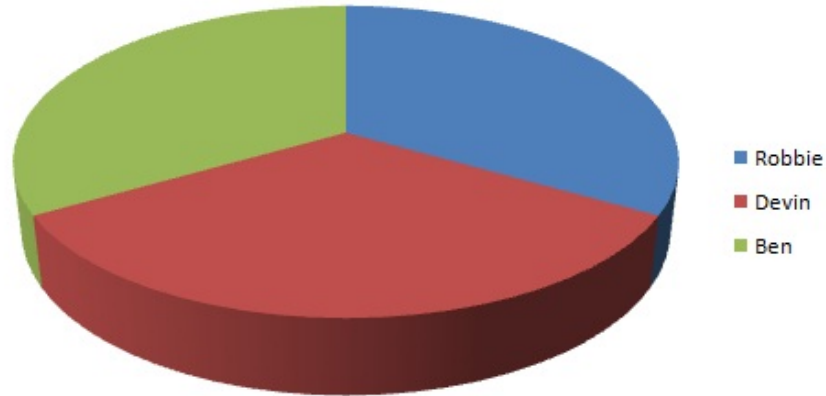
Figure 75 – Project Work Distribution

Budget

The budget of the project was funded by two companies: QuickBeam Energy and Progress Energy. Progress Energy provided a reimbursement maximum of $1,500 and QuickBeam Energy provided a grant of $500. The total costs of all parts for the project was approximately $1,051 and is illustrated in the table below.

Part Name	Company	Amount
12V 12AH Battery	Batteries Plus	$47.91
Capacitors/Inductors/Resistors	Digi-Key	$39.56
Cap 2.2UF 100V	Digi-Key	$40.07
FHS 40 PCB Kit	Digi-Key	$47.99
ZeroG Development Kit	microchip direct	$209.29
OptiMOS 2 Pwr-Tranc	Mouser Electronics	$4.45
Solder Parts/5V reg/16pin IC/Forceps	Radio Shack	$19.84
Soldering Gun	Radio Shack	$95.83
Capacitors	Skycraft Parts & Surplus	$6.82

Figure 76 – Project Budget Table I

Part Name	Company	Amount
Ring 16-14 and 1/16 Tin Bit	The Home Depot	$4.22
9V DC 1A Power Supply	ebay	$5.53
9V DC 500mA Power Supply	ebay	$10.70
Pickit 2 ICD Interface	microchip direct	$19.72
Pickit 2	microchip direct	$34.59
Explorer 16 Development Board	Newark	$143.82
Battery Charger Parts	Digi-Key	$61.79
Flux/misc comp	Skycraft Parts & Surplus	$32.70
PIC24 Prototyping Board	microchip direct	$27.68
Pictures from presentation board	Kinkos	$16.00
Parts for battery charger	Digi-Key	$63.78
Parts for buck	Digi-kKey	$58.35
Progress Energy Symposium board/materials	Staples	$23.25
Enclosure Cases	Radio Shack	$21.44
High Wattage Resistors	Skycraft	$6.00
More breadboards	Radio Shack	$9.67

Figure 77 – Project Budget Table II

Section 8: Conclusion and Summary

The general process of selecting components for this project has been tedious and intensive. Overall we have succeeded in making a successful understanding of what is needed for the construction of this project during Senior Design II. Our sponsor QuickBeam Energy has detailed our project to be the following.

The design for this set of devices is designed to relay information about a string of solar panels between a device at the string junction box to a base station located at the utility house. The premise of this design is for a few very important reasons.

First, a solar cell by nature is a very sensitive piece of electronics made from fragile silicon or similar elements, and for all intensive purposes is a diode that when biased correctly and put in sunlight generates a DC voltage. Just as with normal electronics, the volatile nature of these fragile electronics can also be its downfall. When these devices fail there is no physical means of knowing when or where it has failed. In many installations, a broken or damaged cell may be very difficult to find. Most of these configurations put solar panels in series to get the highest voltage usable by an inverter, which convert it to AC. Higher voltage is necessary to keep the losses across the wires coming from the panels to the inverter very low. In order to achieve higher voltages panels must be put in series. As with any electronic element in series when one element goes out the entire string is no longer effective but with no indication of which device failed. This effect is similar to the problem that plagues owners of Christmas lights. Knowing exactly when the string fails is crucial to keep a stable power generation and revenue from lost from lost generation time to a minimum.

Second, putting devices on each string would require even more wires and possibly complicate a field installation. Not to mention what would be worse than having a monitoring system fail causing lose of time determining where the problem is. To get around this we will use Wi-Fi to wirelessly send the data from one device to another. This would also make it so a system would be extensible meaning if more panels are added more monitoring device that transmit wirelessly would not contribute to anymore complexity of the system.

So with these two basic issues we construct our devices. A string device will monitor the voltage and current, this device will only be powered by the solar panels that it is monitoring. So this means it will require a battery charger and a battery that will need to be able to last at least 24 hours to be able to transmit even when not being powered or at night.

A base station is needed to save the data that is transmitted by the string device and be able to relay that information onto the internet. This device will also need to be remotely connected so that data can be collected without being on site.

Solar Arrays, a heated topic in the energy industry, have many applications as the price per watt has come to a more reasonable level. Power companies and residential homes have become increasingly more interested in installing photovoltaic arrays as a way to become more carbon neutral or "Green". Though they have their advantages, they also have some short falls. As the technology is now becoming more affordable, the use of these has become more widespread; and with use the problems have become apparent. One of the major problems is knowing when a singular solar cell or photovoltaic cell has stopped functioning, which sometimes greatly affects the output of the array. Monitoring each string of cells would be a great way to solve this problem.

Bibliography

- AIM. "Radio Frequency Identification – RFID A Basic Primer." Version 1.11. Association for Automatic Identification and Mobility. Sep. 9. 1999. <http://www.aimglobal.org/technologies/rfid/resources/papers/rfid_basics_primer.asp>
- Aldous, Scott. "How Solar Cells Work." How Stuff Works It's Good to Know. <http://science.howstuffworks.com/solar-cell.htm>
- ATL. "ATmega165P." Atmel Corporation. 2009. <http://www.atmel.com/dyn/products/product_card.asp?part_id=3889>
- ATP. Any Time Products. <http://www.anytimeproducts.com/meg/maildeliverycart.htm>
- AVX. "Multimedia Card Connector." AVX Corporation. <http://www.avxcorp.com/prodinfo_productdetail.asp?I=896&ParentID=92>
- BAM. "Light Travel Dynamo Dymotec® Fitting and Operating Instructions." Busch and Muller KG. <http://www.bumm.de/docu/download/106e.pdf>
- BLS. "Dynamo Power Lights." Bicycle Lighting Systems. <http://nordicgroup.us/s78/dynamo.html#Facts_about_Dynamo_Systems>
- BLT. "Learn." Bluetooth SIG, Inc. 2009. <http://www.bluetooth.com/Bluetooth/Learn/>
- BMA. "Battery Types." British Battery Manufacturers Association. <http://www.bbma.co.uk/batterytypes.htm>
- CEC. "Stored Energy and Batteries." California Energy Commission. <http://www.energyquest.ca.gov/story/chapter05.html>
- DES. "A beginner's guide to switching Regulators." Dimension Engineering. <http://www.dimensionengineering.com/switchingregulators.htm>
- ECS. "HC-49US Quartz Crystal spec. sheet." ECS Inc. International. 2005.
- EERE. "Photovoltaic Technologies" Energy Efficiency and Renewable Energy. U.S Department of Energy. Dec. 29. 2006. <http://www1.eere.energy.gov/solar/photovoltaics.html>
- EGL. "EAGLE 4.1 Schematic. Layout. Autorouter. Brochure." CadSoft Computer, Inc.
- EGM. "Optrex F-51167NCU-FW-AA Color LCD Display." The Electronic Goldmine. <http://www.goldmine-elec-products.com/prodinfo.asp?number=G16239>
- ELT. "Choosing A Rechargeable Battery." Electus Distribution. <http://www.electusdistribution.com.au/images_uploaded/recharge.pdf>
- EXP. "PCB Layout Software." Express PCB. <http://www.expresspcb.com/ExpressPCBHtm/Free_pcb_layout_software.htm>
- FSL. "RS08KA Family." Freescale Semiconductor. <http://www.freescale.com/webapp/sps/site/taxonomy.jsp?nodeId=016246844994879931>

- FSL. "S08QE: Flexis 8-bit HCS08 Microcontrollers." <u>Freescale Semiconductor.</u> <http://www.freescale.com/webapp/sps/site/prod_summary.jsp?code=S08QE&webpageId=1112377972033730441437>
- FSL. "S08QG: Microcontroller Family." <u>Freescale Semiconductor Inc.</u> <http://www.freescale.com/webapp/sps/site/prod_summary.jsp?code=S08QG&webpageId=1112377972033730441437>
- FSL. "ZigBee Standards Overview." <u>Freescale Semiconductor Inc.</u> <http://www.freescale.com/webapp/sps/site/overview.jsp?nodeId=01J4Fs25657725>
- Hart, Jeffrey. Lenway, Stefanie. Murtha, Thomas. "A History of Electroluminescent Display." <u>University of Minnesota.</u> Sep. 1999. <http://www.indiana.edu/~hightech/fpd/papers/ELDs.html>
- HCR. "Shimano Hub Generators and Lights." <u>Harris Cyclery.</u> <http://sheldonbrown.com/harris/lighting/shimano.html>
- IKN. "Power and Charge Batteries." <u>IKON Global Ltd.</u> <http://www.ikonglobal.com/>
- IRD. "IrDA Specifications and Technical Notes." <u>Infrared Data Association.</u> <http://irda.org/displaycommon.cfm?an=1&subarticlenbr=7>
- IRT. "AVR414: RC5 IR remote control transmitter App. Note." <u>Atmel Corporation, Rev. 2534A</u> May 2005.
- ITT. "Push Button Switches." <u>ITT Corporation.</u> 2007. <http://www.ittcannon.com/products/products.asp?pid=1020>
- KGM. "MMC Card Specifications." Version 1.3. <u>Kingmax Digital Inc.</u> July 07. 2004. < http://www.kingmaxdigi.com/product/MMC.pdf>
- KGT. "Flash Memory Guide." <u>Kingston Technology Company, Inc.</u> 2006. <http://www.kingston.com/products/pdf_files/FlashMemGuide.pdf>
- KGT. "MultiMedia Card mobile" <u>Kingston Technology Company, Inc.</u> <http://www.kingston.com/flash/mmc_mobile.asp?id=2>
- Lempert, Phil. "We 'check out' latest supermarket 'smart' cart." <u>Food & Wine, MSNBC.</u> July 20. 2004. <http://www.msnbc.msn.com/id/5462556/>
- LMX. "Infrared Emitters." <u>Lumex Inc.</u> <http://www.lumex.com/product.aspx?id=743>
- LTC. "LT3028 Dual Low Dropout Regulator with Independent Inputs." <u>Linear Technology Corporation.</u> <http://www.linear.com/pc/productDetail.jsp?navId=H0,C1,C1003,C1040,C1055,P7890#simulateSection>
- LTC. "LTC Microprocessor Supervisory Circuit." <u>Linear Technology Corporation.</u> <http://www.linear.com/pc/productDetail.jsp?navId=H0,C3,P1331>
- MCP. "Product Comparison Utility / 8bit microcontroller" <u>Microchip.</u> <http://www.microchip.com/ParamChartSearch/chart.aspx?branchID=1033&mid=10&lang=en&pageId=74>

- Mitchell, Bradley. "Wireless/Networking Infrared." About Inc. The New York Times Company. <http://compnetworking.about.com/od/homenetworking/g/bldef_infrared.htm>
- MOS. "Price Catalog." <http://www.modernoutpost.com/>
- MSE. "F-51373GNC-FW-AH Product Detail." Mouser Electronics Inc. <http://www.mouser.com/search/ProductDetail.aspx?R=F-51373GNC-FW-AHvirtualkey51610000virtualkey805-F51373GNCFWAH>
- MXM. "Choosing Supervisor Outputs." App. Note 939. MAXIM Integrated Products. Dallas Semiconductors. <http://www.maxim-ic.com/appnotes.cfm/appnote_number/939>
- MXM. "DC-DC Converter Tutorial." App. Note 2031. MAXIM Integrated Products. Dallas Semiconductors. <http://www.maximic.com/appnotes.cfm/appnote_number/2031/>
- MXM. "DS2740 High Precision Coulomb Counter." MAXIM Integrated Products. Dallas Semiconductors.<http://www.maxim-ic.com/quick_view2.cfm/qv_pk/3801>
- MXM. "5V-powered multi-channel RS-232 drivers/ receivers." MAXIM Integrated Products. Rev 15. Dallas Semiconductors.
- MXM. "MAXIM603, MAX604 Product Description." MAXIM Integrated Products. Dallas Semiconductors. <http://www.maxim-ic.com/quick_view2.cfm/qv_pk/1131>
- MXM. "Microprocessor Supervisors Offer Big Insurance in Small Packages." App. Note 720. MAXIM Integrated Products. Dallas Semiconductors. <http://www.maxim-ic.com/appnotes.cfm/appnote_number/720>
- MXM. "Microprocessor voltage monitor with dual over/undervoltage detection." MAXIM Integrated Products. Dallas Semiconductors.
- MXO. "Specifications for LCD Module MOP-GL240128D." Matriz Orbital. <http://www.matrixorbital.ca/manuals/mop/graphic/MOP-GL240128D.pdf>
- MXO. "Toshiba CMOS Digital Integrated Circuit Silicon Monolithic T6963C." Matriz Orbital. <http://www.matrixorbital.ca/manuals/mop/graphic/T6963CDS.pdf>
- MXO. Matriz Orbital. <http://www.matrixorbital.com/product_info.php?pName=mopgl240128dbgfw&cName=lcd-mop-graphic-lcds>
- MXO. Matriz Orbital. <http://www.matrixorbital.com/product_info.php?pName=glk24012825wb&cName=lcd-graphic-lcds>
- Neamen, Donald A. "Microelectronics Circuit Analysis and Design" 3rd ed. McGraw Hill. 2006.
- NEMA. National Electrical Manufactures Association. <http://www.nema.org/>
- OTX. "LCD Module Technical Specification." Optrex Corporation. <http://www.optrex.com/SiteImages/PartList/SPEC/51373ahe.PDF>

- OTX. "LCD Module Technical Specifications for Trial." Optrex Corporation. <http://www.optrex.com/SiteImages/PartList/SPEC/11-19-04%20Spec%20of%20F-51900NFU-FW-AC%20(2).pdf>
- PFS. "Power Film Instruction OEM Menu." Power Film, Inc. 2009. <http://www.powerfilmsolar.com/products/oem_components/instructions.htm>
- PMC. Popular Mechanics. http://www.popularmechanics.com/technology/industry/1716862.html?page=5
- PSI. Planar System Inc. <http://www.planarembedded.com/products/el/el-displays>
- PTC. "KEU-5LP Plastic Enclosure Product Description." PacTec Division of LaFrance Corp. <http://www.pactecenclosures.com/Plastic-Enclosures/KEU-5LP.html>
- PWC. Peter White Cycles. <http://www.peterwhitecycles.com/dymotec.asp>
- PWC. Peter White Cycles. <http://www.peterwhitecycles.com/schmidt.asp>
- PYC. "AG-54 Plastic Enclosures." Polycase^{TM} Your Perfect Fit. <http://www.polycase.com/item/ag-54.html#features>
- RPB. "Technical Information, Aluminum Specifications." Rose+Bopla Encluosures.<http://www.rosebopla.com/Prod_Pgs/Techinical_Data/Prod_18_Technical_Data_Aluminum_Specifications.htm>
- RPC. "NEMA Ratings." Rugged PC Review. <http://www.ruggedpcreview.com/3_definitions_nema.html>
- RYS. "High Power Infrared Leds." Reynolds Electronics. <http://www.rentron.com/remote_control/IRLED.htm>
- SAC. "What Are IP Ratings?" Southern Avionics Company. <http://www.southernavionics.com/IP66.htm>
- SDK. "Scan Disk Multimedia card and Reduced-Size Multimedia Card Product Manual." Version 1.3. ScanDisk Corporation. April. 2005. <http://www.sandisk.com/Assets/File/OEM/Manuals/ProdManRS-MMCv1.3.pdf>
- SDK. "Scan Disk Secure Digital Card" Version 1.9. ScanDisk Corporation. Dec. 2003. <http://www.cs.ucr.edu/~amitra/sdcard/ProdManualSDCardv1.9.pdf>
- SELF. "Solar Technology" Solar Electric Light Fund. <http://www.self.org/shs_tech.asp>
- SHO, Solar Home Organization. <http://www.solarhome.org/>
- Simpson, Chester. "Linear and Switching Voltage Regulator Fundamentals." Nacional Semiconductor. <http://www.national.com/appinfo/power/files/f4.pdf>
- SKI. "Liquid crystal Display Graphic Modules." App. Notes Seiko Instruments. <http://graphic-lcd-lcds.shopeio.com/inventory/pdf/G324EX5R1A0.pdf>
- SLA. "Sealed Lead Acid Battery Size Chart." Power Stream Technology. <http://www.powerstream.com/Size_SLA.htm>
- SLC. "Product Catalog – MEC Product Selection Guide." Sorenson Lighted Controls, Inc. 2004. <http://www.solico.com/prodmecpush.shtml> refer on text

- SRT. Sirit Technologies. <http://www.sirit.com/index.php?option=com_content&task=view&id=103&Itemid=112>
- SSD. Union-Tribute Publishing. http://www.signonsandiego.com/uniontrib/20060131/news_1b31food.html
- THG. Tree Hugger. <http://www.treehugger.com/files/2005/03/pedal_power.php>
- TXI. "220nA Supervisor with 10ms/200ms Selectable Delay Time" Texas Instruments Inc. <http://focus.ti.com/docs/prod/folders/print/tps3836e18.html>
- TXI. "Low Cost Baterry Coulomb Counter for Embedded Portable Applications." Texas Instruments Inc. <http://focus.ti.com/lit/ds/symlink/bq26231.pdf>
- TXI. "TI-RFid and Contactless Commerce." Texas Instruments Inc. <http://www.ti.com/rfid/shtml/rfid.shtml?DCMP=TIHomeTracking&HQS=Other+OT+home_p_tirfid>
- TXI. "TLC555 Low Power Timer." Texas Instruments Inc. <http://focus.ti.com/docs/prod/folders/print/tlc555.html>
- TXI. "SN74LVC4245A octal bus transceiver and 3.3v to 5v shifter with 3 stage outputs." Texas Instruments Inc. March 2009.
- Tyson, Jeff. "How ROM Works." How Stuff Works It's Good to Know. <http://computer.howstuffworks.com/rom.htm>
- VanInwegen, Myra. <http://www.myra-simon.com/bike/tips.html>
- VSC. "IR Receiver Modules for Remote Control System." Rev. 1.1. Vishay Semiconductors. Jan 22. 2007. <http://www.vishay.com/docs/84720/tsop382.pdf>
- VSC. "Vishay Products." Vishay Semiconductors. <http://www.vishay.com/search?query=TSAL&type=>
- Wilson, Andrew. Reconn's World. <http://www.reconnsworld.com/ir_ultrasonic_555timer40khzir.html>
- WJC. "WJM1000 Low-Power UHF RFID OEM Reader Module." WJ Communications, Inc. <http://www.wj.com/products/WJM1000.aspx>
- WJC. "WJM3000 RFID Reader Module Based on Gen 2 Reader Chipset." WJ Communications, Inc. < http://www.wj.com/products/rfid_WJM3000.aspx>
- WKP. "Battery." Wikipedia The Free Encyclopedia. <http://en.wikipedia.org/wiki/Electrical_generator>
- WKP. "Die Casting" Wikipedia The Free Encyclopedia. <http://en.wikipedia.org/wiki/Die_cast>
- WKP. "Electrical Generator." Wikipedia The Free Encyclopedia. <http://en.wikipedia.org/wiki/Electrical_generator>
- WKP. "Printed Circuit Board." Wikipedia The Free Encyclopedia. <http://en.wikipedia.org/wiki/Printed_circuit_board>
- WKP. "Radio-Frequency Identification." Wikipedia The Free Encyclopedia. < http://en.wikipedia.org/wiki/RFID>

- WKP. "Silver-oxide Battery." Wikipedia The Free Encyclopedia. <http://en.wikipedia.org/wiki/Silver-oxide_battery>
- WKP. "Solar Cell" Wikipedia The Free Encyclopedia. <http://en.wikipedia.org/wiki/Solar_cell#Silicon>

Appendix A: Reprinting Permissions

Request to Use Information

1 message

Devin McLean <airlinedev@gmail.com>   **Sat, Dec 5, 2009 at 8:46 PM**
To: brainslayer@braincontrol.org

Hello,

My name is Devin McLean and I am part of an Senior Design group at the University of Central Florida in Orlando,
Florida. We are designing a project to monitor solar panel arrays via wireless communication. While
researching, we have come across the DD-WRT firmware, which we would like to use on a router as one of our
communication devices. We would like to request your permission to reuse information (such as figures and
text) from your website in our initial design documentation.

Thank you very much in advance.

Sincerely,

Devin McLean

General Contact

This form is for general inquiries only. For information about a specific product/service, please contact your regional sales representatives. For technical questions, please contact our support center.

Required fields*

Inquiry Details

Subject*   [General Contact ▼]

Details*

> To Whom It May Concern,
>
> My name is Devin McLean and I am part of an Electrical and Computer Engineering Senior Design group at the University of Central Florida in Orlando, Florida. As an ABET accredited university, we are required to design a project that encapsulates our entire undergraduate education. We are designing a project to monitor solar panel arrays via wireless communication. While researching, we have come across products that your company has to offer, which we may purchase for our prototype, such as the Current Transducer FHS 40-P/SP600. We would like to request your permission to reuse information (such as images and text) from your website in our initial design documentation.
>
> Thank you very much in advance.
>
>
> Sincerely,
>
> Devin McLean

Your contact information

Title   ◉ Mr.   ○ Ms.

Last name*   [McLean]

First name*   [Devin]

Company*   [University of Central Florida]

Department   [ ]

Address* | 4000 Central Florida Blvd.

Zip code* | 32816

City/Town/State* | Orlando, Florida

Country* | USA ▾

E-Mail* | devin.mclean@knights.ucf.edu

Telephone |

Fax |

Submit   Cancel

Fw: Permission to reuse information

1 message

Suzanne Hochheimer <SuH@lem.com>   **Wed, Jan 6, 2010 at 5:35 AM**
To: devin.mclean@knights.ucf.edu
Cc: Greg Parker <GAP@lem.com>

Dear Mr McLean

Thank you very much for your email and request to use some LEM information in your design documentation. Please feel free to use any LEM information you need, we would just need you to name LEM as the source of this information.

Do not hesitate to contact me if you need anything else.
Thanks and good luck for your project!
Kind regards,

Suzanne Hochheimer
Corporate Communications Manager
LEM International
chemin des Aulx 8
CH-1228 Plan-les-Ouates/Genève

Tel: +41 22 706 1257
GSM: +41 79 432 0949

From:	LEM Website <system_web@lem.com>
To:	Suzanne Hochheimer/LSA/LEM, Stephanie Ferrolliet/LSA/LEM
Date:	14.12.2009 02:02
Subject:	LEM Website - General Contact

A visitor sent us an email from the website. Hereafter you can find the details of his/her inquiry

CONTACT INFORMATION

Title : Mr.
Last name : McLean
First name : Devin
Company : University of Central Florida
Department :
Address : 4000 Central Florida Blvd.
Zip code : 32816
City/Town/State : Orlando, Florida
Country : USA
E-Mail : devin.mclean@knights.ucf.edu
Telephone :
Fax :

INQUIRY DETAILS

Subject : General Contact
Details : To Whom It May Concern,

My name is Devin McLean and I am part of an Electrical and Computer Engineering Senior Design group at the
University of Central Florida in Orlando, Florida. As an ABET accredited university, we are required to
design a project that encapsulates our entire undergraduate education. We are designing a project to monitor
solar panel arrays via wireless communication. While researching, we have come across products that your
company has to offer, which we may purchase for our prototype, such as the Current Transducer FHS 40-P/SP600.
 We would like to request your permission to reuse information (such as images and text) from your website in
our initial design documentation.

Thank you very much in advance.

Sincerely,

Devin McLean

*** This message is automatically generated by the system. Please do not reply to this system email address.

Gmail

Request to Use Information

1 message

Devin McLean <airlinedev@gmail.com>   **Sat, Dec 12, 2009 at 11:26 AM**
To: publicrelations@linksys.com

To Whom It May Concern,

My name is Devin McLean and I am part of an Electrical and Computer Engineering Senior Design group at the University of Central Florida in Orlando, Florida. As an ABET accredited university, we are required to design a project that encapsulates our entire undergraduate education. We are designing a project to monitor solar panel arrays via wireless communication. While researching, we have come across products that your company has to offer, which we may purchase for our prototype, such as the Linksys WRT54GL wireless router. We would like to request your permission to reuse information (such as images and text) from your website in our initial design documentation.

Thank you very much in advance.

Sincerely,

Devin McLean

Gmail by Google

Devin McLean <airlinedev@gmail.com>

Request to Use Information

1 message

Devin McLean <airlinedev@gmail.com>   **Fri, Dec 11, 2009 at 3:48 PM**
To: Help.Buy@microchip.com

To Whom It May Concern,

My name is Devin McLean and I am part of an Electrical and Computer Engineering Senior Design group at the University of Central Florida in Orlando, Florida. As an ABET accredited university, we are required to design a project that encapsulates our entire undergraduate education. We are designing a project to monitor solar panel arrays via wireless communication. While researching, we have come across products that your company has to offer, which we may purchase for our prototype, such as the ZeroG 802.11 Development Kit for Explorer 16 (AC164136). We would like to request your permission to reuse information (such as images and text) from your website in our initial design documentation.

Thank you very much in advance.

Sincerely,

Devin McLean

National Semiconductor

PRODUCTS DESIGN ORDER COMPANY HOME

COMMENTS AND QUESTIONS

Please tell us how we can serve you better. National's support staff and managers read and value your comments so please do tell us what we can answer or do for you.

World Wide Customer Support Center Phone Numbers

COMMENTS or QUESTIONS (Please type your comments in English.)

Please write your question or comment in the box below. Please be specific and include page urls or part numbers where possible. This information will be helpful in answering your question.

```
To Whom It May Concern,

My name is Devin McLean and I am part of an Electrical and Computer Engineering Senior Design
group at the University of Central Florida in Orlando, Florida.  As an ABET accredited
university, we are required to design a project that encapsulates our entire undergraduate
education. We are designing a project to monitor solar panel arrays via wireless communication.
While researching, we have come across products that your company has to offer, which we may
purchase for our prototype, such as the LM5116 synchronous buck controller.  We would like to
request your permission to reuse information (such as images and text) from your website in our
initial design documentation.

Thank you very much in advance.


Sincerely,

Devin McLean
```

Feedback Category: ★ Sales Contacts

Level of Urgency: ◉ Not Urgent ○ Urgent

Product Folder/Part Number: Buck Synchronous Switching Contro

Revision (Software only)…....:

I want a response

★ indicates required information so that we can reply to you.

☐ Anonymous (If you prefer to remain anonymous, just send us your comments and submit the form)

CONTACT INFORMATION

First Name:★ Devin
Last Name:★ McLean
Your Company Name:★ University of Central Florida
Business Phone:★
Business fax:
Your Job Title:
Street Address:★ 4000 Central Florida Blvd.
City:★ Orlando
State or Province: (for North American destinations only) Florida
Postal ZIP Code: 32816
Country:★ United States
Your Email Address:★ devin.mclean@knights.ucf.edu

Submit Form   Reset

About "Cookies" • National is ISO/TS16949 Certified • Privacy/Security Statement • Contact Us/Feedback
Site Terms & Conditions of Use • Copyright 2009© National Semiconductor Corporation

Gmail
by Google

RE: Contact Inquiry from www.wi-fi.org

1 message

Trisha Campbell <tcampbell@wi-fi.org>   **Mon, Dec 7, 2009 at 12:14 PM**
To: "devin.mclean@knights.ucf.edu" <devin.mclean@knights.ucf.edu>, info <info@wi-fi.org>

Hi Devin,

Thank you for contacting us. You are welcome to use the term "Wi-Fi®" within your design
documentation. We ask that you give the following attribution: "The term Wi-Fi® is a registered
trademark of the Wi-Fi Alliance®."

Trisha Campbell

Marketing Project Manager

Wi-Fi Alliance

From: devin.mclean@knights.ucf.edu [mailto:devin.mclean@knights.ucf.edu]
Sent: Sunday, December 06, 2009 12:55 PM
To: info
Subject: Contact Inquiry from www.wi-fi.org

Wi-Fi CERTIFIED™ makes it Wi-Fi.

First Name: **Devin**

Last Name: **McLean**

Company:

Address:

City:

State:

Zip Code:

Country: **United States**

Email: devin.mclean@knights.ucf.edu

Phone: ext.

Nature of Inquiry: **General Questions / Other** -

How may we assist you?

To Whom It May Concern,

My name is Devin McLean and I am part of an Electrical and Computer Engineering Senior Design group at the University of Central Florida in Orlando, Florida. As an ABET accredited university, we are required to design a project that encapsulates our entire undergraduate education. We are designing a project to monitor solar panel arrays via wireless communication. We would like to use the registered trademark word Wi-Fi within our design documentation.

Thank you very much in advance.

Sincerely,

Devin McLean

How did you hear about us?:

Please rate www.wi-fi.org:
-- **Excellent**
What was the purpose of your visit today?
--
How likely are you to return to www.wi-fi.org?
-- **Very likely**
How likely are you to recommend www.wi-fi.org to others?
-- **0**

Form filled out at approx: **12/06/2009 01:55:29 pm EST**
Sent To: **info@wi-fi.org**

Devin McLean <airlinedev@gmail.com>

Request for Permission to Use Product Details

Marcello Hernandez <MHernandez@zerogwireless.com>   **Thu, Nov 12, 2009 at 11:49 AM**
To: devin.mclean@knights.ucf.edu
Cc: Lien Nguyen <LNguyen@zerogwireless.com>

Hello Devin,

Images can be used for non-commercial use. Logos are not allowed.

Let me know if you have any further questions or request.

Best regards,

Marcello Hernandez

ZeroG Wireless, Inc.

Tel: (408) 738-7551

Fax: (408) 738-7601

www.zerogwireless.com

From: Marcello Hernandez
Sent: Wednesday, November 11, 2009 9:04 PM
To: Tim Colleran
Subject: Fwd: Request for Permission to Use Product Details

I think falls into the marketing team.

- Marcello

Begin forwarded message:

From: Devin McLean <devin.mclean@knights.ucf.edu>
Date: November 11, 2009 8:38:52 PM PST
To: ZGSales@zerogwireless.com
Subject: Request for Permission to Use Product Details

To Whom It May Concern,

My name is Devin McLean and I am part of an Electrical and Computer Engineering Senior Design group at the University of Central Florida in Orlando, Florida. As an ABET accredited university, we are required to design a project that encapsulates our entire undergraduate education. We are designing a project to monitor solar panel arrays via wireless communication. While researching, we have come across products that your company has to offer, which we may purchase for our prototype, such as the ZG2100 Wi-Fi Module. We would like to request your permission to reuse information (such as images) from your website in our initial design documentation.

Thank you very much in advance.

Sincerely,

Devin McLean