Communications Network
for a GPS Atmospheric Imaging System

A Major Qualifying Project Report
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1 Abstract

SRI International recently developed a new ionospheric imaging method which utilizes a network of 9 hard-wired GPS receivers. The task of this project was to design a renewable power system and communications network to support autonomous operation of the GPS receivers. This project drew considerably upon solar power system design, embedded microprocessor programming, and communications theory. The report prepared develops the initial stages of deploying this network, documents the prototyping and design process, and provides recommendations for future work.
2 Executive Summary

The center for GeoSpace Studies at SRI International has developed a method of imaging the density of the ionosphere using a network of GPS receivers. This method incorporates the use of a network of GPS receivers located throughout a geographic region to collect phase delay information of the GPS timing signal. The density is important to study because it affects the propagation of electromagnetic waves through the ionosphere. The primary goal of this Major Qualifying Project is to overcome the limitations of expanding the current network and provide recommendations for future expansion.

Currently, SRI has a scientific proof-of-concept system deployed at the Sondrestrom Research Facility, located in Kangerlussuaq Greenland. This system consists of nine GPS receivers placed in a circular fashion, 500 meters from the research facility. These receivers have hard-wired power and data lines connecting them to a central point at the research station. Due to the distance limitations involved with hard-wired data transmission and the difficulty of laying communication and power lines in the artic, the final implementation of this system needs to incorporate wireless data transmission as well as renewable power.

This report provides a prototype design as well as recommendations for developing the communications network and renewable power components of this system. The specifications for this project are: the system must be able to sustain itself with no external power for up to one year, the GPS data must be collected and wirelessly transmitted over 1 km to the research station, and the system must operate in extreme artic conditions. From these specifications, the scope of this project is divided into two components: integrating the supporting elements necessary for local GPS operation, and designing an appropriate network topology to communicate to all points on the network.

Each GPS receiver is accompanied by three supporting sub-systems: the power system, the communications system, and the central processing unit. These four components are integrated together to form a single point on the network which will furthermore be referred to as a node. Before a design for this system could be proposed, technical research was conducted to evaluate design options for each sub-system. After evaluating existing technologies, a prototype and future recommendations were developed.

The GPS receiver is specified by SRI and was chosen for it’s capabilities to obtain the necessary scientific data. The power system consists of three major components; a solar
panel, a charge controller, and a battery. The solar panel converts the available sunlight into power which is stored in the battery via the charge controller which increases the efficiency of the charging system. The communications system consists of a 900 Mhz radio frequency packet modem which transmits the binary GPS data to the research facility. The central processing unit, furthermore referred to as the nodal processing unit (NPU) is designed to mitigate the communication between the GPS receiver and the RF packet modem, and collects health and status data on the overall system.

The prototype was designed to replace the current system deployed in Greenland with the capability of spacing the nodes further than 500 meters from the research facility. From the prototype and the initial specification of developing a scalable system, design recommendations were made deploying a larger network topology. The network topology must be able to accommodate the bandwidth needed by up to 100 nodes.

In conclusion the prototype demonstrates the proof of concept of this design. This report documents the feasibility of the design and provides recommendations for implementing the system on a larger scale.
3 Introduction

SRI International was founded in 1946 as the Stanford Research Institute in conjunction with Stanford University. In 1970, SRI seceded from Stanford University to become an independent, nonprofit scientific research institute. Their primary objective is to research new technology and pure science.

The Center for GeoSpace Studies at SRI began operating the Sondrestrom Research Facility which is dedicated to the study of the polar upper atmosphere—specifically the ionosphere. The influence of the ionosphere on satellite and radio wave transmission is of great interest to the scientific community at large. Existing Ionospheric imaging techniques provide insight into these influences. Recently, SRI international has developed a new and innovative imaging method using GPS receivers.

This method uses carrier phase delays created by the propagation of the GPS signal through the earth’s upper atmosphere, to image the density of the ionosphere. SRI International has verified the feasibility of this imaging procedure on a small-scale using nine GPS receivers and determined that there is significant potential for this system. To overcome the limitations of the current system (and further validate this imaging technique), the need for deploying an autonomously powered wireless communications network has arisen.

The primary goal of this Major Qualifying Project is to overcome the limitations of the current network, and provide recommendations for future expansion. The following report documents the research conducted from October 2004 - March 2005, describes the prototype that was developed, and details future design considerations.
4 Scientific Background

In order to gain a better understanding of this project and its significance to both SRI International and the scientific community at large, several topics must first be developed. In the following section, the scientific relevance of imaging the ionosphere will be explained. Additionally, a quick survey of existing imaging systems will be discussed. Finally, the theoretical framework from which this project was charged will be developed.

4.1 Why Image the Ionosphere?

Scientists and researchers are beginning to place increasing importance on understanding the ionosphere and its properties. By researching the Ionosphere Scientists are able to better understand Space Physics and Geophysical events. The study of the ionosphere also helps to bridge the knowledge gap associated with Plasma Physics. Another more practical reason for studying the ionosphere is that Ionosphere plays a pivotal role in radio, television, and satellite communications. While Scientists are gaining a better understanding of the ionosphere there is still a great deal to learn about its physics, its chemical makeup and its everyday changes due to solar radiation.

4.2 Existing Systems for Imaging the Ionosphere at SRI

The influence of the ionosphere on satellite and radio wave transmission is of great interest to the researchers at SRI. Within the Engineering Systems Division, the Center for GeoSpace Studies oversees several research outposts and facilities.

The Center for GeoSpace Studies at SRI began operating the Sondretrom Research Facility which is dedicated to the study of the polar upper atmosphere. More specifically, this research is centered on obtaining information about upper atmospheric physics and the interactions of neutral gases with charged space plasma. Integral to this research is the steerable L-band incoherent scatter radar, which measures several parameters of the ionosphere and outer regions of the atmosphere. The facility at Sondrestrom has become an invaluable resource for ionospheric and upper atmospheric research and is one of three atmospheric research facilities operated by the Center for Geospace Studies. While this tool has proven useful to scientists, it also has several drawbacks. At 32 meters wide, the radar is
far from re-locatable once built; also such a large instrument is incredibly expensive to build and maintain in the arctic climate. Another major problem with the radar is that scientists are continually vying for time to use the site for research.

SRI was recently awarded a $44 million dollar contract to build AMISR (Advanced Modular Incoherent Scatter Radar) a modular, “mobile” radar facility in 2003. The AMISR system is a phased radar array that is being deployed to study the ionosphere and upper atmosphere. What makes AMISR particularly useful is that it is able to be remotely operated, allowing scientists from all over the world to use the research instrument. The AMISR system has been deployed in two locations: Resolute Bay, Nunavut Canada and Poker Flat, Alaska.

While all of these sites are effective tools to gather information about the upper atmosphere and ionosphere, scientists at SRI are continuously looking for more practical and effective systems to conduct experiments and gather data. In particular, sensor coverage is still sparse for the ionosphere, with only a handful of imaging systems around the world dedicated to its study. An inexpensive, autonomous, and easily deployable distributed network would increase coverage over larger distances and enable scientists to track the movement and patterns of the ionosphere more effectively. The charge of this project is to design just such a system.

4.3 A New Approach to Imaging the Ionosphere

There are at least 24 operational GPS satellites orbiting the earth at all times. The satellites, operated by the U.S. Air Force, orbit the earth with a period of 12 hours. Ground stations are used to precisely track each satellite's orbit. Each GPS satellite transmits data that indicates its location and the current time. All GPS satellites synchronize operations so that these repeating signals are transmitted at the same instant. The signals, moving at the speed of light, arrive at a GPS receiver at slightly different times due to the varying distance between the receiver to the satellite. The distance to the GPS satellites can be calculated by comparing the time the signal was transmitted to the time the signal was received, thus determining a delay. Theoretically this delay is directly related to distance the signal traveled.

Consider a Single Satellite Orbiting the Earth with four ground-based fixed point receivers:
Given several other key variables like the position and frequency, phase delay can be measured for each GPS receiver as described above. The carrier phase delay represents the lag associated with a radio wave traveling through the ionosphere and will vary depending upon the characteristics of the medium through which it travels. By analyzing these carrier phase delays, a great deal of useful information can be determined about the ionosphere.

A new method SRI is proposing involves using multiple satellites and a passive array of GPS receivers to study the ionosphere. This is part of the Imaging Irregularities in the Ionosphere (I^3) research initiative that is currently being undertaken in the Geospace Studies department at SRI.

Now consider a simplified array system relying on 2 satellites and 4 receivers in three dimensions:
Figure 2: Imaging the ionosphere using multiple satellites

Knowing the rate at which the satellites orbit the earth over time, one can calculate the delay to any number of ground-based receivers over multiple points on a plane. The delay for all of these point sources is calculated over an array using multiple satellites. With some ingenuity, a complicated cross-correlation algorithm, and a bit of signal processing a “shadow” image of the ionosphere can be calculated. This theoretical concept has been tested by SRI researchers at the Sondrestrom Research facility in Kangerlussuaq, Greenland.

Figure 3: Current Setup of GPS Receivers in Greenland
The initial proof-of concept deployment for this concept involved mounting 9 GPS receivers around a central location as shown in Figure 3: Current Setup of GPS Receivers in Greenland. The system continuously streams data at a rate of 10 Hz from 12 GPS Satellites which are hardwired for power and data transmission.
5 Technical Research

The initial scientific feasibility for this project was proven through the current setup of nine GPS receivers in Sondrestrom Greenland. Currently these GPS receivers are hardwired to both power and communication lines. The challenge of this project was presented according to the following description:

The focus of this project is to develop a robust wireless communications network capable of handling raw streaming GPS data for a large grid of stations from 500m to 1Km apart. The separation of receivers and need for operation during extended periods of time with limited power is a focal point of this project. 6

Due to complexity of this system it was necessary to define subsystems that could be researched and developed independently. The subsystems are: The GPS Receiver, the Power System, RF Data Transmission, and Nodal Intelligence. The following sections describe the technical research and design options of each of these subsystems.

5.1 GPS Receiver

The existing GPS sensor network in Sondrestrom, consists of 9 Novatel “Smart Antenna” GPS receivers 7 via RS422 serial cable to the central data collection point at the Sondrestrom base station. SRI provided this component as a given for the system. The Smart Antenna is a rugged, self contained GPS receiver antenna designed for harsh environments. The Smart Antenna can provide both the both the carrier phase delay and position data for a variety of applications and can be seen in Figure 4.

The Novatel Smart Antenna unit consists of three primary subsystems that can be purchased separately from Novatel: the L-band 26dB GPS antenna, the SuperStar II OEM GPS receiver, and a serial interface card.
One of the primary design challenges involved with integrating this device was supplying it with an adequate power supply. With a typical draw of 1.8 watts at 14 V DC, the GPS receiver consumes more power than the other sub-systems combined. Another critical design consideration is interfacing the GPS data output. For this application, the receivers have been configured to output a serial data stream of 12 channels, collecting data from each channel at 10Hz; the output data rate has been rounded up to about 1.5KBps for bandwidth estimations for the communications system. (The attached CD –ROM contains a User’s Manual)

5.2 Power System

The major engineering constraints that limited viable power options are the following:

- Must Operate at -40 C
- Must be completely autonomous and self-sustaining
- Maximizes the efficiency of recharge and battery life

Based upon these initial constraints, the power subsystem was researched according to the following categories: powering the system, the potential renewable energy available, and maximizing charge storage via charge controller.

5.2.1 Batteries

The principles of storing charge in a battery can be applied to all types of batteries. Voltage and current is the product of an electrochemical reaction that transfers electrons
from one pole of the battery to the other. A lead acid battery is composed of cells, each containing two plates. The two plates are created from lead and lead dioxide. The plates are submerged in a sulfuric acid electrolyte which creates a potential between them. When a load is attached across the plates lead begins to combine with the sulfuric acid and creates free electrons. This electron travels across a load to the other plate and combines with the second plate (lead dioxide), whose byproduct reaction creates water. As a battery loses charge from one plate to the other, lead sulfate builds up on each plate, and the acid becomes diluted by water build up. In order to reverse this process the battery must be charged using an independent power source. This entire cycle comprises one complete discharge and recharge cycle of the battery. Through the addition of these cells and physical manipulation to characteristics of each cell different potential voltages and extended life between recharge can be achieved.  

The knowledge of extremely low temperature ranges as well as extended period of operation limited the battery options severely from the start. The deep cycle lead acid battery became the only potential option which could handle both the extreme cold as well as extended discharge. Another consideration is the temperature effect on battery capacitance. This relationship, illustrated in Figure 5, is standard across all lead acid batteries.
As the temperature approaches \(-40^\circ\text{C}\), the capacitance drops to 30 \% of the rated capacitance. The extreme cold temperature range (-40\(^{\circ}\) C) in Greenland is accounted for later in Section 6.2.4--Power System Integration.

Before the specific battery was chosen, research was conducted to analyze potential options. The three most common applications for batteries are automotive, marine, and deep-cycle. Automotive batteries were rejected due to the inherent construction which delivers a large charge over a short period of time. Automotive batteries are seldom discharged more than 10 \%, and are rated for only 20-150 deep cycle discharges before failure. A marine battery is also not suited for our project because it also is not rated for deep discharge cycles since it is a cross of deep cycle and automotive. They deliver greater charge in a shorter period than a true deep cycle and life cycles are based upon a maximum of 50\% discharge reducing the available capacity by half before recharge is needed. Deep cycle batteries are most commonly used for powering systems with access to renewable power since they are built to deliver constant power down to 80\% depth of discharge\(^{10}\).

Deep Cycle batteries that meet the initial engineering constraints include flooded, gelled, and absorbed glass mat (AGM). A flooded deep cycle battery was rejected from the start due to the knowledge that it could not withstand temperatures below 5 degrees C leaving only gel and AGM technologies\(^{11}\).

5.2.1.1 Gel Cell

A gel cell battery is a specific type of lead acid battery whose acid has been ‘gelled’ using a solution with silica gel. In regular lead acid batteries oxygen is normally produced on the positive plate and recombines with hydrogen given off by the negative plate and produces water. With the gel technology oxygen is trapped in the cell by a pressurized vent, and travels to the negative plate through gaps in the gelled electrolyte\(^{12}\). Due to this combination gel cell batteries are constructed with a positive internal pressure. The advantages of having a gelled solution rather than liquid in the battery is there is no spillage hazard since there no liquid, which also leads to the lowering of operating temperatures since water damage due to freezing is non existent. Along with the cold operating temperature gel cells rate of self-discharge is lower the colder the temperature becomes. A typical gel cell will discharge up to 10\% and as little as 4\% at colder temperatures per month when not in use. A physical
property of using a gelled acid is the creation of more electrolytes which allows a larger number of deep cycle discharges, and also creates lower internal resistance than regular flooded cells. In comparisons of efficiency, flooded cells convert approximately 15-20 % of electrical energy into heat, while gel cells only 10-15%. In larger battery banks this potential 10% difference can significantly affect the total capacity.

The gelled property of these batteries can also create problems. Gel cell batteries must be charged at a rate of C/20 (capacitance/20) to prevent damage due to excess gas. Also charging of these batteries must be done at a lower voltage and within finer tolerances than that of a flooded lead acid battery. If overcharged, gaps are permanently created in the gel which causes loss in total battery capacity. In hot operating conditions the silica gel can react with water in the air causing premature battery failure.

5.2.1.2 Absorbed Glass Mat

Absorbed Glass Mats are another specialized type of a lead-acid battery. The acid is absorbed and immobilized between the positive and negative plates by a fine fiberglass mat. This allows a fast, efficient reaction between the plate materials and acid, which contributes to a lower internal resistance resulting in a recharge efficiency minimum of 96%. Another advantage related to recharging an AGM is the charge voltages. They are the closer to those of standard lead-acid batteries making it compatible with most commercial charge controllers. Within an AGM all the hydrogen/oxygen recombination is done using a gas phase transfer, creating a non-spill able battery capable of working in extremely cold conditions (rated down to -40 C). The self discharge of these types of batteries is between 1-3 % over the month, approaching 1% in colder conditions. The major disadvantage of an AGM is that it is only suitable for very specific applications. As temperatures increase the AGM is prone to a greater capacity loss, and less deep cycle recharges. Also cost of an AGM can be 2 to 3 times that of a flooded wet cell battery rated at the same capacity.

Supporting the use of Gel Cell and AGM technology other projects were researched which performed under similar conditions. The three most relevant projects included GPS Observations for Ice Sheet History (GOFISH), Artic Powered Ice Movement, and the Ivotuk project SRI is currently working on in Alaska. GOFISH was conducted in 2000 and involved GPS receivers used to measure the movement of Ice in the Artic. This system incorporated 5 Deka gel cell batteries, and operated down to -20 C. After one year of operation 2 of the
batteries were damaged due to a hypothesized overcharging, but the system was still functional. The second Artic Ice Movement project was conducted in Antarctica 2001, and drew a continuous 6.5 Watt power draw. This system incorporated 3 x 75 Amp Hour (Ah) GelTech batteries. From personal communications with Paul Tregoning\textsuperscript{18}, the system operated for 220 days total over the span of 3 years at temperatures dropping down to -50 C with no damage to the batteries of system(2005). From the SRI website, as well as personal communication with Roy Stehle\textsuperscript{19}, a professional in the field of renewable energy, the third project Ivotuk, based in Alaska, analyzes carbon flux in relation to global warming. The site in Alaska utilizes the AGM technology with Concorde series 110 Ah batteries (2005). The batteries have proven robust; however the system is currently down due to complications with wind turbines.

\subsection{5.2.2 Renewable Energy}

Hardwired power is not a viable option to operate the nodes due to the remote geographic deployment. Therefore, each node must be independent and self-sustaining. One of the major driving constraints on the system is that it relies on renewable power.

There are several options for renewable energy. The most abundant of these energy sources are water, wind, and solar. Each of these options present unique benefits and difficulties.

\subsubsection{5.2.2.1 Hydropower}

To use hydropower each node would have to be deployed at a location near moving water. This is not a realistic constraint to put on a system that will potentially be composed of approximately 100 nodes with 500m to 1Km distances between each. Additionally, this system is intended to be used in artic environments at temperatures well below the freezing point of water. Hydro-electric power is therefore, not a realistic renewable energy source.

\subsubsection{5.2.2.2 Wind Power}

Wind, however, is a potentially viable option. Wind is an abundant resource in arctic regions. The cold climate reduces the amount of foliage that can grow there, and the lack of foliage allows for strong wind speeds close to the ground\textsuperscript{20}.

Although wind speed is variable over large ranges, wind speed averages serve as an adequate starting point to examine this option. Strong winds carry exponentially more
power than weak winds; therefore averages actually underestimate the power carried by wind. At Kangerlussuaq, Greenland wind speed year-round is typically between 6 and 10 miles per hour measured at 3 meters above ground. The following graph illustrates this using weekly wind averages collected over the last seven years.

![Average Winds Graph](image)

Figure 6: Average Wind Speeds for Kangerlussuaq, Greenland [Appendix I - Kangerlaussauq 7 Year Wind Averages]

Although wind is a plentiful resource, there are several difficulties in harnessing its energy. One problem is that wind turbines must be mounted several meters from the ground to optimize the power that wind generates. As you approach closer to ground level, wind speed exponentially decreases, and becomes much more chaotic with larger gusts. Mounting poles are expense and can be difficult to install. Furthermore, wind turbines have many moving parts, without which they cease to function. If the turbine freezes over in a storm, the turbine would no longer be able to provide power to the battery. Moving parts tend to break faster and more frequently than stationary parts, resulting in increased maintenance. Wind is certainly a viable option for a renewable energy source; however, it does present some complicated, and possibly costly, design considerations.
5.2.2.3 Solar Power

The final option is solar power. To generate an accurate model of solar power this section develops the relationships between the following.

- Sunlight Hours
- Insolation
- Cloud Cover
- Photo Voltaic (PV) Panels

Figure 7, obtained from an online java-applet, provides an indication of how many hours of sunlight is available throughout the entire year at a provided geographic coordinate, in this case Kangerlussuaq, Greenland.

![Sunlight Chart for Kangerlussuaq, Greenland](image)

Figure 7: Sunlight Chart for Kangerlussuaq, Greenland
The black area indicates night-time, and the white areas indicate day-time. The areas of all white illustrate the 24 hours of sunlight present within the summer. The green, innermost line illustrates sunrise and sunset.

Figure 7 was important in determining sunlight hours, however, it does not account for insolation. Insolation is a measure of sunlight intensity in Watts/m² and directly affects PV panel performance. Insolation is dependent on the tilt of the Earth’s axis, and yearly changes in planetary position throughout orbit. Both factors affect angles of incidence and contribute to a 47° shift of the sun’s path on the horizon.²³

If directly perpendicular the sun will strike a surface and produce the greatest intensity; however if the sun is a few degrees above the horizon of the surface the intensity approaches zero. Figure 8 illustrates this change in intensity over the same area.

![Figure 8: Angle of Incidence Illustration²¹](image)

At 45 degrees the intensity of light is spread over a larger area due to the difference in angle of incidence. Between the horizon and the perpendicular positions the sun will produce a predictable change in intensity proportional to the sine function. This principle is applied to the insolation value at specific latitudes in the same fashion. Figure 8 below illustrates the yearly average at different latitudes²⁰.
Important in this figure is the comparison of the equator to other latitude values. At the equator (0°), the insolation values throughout the year remain nearly constant since the angle to the sun changes the least, while at 30° North (closer to Greenland), these values fluctuate seasonally from below 300 W/m² to close to 500 W/m².

To develop an accurate model of the potential solar power available, insolation values at 77° N, 67° W (Sondrestrom, Greenland), were researched. Figure 10 illustrates these insolation values for the 2004 year as evaluated by NASA.
Figure 10: Insolation Values for Sondrestrom Greenland\textsuperscript{24}

Figure 10 illustrates the insolation value at the top of the atmosphere, and neglects cloud cover. During an overcast day, the sunlight cannot penetrate the clouds and therefore cannot generate any insolation at ground level. With minimal or no insolation a PV panel power output will approach 0.

Figure 11: Percentages based upon 8760 images of the sky taken by the Axis 2100 Network Camera currently deployed at Sondrestrom station

No trends were generated from this data, so in the final projected runtime calculations each day was accounted for. Daily insolation and cloud cover factors greatly influence the amount of available solar power and are therefore factored in when generating a model. The formula explaining the relationship between these factors is as follows:
(\%Cloud\_Cover) \times (Daily\_Insolation\_Value) = (Ground\_Insolation)

The *Ground_Insolation* refers to the amount of power available and is measured in Watts/m². With accurate values for potential solar power PV panels can now be analyzed. PV panels generate electricity from semi conducting cells. The semiconductors within each cell react to sunlight and create free electrons depending on the insolation value. A larger insolation value creates a proportionally larger number of free electrons which ultimately creates more charge. This charge is also related to the type of semiconductor material used within the PV panel. The three commercial PV panel technologies include monocry stalline, polycrystalline, and amorphous silicon.²⁵

Monocry stalline silicon is grown from a single crystal and then cut into wafers. Polycrystalline panels are created out of the growth of many silicon crystals together, and amorphous silicon is created from a thin semi-conducting film. The major difference between these is cost and efficiency. While amorphous silicon is the least efficient and can cost up to 5 times less than the mono and polycrystalline modules. Figure 12 illustrates the typical efficiencies of each PV panel.

<table>
<thead>
<tr>
<th>Typical Efficiency</th>
<th>Amorphous Silicon</th>
<th>Monocry stalline Silicon</th>
<th>Polycry stalline Silicon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Module</td>
<td>3 - 6 %</td>
<td>12 - 15 %</td>
<td>10 - 15 %</td>
</tr>
</tbody>
</table>

*Figure 12: Comparison of Efficiencies for the 3 commercial PV panels*

PV panels are typically tested to a standard 1000 W/m² insolation value. To determine the power generated by the panel the insolation available (*Ground_Insolation*) is divided by the tested value. At an insolation value of 500 W/m² the panel will produce \( \frac{500\,W/m^2}{1000\,W/m^2} \) or \( \frac{1}{2} \) the rated power. This relationship proved valuable in generating an accurate model developed later.

PV panels using solar power presents its own set of complications and drawbacks, however the low maintenance, physical durability, and operation in extreme temperatures were considered when finalizing a design. PV panels require little to no maintenance because they have no moving parts. Solar modules typically last for 20 years or more²⁶. Cold weather is actually preferable to warm weather for operating a solar panel. PV module
efficiency is improved about 0.5 percent for every degree C decrease in temperature.\textsuperscript{27} Designing a solar array sufficient to power the system does present a challenge. Once this obstacle is overcome, solar power becomes another viable option.

### 5.2.3 Charge Controller

The use of batteries requires the installation of another component called a charge controller. Decreased battery life, and severe battery damage can occur to a battery due to irregular charging. A charge controller increases battery life by proper regulation of the charge cycle and to prevent overcharge. In a renewable energy power system the use of a charge controller is essential for maximizing battery life.\textsuperscript{28}

There are three basic types of charge controllers: simple single stage controllers, pulse width modulated controllers, and controllers with Maximum Power Point Tracking (MPPT). Optimally a battery is charged with constant DC power source. A standard 3 stage charge cycle is shown below in Figure 13.

![Figure 13: Charging Algorithm for Standard Lead Acid Battery\textsuperscript{29}](image)

The three stages shown are bulk, absorption and float. Figure 11 illustrates the relationship between voltage and current throughout each stage. In the first stage the majority of battery
capacity is restored. This is followed by a constant voltage stage where the current drops lower. The last stage is a float stage where the battery is slowly filled to completion with minimal current.

Simple two stage controls rely on relays or shunt transistors to control the voltage, and operate in the bulk and absorption conditions. These essentially just short or disconnect the solar panel when a certain voltage is reached, and never fully charge the battery. Although this limits damage to the battery, as much as 30% of the battery capacity can go unused.

Three-stage, pulse width modulated (PWM) chargers build upon the two stage model by adding an equalize or float stage. The equalize stage uses PWM to allow current to trickle into the battery when it is nearly at full charge. This feature protects the battery and ensures more complete charge, and is ideal with a guaranteed supply power\textsuperscript{29}.

Maximum power point tracking (MPPT) controllers are a final option. These also have PWM and other features not found in standard controllers. MPPT type controllers are ideally suited for applications where power is limited and efficiency becomes crucial. MPPT type controllers deliver 10% to 30% increase in current to the battery by intelligently distributing power (limiting voltage and effectively delivering larger current). They are usually more expensive than most PWM controllers however, but often the extra cost is more than offset by the greater power that actually reaches the batteries\textsuperscript{30}.

\section*{5.3 Transceiver}

The initial specification of this project requires that all GPS nodes operate autonomously at a distance greater than 1000m. This requirement demonstrates the need for a wireless data transmission device. This section will survey the options for communicating wireless and the devices that meet the general specifications.

Specific to this project the major areas of consideration for designing the RF data transmission system are the following:

\begin{itemize}
  \item Transmission protocol
  \item Data throughput rate
  \item Transmit power
  \item Power consumption
  \item Transmission range
\end{itemize}
For this project the goal is to maximize data throughput, minimize transmit power and power consumption, while trying to maximize range.

5.3.1 Evaluating Transmission Protocols

There are a wide range of transceivers available on the market, with varying specifications related to bandwidth, power consumption and range. Data rates on RF equipment range from kilobits to megabits per second; while the transmission range varies from meters to kilometers. Below is a chart briefly outlining available technologies and standards.

<table>
<thead>
<tr>
<th>Wireless Technologies</th>
<th>Range</th>
<th>Bandwidth</th>
<th>Power Consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>BlueTooth</td>
<td>0 - 150 m</td>
<td>700 Kbps</td>
<td>Low Power &lt; 500 miliwatts</td>
</tr>
<tr>
<td>WiFi (802.11)</td>
<td>100 - 300 m</td>
<td>54 Mbits</td>
<td>High Power &gt; 2 watts</td>
</tr>
<tr>
<td>RF Packet Radios</td>
<td>0 - 20 km</td>
<td>15 Kbps</td>
<td>Medium Power 500 – 1500 miliwatts</td>
</tr>
<tr>
<td>Zigbee</td>
<td>0 - 150 m</td>
<td>20 - 250 Kbps</td>
<td>Low Power &lt; 500 miliwatts</td>
</tr>
</tbody>
</table>

![Figure 14: Wireless Technologies vs. Specifications](image)

From this chart it is easy to see that some technologies would not be feasible for this project. The range on the BlueTooth and Zigbee technology is too short for this application, and extending the range would not be practical. WiFi solutions can be built to achieve the necessary range, but the power consumption is too much to be sustained by a renewable power system. This leaves the technology of RF packet radios; they have the necessary range and power consumption. These radios also have serial interfaces which allow for easy connection to the GPS receiver. The tradeoff associated with the RF packet radios is the limited bandwidth.

From our project specifications the bandwidth of the RF Transceivers must be able to support a constant data-rate from the GPS receivers. The GPS receivers stream data at approximately 1.5 KBps. This data stream will be buffered by the nodal processing unit, described further in the Nodal Processing Unit Section, and then streamed to the RF transceiver. The RF Packet modems are capable of sustaining a theoretical 15 Kilobytes per second throughput rate. This is adequate but network efficiency and packet loss may reduce the theoretical data rate down significantly, on the order of 10-50%. Figure 1: Phase Delay
of a GPS Signal shows the specifications of a variety of RF packet modems generated from the Manufacturer’s Data Sheet.
<table>
<thead>
<tr>
<th>AeroComm ConnexLink RF Serial Device</th>
<th>Warwick Wireless X7200 Radio Model</th>
<th>Coyote DataCom SCADA Data Radio Modem</th>
<th>FreeWave Packet Modems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost $115</td>
<td>$200</td>
<td>$399</td>
<td>$500+</td>
</tr>
<tr>
<td>Operating Temperatures</td>
<td>-40 C to 80 C</td>
<td>-10 C to 55 C</td>
<td>-30 C to 70 C</td>
</tr>
<tr>
<td>Frequency Characteristics</td>
<td>902-928 MHz</td>
<td>458.5-458.95 MHz</td>
<td>902 - 928 MHZ</td>
</tr>
<tr>
<td>Range</td>
<td>Up to 20 Miles</td>
<td>10-20kM (LOS)</td>
<td>* Up to 30 Miles</td>
</tr>
<tr>
<td>Channels</td>
<td>Up to 32</td>
<td>25</td>
<td>50</td>
</tr>
<tr>
<td>Data Rate Transmission</td>
<td>115.2 kbps</td>
<td>10-20kbits</td>
<td>10 kbps</td>
</tr>
<tr>
<td>Baud Rate Serial-In</td>
<td>up to 115.2 Kbps</td>
<td>up to 1.2-56.7 Kbps</td>
<td>2.4, 4.8, 9.6,</td>
</tr>
<tr>
<td>Supply Power</td>
<td>6Vdc to 18 Vdc</td>
<td>7.18 Vdc</td>
<td>10-26V</td>
</tr>
<tr>
<td>Transmit Power Output</td>
<td>1000mW variable</td>
<td>1-40mW</td>
<td>5-500 mW</td>
</tr>
</tbody>
</table>

**Figure 15: Survey of RF Packet Modems**

All of the RF packet radios in the chart above satisfy the engineering specifications of this project; other factors that would contribute to choosing a model would be price and availability.

### 5.4 Nodal Processing Unit

The primary responsibility of the NPU subsystem in each sensor will be to buffer data acquired from the local GPS Receiver and forward it to the wireless transmission device. Another role of the NPU will be to minimize critical data loss by storing GPS Data into memory in the event that a transmission link becomes temporarily unavailable. Additionally, the Nodal Processing Unit will need to acquire local health and status data and forward this information to the exit point. Examples of health/status data include: current battery charge status, remaining battery life, voltage output of solar panel, etc. Finally, in the event that the sensor system needs to be restarted or reconfigured, the NPU must have the capability to issue the proper commands to both the GPS receiver and wireless communication device.
Based on these responsibilities, the NPU must adhere to the following design considerations:

- the device must have two serial ports to allow information to continuously stream in from the GPS receiver and to allow constant transmission out via the wireless device;
- the device must contain on-board data-acquisition capabilities to retrieve local health and status readings;
- the power consumption of the device must be minimal; and
- the device must be rugged and able to handle the extreme arctic climate.

The following sections depict research into a variety of solutions for the nodal processing unit.

5.4.1 PC-104 Computer Boards

The Center for GeoSpace Studies at SRI International has used the PC-104 form factor in several projects including the recent AMISR receiver. Because SRI has relied on this technology in the past, this approach was investigated. There are a wide variety of PC-104 products ranging from analog interface devices to touch-screen controller drivers.

![PC-104 Board](image)

**Figure 16: PC-104 Board**

PC-104 is a standard for computing devices that is composed of a modular system architecture that uses 3.5" square boards that snap together. PC/104 products are widely
used, because the "stack through" bus, which uses ISA bus technology, provides a compact and rugged design for building process control and embedded systems. PC104 gets its name from the popular desktop personal computers initially designed by IBM called the PC, and from the number of pins used to connect the cards together (104). Power requirements and signal drive are reduced to meet the needs of an embedded system.

Because PC104 is essentially a PC with a different form factor, most of the program development tools used for PC’s can be used for a PC104 system. This reduces the cost of purchasing new tools and also greatly reduces the learning curve for programmers and hardware designers. PC104 based systems are used in a variety of places including factories, laboratories, processing plants, vehicles, and almost anywhere devices must be controlled by a programmable computer. Additionally, PC104 systems are designed to be more rugged than desktop systems.

While many potential solutions using PC-104 were identified, no device could be found that met the ultra-low power consumption constraint. Also PC-104 solutions were too robust in their computing and data acquisition capabilities, offering several unnecessary extra options and peripherals. Another draw-back to using a PC-104 board is that they are very expensive, costing about $500-$1,000 per unit.

5.4.2 Embedded Microprocessors

Embedded microprocessors are a viable option for the nodal processing unit; they are inexpensive, draw little power, and are easily customizable. There are many microprocessors available on the market designed for specific applications. These applications run from simple calculators to digital processing. Most microprocessor run an assembly program from memory; while many more run real-time operating systems and complex programs built in high level programming languages.

There are many manufacturers building embedded microprocessors today. Some include the Intel StrongARM family of microprocessors, the PIC microcontroller and the Parallax Basic Stamp. All of these microprocessors draw low power and are designed for extreme environments; the major design considerations of this project rely on the microcontroller’s data acquisition capabilities, memory size, and its ability to interface with serial devices.
5.4.3 GumStix “Way Small” Computers

An embedded platform option that was identified by SRI International in an initial meeting was the GumStix microprocessor system. The GumStix Corporation offers a variety of embedded systems and full computers that are incredibly compact and powerful. These systems have moderate comparative power draw at 1W and offer the option of expansion boards that accommodate USB, serial, GPIO, and blue-tooth interfacing capabilities.

![GumStix Embedded Computer](image)

**Figure 17: GumStix Embedded Computer**

Both the embedded processor version and “Waysmall” computer provides a full gcc-3.4 (with C++) cross-compile environment including bootloader, kernel, user space and build environment. The most significant feature of the product line offered by GumStix is the computing power and capabilities obtained in such a remarkably small unit; compared to other similar commercially available products, the GumStix computer is two to three times smaller. Another attractive feature of these microprocessors is the reasonable price; a full “Waysmall” computer system runs from $139 - $219 and the GumStix embedded platform runs from $109 - $184 depending on the expansion boards and customizable options. These devices also operate at a relatively low power, drawing about 200mA at 5V.
5.5 Network Topology

In wireless networking, there are three major aspects that govern design: transmission, control, and topology. Transmission can be defined as all communications between the nodes. The frequency on which the devices communicate is a transmission consideration. The control principle can be defined as the system intelligence which dictates how the nodes communicate in the system as a whole. One control consideration is how the information collected in the field is relayed back to a central source. Network topology describes the virtual configuration of the nodes. The wireless network topologies we researched can be broken down into three major categories: linear, star and mesh.

![Network Topologies Diagram](image)

*Figure 18: Multiple Network Topologies Depicting Nodes and Branches*

5.5.1 Linear Topology

In a linear network setup the sensors are virtually grouped into straight lines. Each node transmits data to the next predetermined node. The next node in the line receives that information, adds additional data, and then transmits it to the next predetermined node. This process continues until all of the data from the nodes in that line are transmitted to a central node.
The following are advantages to the linear topology:

- Easy to implement
- Easy to debug
- Transmission distance is limited to the distance between neighboring nodes
- Store and forward capabilities

The following are disadvantages to the linear topology:

- Lack of Redundancy; if one link goes down the data is not immediately accessible
- Takes longer for real time data acquisition; this delay is proportional to the distance to be traveled as well as the delays inherent in data hops throughout. Depending on these factors delays expected can be as small as microseconds, or as large as minutes.

5.5.2 Star Topology

A star topology involves a single connection from each node to a central node. All peripheral nodes communicate their data to the central node. The central node usually then organizes and transmits all of the collected data to another location. In many star topologies, the central node is capable of longer transmission ranges than the peripheral nodes. This central node may even process some of the data before it is transmitted to the central processing location.

The positives of the Star Topology are:

- The ability to do some “pre-processing” of data before it is transmitted

The negatives of the Star Topology are:

- Lack of Communications Redundancy
- Larger communication distance; each sensor needs to be able to reach the central hub.

5.5.3 Mesh Topology

A mesh network is a network where each node has the ability to communicate with every other node within transmission range. This type of network is independent of node location. Node placement does not have to follow a predetermined pattern. Each node can choose the best node to communicate with by evaluating a set of criteria. These criteria may
include physical distance, network activity, or programmed priority schemes. The following is an example of how a node may change its transmission path based on these criteria. Node A is closest to node B and usually be where A would transmit to; however, if node B were busy communicating with another node, node A could select an alternate node to transmit its data to. The mesh topology is flexible in how data arrives to the central location from the nodes.

The advantages of Mesh Topology are:

- Many data paths
- High fault tolerance to broken communications links

The disadvantages of Mesh Topology are:

- Requires more network overhead
  - Hardware required must be compatible with mesh implementation
  - Software must support the communication between multiple nodes.
- More complicated routing procedures to deal with QoS (Quality of Service)
6 Design

The following sections outline the design of the overall system, and address how this project satisfies the system requirements.

6.1 Design Milestones

When the idea for this system was first introduced the specifications and requirements were undefined. At the onset of this project Craig Heinselman a scientist at SRI had a scientific method for imaging the Ionosphere using GPS receivers. The current setup in Sondrestrom, Greenland had been running for approximately 1 year, from which a data set had been collected. From this data Craig and his associates have proven that the use of GPS receivers for this type of Ionospheric imaging is a viable one. After initially speaking with Craig Heinselman and Todd Valentic the initial goals of the network was defined as the following:

- Develop a wireless network capable of intelligently routing GPS 10Hz carrier phase information to a central data collection point.
- Account for a projected 1.5 Km distance between GPS receivers
- Flexibility to scale from the nine GPS nodes up to 100
- Capability for artic deployment (harsh weather)
- Each GPS Receiver must be independently powered

To transform this broad system goal into accomplishable objectives; two major milestones were implemented to create measurable and achievable goals. The two milestones are outlined below:

Milestone 1:
- Autonomous Power
  - Running Both GPS and Aerocomm Modems off battery power
  - The Solar Panels have the Ability to Recharge the Battery
- GPS data streaming directly to Aerocomm Modems
  - No Flow Control
  - No Data Buffering
  - 3% Data Loss Tolerable
Milestone 2:

- Expand upon Milestone 1
- Introduce the MSP430 as the Nodal Processing Unit
  - Prove that the MSP430 can Relay Data Between GPS Receiver and Aerocomm Modems
  - Demonstrate the MSP430 can Buffer GPS Data
  - Demonstrate the Analog to Digital Converter on the MSP430 can be used to Measure Health and Status Data

The following sections demonstrate the proof of concept of the design through prototyping and testing as well as future recommendations based on scientific research. In order to make the design process manageable, the network system was broken down into four independent subsystems to design test and later integrate. These systems were:

- Power
- GPS Receiver
- Communications
- Nodal Processing.

6.2 Power System Design

Section 5.2 Power System developed general constraints and limited the scope of viable options to create a renewable power system. These constraints were analyzed further to determine the specific products incorporated in our prototype and serve as a basis for the final design discussed in the following section. The power system design is broken into the following sections: The Battery System, The Solar System, The Charge Controller, and The System Integration. The following constraints govern the design process:

- 5 Watt Load
- Power Load for 10 days with no sun
- Limit discharge to 30% of initial capacity
- Operate in temperatures as low as -40 C

6.2.1 The Battery System

In the section 5.2.1 Batteries indicated two viable options for battery operation in the extreme arctic climate. These are: Gel Cells and Absorbed Glass Mats (AGM) batteries.
The analysis seen in Appendix J – Evaluation Gel Cell vs. AGM, illustrates the advantages of using the AGM over the Gel Cell. Two important conclusions are drawn from the analysis:

- An AGM can recharge over a wider range of voltages resulting in a minimum recharge efficiency of 96%
- At a 30% depth of discharge (recommended maximum depth to prevent damage) an AGM is rated for twice the number of lifetime cycles than a Gel Cell.

Based upon the power consumption requirements of the GPS receiver which operates at a nominal voltage of 12V, the initial calculations demonstrated the need for at least a 100 Amp hour battery. Based on these initial assumptions, the 48 Amp hour, 12 Volt, Concorde PVX 490T Appendix N - Concorde SunXtender Datasheets battery was selected for experimentation. The tests conducted on this battery provided a model to accurately predict the behavior of larger batteries. These tests can be seen in 0 Power System Experiments and demonstrate the various conditions the battery was subjected to. The conclusions drawn from these experiments can be summarized as follows:

- It is possible to charge an AGM using Solar Power
- For any given voltage, one can determine the depth of discharge based upon the standard 12 Volt Lead Acid Table [included in Appendix K – Voltage vs. State of Charge]
- The AGM recharges with 96-100% efficiency

The projected 5 Watt load will draw a total of 120 Watts per day (5 Watts * 24 hours). To satisfy a 10 day operation constraint (developed in next section), 1200 Watts total is required (120 Watts * 10 Days). If a 100 Ah battery was used, the 10 day operation could be achieved; however the battery will be drained to 100%. Draining a battery to this level can permanently damage the battery. To ensure that the depth of discharge is above 30 % and a 10 day operation is met, 30 Ah is added to the 100 Ah needed, resulting in the recommended 12 Volt Concorde SunXtender 130 Ah AGM battery.37

6.2.2 Renewable Energy

Solar and Wind power are the only two viable renewable energy resources that can be implemented at Sondrestrom, Greenland. After talking with Roy Stehele above, a professional in the field of renewable energy, solar power became the more attractive design option for several reasons. Solar power is more feasible than wind due to lack of moving parts. The maintenance required for wind turbines implemented in the harsh, artic climate
far exceeds that of solar power. Cost and flexibility are other factors in choosing solar power. Solar panels are cheaper per watt, and commercially provide various power ratings from tenths to hundreds of watts allowing scalable models. Wind turbines, however, do not have the same flexibility, and product research indicated a minimum cost of $900 [Section 7.1].

Analysis of the potential solar power available at Sondrestrom [Figure 19] indicates that it is impossible to operate the system for a one year period using only PV panels. The design goal then shifted to power the system for as many days of the year as possible. A model was built based upon the 2004 daily solar power available seen in Appendix H - Potential Solar Power at Kangerlaussauq (2004). Within this model a potential operational period was developed seen in Figure 19.

![Potential Ground Insolation](image)

**Figure 19:** Potential Ground Insolation based on data shown in Appendix H - Potential Solar Power at Kangerlaussauq (2004).

This operational period, due to the sunlight patterns at the higher latitude, ranges from approximately the second week of March to the second week of September. The irregular dips within Figure 19 are accounted for by storms and overcast which blocked sunlight therefore available solar power. The 2004 data also indicated a maximum series of 5 day with negligible sunlight. To account for the variability of cloud cover from year to year, 5 days is doubled to yield a 10 day minimum battery only runtime.
6.2.2.1 Solar Power

The three available options for PV panels developed in Section 5.2.2.3 included: amorphous, monocrystalline, and polycrystalline. An Amorphous panel was rejected because of inherent physical characteristics which does not generate enough power, and would require a larger number of panels if implemented. A monocrystalline panel produces enough power, however research indicated a lower durability, and a much higher cost. The polycrystalline panel offered an affordable, powerful option and was used in our prototype.

The [Power System Experiments] outline the testing of the British Petrol 350 U panel, as well as other polycrystalline panels in a variety of controlled experiments. The conclusions taken from these tests are relevant to the feasibility of implementing a Polycrystalline PV array. The conclusions are summarized as follows:

- It is possible to charge an AGM using solar power
- Extra power not drawn by the load will recharge the AGM battery
- Different power ratings are scalable in a linear fashion
- Insolation and Cloud cover greatly effect the power output of PV panels

Using these conclusions and analyzing the relationship between battery size and panel output the design recommended is 2 British Petrol (BP) 3125 polycrystalline panels. The datasheets in Appendix L - BP Solar Datasheets, indicate that the BP 350U test results can be scaled to the BP 3125. The important characteristics of the BP 3125 panel are:

- 125 Max Watt Power Output
- 7 Amp Short Circuit Current
- The I-V Curve Demonstrating the Optimized Operation

A 125 Watt panel was chosen due to the analysis of 2004 insolation values and cloud cover at Sondrestrom, Greenland. Combining the potential solar output the BP 3125 specifications Figure 20 demonstrates the amount solar power one BP3125 can generate.
Figure 20: BP Solar 3125 power projection incorporating cloud and insolation in 2004

Figure 20, similar to Figure 19, exemplifies the seasonal changes in power. Toward the middle of the graph, higher watts coincide with months closer to the summer when the sun is out 24 hours a day. The outskirts of this graph shows the power produced approaching 0, which coincides with winter months when the sun may not break the horizon.

The irregularities throughout the graph are directly related to the cloud cover. If the sky is overcast, insolation values can drop to zero, severely limiting the amount of power the PV panel can produce.

To maximize the number of operational days, spring and late summer months are analyzed. During these months, there is limited insolation which decreases the window for power to be put back into the system. It is more important during this period to produce more current rather than a higher voltage. The BP 3125 panel is recommended for this reason. A panel with larger power output but lower current will take longer to recharge the AGM, and the power transferred will not be optimized. Although the proper charge controller can intelligently transform this power, maximizing current input at the most fundamental level improves overall efficiency. A larger panel rated for similar current or greater current may generate a longer projected runtime, but the trade off then becomes cost. The cost to benefit ratio simply does not justify larger panels over an 81 node system.
Figure 21 quantifies the data to illustrate how many days throughout the year one solar panel can generate sufficient power (120 Watts) to operate the load for one entire day. The 120 Watt per day draw was generated with a projected 5 watt load @ 12 Volts. On is designated by a ‘1’, and Off by a ‘0’.

![One Year Operation with 3125](image)

**Figure 21: Illustrates the number of days a BP3125 can produce 120 Watts (On = 1, Off = 0)**

The total number of days that the BP 3125 panel can source the necessary 120 Watts, is 171 days, or approximately 49% of the year. Although PV panels rated for lower power may produce a similar graph, what is not shown here is the need for surplus power. The PV panel must generate sufficient power for the load needed that day and also recharge the battery bank to account for days without sunlight. This relationship is developed in more detail in the Power System Integration section below.

Two PV panels are essential to the functionality of the solar panel implementation. Two panels allow maximum runtime throughout the defined operational period. To reduce downtime from winter to spring months, one panel must be angled to maximize the available rising insolation values. The recommended angle for this is 27.4° above the horizon, and was generated from the optimum average angle of incidence from March 9th to May 4th. The second panel should be optimized for days approaching the end of the operational period when isolation values decrease. A recommended 22.4° angle above the horizon was generated by optimum average angles of incidence from August 20th to
September 11th [Appendix H - Potential Solar Power at Kangerlaussauq (2004)]. Although this configuration will not produce the full potential power during the 24 hour periods of sun the potential energy far exceeds the power needed to recharge the system.

6.2.3 Charge Controller

In order to properly integrate the AGM battery, and PV panel, a charge controller is recommended. As mentioned in the Section 5.2.3, the three viable options for charge controllers include two stage, three stage, pulse width modulation, and MPPT controllers. Two stage, three stage, and pulse width modulation controllers are well suited for constant power supplies, and do not offer the flexibility of the MPPT controller. The MPPT charge controller offers most efficient conversion of solar power, operates over extreme temperature ranges, and is fully compatible with the AGM technology. The product used in the prototype, as well as the recommended design is the MPPT SolarBoost 2000E.

The SolarBoost is a 12 Volt battery charger which offers many features including: the extreme operating temperatures (down to -40 C), compatibility with AGM, overcharge protection, and ability to intelligently limit voltage, effectively delivering larger current at lower voltage [Appendix M - SolarBoost 2000E MPPT Datasheet]. Several tests were conducted to test the Solar Boost 2000E. The following conclusions were drawn from these tests [Power System Experiments]:

- MPPT limits voltage and increases current when the PV panel generates sufficient power at high voltages
- When PV power is insufficient to activate MPPT, the charge controller directly connects the solar panel to the battery, providing almost all of the available current to the battery.
- The charge controller protects battery from overcharge
- Charge efficiency remained over 90% throughout all tests.

6.2.4 Power System Integration

A test of the fully integrated power portion of the prototype was conducted [Power System Experiments]. This test proved conclusively that it is possible to power a load and recharge a battery simultaneously using solar power for three days. Earlier tests proved that
each prototype component scales to its corresponding recommended size rating. A block diagram of the integrated power system can be seen in Figure 22.

![Block Diagram of Power System](image)

**Figure 22: Power System Block Diagram**

Based on this final test, and the mathematical models design for the operation in Greenland, an integrated model of the power system can be generated. Using the **BP 3125 Solar panel, Concorde SunXtender 130 Ah battery, the SolarBoost 2000E, and a 5 watt simulated load a model was created using the following data and assumptions:

- Solar Insolation Values generated by NASA
- Cloud Cover generated from Axis 2100 images
- Average Temperature and effect on total capacity
- 70% depth of discharge cut off

The model for this complete system delivers 225 days of runtime, 61.1% of the year, at Kangerlaussauq, Greenland. Figure 23, below, illustrates the total battery watts throughout one year of operation.
To determine the amount of battery charge, the total potential power available based on solar insolation values and cloud cover was calculated. This value was then multiplied by the battery capacity at the average temperature for that day. A value of 468 watts translates to a ‘dead’ battery, or 30% of capacity (.30 * 130Ah * 12 Volts = 468 watts). The value held in the middle of the graph indicates a full battery, 1560 watts (130 Amp hours * 12 Volts = 1560 watts). The battery will remain near 100% charge during the summer, then cut off in the late fall when depth of discharge reaches 70%. Another interpretation of this data can be seen below.
System Integration
BP 3125 and Concorde 130 Ah

Figure 24: Projected Runtime of Entire system Integrated (On = 1, Off = 0)

Figure 24 assigns a 1 to a day where the system is in operation and a 0 when the system is off. This graph represents a conservative model using only one BP 3125 PV panel with one 130 Ah Battery. The blue area represents the 225 days the system is running throughout the operational period.

Both Figure 23 and Figure 24, are modeled using one BP 3125 Solar panel, and assume that only one panel will be working at a time. When implementing this system using two BP 3125 panels optimized within the recommended 10° angle [Appendix H - Potential Solar Power at Kangerlaussuaq (2004)], each will contribute to a total higher power output. An additional 50 Watts throughout the period of operation is a more realistic total PV panel power output, which creates an effective 175 Watt panel. Figure 25 is the interpretation of this model.
The numbers generated from this graph show the system would be powered 248 days, or an additional 23 days of operation. The extra days occur in the spring and fall months when more of the solar power available is used.

A relationship was created to illustrate the value of battery size and runtime. The conclusion of this analysis indicates that after meeting the 10 day no sun operation minimum, choosing a larger battery size does not significantly influence amount of total run time. Figure 25 shows the projected scenario when a 260 Ah battery (double the original 130 Ah), using a 125 Watt Panel.
Doubling the battery capacity at each node would increase operation to 225 days, only 10 more days than using half the battery size. As varying numbers are put into this model, a relationship becomes clear between increasing the battery size vs. increasing the solar panel output. To match the increase in runtime between the 125 Watt panel model to the effective 175 Watt panel, approximately four more AGM batteries would be needed. Although the price per panel is $525, and the price per battery is $180, when factoring in the number of batteries necessary to see the same increase in runtime the price cancels, and maintenance becomes a factor. Due to the harsh climate and drastic temperature changes throughout the year, the AGM batteries are more prone to failure at approximately 2-5 years, while BP manufacturers guarantees 20 years of service.

6.3 GPS Receiver Design

As discussed in the technical research, the GPS receiver was provided as a given for the project. Because of this, there were only two major design issues involved with this subsystem:

- Converting the RS422 serial protocol to RS232 at the physical layer
- Understanding and collecting the output data stream
6.3.1 Serial Conversion

The Smart Antenna Model used for the 9-node hard-wired system in Greenland utilized the RS422 serial standard. As RS422 uses differential transmit/receive channels to communicate, it can be used to send and receive data at significantly greater distances than the RS232 serial standard. The trade-off associated with using this standard is that often (as was the case in this application) RS422 is not compatible to the more widely used RS232 serial protocol. The table below highlights a few of the other important characteristics to consider when designing a system to convert serial standards.

<table>
<thead>
<tr>
<th>SPECIFICATIONS</th>
<th>RS232</th>
<th>RS422</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mode of Operation</td>
<td>SINGLE-ENDED</td>
<td>DIFFERENTIAL</td>
</tr>
<tr>
<td>Total Number of Drivers and Receivers on One Line (One driver active at a time for RS485 networks)</td>
<td>1 DRIVER 1 RECVR</td>
<td>1 DRIVER 10 RECVR</td>
</tr>
<tr>
<td>Maximum Cable Length</td>
<td>50 FT.</td>
<td>4000 FT.</td>
</tr>
<tr>
<td>Maximum Data Rate (40ft. – 4000ft. for RS422/RS485)</td>
<td>20kb/s</td>
<td>10Mb/s-100Kb/s</td>
</tr>
<tr>
<td>Maximum Driver Output Voltage</td>
<td>+/-25V</td>
<td>-0.25V to +6V</td>
</tr>
</tbody>
</table>

Figure 27: RS422 and RS232 Serial Standards

Another major problem that exists between the two standards is that while RS422 is purely an electrical specification, the RS232 standard is a collection of connection standards between different pieces of equipment. This is a rather old standard, and has been revised many times over the years to accommodate changes to communications technology. The most rudimentary version uses three wires-- transmit, receive, and a common signal ground while a fully implemented RS232 connection can have as many as 25 wires between each end.

Another problematic issue with RS232, is that the standard differs between whether a device is Data Terminal Equipment (DTE) or Data Communication Equipment (DCE). Communication cannot be established between two devices unless the unique protocol to each device is discovered.
In order to facilitate integration, a RS422 to RS232 bidirectional converter was used. Data Comm for Business (DCB) provides an adequate solution that solved the conversion issue rather easily. The Model-064 converter served well as a “black box” solution to convert differential transmit and receive signals to single line, common ground RS232. While the solution proved effective for fast development, it also proved costly at $89. The DCB converter also requires an external 12 volt power supply that adds to the overall power consumption of the system.39

After further research, a more cost-effective design solution was identified. Converting bi-directionally between two serial standards became as simple as learning about two Integrated Circuit components that were ten times cheaper than the DCB “black box” solution.

To communicate from the GPS receiver to the Nodal Processing Unit, a differential line receiver was used. The National Semiconductor 26LS32 Quad Differential Receiver is an integrated circuit that is specifically designed to convert a RS422 differential signal to the TTL logic output that the NPU can understand.

In order to communicate from the NPU to the GPS receiver, a differential line driver was implemented. The National Semiconductor 26LS31 Quad Differential Line Driver is an IC that is designed to convert a TTL level input into a differential output. Both ICs have an enable pin and 5 Volt supply. Figure 28 illustrates the circuit that was designed.

Figure 28: RS422 to RS232 Drivers
6.3.2 Serial Output Data Stream

In 19200 Binary Mode, the GPS receiver is capable of outputting 20 different messages depending upon the request initiated by the listening device. The exact serial connection that is used is 19200 8-N-1: 19200 baud: 8 data bits, no parity, 1 stop bit, no flow control.

Output messages range from the receiver’s geographic location, to hardware/software self identification, to satellite status information. The message of particular interest in this application is the carrier phase delay of the GPS L-band signal. When the receiver is sent a “Message 23: Measurement Block Data” request, it will output a stream of data that contains the carrier phase delay from each of 12 satellites in orbit, sampling each satellite 10 times per second. The data rate was experimentally determined to be approximately 1.5KB/sec on average. (Refer to Section 0) An average is used because the size of this data stream is

<table>
<thead>
<tr>
<th>MESSAGE</th>
<th>BYTE</th>
<th>DESCRIPTION</th>
<th>UNIT</th>
<th>TYPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>23 Measurement Block Data (1, 2, 5, 10 Hz)</td>
<td>5-6</td>
<td>Reserved</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>Number of measurement blocks (N)</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>8..15</td>
<td>Predicted GPS Time</td>
<td>s</td>
<td>double</td>
</tr>
<tr>
<td>16</td>
<td></td>
<td>bits 0..5: SV# (0..31)</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td></td>
<td>bit 6: reserved</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>bit 7: Toggle at each</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ephemeris Transmission</td>
<td></td>
<td></td>
</tr>
<tr>
<td>17</td>
<td></td>
<td>SNR (Signal to Noise Ratio)</td>
<td>0.25 dB/Hz</td>
<td>Uchar</td>
</tr>
<tr>
<td>18..21</td>
<td></td>
<td>Code Phase range: 0...2096103999</td>
<td>1/1024 half chip</td>
<td>Ulong</td>
</tr>
<tr>
<td>22..25</td>
<td></td>
<td>Integrated Carrier Phase</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td></td>
<td>bit 0-1:</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>0: Ready</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>1: Phase Unlock</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>2: Cycle Slip Detected</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>3: Not Ready</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>bits 2-11: Carrier Phase range: 0-1023</td>
<td>1/1024 cycles</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td></td>
<td>bits 12-31: Integrated Number of Cycles</td>
<td>cycles</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td></td>
<td>range: natural roll over</td>
<td></td>
<td></td>
</tr>
<tr>
<td>26</td>
<td></td>
<td>Cycle_Slip Counter increment by 1 every time a cycle slip is detected during a 10ms period range: natural roll over Measurement block #2</td>
<td>N/A</td>
<td>Uchar</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Measurement block #N</td>
<td>as per meas. block 1</td>
<td>as per meas. block 1</td>
</tr>
</tbody>
</table>

Figure 29: GPS Message Description

variable depending upon the number of measurement blocks contained in the signal at a given time. The message output breakdown is Figure 29: GPS Message Description.
For a comprehensive description of how to interface with the GPS receiver, the reader should refer to the Data Link Layer Section of the Novatel SuperStar II User’s Manual. (Included in attached CD-ROM)

Upon understanding the output stream of the GPS device, the only remaining issue became integrating it with an external device. In accords with milestone one, the GPS receiver is directly connected to the Aerocomm receiver while in milestone two, the receiver is connected to the Nodal Processing Unit first. In both of these cases, once serial conversion was complete, integrating with these devices merely required connecting the receive, transmit, and signal ground lines to the appropriate lines on the receiving device by using the appropriate serial protocol as discussed above in line with a serial cable and adapter.

6.4 Communications System Design

The communications system of this project encompasses the transmission of both GPS data as well as general heath and status information about the overall state of the system. The design specifications for the communications system are as follows:

- Capable of Transmitting the GPS Data (Appprox 1.5 KB Per Second)
- Maintain Data integrity (Maximum of 3% Data Loss Deemed Acceptable)
- Capable of Transmitting the Health and Status Data
- Capable of Transmitting up to 2 Km Line of Sight
- Operate with Low Power Consumption

6.4.1 Aerocomm RF Modem Operational Specifications

After reviewing the technical research on wireless data transmission two available technologies satisfy the initial requirements of this project. Radio frequency packet modems and the 802.11 protocol are both feasible design choices. Both options are viable due to their transmission range and bandwidth capability. For this system, the RF packet modems are best suited due to their low power consumption.

The RF packet modems are available at two main operating frequencies, 900 Mhz and 2.4 Ghz. Because of the potential for greater propagation loss on the 2.4 Ghz frequency, the
Aerocomm 900 MHz Connexlink model AC4490 – 1000 was selected as the transceiver for the nodes. The key specifications most relevant to this project are:

- Interface Rate: 115,200 bps
- RF Data Rate: 76,800
- Power Consumption: 1300mA @ 100% Tx Duty Cycle
- Range: Up to 20 Miles

Additional Specifications can be found in the Aerocomm 900 MHz AC4490 User’s Manual. (See attached CD-ROM)

After initially testing of the 900 MHz Aerocomm modems it was recognized that the actual throughput rates were not identical to those indicated on the data sheet. The specifications of the modems are somewhat deceiving. The actual RF Data rate is the critical aspect as opposed to the interface rate. Although these modems can be interfaced to at rates up to 115,200 bps, the theoretical maximum of streaming data throughput of the modems is only 76,800 bps. Figure 30 illustrates the theoretical maximum throughput rates:

<table>
<thead>
<tr>
<th>RF Mode</th>
<th>One Beacon Mode</th>
<th>Parity Mode</th>
<th>Throughput (bps) Half Duplex</th>
<th>Throughput (bps) Full Duplex</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stream</td>
<td>Disabled</td>
<td>Disabled</td>
<td>57.6k</td>
<td>N/A</td>
</tr>
<tr>
<td>Stream</td>
<td>Disabled</td>
<td>Enabled</td>
<td>28.8k</td>
<td>N/A</td>
</tr>
<tr>
<td>Acknowledge</td>
<td>Disabled</td>
<td>Disabled</td>
<td>38k</td>
<td>19k</td>
</tr>
<tr>
<td>Acknowledge</td>
<td>Enabled</td>
<td>Disabled</td>
<td>48k</td>
<td>24k</td>
</tr>
<tr>
<td>Acknowledge</td>
<td>Disabled</td>
<td>Enabled</td>
<td>19k</td>
<td>9.5k</td>
</tr>
<tr>
<td>Acknowledge</td>
<td>Enabled</td>
<td>Enabled</td>
<td>24k</td>
<td>12k</td>
</tr>
</tbody>
</table>

Figure 30: Throughput Figures for 900 MHz Aerocomm Modems

The Aerocomm modems have 4 basic parameters that affect operation: stream mode, acknowledge mode, full duplex and half duplex modes. After extensive testing with the Aerocomm modems it was proven that the half duplex mode would not be feasible for this application.
The Aerocomm server continually transmits a timing frame shown in Figure 31 as the hop-frame; this frame is used to control the full and half duplex transmission methods. When the server and client are in full duplex modes the server transmits on even hop times while the client transmits on odd hop times, this insures that there are no data collisions. When operating in half duplex both modems transmit at will, when the client and server are attempting to transmit at the same time RF packet collision occurs.

There is one critical difference between stream and acknowledge mode that should be noted. In stream mode, the sending modem does not wait for a received packet reply from the receiving modem. For this system, the stream mode is not a feasible option due to the fact that no data redundancy is present and when data loss occurs, there is no form of data loss detection built into the protocol.

The only remaining option is the acknowledgment mode which operates at a theoretical 19Kbps. The tests conducted proved an actual throughput rate 20Kbps with a range of 3 miles. The full details of the experiment are located in Section 0.

When choosing the 900 MHz modems it was not initially apparent that there would be so such significant overhead in the networking protocol. The actual throughput rate of 20Kbps would not be adequate as the system size scales up to an 81-node topology. Due to the constant 10.2Kbps of streaming data from the GPS receiver, the Aerocomm modem would be operating at close to a 50% duty cycle.

After becoming aware of this design hurdle, the 2.4 GHz model was reevaluated for it’s maximum RF throughput rate of 882,000 bps. The key specifications most of the
Aerocomm 2.4 GHZ modems are:

- Interface Rate: Up to 882,000 Kbps
- RF Data Rate: 882,000 Kbps Fixed
- Power Consumption: 472mA @ 100% Tx Duty Cycle; 110mA @ 100% Rx Duty Cycle
- Range: 10,000 feet

Additional Specifications can be found in the 3.4 GHZ Aerocomm AC5124-200 Modem User’s Manual. (See attached CD-ROM)

After analyzing the specifications with greater scrutiny, the 2.4 GHz Aerocomm modems have a maximum effective data throughput rate of 250 Kbps – 300 Kbps after network overhead. Using this Aerocomm model would allow for enough network throughput to buffer the GPS data stream for a number of seconds and operate the transmission link on a significantly smaller duty cycle as compared to the more constant link on the 900 Mhz modems, thus reducing overall power consumption. Therefore, the Aerocomm AC5124 – 200 is the recommended modem for use in this system.

6.4.2 Aerocomm Modem Physical Specifications

The 900 MHz and 2.4 GHz modems are available in two form factors: the actual OEM module, (which consists only of the electronics needed for the transceiver) and the Connexlink modems. (which provide a serial interface board to the transceiver) The Connexlink versions were used in testing due to their existing serial interface. The Connexlink modems have four lights on the outside to indicate modem operation. The four lights indicate: Power, Link, Tx and Rx. The link light illuminates when another modem is in range for transmission.
Figure 32: Aerocomm OEM Module and Connexlink Modem

Figure 32 shows the two different products available from Aerocomm. The Connexlink modem (right) is an integrated system that contains the OEM module (left) sitting on-top of a daughter serial control card.

6.4.3 Aerocomm RF Communications Modes

The Aerocomm modems are configurable for custom operation in different modes and network topologies. The following sections discuss how the Aerocomm modems are configured for optimum performance in this system.
6.4.3.1 RF Transmission Protocol

The 2.4 GHz Aerocomm modems use the Carrier Sense Multiple Access (CSMA) Protocol as defined in the IEEE 802.3 standard. CSMA works as follows:

![Figure 33: Carrier Sense Multiple Access Protocol Flow Diagram](image)

1. The transmitter is always idle until data is received for transmission
2. When data is received the transmitter attempts to send the first frame of data
3. If a collision occurs, ie. another device is already occupying the channel, the transmitter waits a random time and then tries again.

This transmission method works well when all of the devices are not trying to constantly stream data. In this system, the 8 GPS receiver nodes are constantly streaming data which could create a number of collisions; thus decreasing the overall throughput of the network.

Network performance can be improved by utilizing the fact the amount of data being streamed out is substantially less than the total available bandwidth of the RF link. The GPS data can be buffered before transmission allowing larger amounts of data over a shorter period. This method is much more efficient than sending data constantly. With the use of the on-the-fly programming capabilities of the Aerocomm modems, a Time Division Multiple Access Protocol can be implemented which will be further discussed in section 6.6.1 Small Scale Topology, to achieve greater network performance.
6.4.3.2 On the Fly Programming

Many of the configuration parameters of the 2.4 GHz Aerocomm modems can be configured on the fly. Parameters such as data destination address, transmit power, and RF packet size can be reprogrammed on the fly allowing for a more adaptable and versatile network. These parameters are stored locally on EEPROM within the Aerocomm modem. Additionally status parameters such as number of dropped packets and the last received signal strength are also stored in the EEPROM and can be retrieved. The main parameters that are relevant to this system are:

- Transmit Attempts
- Fixed packet length (low / high)
- Serial Interface Mode
- RF Mode
- Destination Address
- Point to Point vs. Point to Multipoint configuration
- Status Data (i.e. Dropped packets)

The modems are programmed on the fly by transmitting a special data sequence, thereby sending the modem into programming mode. The modem then listens for commands to write or read from the EEPROM.

The specific commands for programming the Aerocomm modems as well as the default values can be found in the User Manual found in the Attached CD-ROM.

6.5 Nodal Processing Unit

Most of the design work conducted for the Nodal Processing Unit involved proving the viability of the microprocessor chosen as developed by Milestone 2. (See Section 6.1: Design Milestones) While a complete and comprehensive design solution is outside the scope of this project, several important functions have been implemented. Additionally, design considerations and future recommendations are outlined to aid in future work involving the Nodal Processing Unit.

The NPU subsystem must continuously buffer data from the GPS receiver to the wireless transceiver. In the event that the device loses a transmission link, the NPU must store the GPS data in on-board memory as well as provide boot routines for both external
sub-systems. Additionally, the NPU must collect and forward local health and status signals like battery voltage, temperature, and available buffer size.

After researching existing technologies, the design considerations were modified to accommodate more precise technical specifications. The following list provides the final design criteria that were used to design an appropriate intelligence system:

- the system must have a serial data output that is capable of sending and receiving data via the RS232 transmission protocol
- the system must have adequate re-writable memory to store up to 3-5 minutes of streaming GPS data at 1.5 KBps; which translates to 512KB of memory
- the system must contain non-volatile memory capable of providing the boot sequence to the GPS receiver and wireless device
- the system must contain on-board data-acquisition capabilities to retrieve local health and status data; namely, several on-board analog-digital converters that can be configured to measure current, voltage and temperature readings
- the power consumption of the system must be as minimal as possible, preferably drawing no more than 0.5 W
- the system must be rugged and able to withstand extreme arctic conditions with temperatures as low as -40°deg C.

After considerable research, it became increasingly evident that it would be difficult to find a single device to fulfill all of these responsibilities. To simplify the design process, the nodal processing unit was divided into the following subsystems:

- Microprocessor
- Memory System
- Serial Interface Circuitry
- Data Acquisition System
6.5.1 Microprocessor

After considerable research into various embedded technologies, the Texas Instruments Mixed Signal Processor *TI MSP430* was chosen as it is very robust in terms of peripheral interfacing and has incredibly low power consumption.

One of the most remarkable features of the *MSP430* is that it is specifically designed for ultra-low power and battery driven applications. The *TI MSP430* is designed to accommodate three operating modes: RAM retention mode, real-time clock mode, and active mode. In RAM retention mode, the device is suspended in a “storage mode” that allows all interrupts and peripherals to be active while maintaining the integrity of the RAM; the microprocessor draws only .1uA and could potentially sit idle for several years without depleting its power supply. The real-time clock mode is designed to serve as a “sleep mode” in which the processor resides when not executing instructions. In this mode, the
microcontroller draws only .8uA and maintains its real-time clock, has all interrupts active, and supplies power to all peripheral devices. While executing instructions, manipulating registers, or using the ALU the MSP430 enters active mode and still only draws a maximum current of 250uA. All current values are derived assuming a 3.3 volt supply voltage.

The MSP430 utilizes a 16-bit RISC (Reduced Instruction Set Computing) CPU with sixteen 16-bit registers. As the name suggests, the instruction set in RISC architectures have been stripped down to facilitate easier decoding and quicker processing. The MSP430 is composed of only 27 instructions and has seven addressing modes; the architecture also supports direct memory-to-memory transfer, allowing for the user to manipulate data in memory without moving it through the CPU; allowing for a sizeable boost in performance and processing speed. This architecture is efficient both in power consumption and in execution speed.42

![MSP430 System Architecture](image)

**Figure 35: MSP430169 System Architecture**

The MSP430 family offers several options depending upon the requirements for programming space, onboard memory, and desired peripherals.43 The MSP430F169 was chosen as it met the design criteria best with its on-board peripherals. As shown in Figure 35 above, the MSP430169 model has an on-board 12-bit, 8-channel A/D converter, 2 USART controllers for serial data interfacing and transfer, and an I2C bus controller. These
on-board peripherals greatly reduce the time involved with developing the memory, data acquisition, and serial interfacing systems. As the MSP430 microprocessor is widely used in a variety of applications, there are a number of application notes available on the TI website, many of which are similar to the applications intended for the NPU system. Additionally, as the MSP430 family is used widely in industry, there are a number of resources that are widely available to expedite design and development time.

Another benefit associated with choosing the MSP 430 microprocessor is the programming environment. The MSP is a flash-programmable integrated development environment that includes a debugger, JTAG interface and C compiler. Programming the microprocessor is quite simple and the programming environment allows the user to read register and memory values right from the desktop.44

6.5.2 Interfacing to External Memory

The MSP430F169 comes equipped with onboard memory (2KB of SRAM, 60KB of Flash); however, the memory requirements for our buffering application make interfacing with external memory compulsory. With an approximate output stream of 1.5KBps and allowing at least 5 minutes of GPS data storage, our system needs to accommodate 512 KB of external memory.

Memory applications typically operate using DRAM, SRAM, FLASH, or EEPROM. The following requirements govern the design of the memory element:

- Power may become unavailable at any time; therefore the memory must be non-volatile.
- Each data element must be written and read one byte at a time.
- The memory space must be rated for hundreds of thousands of write cycles.

These three constraints reduce the memory options by half. DRAM is volatile memory. It requires constant power to refresh and maintain its memory space. While its memory space is byte readable and writeable, FLASH memory is not designed to be constantly rewriting the same bytes over and over. FLASH requires the ability to erase entire sectors of its memory before it can write new data to the sector. This would effectively erase a portion, if not all, of the memory buffer each time the buffer filled.

Two options remain, SRAM and EEPROM. Both satisfy the third requirement, so other factors must be examined to make a decision. As mentioned above in the
microprocessor section of this chapter, Texas Instruments offers application support for MSP430F169. One of the application notes available is a comprehensive description of how to interface with EEPROM memory using the Inter-Integrated Circuit (I2C) bus. Thorough application notes greatly reduce development time. For this reason, EEPROM was selected for the prototype.

Interfacing with external devices using the I2C bus is a fairly straightforward process. The I2C bus specification allows devices to be connected using only two wires, the serial data line (SDA) and a serial clock line (SCL).

![I2C Bus Architecture](image)

**Figure 36: I2C Bus Architecture**

Each device on the I2C bus has a unique address, and most can operate as either a transmitter or receiver.

![I2C Transmission Protocol](image)

**Figure 37: I2C Transmission Protocol**

The microprocessor is always the master device in this configuration, but both chips may act as a transmitter or receiver. The microprocessor initiates read and write cycles by sending a start bit, followed by an address byte and a read/write bit, over the SDA. The EEPROM then sends an acknowledge bit to show that it is ready to transmit/receive data. At this point the transmitter begins to send data bytes over the SDA line, and clock signals over the SCL line. After each data byte, the receiver sends an acknowledge bit to let the
transmitter know it is ready for the next byte. When all data has been sent, the transmitter sends a stop bit to free the I2C bus. The figure below illustrates this sequence.

![Figure 38: Data Stream](image)

These basic principles hold true for communication between the microprocessor and any slave on the bus.

The hardware needed to accomplish the I2C bus configuration is minimal. The following schematic shows how the 24AA512 EEPROM is interfaced with the MSP430F169 via the I2C bus.

![Figure 39: MSP430 and I2C Memory Schematic](image)

The software to achieve I2C communication is significantly more complicated than the hardware. TI has developed a comprehensive file that neatly organizes several important functions into one document. The file, **I2Croutines.c**, includes such useful functions as: EEPROM Byte Write, EEPROM Acknowledge Polling, EEPROM Random Address Read, and EEPROM Current Address Read. These functions are used in the program **I2CEEPROM.c** to demonstrate that the MSP430F169 is capable of communicating over the I2C bus accurately and repeatedly. For the commented code of **I2Croutines.c** and **I2CEEPROM.c** please refer to Appendix G – MSP430 Code
Due to the simplicity of the I2C protocol, these code examples could easily be modified to interface with most other I2C compatible devices. With this supposition in mind, the choice of memory for the final design must be revisited. Both EEPROM and SRAM meet the minimum requirements for one year of operation in Greenland, however, after one year, an EEPROM chip would be nearing the end of its write cycle lifetime. SRAM, on the other hand, has a nearly limitless number of write cycles. Therefore, SRAM is the memory of choice for the external buffer.

6.5.3 Serial Interfacing with the MSP430

Designing the serial controller for the MSP430 involves both hardware and software. The hardware aspect is fairly straightforward; however, the software side becomes rather complicated.

The hardware is designed to allow the +/- 12 Volt lines of the RS232 standard to communicate with the TTL input/output lines (5V) of the MSP430. This is accomplished quite easily using only a resistor and several inverter gates as illustrated by Figure 40: MSP430 Serial Interface Schematic

![Figure 40: MSP430 Serial Interface Schematic](image)

This configuration must be done on each USART controller being used. Additionally, a 32 KHz crystal clock must be placed between the XIN and XOUT pins of the MSP430 for timing regulation.
The software aspect of the serial controller is significantly more complicated than the hardware aspect. Numerous registers must be initialized and maintained to reliably operate the USART serial controllers.

The difficulty in working with the serial controller arises from imperfections in the crystal clock. The crystal clock is not a perfect 32 KHz; therefore, steps must be taken in the software to ensure that any imperfections are accounted for. There is a modulation register in the microprocessor used to solve this problem. When initialized correctly, this register will account for the imperfections of the clock. Initializing this register properly is a difficult process, however. The MSP430 user guide48 provides an ideal starting point for this number; however, the only way to get this register initialized properly is through trial and error. The crystal clock of the prototype requires that the modulation register be set to 0x55 for error-free operation.

The MSP430 has two USART controllers, USART0 and USART1. These two serial controllers are what make bi-directional communication between the GPS receiver and the Aerocomm RF packet modem possible. As GPS data comes in on USART0, it is buffered into memory, and then transmitted to the Aerocomm modem over USART1. When the Aerocomm receives instructions to be transmitted to the GPS, USART1 receives the message and USART0 forwards it to the GPS receiver. No memory buffering is required when transmitting from the Aerocomm to the GPS.
6.5.4 Utilization of the Analog to Digital Converter

The capabilities of the on-board analog-to-digital converter (ADC) proved to be quite robust and easy to implement. A variety of example applications utilizing the ADC for the MSP430F169 are available on the TI website to download.\textsuperscript{49} The primary purpose of programming the ADC module was to demonstrate the capability of the MSP430 to serve as a data acquisition unit. In order to prove that health and status data could be collected at the nodal level using the MSP430, a simple and useful battery monitor application was created.

The Battery Monitor was charged with the following tasks:
- Disconnect the load from the circuit to prevent deep discharge
- Reconnect load to ensure three day sustainability before next shutdown

As previously discussed, the ADC module of the MSP430 features 8 input channels (P6.0-P6.7) and can sample in four modes: single-channel single-conversion, sequence of channels, repeat single-channel, and repeat sequence of channels. As shown by the figure below, minimal external circuitry was required to interface the A/D module with the battery.
Before applying a voltage to an input channel on the ADC, it is important to note that the maximum voltage that can be applied is limited by the reference voltage. In order to resolve this issue, it was necessary to construct a voltage divider to scale a desired range of voltages down to the 0-3.6Volt threshold that the MSP can tolerate. One percent resistor values of 11k and 3k were used to ensure that input voltages stayed within an accurately predictable voltage window of 0-14 volts. These resistor values were also chosen to ensure that the maximum current limit of the channel input of the A/D converter will never exceed 1.6mA when connected to the battery. Additionally, capacitors were placed on the input pin to avoid line spikes or surges.

The MSP430 will generate a 12-bit core hexadecimal value (000-FFF) that corresponds to two programmable/selectable voltage levels (Vr+ and Vr-) to define the upper and lower limits of the conversion. Vr+ was tied to the input power of 3.3V and Vr- was tied to ground. The conversion formula for the ADC hexadecimal result, $N_{adc}$ is:

$$N_{adc} = 4095 \times \frac{V_{in} - V_{r-}}{V_{r+} - V_{r-}}$$

Where $V_{in}$ represents the voltage-divided analog input, and 4095 is the number of quantization levels in a 12-bit conversion. This 12-bit hexadecimal value is stored in the conversion register ADCMEM0 and is later assigned to the variable $N_{adc}$ in the code. Upon being stored into the variable, the program performs calculations and makes decisions according to the following diagram:
As shown above, the code samples an analog value and converts the hex core voltage to the corresponding input voltage on the pin. Next, the program converts this voltage to the actual voltage on the battery by applying the voltage divider formula:

$$V_{out} = V_{in}\times\frac{R_2}{R_2 + R_1}$$

At this point the program makes a decision as to whether or not the battery should be disconnected from the load; if disconnected, it then determines whether or not the voltage is at a suitable level to reconnect the load and ensure the battery is capable of sustaining itself with no renewable energy for three days.

A voltage of 11.70 volts was chosen in order to protect the battery from becoming overly discharged (30% charge remaining), thereby preventing damage and increasing both efficiency and lifespan. When a voltage below 11.70 volts is detected across the battery, the NPU will discontinue outputting a 3.3V voltage on Pin 1.0 which is tied to the base pin of a MTP12P05 power MOSFET. When the base voltage of the MOSFET goes to 0 volts, the switch inside opens and voltage across the load is disconnected.

When the voltage of the battery goes above 12.1 volts, the NPU will resume placing a 3.3V output to the base of the MOSFET. A voltage level of 12.10 volts (50% charge remains) was chosen to ensure that the battery would sustain itself for an additional 3 days.
With a 5-Watt load connected to the battery with no recharging, the battery will last about three days at this voltage until it goes below 30% remaining charge again.

Again, the primary goal of this design feature was to demonstrate the ADC module of the MSP430 could be used to obtain health and status information, thereby proving that the MSP430 would be an effective design choice for the Nodal Processing Unit. There are many ways in which the functionality of the ADC could be improved and utilized to provide more meaningful tasks to the system; this will be developed in greater detail in the Analog to Digital Module Recommendations. An analog circuit that fulfills the same design specifications was also developed in the event that the NPU would not be a feasible. This analog battery monitor circuit is described in detail in the Experiment Results Section.

6.6 Network Topology

One of the major specifications for this system is scalability. The initial specification given by SRI states the system should be able to scale approximately from 9 to 100 nodes. After reviewing the network topologies discussed in the Network Topology section of the Technical Research, the network design best suited for the specification of scalability is a hybrid between the star and tree topologies. Additionally the topology should be able to support a sizeable amount of bandwidth. At the largest end of the specification, assuming the GPS receivers are streaming continuously at 1.5KBps, the exit point should be able to support a total of 125KBps data coming off the network. This system is broken into two deployment sizes based upon the project milestones outlined in section 6.1; the small scale topology consists of 9 nodes while the larger is scalable up to 100 or more. The small and large scale topologies are described below.

6.6.1 Small Scale Topology

The small scale topology consists of 9 nodes arranged equidistantly from a center point. As seen in Figure 44 below, this is a star topology with each node communicating directly to the center node following a Time Division Multiple Access (TDMA) scheme, where each node is given a time slot to transmit data.
As each node is waiting for its specific transmission time slot, it is buffering GPS data into memory. This type of scheduling depends heavily on an accurate timing signal to make sure that each of the nodes are synchronized. If any of nodes are out of sync, transmission in overlapping time slots will create data loss as well as possible data corruption. The system will use the GPS timing signal as the clock. The use of this scheduling method substantially reduces the power consumption by using a store-and-burst method of communication. Figure 44 demonstrates how the TDMA protocol works. The full 30KBps bandwidth channel of the Aerocomm is fully utilized by sending approximately 8 seconds of buffered GPS data in one second of transmission time. The duty cycle of the Aerocomm modems would be 11 percent.

6.6.2 The Small Scale Parent Node

In the design of the small scale system, it was assumed that due to the existing setup in Sondrestrøm Greenland that the parent node will be hard wired and connected to a facility via power and data. The data that is collected from the Aerocomm will be parsed by
a computer within the facility to separate the data streams from each node. As the system scales from nine nodes upward the parent plays a more complicated role.

Normally, for this type of star topology with one server and many clients, the default mode for the Aerocomm is in the point to multi-point configuration. In this mode, all of the clients transmit at the same time and use a Carrier Sense Multiple Access Protocol (CSMA) to deal with collision detection as described in the communications section 6.6.1 Small Scale Topology. Due to the nature of this standard, (and the additional network overhead it creates) the Aerocomm modems would be configured to run in the point-to-point mode. To accomplish the TDMA protocol, the modems must be continually reprogrammed; specifically the destination address of the client. This further emphasizes the need for a Nodal Processing Unit (NPU) to act as the heart of the network intelligence. For both the small and large scale topologies, the parent node controls the scheduling in a polling implementation. The parent node receives data from a uniquely identified child node during the specified time slot for that given node. This is accomplished by changing the media access control (MAC) address of the destination host to the clients address just before the specified time interval.

6.6.3 Large Scale Network Topology

The large scale topology consists of adding additional 9-node clusters which consist of eight children and one parent. In the larger topology, the parent nodes are running on self-sustaining power and would need to use a different method of RF communication to transmit the data collected by the nine nodes with-in its control to the exit point of the network. The proposed design, further outlined in the recommendations section 6.6.3 Large Scale Network Topology is to implement directional 802.11 wireless standard at the parent node. Each nine node cluster is effectively streaming 13.5KBps of data. The parent node would then be polled by the exit point of the network in a similar TDMA protocol implemented by the child-to-parent node communication. Polling reduces the transmit power consumption drastically. This is very important when using the 802.11 standard because it requires significantly more power than the Aerocomm modems.
6.7 System Integration

6.7.1 Prototype Integration

This section describes the integration of the individual sub-systems into the prototype. Some of the components require additional circuitry to be fully integrated. The list below describes the exact components used in each sub-system of the prototype:

- **Power**
  - 1 BP350U 50 Watt Solar Panel
  - 1 Solar Boost 200E Charge Controller
  - 1 48 Amp Hour Concord SunXtender PVX490T Battery

- **GPS Receiver**
  - 1 Novatel RS422 Smart Antenna

- **Communications**
  - 2 Aerocomm 900 Mhz Connexlink AC4490 – 1000 Modems

- **Nodal Processing Unit**
  - MSP430 Development Kit
  - MSP430F169 Microprocessor
  - Microchip 24AA512 EEPROM

The following shows how all of these sub-systems are integrated in the prototype. The Aerocomm modem does not require the use of additional hardware to be integrated properly, while the GPS receiver and the Nodal Processing Unit need additional supporting circuitry. The supporting circuitry can be broken into two categories, power and data circuitry. The overall schematic can be seen in Figure 45.
Figure 45: Full System Schematic

GPS Receiver Power

The GPS receiver is powered by 12 Volts over the RS422 standard, so no additional circuitry was needed to power the GPS receiver since it can accept an input voltage range of 9 – 36 Volts DC.

GPS Data

The GPS receiver uses the RS422 protocol, and the Aerocomm modem uses the RS232 protocol so the use of a RS422 to RS232 converter was used to match the signal standards between the two devices.

Aerocomm Power

The Aerocomm modem is power by 12 Volts directly from the battery. The input voltage range is 6 – 18 Volts DC.
**Aerocomm Data**

The Aerocomm modem uses the RS232 serial standard, after the GPS data is converted to the RS232 standard by the RS422 to RS232 converter no additional circuitry is required.

**Nodal Processing Unit Power**

The MSP430 and associated data circuitry need 3.3 Volts and 5 Volts respectively. The 3.3V and 5V are created by National Semiconductor Buck Regulators models (LM2676T-3.3 and LM2676T-5.0). The efficiency of these regulators are between 93%-96% over the full range of current draw.

**Nodal Processing Unit Data Circuitry**

The NPU needs three types of data circuitry, interfaces for both serial controllers (one for the GPS receiver and one for the Aerocomm modem), the circuitry for the I2C bus where the memory resides, and the external circuitry required by the Analog to Digital Converter. The schematics for the serial interfaces can be seen in Figure 40. The Schematics for the I2C bus can be seen in Figure 36. The ADC circuitry creates a reference value which represents the voltage of the battery at the cut off point, and reduces the actual voltage of the battery which is the compared to the reference within the ADC. The schematic for the ADC circuitry can be seen in Figure 42.

After the integration of all of these sub-systems a switch panel was integrated to control the power to each sub-system. The ability to switch each component off individually is very important to the testing process.

**6.7.2 Integration Issues**

After designing and building all of the necessary component to integrate each sub-system some problems were encountered. As discussed in the previous design section each of the sub-systems were tested individually and proved successful. There were no unforeseen issues integrating the Aerocomm and GPS systems. The NPU had some
integration issues due to the modulation issues, but after an iterative process of changing the modulation values, bidirectional communication was successful.

### 6.7.3 Total Power consumption

The total overall power consumption is an important number to know because it is directly related to the number of operational days in a year. The total overall power consumption of this system is approximately 3.5 Watts this takes into account a 10% duty cycle on the Aerocomm modems due to the scheduling algorithm.

### 6.7.4 Financials

The financial analysis of this system is an important aspect due to the initial specifications of scalability. The overall cost of the prototype can be seen in the Figure 46: Financial Information:

<table>
<thead>
<tr>
<th>Financial</th>
<th>Power System:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Concorde SunXtender $79.99</td>
</tr>
<tr>
<td></td>
<td>Solar Boost 2000E $198.00</td>
</tr>
<tr>
<td></td>
<td>BP 350 U $279.00</td>
</tr>
<tr>
<td>NPU</td>
<td></td>
</tr>
<tr>
<td>MSP 430 F169</td>
<td>$13.24</td>
</tr>
<tr>
<td>Dev. Kit MPS</td>
<td>$200.00</td>
</tr>
<tr>
<td>LM 2676</td>
<td>$5.00</td>
</tr>
<tr>
<td>EEPROM</td>
<td>$2.78</td>
</tr>
<tr>
<td>Quartz Oscillator</td>
<td>$5.00</td>
</tr>
<tr>
<td>Hex Inverter</td>
<td>$0.75</td>
</tr>
<tr>
<td>Misc. IC’s</td>
<td>$6.00</td>
</tr>
<tr>
<td>Communications</td>
<td></td>
</tr>
<tr>
<td>AeroComm Modems</td>
<td>$400</td>
</tr>
<tr>
<td>GPS Receiver</td>
<td>$900</td>
</tr>
<tr>
<td>Total</td>
<td>$2,089.76</td>
</tr>
</tbody>
</table>

**Figure 46: Financial Information**
7 Recommendations for Future Work

7.1 Power System Recommendations

The recommendations within this section are broken into two parts: Immediate Considerations required to fully implement the recommended design and Alternative Power Recommendations which evaluates the feasibility of using wind. The recommendations within Immediate Considerations is limited to the child nodes within a 9 node array, and the Alternative Power analysis can be scaled to accommodate the power requirements of both child and parent nodes of a larger array.

7.1.1 Immediate Considerations

Before the recommended design can be fully implemented, it will first be necessary to validate the scientific data that has been used in this project. The following data should be re-evaluated to verify the model and validate our assumptions:

- Insolation values
- Cloud Cover
- SolarBoost 2000E temperature sensor

The research conducted in Section 5.2.2.3 illustrated the dependency of a solar panel output and insolation. Insolation is directly affected by the cloud cover. Data should be collected at Sondrestrom and compared to the projected power available for different insolation/cloud cover scenarios within the projected model. Also a charging test should be conducted at the temperature ranges in Greenland using the Solar Boost 2000E temperature sensor.

7.1.2 Alternate Power

To overcome the projected non-operational period during the winter months, an alternative renewable energy source must be developed. Section 5.2.2.2 [Wind Power] indicated that wind is a viable renewable energy source. The wind averages over the past 7 years was measured 3 meters above the ground at the Kangerlausaug Airport50 and are located in Appendix H - Potential Solar Power at Kangerlausauq (2004)
After analyzing the data used to generate the graph above, wind turbines that operated within this specified wind speed were researched. The following table illustrates wind turbines and power output (Watts) compared to the wind speed available. The values in this table were generated from SouthWestern Power\(^5\). Also included in this table is the price per turbine.

<table>
<thead>
<tr>
<th>Knots</th>
<th>Aero4Gen</th>
<th>Aero6Gen</th>
<th>Whisper H40</th>
<th>Whisper HV80</th>
<th>Air X Industrial</th>
<th>Air X Marine</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>-</td>
<td>-</td>
<td>18.11 32.39095 2.443335 2.443335</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.25</td>
<td>-</td>
<td>-</td>
<td>21.01 38.08431 3.029708 3.029708</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.5</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>5.75</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>6</td>
<td>-</td>
<td>-</td>
<td>34.78 65.45 6.26 6.76</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.25</td>
<td>-</td>
<td>-</td>
<td>38.79 74.33 7.24 7.14</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.5</td>
<td>-</td>
<td>6</td>
<td>43.02 82.08 8.45 8.35</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.75</td>
<td>-</td>
<td>7.5</td>
<td>47.48 91.21 9.62 9.22</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>-</td>
<td>9</td>
<td>52.18 101.96 10.98 10.98</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7.25</td>
<td>-</td>
<td>10.5</td>
<td>62.29 121.78 13.95 13.95</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>7.5</td>
<td>-</td>
<td>12</td>
<td>67.71 131.52 15.52 15.52</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7.75</td>
<td>-</td>
<td>13.2</td>
<td>73.35 142.83 17.12 17.12</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>6</td>
<td>14.4</td>
<td>79.24 153.71 18.77 18.97</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8.25</td>
<td>6.5</td>
<td>15.6</td>
<td>85.36 165.38 20.84 20.84</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8.5</td>
<td>7</td>
<td>16.8</td>
<td>91.71 176.57 22.71 22.71</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8.75</td>
<td>7.5</td>
<td>18</td>
<td>98.28 188.42 24.71 24.71</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
All cells with dashes indicate a 0 power rating. For each turbine, the minimum wind speed to cause the blade to turn was about 6 knots. The operating wind speed of the Aero6Gen does not exceed 12.25 knots and is also indicated by a dash. Combining the data from the wind averages and the power ratings for the wind turbines yields the graph below.

Figure 48: Listing of Wind Turbines, Cost and Power (Watts)

<table>
<thead>
<tr>
<th>Power (Watts)</th>
<th>0</th>
<th>500</th>
<th>1000</th>
<th>1500</th>
<th>2000</th>
<th>2500</th>
<th>3000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Day</td>
<td>1</td>
<td>37</td>
<td>73</td>
<td>109</td>
<td>145</td>
<td>181</td>
<td>217</td>
</tr>
<tr>
<td>Aero6gen Watts Daily</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Air X Industrial/Marine Watts/Day</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Whisper H40 Watts/Day</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Figure 49: Daily Output Power for Wind Turbines
Figure 49 illustrates the projected daily power output from the wind turbines at Kangerlussuaq, Greenland. Not included within this figure were the Whisper HV80, and the Aero5Gen Turbine. The Whisper HV80 wind turbine produced an enormous amount of power that far exceeded the needs of our system, while the Aero4Gen did not produce enough. The Whisper H40 also exceeds the needs of the current system, but could be deployed if a larger power requirement was needed at the parent node.

Not included within this data are the hourly wind speed averages. After analyzing data taken at the SRI in autonomous instrument platform Ivotuk, Alaska it is clear that throughout the day the wind speed typically gusts and subsides sporadically.

Other considerations inherent in deploying a wind turbine include additional implementation components to maximize performance and protect the system. These components are listed below with the estimated cost.

<table>
<thead>
<tr>
<th>Component</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 Amp Cut off Circuit</td>
<td>$50</td>
</tr>
<tr>
<td>27 ' Tower</td>
<td>$120</td>
</tr>
<tr>
<td>Stop Switch</td>
<td>$18</td>
</tr>
<tr>
<td>Galvanized Augers</td>
<td>$150</td>
</tr>
<tr>
<td>Dump Load</td>
<td>$80</td>
</tr>
<tr>
<td>Misc. Pipe and Wire</td>
<td>$100</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$518</strong></td>
</tr>
</tbody>
</table>

Although the operating temperature of each wind turbine was specified to $-40^\circ$C, further research needs to be conducted to determine the specialized components needed. At the SRI site in Ivotuk, Alaska a major problem that has been encountered is freezing. Snow and ice freezing on the turbine blades cause components to fail. Blades on turbines are created to furl and unfurl depending on wind speeds to prevent too much power from being generated, and protect the turbine, however, when deployed in a similarly harsh climate at Ivotuk they froze and tripped the circuit breaker.

The attractiveness of wind turbines, however, is not to be discredited. When integrating the power data from the wind turbines into the power model, the results proved very encouraging. In the summer months, the wind averages tended to decrease, while the sunlight values increased. This trend is accounted for by the snow cover throughout the winter, which creates less friction on potential airflow. A recommended
turbine to implement for this system is the Air X Industrial. The cost of a whole turbine system is $1394, including all necessary towers and cables. The Air X Industrial comes with Teflon coated blades and is rated for extreme environments. SouthWest Power indicated that custom components can be ordered for operation in environments similar to Greenland.52

7.2 GPS Unit Recommendations

Aside from purchasing RS232 GPS receivers in the future, the only other recommendation would be to look into separating the Smart Antenna into more practical and cost-effective sub-systems. As developed in the Technical Research, the Novatel Smart Antenna GPS receiver is essentially broken into three components: a proprietary GPS antenna patch antenna, a Super Star II OEM GPS receiver card, and a serial interface card. The only Novatel product that SRI would really need to continue to use in a larger-scale system design would be the SuperStar II receiver card that is contained within the smart antenna unit.

The Superstar II card can be purchased separately and can be programmed for specific embedded applications using its Application Programming Interface (API). By embedding the GPS receiver into the Nodal Processing Unit, there would be a significant decline in the power consumption as the 3.3V OEM card draws a mere .5W as compared to the 1.8W draw of the Smart Antenna. More significantly though, is the price difference; while the Smart Antenna product by Novatel typically retails for around $800-$1000, the OEM board can be purchased alone for about $180 per module.

If the OEM card were embedded, it would still be necessary to purchase or design an external L-band GPS antenna. The Super Star II user manual provides adequate specifications to aid in selecting the appropriate antenna or cable in the antenna specifications section.
7.3 *Communications Recommendations:*

The following sections outline the recommendations for the communications systems of both the child and parent nodes.

7.3.1 Child Node Recommendations

The largest recommendation for the child node communications system is to fully test the Aerocomm 2.4 Ghz modems. Throughput and range are the major things that need to be tested. On the Aerocomm website there are product integrators that have used these exact modems achieving over 200KBps and 1km in range. The ability to reprogram the modems on the fly has already been tested with the 900 Mhz modems but testing on the 2.4 Ghz modems still needs to be done.

7.3.2 Parent Node Recommendations

The primary recommendation for the parent node communications system is to develop the use of directional 802.11 to transmit the larger amount of data collected by each 9 node cluster. To use 802.11 at the parent node level, the use of a different Nodal Processing Unit may be necessary. Research conducted on the MSP430 TI processor indicated that interfacing with the TCP/IP stack that is needed by 802.11 protocol is not feasible. Directional Antennas and their range must be further researched. Todd Valentic at SRI has mentioned that he has experience with creating a directional 802.11 network over a distance of eight plus miles.

The 802.11 standard is one that is quite power intensive. For use at the parent level this power consumption would need to be evaluated, and the possible use of scheduling the transmission so that each parent node is only transmitting for the least amount of time, and thus consuming less power. This is the same idea as using the TDMA protocol at the child node level.
7.4 Nodal Processing Unit Recommendations

The following sections outline the recommendations for the Nodal Processing Unit. These recommendations include the serial interface, the interface to memory, and the analog to digital converter.

7.4.1 I2C UART and Serial Controller

The MSP430’s peripheral capabilities are greatly expanded through the use of the I2C bus; however, through testing, it has been discovered that there are complicating issues involved with using the USART0 controller and the I2C bus as they are contained on the same module. The USART0 control register is used to set the USART into SPI, I2C, or UART mode. Although the processor’s documentation says that switching between modes is possible, when the outlined steps are followed, the USART fails to switch modes. Once the code initializes the I2C, it locks the control register and appears to refuse to release it.

Developing the capability to use both the I2C bus UART control simultaneously would likely prove difficult and time consuming. There are several solutions to this problem that would prove both simpler and more time efficient.

The first and most obvious solution is to not use the I2C bus for memory buffering at all. Instead, the SRAM could be hard wired to the parallel I/O ports of the MSP430. The obvious drawback to this approach is that the I2C bus becomes unavailable to any peripheral device; however, if a memory buffer is the only device on the bus, this is not a problem. Parallel I/O is a proven and well documented method of transferring data to and from the microprocessor, and allows both USART controllers to be dedicated to serial data transfer.

If the I2C bus must be used to access peripheral devices, then the MSP430F169 is no longer the ideal processor for this application. Instead, another microprocessor should be selected. The new chip should either have three USART controllers or separate, dedicated I2C and UART controllers.

7.4.1.1 Network Intelligence Recommendations

The software for implementing the TDMA protocol needs to be developed. A method of synchronizing the CPU clock with the GPS clock, so that each node both child and parent are synchronized. Once the clocks are synchronized each of the child nodes within a
nine node cluster need to be assigned a time slot, and the parent then needs to have a list of which node is assigned each time slot so on the fly reprogramming for listening to each child node can be programmed.

7.4.1.2 Network Protocol Development Recommendations

The network protocol for transmitting data will need to be developed for interjecting the health and status information into the data stream. Things like how often the health and status information will be sampled will need to be determined. Currently the GPS data is being sent to the Aerocomm modem as it is received by the NPU. Ultimately the GPS data should be packetized into packet containing header and footer information as well as a checksum calculation on the GPS data so that data redundancy measures can be implemented.

7.4.1.3 System Control Recommendations

The nodal processing unit should be able to have total control over the child node system. This includes the capability of initializing the GPS receiver to send out the 10Hz data should the GPS receiver go through a hard reboot. The GPS receiver should also be able to program the Aerocomm on the fly.

7.4.1.4 Analog to Digital Module Recommendations

A number of peripheral features and functions could be implemented at the child node by expanding the Analog to Digital module. The A to D module contains eight-channels that are capable of being multiplexed to up to 24 external devices. This would allow the AD module to monitor various health and status conditions, as well as allow for expansion for the Child Node to serve as a integrated weather station. The following list describes potential external readings that could be collected and forwarded from a child node to a central location:
- Battery Voltage
- Charge Status (percent charged, full, discharged etc.)
- Local temperature (A/D module contains built-in thermistor)
- Solar Panel Output Current
- Battery Temperature
- Wind Speed (low-voltage anemometer)
- Barometric Pressure
- Humidity
- Local Insolation Readings

Another useful function of the A/D converter in collecting this data would be to allow the user to make on-the-fly decisions with regards to shutting the system down remotely. For instance, if a significant Ionospheric event was due (like the Aurora) the user could remotely power down the system to save battery voltage for when gathering data is most important. Having a local voltage calculation available would also allow the user to power down certain nodes uniformly and symmetrically to expand the overall battery life of the system at the cost of imaging resolution.

7.4.2 Parent Node Recommendations

The Parent Node NPU recommendations are to evaluate the use the MSP430 as the processor for the parent node. Due to the developed use of 802.11 protocol for transmitting the larger amount of GPS data collected at each nine node cluster the need for the TCP/IP at the NPU level is necessary. Research has shown no simple way of integrating the MSP430 into a TCP/IP based environment.

The recommendation is to look into using the gumstix\textsuperscript{53} as an embedded system with the capability of using a compact flash 802.11 wireless card. With the advent of a new NPU power consumption will have to be investigated, especially since the gumstix draws orders of magnitude of power than the MSP430 and 802.11 draws significantly more power than the Aerocomm modems.
Appendix A – Experimental Results

Power System Experiments

The results in this section prove the feasibility and support the proposed model power system mentioned in the Power System Design Section. Datasheets for all devices used in this document are provided in the Appendices. The experimental results generated from the tests conducted are documented herein, and organized as follows:

Solar Power Feasibility
- 12-Volt Golf Cart Battery
Voltage vs. Depth of Discharge
- 100 Watt Light Bulb Test
- 6 Watt Load
Charging Efficiency
- DC Power Supply Recharge
- Effective 25 Watt Solar Panel Test
Complete System
- 2.5 Watt Load Test
- Three Day Test with Sun Catcher
- 50 Watt Panel Test

Solar Power Feasibility

12 Volt Golf Cart Batteries Solar Test

Conditions:
This test required a 14.5 Watt Solar Catcher Professional panel and a 12 Volt Lead Acid Battery. This test was conducted on a clear day, with minimal cloud coverage. The solar panel was angled at 45 Degrees from the horizon and connected with a 12 Volt DC adapter to the terminals of the 12 Volt Lead Acid Battery. The setup of solar panel and battery was checked upon every 15 minutes. The effective 12 Volt Battery was rated at 10 Ah.

Results:

12-Volt Golf Cart batteries Solar Test
Time Started 11:15
Time Finished 3:34
Initial Voltage 11.78
Final Voltage (With Settle Time) 12.28
Voltage Across Shunt 0.004
Calculated Shunt Current .8 Amps
Shunt Rating = 100 mV @ 20 Amps.
Conclusions:
The proof that a solar panel can charge a 12 Volt battery comes from the understanding the relationship between voltage at the terminals and potential capacity. In short, the higher the voltage is, the greater the potential. The details of this relationship are developed in later tests which demonstrate that for any given voltage the capacity can be calculated. In order to accurately determine the capacity after charge is put into the battery, a 3 hour settle period was allowed for the charge to dissipate throughout the cell. The higher final reading indicated that charge was placed back into the battery using the SunCatcher Professional panel.

Voltage vs. Depth of Discharge
Two tests were conducted on the prototype Concorde Series PVX 490T AGM to prove the accuracy of the Voltage vs. Charge table seen in Appendix K – Voltage vs. State of Charge. The method implemented in both tests required the draining of the AGM over a known period of time with a fixed resistive load.

100 Watt Light Bulb Test
Conditions:
This test was conducted indoors by connecting the Concorde PVX 490T 48 Ah battery to a 100 Watt light bulb. To do this we first connected two wires to the battery which ended in 12 Volt DC adapter, which was then connected to the DC to AC converter. A standard office lamp with a 100 Watt light bulb was then connected the converter.

Concorde PVX 490T → DC to AC Converter → 100 Watt Light

After the specified time the 100 Watt load was disconnected and a 3 hour settle period was allowed before the final Voltage reading was taken.

Results:

<table>
<thead>
<tr>
<th>Voltage while draining</th>
<th>Volts Measured</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial Voltage</td>
<td>12.45</td>
</tr>
<tr>
<td>Final Voltage (After 3 hours)</td>
<td>11.89</td>
</tr>
<tr>
<td>Time Started</td>
<td>12:50 PM</td>
</tr>
<tr>
<td>Time Finished</td>
<td>3:20 PM</td>
</tr>
<tr>
<td>Voltage while draining @</td>
<td>12:50 PM</td>
</tr>
<tr>
<td>Volts Measured</td>
<td>12.00</td>
</tr>
<tr>
<td>Time Started</td>
<td>1:00 PM</td>
</tr>
<tr>
<td>Time Finished</td>
<td>2:06 PM</td>
</tr>
<tr>
<td>Voltage while draining @</td>
<td>2:01 PM</td>
</tr>
<tr>
<td>Volts Measured</td>
<td>11.92</td>
</tr>
<tr>
<td>Time Started</td>
<td>2:10 PM</td>
</tr>
<tr>
<td>Time Finished</td>
<td>2:13 PM</td>
</tr>
<tr>
<td>Voltage while draining @</td>
<td>2:10 PM</td>
</tr>
<tr>
<td>Volts Measured</td>
<td>11.75</td>
</tr>
<tr>
<td>Time Started</td>
<td>2:13 PM</td>
</tr>
<tr>
<td>Time Finished</td>
<td>2:13 PM</td>
</tr>
<tr>
<td>Voltage while draining @</td>
<td>2:13 PM</td>
</tr>
<tr>
<td>Volts Measured</td>
<td>11.74</td>
</tr>
</tbody>
</table>
Calculations:
Total Potential Watts of Battery at start:

\[ \text{From Table-12.45 Initial Voltage} = 84\% \]
\[ \text{Total Available Watts} = 12 \text{ V} \times 48 \text{ Ah} = 576 \text{ Watts} \]
\[ 576 \times 84\% = 483.84 \text{ Watts} \]

Total Watts Drained:

\[ \text{Time Started – Time Finished} = 2.5 \text{ hours} \]
\[ 100 \text{ Watts} \times 2.5 \text{ hours} = 250 \text{ Watts Drained} \]

Percentage of total remaining

\[ \text{Initial Watts} - \text{Drained Watts} = \]
\[ 483.84 - 250 = 233.84 \text{ Watts remaining} \]
\[ \text{Watts Remaining}/\text{Total Potential Watts} \]
\[ 233.84/576 = 40.5\% \]

Settle Voltage and Table %:

11.89 or approximately 40\%

Conclusions:

The results from this test verified the predictions of the Voltage vs. Charge table. Also it can be concluded that during the time of discharge under a 100 Watt load the battery voltage reading was lower than the total potential capacity. A settle time was incorporated in the test to allow charge to equalize throughout the battery. During the time that charge is induced or removed from a lead acid battery the voltage at the terminal can be significantly higher or lower than the actual state of charge. As a smaller load was applied in later tests this voltage difference significantly decreased.

6 Watt Load:

Conditions:

This test was a 20 hour test conducted by connecting a series of high power resistors to create an effective 28.5 Ohm resistance. This test was conducted indoors and was achieved by connecting 18 Gage wire from the battery to either end of the battery. The purpose of this test was to prove the reliability of the Voltage vs. Charge table [Appendix K – Voltage vs. State of Charge] under a more realistic load. The results are shown below:

Results:
<table>
<thead>
<tr>
<th></th>
<th>Time</th>
<th>Voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Initial Voltage (V)</strong></td>
<td>12.56</td>
<td>9:30</td>
</tr>
<tr>
<td><strong>Final Voltage (V)</strong></td>
<td>12.32</td>
<td>9:31</td>
</tr>
<tr>
<td><strong>Time Started</strong></td>
<td>1:30 PM</td>
<td>9:35</td>
</tr>
<tr>
<td><strong>Time Finished</strong></td>
<td>9:30 AM (next day)</td>
<td>11:00</td>
</tr>
<tr>
<td><strong>Total Time</strong></td>
<td>20 hours</td>
<td>11:30</td>
</tr>
<tr>
<td><strong>Approximate Watts Drawn</strong></td>
<td>120 Watts</td>
<td>12:00</td>
</tr>
<tr>
<td><strong>Percentage drawn</strong></td>
<td>0.215</td>
<td>1:00</td>
</tr>
</tbody>
</table>

**Calculations:**

12.56 is approximately 93% depth of Discharge

\[
\text{Initial Watts} = (12 \text{ Volts} \times 48 \text{ Ah}) \times 0.93 \\
= 535.68 \text{ Watts} \\
\text{Watts Drawn} = 120 \text{ Watts (approximate)} \\
\text{Finish Watts} = 535.68 - 120 \\
= 415.68 \\
\text{Finish %} = 72.16 \%
\]

**Conclusions:**

The final projected percentage of charge was 72.16%, while the actual final Voltage when compared to the Voltage vs. Charge Table was 70%. This 2% can be accounted for the varying load. The load was calculated at 6.1 Watts for a 12 Volt battery, however the fractions of Volts the battery is actually at throughout the discharge would source more current according to Ohm's Law V= IR. This test further supports the validity of the Voltage vs. Charge Table. Another important result is that while under a 6 Watt load, the battery read .05 Volts lower than the true state of charge. This settling effect discussed earlier is important in defining when to turn the battery off, and what the true state of charge has left in the battery.

**Charge Efficiency:**

**DC Power Supply Recharge**

**Conditions:**

This test was conducted using a DC power supply to test the recharge efficiency when connecting the Solar Boost 2000E with the Battery under a constant Current. The DC power supply was calibrated to 18 Volts before the test, and a current limit to 6 amps. The DC power supply ran to the Solar Boost 2000E, and from the 2000E to the battery. The results from this test are shown below.

<table>
<thead>
<tr>
<th></th>
<th>Time</th>
<th>Voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>6 Amp Recharge</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Initial Voltage</strong></td>
<td>12.32</td>
<td>9:20</td>
</tr>
<tr>
<td>Final Voltage</td>
<td>12.67</td>
<td>9:25</td>
</tr>
<tr>
<td>Initial charge</td>
<td>71%</td>
<td>9:30</td>
</tr>
<tr>
<td>Final Charge</td>
<td>99%</td>
<td>9:35</td>
</tr>
<tr>
<td>Total Charge Time</td>
<td>2.25 hours</td>
<td>9:40</td>
</tr>
</tbody>
</table>

9:44 | 13.06 |
9:49 | 13.07 |
9:54 | 13.1 |
10:00 | 13.12 |
10:05 | 13.14 |
10:10 | 13.16 |
10:15 | 13.18 |
10:20 | 13.21 |
10:33 | 13.27 |
10:49 | 13.36 |
11:00 | 13.43 |
11:15 | 13.56 |
11:25 | 13.67 |
11:30 | 11.82 |
11:35 | 14.00-13.98 |

1 hour of rest | 12.67 Volts |

Calculations:

**Charging a 12 Volt Battery @ 6 Amps for 2.25 hours =**

12 Volts * 6 Amps = 72 Watts
72 Watts * 2.25 Hours = 162 Watts Total

**Initial Watts**

.71 * 576 Watts Total = 408.96 Watts

**Final Watts**

.99 * 576 Watts Total = 570.24

**Final Watts – Initial Watts =**

570.24 – 408.96 = 161 Watts

**Recharge Efficiency**

1 Watt difference
1 Watt / 576 Total Watts
= .17%
= 99.73 % Efficient

Conclusions:

The results generated indicated approximate 100 % recharge efficiency. This is promising considering the charge controller was drawing some power. The charge controller is rated from 93-100 % efficiency. This rating is for the MPPT conversion efficiency. The DC power supply regulated the Current, making it impossible to initiate the MPPT. As long as the Voltage remained above the Battery Voltage current was drawn at a constant 6 Amps. At the end of the test, however once the voltage at the battery terminals hit the designated 14.00 V cut-off the Charge Controller stepped down the current to 2.0
amps. This happened for less than a minute, and indicated to us that it does protect the battery from overcharge. Further tests were done to support this further. This test also illustrated the effect of putting charge into the battery. After a recharge period, 3 hours was allowed before measuring the final Voltage. This allowed the charge to settle throughout the battery. This result indicated that measuring the voltage while the battery is under recharge cycle will be slightly inaccurate. Measurements are far more precise when the battery had adequate time for charge to internally equalize or settle.

**Effective 25 Watt Solar Panel Test**

**Conditions:**

Using the Solar Catcher Professional 14.5 Watt Panel in parallel with a Mercury II 11.5 Watt Solar panel a 25 Watt PV panel was created. Both polycrystalline panels were connected to the Solar Boost2000 E. The Solar Boost 2000E was then connected to the Concorde PVX 490T, as shown below:

\[
\text{Solar Catcher} \quad + \quad \rightarrow \quad \text{SolarBoost2000E} \quad \rightarrow \quad \text{Concorde PVX 490T}
\]

**Mercury II**

The voltage was measured from reading the Solar Boost 2000E, which was connected across the terminals. The current was also determined from the LCD display on the unit. This test was conducted on a clear day with 0% cloud cover. The test ran for 3 hours, and the results are shown below:

<table>
<thead>
<tr>
<th>2 Solar Panel Test</th>
<th>Time</th>
<th>Voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial Voltage</td>
<td>11.89</td>
<td>11:30</td>
</tr>
<tr>
<td>Final Voltage</td>
<td>12.2</td>
<td>11:40</td>
</tr>
<tr>
<td>Start Time</td>
<td>11:30 AM</td>
<td>11:53</td>
</tr>
<tr>
<td>Finish Time</td>
<td>3:30 PM</td>
<td>12:33</td>
</tr>
<tr>
<td>Total Time</td>
<td>4 Hours</td>
<td>12:45</td>
</tr>
<tr>
<td>Average Current</td>
<td>2.4 amps</td>
<td>12:57</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1:00</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1:10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1:20</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1:27</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1:31</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1:33</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1:48</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1:52</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2:03</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2:13</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2:21</td>
</tr>
</tbody>
</table>
Calculations:
Initial Watts
11.89 Volts = 345.6 Watts
Final Watts
12.20 Volts = 224.64 Watts
Total Watts Delivered
345.6 Watts - 224.6 Watts = 121.0 Watts
Predicted Watts
2.4 Amps * 4 hours = 9.6
12.89 Volts * 9.6 = 123.744 Watts

Conclusions:
This test proved charge efficiency while implementing both the Solar Boost 2000E and an effective 25 Watt Solar Panel. In calculating the predicted watts the initial voltage was used give a more accurate prediction. The MPPT did not enable, and the Solar Boost 2000E merely passed the current from the panels to the battery. The minimal draw of the Solar Boost did not affect the outcome of this efficiency.

2.5 Watt Load Test
Conditions:
This test was conducted over a 24 hour period and involved connecting the entire power system with an approximate 2.5 Watt load. For a period of 20 hours the test was conducted indoors and the battery was simply drained. On the next day, the system was placed outside for a period of 4 hours of clear sunlight the system and the solar panel optimized. The system was wired in the following fashion: the 14.5 Watt Solar Catcher Panel was connected to the Solar Boost 2000E. The Solar Boost was next connected to the Concorde SunXtender. The load was applied simultaneously across the terminals. After the four hours, the system was dismantled and a 3 hour settle time was allowed for an accurate voltage at the terminals. The results from this test are shown below:
Results:

First Model System Test Results:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Start Time</td>
<td>4:00 PM</td>
</tr>
<tr>
<td>Finish Time</td>
<td>4:00 PM</td>
</tr>
<tr>
<td>Resistance</td>
<td>58 Ohms</td>
</tr>
<tr>
<td>Load = V^2/R</td>
<td>2.48 Watts</td>
</tr>
<tr>
<td>Initial Voltage</td>
<td>12.29</td>
</tr>
<tr>
<td>Final Voltage</td>
<td>12.27</td>
</tr>
<tr>
<td>Start Time in Sun</td>
<td>10:30 AM</td>
</tr>
<tr>
<td>End Time in Sun</td>
<td>2:30 PM</td>
</tr>
<tr>
<td>Hours in Sunlight</td>
<td>4 hours</td>
</tr>
<tr>
<td>Average Solar Panel Current</td>
<td>0.95 Amps</td>
</tr>
</tbody>
</table>

Calculations:

Power Delivered to Battery From Sun Panel:

\[ 0.95 \text{ Amps} \times 4 \text{ Hours} = 3.8 \text{ Amp Hours} \]
\[ 3.8 \times 12 \text{ Volts} = 45.6 \text{ Watts} \]

Total Watts Drawn From System:

\[ 2.48 \text{ Watts} \times 24 \text{ hours} = 59.52 \text{ Watts} \]

Total Watts

\[ 12.29 \text{ Volts} = 391.68 \text{ Watts} \]
\[ 12.27 \text{ Volts} = 380.16 \text{ Watts} \]
\[ \text{Difference} = 11.52 \text{ Watts} \]

Predicted Watts & Final Watts

\[ \text{Initial Watts} - \text{Total Watts Drawn} + \text{Power Delivered} \]
\[ 391.68 - 59.52 + 45.6 \]
\[ = 377.76 \text{ Watts} \]

Actual Watts

\[ 380.16 \text{ Watts} \]

Conclusions:

This test proved the feasibility of charging the battery connected to a load with a polycrystalline panel. The reason why there are higher potential watts at the end of this test can be due to the Solar Panel generating greater than .95 Amps. This system was not connected to an automated Data Acquisition unit and the average Current was taken by reading the Solar Boost every 20 minutes. During these times, the current may have been greater than .95 generating more power. Also this .95 was multiplied by an assumed 12 Volts. The 12 Volts was actually closer to 12.27 during the test, and could have generated the extra 3 Watts. For our purposes the tolerances on this test are within the needs of our project, and prove the feasibility of our model system.
Complete System
Weekend Test with 2.5 Watt Load

Conditions:
This test was to prove the feasibility of our system using an approximate 2.5 Watt load, and ran from Friday to Monday and tested the feasibility of leaving a system out overnight running only off solar power. The only resource available to collect data was one channel of a Data Acquisition Unit. Using a 2.5 Watt load and optimizing the 14.5 Watt Solar Catcher at 12 noon the unit took a voltage reading every 30 seconds. The system was connected as follows:

Solar Panel → Charge Controller → Battery → 2.5 Watt Load

The Data Acquisition Unit was attached in parallel to the battery and drew less than .003 Watts. The graph shown in Figure 50 below represents the total 8615 data points taken and a 10 point moving average.

Results:

![Complete 2.5 Watt Power System Test](image)

Figure 50: Complete 3 Day Test illustrating the voltages across the terminals

Conclusions:
From beginning to end, this graph represents an accurate model of the voltage differences between night and day hours. At times when the sun was out, the voltages drastically increased as shown by the peaks. Spikes throughout these sunlight hours can be accounted for by cloud cover. From the tests above it is proven that during a constant discharge (non-sunlight hours) the voltage level is within .05 Volts of the true reading. Based upon this assumption and extrapolated from data used to produce this graph the trend between the first day and last day shows the total watts left in the battery was less. This trend is highlighted by use of arrows in the graph. The voltage increase during the second day was not as high as that of the third day due to overcast cloud cover. However, between the second and third day, the total watts remained equal as shown by the voltage indicated by the arrows within those days. This test proved the predictability of a complete scalable power system integration.

50 Watt Panel Test

Description:

This test was designed to determine the scalability from a 14.5 Watt panel to a more realistic prototype 50 Watt panel. This test was conducted outdoors on a relatively clear day. It was conducted in a similar fashion to that of the previous tests in that it was connected in the following manner:

Solar Panel → Charge Controller → Battery → 6 Watt Load

The potential sunlight that was received by the panel was measured by reading the scale on an adjacent panel aligned at the same angle. This panel was the Motorola X version and was scaled from 0-130 to indicate the level of sunlight. After the 4 hour period of Sunlight the system was dismantled and voltage measurements were taken. The results from this test can be seen in the below:

<table>
<thead>
<tr>
<th>Results:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Time Started</td>
<td>11:30</td>
</tr>
<tr>
<td>Time Finished</td>
<td>3:30</td>
</tr>
<tr>
<td>Initial Voltage</td>
<td>12.44</td>
</tr>
<tr>
<td>Final Voltage</td>
<td>12.67</td>
</tr>
<tr>
<td>Motorola Rating</td>
<td>% of scale</td>
</tr>
<tr>
<td>BP 350 Current Amps</td>
<td>1.2</td>
</tr>
<tr>
<td>BP 350 Current Amps</td>
<td>2.1</td>
</tr>
<tr>
<td>MPPT Current Amps</td>
<td>1.8</td>
</tr>
<tr>
<td>MPPT Current Amps</td>
<td>2.3</td>
</tr>
<tr>
<td>MPPT Current Amps</td>
<td>2</td>
</tr>
</tbody>
</table>

92
Calculations:

Initial Watts
12.47 Volts = 478.72 Watts

Final Watts
12.67 = 558.72 Watts

Predicted Watts Delivered
558.72 Watts - 478.72 Watts = 80 Watts

Calculated Watts Total Delivered:

Approximate Watts Delivered to Battery
= [Avg. MPPT * hours + Avg. Overcharge * hours] * 12 Volts
= [(2.69 * 2.75 hours) + (1.15 * 1.25 hours)] * 12
= 106.02 Watts

Watts Drawn by Load
= 6.15 Watts * 4 Hours
= 24.6 Watts
= 106.02 - 24.6
= 81.6 Watts

Conclusions:
The MPPT, and overcharge protection from the Solar Boost 2000E worked as expected. The points in the table when the readings were stopped being taken from the Motorola was the point when the Solar Boost limited the power going to the battery, protecting it from overcharge.

When the MPPT reached peak performance in this test at 3.4 amps, the panel reached the 94% scaled sunlight. Comparing the output current from the panel to the output current to the battery the MPPT produced an additional 21 % more current to the battery. The BP 350U panel is only rated for a 3 Amp short circuit, however the MPPT technology produced
greater than this on different data points. This test confirmed that the larger the panel, the more power it will produce, and the less time it will take for a battery to recharge.

According to the calculations the total calculated watts delivered exceed the predicted watts delivered by 1.6 Watts. This fraction of a watt can be accounted for due to the fact that the load is a constant 28.5 Ohm resistance. According to the equation $V = IR$, for a constant Resistance value, as the Voltage increases, the Current does as well. This would drain more power from the battery than 6.15 Watts.

**Analog Battery Monitor Experiment**

**Test Description and Conditions**

The following circuit was designed to disconnect the load from the battery in the event that the battery becomes discharged below 30% to maximize lifespan and charging efficiency.

![ADC Load Cutoff Circuit](image)

**Figure 51: ADC Load Cutoff Circuit**

To prevent battery damage, the circuit in Figure x was designed to disconnect the load at a predetermined level of load voltage. Electronic Design recommended this circuit as it is commonly used in applications utilizing 12 volt car batteries. The circuit relies on the MTP12P05 power MOSFET and the Maxim 8212 low-voltage battery monitor. This load voltage, $V_{TRIP}$, is closely proportional to the battery voltage. $R_1$ and $R_2$ determine the level of $V_{TRIP}$ that corresponds to voltage of 1.15V at pin 3 of IC$_1$. A voltage of 1.15V at pin 3 of IC$_1$ causes the internal comparator to trip. Thus,
\[ V_{\text{TRIP}} = 1.15(R_1 + R_2)/R_1 \]  Pressing reset or pulling pin 3 above 1.15V with a transistor reconnects the load. Battery drain with the load disconnected is 5 \( \mu \text{A} \), so the circuit can remain with the load disconnected for an extended period without causing a deep discharge of the battery.

**Test Results**

The disconnect circuit worked without any major design issues. It was determined that precise 1\% resistors were needed to synthesize the voltage disconnect point. Once precision resistors were placed in the circuit, the load would disconnect when the battery voltage dropped below 11.75 Volts.

**Test Conclusions**

This circuit is an effective and easy-to-implement low-power analog cut-off circuit. However, after further consideration, it was realized that the A/D conversion functionality of the NPU eliminates the need for such a circuit in the first place. Instead of having an analog comparator IC circuit, the NPU can continuously monitor the battery voltage and disconnect the base pin of an appropriately rated power MOSFET.

**Experimental Results for the Communications System**

**General Testing Conditions**

The 900 Mhz Aerocomm tests were performed in many different fashions. The main experiments tested range and throughput of the modems. Four main testing locations were used. The following is a list of testing locations as well as a brief description of the types of tests preformed.

The Engineering Systems Division Building at SRI to the large dish behind Stanford; approximately 6 km in distance.

Tests conducted included range, throughput and data redundancy tests of the modems with both 3dB and 7dB antennas

From one part of the Engineering Systems Division Building roof at SRI to the opposite side of the roof; approximately 100 feet

Tests conducted included range, throughput and data redundancy tests of the modems with the 3dB antennas

Tests conducted included varying transmission power tests and stream vs acknowledgement mode tests
From one end of the Engineering Systems Division parking lot to another location in the parking lot; approximately 30 feet
Tests conducted included range, throughput and data redundancy test of the modems with the 3dB antennas
Tests conducted included varying transmission power tests and varying RF packet size
From a point behind the Palo Alto airport to a car moving to varying distances along the salt evaporation flat
Test conducted included range and data redundancy
Tests conducted included evaluating retransmit tries vs. link present

900 Mhz Aerocomm Initial Test Out of the Box Configuration

Test Description and Conditions:

After receiving the 900 Mhz Aerocomm modems the first test that was preformed was a range test. The conditions for the test were as follows:
Location: SRI roof to Dish at Stanford
Range: 6km
Transmit Power: 50 / 60 (hex)
Transmit Retries: 4 / 255 (dec)
RF Transmit Mode: Acknowledgment Mode
Network Topology: Point to Point
Antennas: 7dB at SRI and 3dB at Stanford
The data was being transmitted from a Python script running on a Linux computer at SRI to the receiver at Stanford.

Initially the data being transmitted was a string of characters. After the first test was not totally successful the data was changed to sequential numbers; for example (1 then 2 then 3 etc…)

Test Results:

When the sequence of characters was being transmitted from SRI to Stanford, it was apparent that not all of the characters were being received. Due to the fact that the same characters were being transmitted, it was very hard to discern what was exactly happening. The transmission script was changed to transmit a number starting at 0, sleep for 1 second, increment that number and retransmit. The data stream should have been as follows: 1 (1 second time delay), 2 (1 second time delay), 3 (on the screen it
should have looked like 1 2 3). The data that was actually being received was not all consecutive. It seemed to be randomly not receiving some of the numbers, for example what would be received at Stanford was: 1 4 6 9

**Conclusions:**

Data was being lost, in one form or another. It was a little discouraging since the specifications of the modems said that 20 miles line of sight could be obtained. This test proved that data loss was present at a little over 6 km. After looking though the manual of the Aerocomm modems, the conclusion was made that the number of retransmit times was far to low for the link quality that was present. Although line of sight was present there were many things that could have interfered with the signal quality, mainly trees and buildings just below the line of sight. It would later be proven that by increasing the number of retransmit times the data integrity could be maintained over this distance.

**Shorter Range Test with Out of the Box Configuration**

**Test Conditions and Description:**

Due to the previous test’s failure to maintain data integrity the next test was preformed. The range would be reduced, and the obstacles in the line of sight would be removed. The conditions of the test were as follows:

Location: Fixed Point Behind the Palo Alto Airport to Mobile Vehicle
Range: Approximately 300 meters, 500 meters, 1000 meters, 1200 meters
Transmit Power: 50 / 60 (hex)
Transmit Retries: 4 / 255 (dec)
RF Transmit Mode: Acknowledgment Mode
Network Topology: Point to Point
Antennas: 3dB at Both Points
The data was being transmitted from a Python script running on a laptop computer located at a fixed point to a mobile vehicle.

**Test Results:**

The test was to prove the throughput and data integrity of the modems in a more controlled as smaller test environment. The test again was the consecutive data being
transmitted with a smaller sleep time. Decreasing the sleep time increases the amount of data being transmitted per unit time thus increasing the transmitted data rate. The tests proved positive for the different ranges and no data was lost, the sleep time was also varied on the computer to simulate different data rates, but later tests proved that this method of simulating data rate was not exactly valid.

Another test was also preformed which gave some preliminary data on retransmit tries. When the vehicle went behind a building and the link like on the Aerocomm modem went down sometimes no data was lost, and this happened because the retransmit tries were coming into play, when the link went down the modem started trying to retransmit the data, due to the fact the modem was in the acknowledgment mode, eventually with the down link no acknowledgment of a received packet would be received by the transmitter so it would increment the retransmit tries counter and try again. If the car moved into line of sight and the link was restored before the max number of retransmit tries was reached no data loss would be present, if the number of retransmit tries is reached data would be lost. Although this was only a primitive experiment it demonstrated the effect of retransmit tries on data integrity.

Conclusions:

Overall test results were positive, no data was being lost, but actual throughput rate was not being tested in a valid fashion. It was somewhat frustrating because you would think the manufacturer would have a product / software to test throughput, but they do not.

**Stream vs. Acknowledgment Mode Test**

**Test Conditions and Description:**

Seeing as how the data sheets showed a discrepancy between interface rate and actual RF rate, actual throughput needed to be tested. The stream mode’s max theoretical throughput is 57000 bps and the acknowledgment mode’s max theoretical throughput is 38000 bps. At this point in testing a valid method of testing throughput was not totally developed. This test simply evaluated the feasibility of the stream and acknowledgment in a system constantly streaming data.
Location: Vehicle to Vehicle in the SRI Parking Lot
Range: Approximately 30 Feet
Transmit Power: 30 / 60 (hex)
Transmit Retries: 4 / 255 (dec)
RF Transmit Mode: Stream and Acknowledgment Mode
Network Topology: Point to Point
Antennas: 3dB at Both Points
The data was being transmitted from a Python script running on a laptop computer located at a fixed point to another vehicle across the parking lot.

Note: The transmit power was changed due to a suggestion from the application engineer at Aerocomm stating that if both transceivers are too close together at max transmit immense data loss can occur.

Test Results:
While in stream mode, two way communication across the RF link becomes extremely hard. Due to the fact that the client side is streaming data constantly; sending packets from the server to the client is not always possible. During the testing sometimes while receiving data, no matter how many times the server attempts to transmit to the client the data never goes though.

Conclusions:
Due to the way that the stream mode operates it is not feasible for this application. This is not good because it limits the operation of the modems to the acknowledgment full duplex mode. That means the max theoretical throughput is 38000 bps.

Simulated Throughput Tests

Test Conditions and Description:
Currently at this point in the testing it was crucial to develop a method of testing the throughput that was accurate. Up to this point the preliminary throughput tests were just changing the rate at which a message was being transmitted. The major problem with this method was that achieve rates between 1 – 2 KBps required a sleep time that was actually faster than the clock speed available for the python script, for example the
fastest clock speed available for a python script was around 50 Hz and the sleep time needed to achieve the throughput rates was above 100 Hz.

The solution to this problem was to make the message size much larger and send it less often, thus increasing the sleep time making the cycle rate of the sleep portion of the script below 50 Hz.

The script developed to test the throughput generated a file of a specific size, sent that file at the specified rate. At this point the transmission program and the receiver program compute a MD5 checksum on the file and compare the checksums; if they are equal no data loss is present.

Location: Parking Lot, Rooftop, and Stanford Locations
Range: Approximately 30 Feet, 100 Feet, 6km
Transmit Power: 30 / 60 (hex) and 60 / 60 (hex)
Transmit Retries: 4 / 255 (dec) and 200 / 255 (Dec)
RF Transmit Mode: Acknowledgment Mode
Network Topology: Point to Point
Antennas: 7dB at SRI and 3dB at Stanford and 7dB at SRI and 7dB at Stanford

Test Results:

The first tests which were short range proved that the with the new python scripts that actual throughput information could be recorded. Both the short range tests showed that the best throughput rate in the full duplex acknowledgment mode was approximately 20,000 bps. This test showed that there is approximately 47% network overhead [(38,000 – 20,000) / 38000], a slightly larger number as compared to other standard networking protocols. Ethernet for example has approximately 40% network overhead. That 47% is actually not truly what the overhead is because the theoretical max throughput of the RF channel is 76,800 bps, which includes all of the overhead created by the acknowledgment mode. Thus the actually overhead is [(78000 – 20000) / 78000] = 75% overhead which is outrageous.

The third test was to prove that this throughput of approximately 20,000 bps could be obtained at a greater distance. The test was between SRI and Stanford and proved successful with max power and the number of retransmit tries up too 200. The test was for approximately 10 minutes worth of data and no data loss was present.
Conclusions:

The actual throughput of the 900 Mhz modems was quite discouraging with an actual throughput of 20,000 the data rate needed by the GPS data of 1.5 KBps does not leave much room for playing network topology games to reduce power consumption and increase overall network efficiency. At this point it was obvious that the 900 Mhz radios were not a viable option for the communications network of the system.

GPS Experiments

GPS Receiver Data Rate Experiment

Test Description and Conditions

The purpose of this test is to determine an approximate experimental data rate of the GPS receiver while streaming MSG 23: Measurement Block Data, 10 Hz. When this message is sent to the GPS receiver, it will output a stream of data that contains the carrier phase delay of the GPS L-band signal from each of 12 satellites in orbit, sampling each satellite 10 times per second. The size of this data stream is variable depending upon the number of message blocks contained in the output message.

In order to measure this data experimentally, the GPS data was logged directly from the serial port to a text file for a predefined amount of time. This functionality is built directly into the Smart Antenna “Star View” interface application software. After logging the streaming data into a file, the file size was calculated and this size was divided by the time in seconds to determine the data rate. As the data rate is variable it was important to determine a reliable calculation for bandwidth, network models, buffer memory needs etc. The table depicting the results is shown below:

Test Results

<table>
<thead>
<tr>
<th>Time</th>
<th>Trial</th>
<th>File Size (KB)</th>
<th>Data Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 minute</td>
<td>1</td>
<td>60</td>
<td>1</td>
</tr>
<tr>
<td>1 minute</td>
<td>2</td>
<td>59</td>
<td>0.983333</td>
</tr>
<tr>
<td>1 minute</td>
<td>3</td>
<td>62</td>
<td>1.033333</td>
</tr>
<tr>
<td>5 minutes</td>
<td>1</td>
<td>405</td>
<td>1.35</td>
</tr>
<tr>
<td>5 minutes</td>
<td>2</td>
<td>413</td>
<td>1.376667</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-----------------</td>
<td>-------</td>
<td>-----</td>
<td>---------</td>
</tr>
<tr>
<td>60 minutes</td>
<td>1</td>
<td>3825</td>
<td>1.0625</td>
</tr>
<tr>
<td>60 minutes</td>
<td>2</td>
<td>4639</td>
<td>1.288611</td>
</tr>
<tr>
<td>3 hours</td>
<td>1</td>
<td>12715</td>
<td>1.177315</td>
</tr>
</tbody>
</table>

**Test Conclusions**

After several trials, we concluded that approximate data rate of the GPS in Measurement Block Data 10 Hz mode was 1.25kB/sec.

**Nodal Processing Unit Experiments**

**Serial Controller Testing**

The serial controller is essential to achieving milestone two. Without this functionality, the MSP430 would be incapable of communication with the GPS receiver or the Aerocomm modem. The development of the serial controller was an iterative process completed in three major steps. The first step is to ensure that the hardware functions as a loop back adapter when the transmit and receive pins are tied together. The second step is to untie these pins and have the MSP430 transmit back whatever it receives. This step should be done for both USART0 and USART1. The final step is to integrate USART0 and USART1 such that what is received on USART0 is transmitted on USART1 and that which is received USART1 is transmitted on USART0. This configuration is what makes bidirectional communication between the GPS and Aerocomm modem function.

Step one is a trivial, but essential step. This simple circuit reduces the voltage range from +/-12 volts to TTL logic levels of 0 and 5 volts. This is the recommended voltage range to ensure safe and reliable communication with the MSP430. The inverters are used instead of buffers because the MSP430 understands an inverted signal as compared to the signal transmitted over the RS232 standard. One circuit must be created for each USART controller being used; two for bidirectional communication. The following circuit illustrates how the hardware loop back adapter is constructed.
Once the hardware loop back of step one has been completed and tested, the transmit and receive pins should be disconnected from one another and tied to the appropriate transmit or receive pin (i.e. URX0 pin for USART0 receive pin). The code below illustrates how step two is accomplished for USART0.

```c
#include <msp430x16x.h>
unsigned int received = 0x55;
void main(void)
{
    WDTCTL = WDTPW + WDTHOLD;  // Stop WDT
    P3SEL |= 0x30;              // P3.4,5 = USART0 TXD/RXD
    ME1 |= UTXE0 + URXE0;      // Enable USART0 TXD/RXD
    UCTL0 |= CHAR;             // 8-bit character
    UCTCL0 |= SSEL0;           // UCLK = ACLK
    UBR00 = 0x03;              // 32k/9600 - 3.41
    UBR10 = 0x00;              //
    UMCTL0 = 0x55;             // Modulation
    UCTL0 &= ~SWRST;           // Initialize USART state machine
    IE1 |= /*URXIE0*/ + UTXIE0; // Enable USART0 RX/TX interrupt

    _BIS_SR(LPM3_bits + GIE);  // Enter LPM3 w/ interrupt
}
#pragma vector=UART0RX_VECTOR    // Compiler specific command
__interrupt void uart0_rx (void) // Interrupt program
{
    if((RXERR & U0RCTL) == 0x01)   // Test to ensure that received data is valid
    {
        // If it is not valid...
        received0 = RXBUF0;        // RXBUF0 read to set buffer clear flag
        received0 = 0x00;          // Invalid data received, move null character into received0
    }
    else                         // Otherwise data is valid
```
The code initializes the USART for UART mode at 9600 baud and 8 bit characters (etc.). Once initialization is complete, the MSP430 goes into low power mode (LPM3). The microprocessor remains in low power mode until it is interrupts by a start bit on it’s receive pin. This bit wakes the microprocessor from LPM3 and activates the receive interrupt. The receive interrupt service routine (ISR) then stores the received character and enables the transmit interrupt. The transmit ISR then transmits the character back to the serial port that sent it, thus completing the loop back. Once both ISRs have been serviced, the MSP430 returns to LPM3 until another start bit appears on the receive pin.

The final iteration of creating a bidirectional serial controller is to combine the USART0 and USART1 serial controllers into one program. The code follows the same flow as above with a few exceptions. Characters received on one USART are always transmitted on the opposite USART controller (i.e. data received on USART0 is transmitted on USART1). The following code is used to achieve bidirectional serial communication.

```c
#include <msp430x16x.h>
unsigned int received0, received1;
#define MAX_BUFFER 32
unsigned char buffer[MAX_BUFFER];
unsigned int head, tail;
unsigned char character;

void main(void)
{
    WDTCTL = WDTPW + WDTHOLD;            // Stop Watch Dog Timer
    P3SEL |= 0xF0;                        // P3.4,5 = USART0 TXD/RXD &
    P3.6,7 = USART1 TXD/RXD
    ME1 |= UTXE0 + URXE0;                 // Enable USART0 TXD/RXD
    ME2 |= UTXE1 + URXE1;                 // Enable USART1 TXD/RXD
    UCTL0 |= CHAR;                        // 8-bit character (USART0)
    UCTL1 |= CHAR;                        // 8-bit character (USART1)
    UTCTL0 |= SSEL0;                      // UCLK = ACLK (USART0)
    UTCTL1 |= SSEL0;                      // UCLK = ACLK (USART1)

    TXBUFO = received1;                   // Transmit character received from USART1
    IE1 |= UTXIE0;                        // Re-enable the Receive interrupt on USART0
    IE1 &= ~URXIE0;                       // Disable the this Transmit interrupt
}
```
UBR00 = 0x03;                         // 32k/9600 - 3.41 (USART0)
UBR10 = 0x00;                         //
UMCTL0 = 0x4a;                        // Modulation
UBR01 = 0x03;                         // 32k/9600 - 3.41 (USART1)
UBR11 = 0x00;                         //
UMCTL1 = 0x4a;                        // Modulation
UCTL0 &= ~SWRST;                      // Initialize USART state
machine (USART0)
UCTL1 &= ~SWRST;                      // Initialize USART state
machine (USART1)
head = 0x00;
tail = 0x00;
IE1 |= URXIE0;              // Enable USART0 RX/TX interrupt
IE2 |= URXIE1;              // Enable USART1 RX/TX interrupt
_BIS_SR(GIE);

while(1)
{
  if(head != tail)
  {
    character = buffer[tail];
tail = (tail +1) % MAX_BUFFER;
TXBUF1 = character;
while(!(IFG2 & UTXIFG1));
  }
}

#pragma vector=UART0RX_VECTOR           // Compiler specific command
__interrupt void usart0_rx (void)       // Interrupt program
{
  buffer[head] = RXBUF0;
  head = (head + 1) % MAX_BUFFER;
}

#pragma vector=UART1RX_VECTOR
__interrupt void usart1_rx (void)
{
  if((RXERR & U1RCTL) == 0x01)          // Test to ensure that received
data is valid
  {
    // If it is not valid...
    received1 = RXBUF1;                 // RXBUF1 read to set buffer
clear flag
    received1 = 0x00;                   // Invalid data received, move
null character into received0
  } else // Otherwise data is valid
  received1 = RXBUF1;                 // RXBUF1 is read into
received1
IE2 &= ~URXIE1;                       // Disable the Receive
interrupt until this character has been transmitted
IE1 |= UTXIE0;                        // Enable the USART0 Transmit
interrupt
}

#pragma vector=UART0TX_VECTOR
__interrupt void usart0_Tx (void)
{
    TXBUF0 = received1;                  // Transmit character received
    from USART1
    IE2 |= URXIE1;                      // Re-enable the Receive
    interrupt on USART1
    IE1 &= ~UTXIE0;                     // Disable the this Transmit
    interrupt
}

#pragma vector=UART1TX_VECTOR
__interrupt void usart1_Tx (void)
{
    TXBUF1 = received0;                  // Transmit character received
    from USART0
    IE1 |= URXIE0;                      // Re-enable the Receive
    interrupt on USART0
    IE2 &= ~UTXIE1;                     // Disable the this Transmit
    interrupt
}

This software combined with the hardware configuration above, was tested using two
computers to simulate the GPS and Aerocomm modems. A serial cable was attached
from each computer to one of the UARTs. HyperTerminal was then used to transmit
characters back and forth between the PCs. First, one character was transmitted from
one PC to another to test half-duplex capabilities from UART0 to UART1. Next, one
character was transmitted from UART1 to UART0 to test half-duplex in the other
direction. After both tests proved successful, full-duplex was tested. This was done
by holding down a key on each computer. While both keys were depressed, the
corresponding characters appeared on each receiving PCs HyperTerminal window.
There was no apparent data loss in the transmission.
**Memory Buffer Test**

In the event that a RF link goes down temporarily, it is useful to have a memory buffer to store several minutes of GPS data to reduce data loss during the down time. The memory buffer, like the serial controller, has both hardware and software considerations. The hardware is simplified by using an I2C compatible EEPROM. The EEPROM is tied to the MSP430 using only two wires, the serial data line (SDA) and serial clock line (SCL). The following schematic displays this configuration.

![Schematic of I2C Interface with the MSP430](image)

**Figure 53: I2C Interface with the MSP430**

Software for most I2C devices follows the same general flow. After initialization of the UART controller for I2C mode, memory can be written to or read from at any time. The program writes a sequence to the EEPROM byte by byte. After each byte is written to memory, the EEPROM must acknowledge to the MSP430 that it is ready for the next byte. Once all bytes have been written, the EEPROM is read back into a variable to ensure that all data was written properly. The following code illustrates the case of implementing read and write cycles with the MSP430.

```c
#include "msp430x16x.h"
/
*/--- external functions of file "I2C routines.c" -----------------------------*/
extern void InitI2C(void);
extern void EEPROM_ByteWrite(unsigned int Address,unsigned char Data);
extern unsigned char EEPROM_RandomRead(unsigned int Address);
extern unsigned char EEPROM_CurrentAddressRead(void);
extern void EEPROM_AckPolling(void);
/
*/---------------------------------------------------------------*/
void main(void)
{

```
volatile unsigned char Data[18] = "Now for the output";
volatile unsigned char var1[18] = "This is some input";
unsigned int saver = 0x0000;
unsigned int i;

WDTCNTL = WDTPW+WDTHOLD; // disable Watchdog
P1DIR = 0xFF;           // termination of unused pins
P2DIR = 0xFF;
P3DIR = 0xF5;
P4DIR = 0xFF;
P5DIR = 0xFF;
P6DIR = 0xFF;

InitI2C();          // Initialize I2C module
_EINT();

for(i = 0; i < 18; i++) // Write each byte to memory in turn
{
   EEPROM_ByteWrite(saver,Data[i]); // Write the current byte to the EEPROM
   EEPROM_AckPolling();            // Wait for EEPROM write cycle completion
   saver++;
}
var1[0] = EEPROM_RandomRead(0x0000); // Read the data at the first memory
                                      // location of the EEPROM & Store it in var1[0]

for(i = 1; i < 18; i++)                  // Read each subsequent memory location &
var1[i] = EEPROM_CurrentAddressRead(); // store it in the next element of var1
                                      // var1 initially held "This is some input", it now contains
                                      // the data stored on the EEPROM "Now for the output"

while (1);

Analog to Digital Conversion Test

Test Description and Conditions
The purpose of this initial experiment was to demonstrate the functionality and robustness of the on-board Analog to Digital Converter of the MSP 430. Multiple channels were sampled on the Input Channels of the MSP 430. Additionally multiple sampling modes and clock times were tested to illustrate the robustness and ease of adaptability of the ADC features. The following code was used and various variables were manipulated.

//******************************************************************************
// MSP-FET430P140 Demo - ADC12,
//
// This example shows how to perform A/D conversions on a sequence of channels.
// A single sequence of conversions is performed - one conversion each on
// channels A0, A1, A2, and A3. Each conversion uses AVcc and AVss for the
// references. The conversion results are stored in ADC12MEM0, ADC12MEM1,
// ADC12MEM2, and ADC12MEM3 respectively and are moved to 'results[]' upon
// completion of the sequence. Test by applying voltages to pins A0, A1, A2,
// and A3, then setting and running to a break point at the "_BIC...
// instruction in the ISR. To view the conversion results, open a watch window
// in C-Spy and view 'results' or view ADC12MEM0, ADC12MEM1, ADC12MEM2, and
// ADC12MEM3 in an ADC12 SFR window.

// Note that a sequence has no restrictions on which channels are converted.
// For example, a valid sequence could be A0, A3, A2, A4, A2, A1, A0, and A7.
// See the MSP430x1xx User's Guide for instructions on using the ADC12.

//
// MSP430F149
// ------------------------------
// | A0 | <--- Vin0
// | A1 | <--- Vin1
// | A2 | <--- Vin2
// | A3 | <--- Vin3
// |

// M.Mitchell
// Texas Instruments, Inc
// January, 2002
// Built with IAR Embedded Workbench Version: 1.25A
// December 2003
// Updated for IAR Embedded Workbench Version: 2.21B
//
// Modified by Chris Hamman for SRI International, February, 2005 *code
//*******************************************************************************/

#include "msp430x14x.h" // Standard Equations

static unsigned int results[4]; // Needs to be global in this example
  // Otherwise, the compiler removes it
  // because it is not used for anything.

void main(void)
{
  WDTCTL = WDTPW+WDTHOLD;    // Stop watchdog timer
  P6SEL = 0x0F;               // Enable A/D channel inputs; able to choose any sampling pins from
  \ manipulating this value
  ADC12CTL0 = ADC12ON+MSC+SHT0_2; // Turn on ADC12, set sampling time
  ADC12CTL1 = SHP+CONSEQ_1;    // Use sampling timer, single sequence, to modify sampling
  \ timer use different variable
                  //for SHT Register using bit pattern found in Manual Pg 17-21
  ADC12MCTL0 = INCH_0;        // ref+=AVcc, channel = A0
  ADC12MCTL1 = INCH_1;        // ref+=AVcc, channel = A1 Playing with the numbers here will
  \ alter the channel
  ADC12MCTL2 = INCH_2;        // ref+=AVcc, channel = A2
  ADC12MCTL3 = INCH_3+EOS;    // ref+=AVcc, channel = A3, end seq.
  ADC12IE = 0x08;             // Enable ADC12IFG.3 This code sequence will call the interrupt required
  \ to make the conversion
  ADC12CTL0 |= ENC;           // Enable conversions
  _EINT0;                     // Enable interrupts

  while(1)
{ //This routine will interrupt the processor until a conversion is complete and the Interrupt Service Routine is Complete
  ADC12CTL0 |= ADC12SC; // Start conversion
  _BIS_SR(LPM0_bits); // Enter LPM0
}

#pragma vector=ADC_VECTOR
__interrupt void ADC12ISR (void)
{ //When Interrupt flag is cleared, the Service Routine will store the results in the memory registers
  results[0] = ADC12MEM0; // Move results, IFG is cleared
  results[1] = ADC12MEM1; // Move results, IFG is cleared
  results[2] = ADC12MEM2; // Move results, IFG is cleared
  results[3] = ADC12MEM3; // Move results, IFG is cleared
  _BIC_SR_IRQ(LPM0_bits); // Clear LPM0, SET BREAKPOINT HERE
}

Test Results
Full functionality of application notes was achieved. Able to manipulate sampling times, which ADC input pins were sampled, and all four sampling modes.

Test Conclusions
The analog to digital converter module is capable of supporting a battery monitor. Furthermore, pending a successful design, the ADC should be employed for other functions required by the final NPU system.
## Appendix B – Aerocomm Programming Information

<table>
<thead>
<tr>
<th>Parameter</th>
<th>EEPROM Address</th>
<th>Length (Bytes)</th>
<th>Range</th>
<th>Default</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Product ID</td>
<td>00h</td>
<td>40</td>
<td></td>
<td></td>
<td>40 bytes - Product identifier string. Includes revision information for software and hardware.</td>
</tr>
<tr>
<td>Sub Hop Adjust</td>
<td>36h</td>
<td>1</td>
<td>0 – FFh</td>
<td>66h</td>
<td>This value should only be changed when recommended by Aerocomm.</td>
</tr>
<tr>
<td>Range Refresh</td>
<td>3Dh</td>
<td>1</td>
<td>1 – FFh</td>
<td>18h</td>
<td>This byte specifies the maximum amount of time a transceiver will report in Range without having heard a beacon (equal to hop period * value). Do not set to 0h.</td>
</tr>
<tr>
<td>Stop Bit Delay</td>
<td>3Fh</td>
<td>1</td>
<td>0 – FFh</td>
<td>FFh</td>
<td>For systems using the RS-485 interface or Parity Mode, the serial stop bit might come too early (especially at slower interface baud rates). Stop Bit Delay controls the width of the last bit before the stop bit occurs. FFh = Disable Stop Bit Delay (12us) 00h = (256 * 1.6us) + 12us 1 – FFh = (value * 1.6us) + 12us</td>
</tr>
<tr>
<td>Channel Number</td>
<td>40h</td>
<td>1</td>
<td></td>
<td></td>
<td>AC4490-200: 00h – 2Fh AC4490-1000: 10h Set 0 = 00 – 0Fh (US/Canada) – AC4490-200 Set 1 = 10 – 2Fh (US/Canada): AC4490-200/1000</td>
</tr>
<tr>
<td>Server/Client Mode</td>
<td>41h</td>
<td>1</td>
<td>0 – 02h</td>
<td>02h</td>
<td>01h = Server 02h = Client</td>
</tr>
<tr>
<td>Baud Rate Low</td>
<td>42h</td>
<td>1</td>
<td>0 – FFh</td>
<td>FCh</td>
<td>Low Byte of the interface baud rate. Default baud rate is 57,600.</td>
</tr>
<tr>
<td>Baud Rate High</td>
<td>43h</td>
<td>1</td>
<td>00h</td>
<td>00h</td>
<td>Always 00h</td>
</tr>
</tbody>
</table>
Aerocomm Programming Information Continued:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>EEPROM Address (Bytes)</th>
<th>Length</th>
<th>Range</th>
<th>Default</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control 0</td>
<td>45h</td>
<td>1</td>
<td>00000100b (14h)</td>
<td>Settings are: BIT 0: One Beacon Mode 0: Beacon every hop 1: Beacon once per hop cycle</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>BIT 6: DES Enable 0: Disable Encryption 1: Enable Data Encryption</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>BIT 5: Sync to Channel 0: Don’t Sync to Channel 1: Sync to Channel</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>BIT 4: AeroComm Use Only</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>BIT 3: AeroComm Use Only</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>BIT 2: RF Mode 0: RF Stream Mode 1: RF Acknowledge Mode</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>BIT 1: RF Delivery 0: Addressed 1: Broadcast</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>BIT 0: AeroComm Use Only</td>
</tr>
<tr>
<td>Frequency Offset</td>
<td>40h</td>
<td>1</td>
<td>0 - FFh</td>
<td>00h</td>
<td>Protocol parameter used in conjunction with Channel Number.</td>
</tr>
<tr>
<td>Transmitter Retries</td>
<td>4Ch</td>
<td>1</td>
<td>0 - FFh</td>
<td>10h</td>
<td>Maximum number of times a packet is sent out in Addressed Acknowledge mode.</td>
</tr>
<tr>
<td>Broadcast Attempts</td>
<td>4Dh</td>
<td>1</td>
<td>0 - FFh</td>
<td>04h</td>
<td>Total number of times a packet is sent out in Broadcast Acknowledge mode.</td>
</tr>
<tr>
<td>API Control</td>
<td>56h</td>
<td>1</td>
<td>01000011b (43h)</td>
<td>Settings are: BIT 7: AeroComm Use Only 0: AeroComm Use Only 1: AeroComm Use Only</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>BIT 5: Unicast Only 0: Receive Addressed and Broadcast packets 1: Only receive Addressed packets</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>BIT 4: Auto Destination 0: Use Destination Address 1: Automatically set Destination to Server</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>BIT 3: Client Auto Channel 0: Use Programmed Channel 1: Find Server on Any Channel</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>BIT 2: RTS Enable 0: RTS Ignored 1: Transceiver obeys RTS</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>BIT 1: Duplex Mode 0: Half Duplex 1: Full Duplex</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>BIT 0: Auto Config 0: Use EEPROM values 1: Auto Configure Values</td>
</tr>
<tr>
<td>Interface Timeout</td>
<td>58h</td>
<td>1</td>
<td>2 - FFh</td>
<td>04h</td>
<td>Specifies a byte gap timeout, used in conjunction with RF Packet Size, to determine when a packet is complete (0.5ms per increment)</td>
</tr>
</tbody>
</table>
Aerocomm Programming Information Continued:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>EEPROM Address (Bytes)</th>
<th>Length (Bytes)</th>
<th>Range</th>
<th>Default</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sync Channel</td>
<td>5Ah</td>
<td>1</td>
<td>0 – 36h</td>
<td>01h</td>
<td>Used to synchronize the hopping of collocated systems to minimize interference.</td>
</tr>
<tr>
<td>RF Packet Size</td>
<td>58h</td>
<td>1</td>
<td>1 – FFh</td>
<td>46h</td>
<td>Used in conjunction with Interface Timeout, specifies the maximum size of an RF packet.</td>
</tr>
<tr>
<td>CTS On</td>
<td>5Ch</td>
<td>1</td>
<td>1 – FFh</td>
<td>D2h</td>
<td>CTS will be deasserted (High) when the transmit buffer contains at least this many characters.</td>
</tr>
<tr>
<td>CTS On Hysteresis</td>
<td>5Dh</td>
<td>1</td>
<td>0 – FFh</td>
<td>ACh</td>
<td>Once CTS has been deasserted, CTS will be reasserted (Low) when the transmit buffer contains this many or less characters.</td>
</tr>
<tr>
<td>Max Power</td>
<td>63h</td>
<td>1</td>
<td>0 – 60h</td>
<td>Set in production and can vary</td>
<td>Used to increase or decrease transmit power output.</td>
</tr>
<tr>
<td>Modern Mode</td>
<td>6Eh</td>
<td>1</td>
<td>E3h, FFh</td>
<td>FFh</td>
<td>E3h = Enable Modem Mode, FFh = Disable Modem Mode</td>
</tr>
<tr>
<td>Parity Mode</td>
<td>6Fh</td>
<td>1</td>
<td>E3h, FFh</td>
<td>FFh</td>
<td>E3h = Enable Parity Mode, FFh = Disable Parity Mode</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>Note</strong>: Enabling Parity Mode cuts throughput in half and the Interface Buffer size in half.</td>
</tr>
<tr>
<td>RS-485 DE</td>
<td>7Fh</td>
<td>1</td>
<td>E3h, FFh</td>
<td>FFh</td>
<td>E3h = G00 is active Low DE for control of external RS-485 hardware, FFh = Disable RS-485 DE mode</td>
</tr>
<tr>
<td>Destination ID</td>
<td>70h</td>
<td>6</td>
<td>FF, FF, FF, FF, FF, FF, FFh</td>
<td>Specifies destination for RF packets.</td>
<td></td>
</tr>
<tr>
<td>System ID</td>
<td>76h</td>
<td>1</td>
<td>0 – FFh</td>
<td>01h</td>
<td>Similar to a network password.</td>
</tr>
<tr>
<td>MAC ID</td>
<td>80h</td>
<td>6</td>
<td></td>
<td></td>
<td>Factory programmed unique IEEE MAC Address</td>
</tr>
<tr>
<td>DES Key</td>
<td>D0h</td>
<td>7</td>
<td>0 – FFh</td>
<td>0D, 1D, 2D, 3D, 4D, 5D, 6Dh</td>
<td>56 bit Data Encryption key</td>
</tr>
</tbody>
</table>
Appendix C – Aerocomm Timing Information

Stream Mode with Interface Timeout:

- **Local_RXD**
  - Packet Data
  - Interface Timeout
  - Wait for Hop

- **Remote_RXD**
  - RF Packets

- **Remote_TXD**
  - Received Data
  - Hop Period
  - Hop Time

Hop_Frame

Stream Mode with Fixed Packet Length:

- **Local_RXD**
  - Packet Data
  - Wait for Hop

- **Local_TXD**
  - RF Packets

- **Remote_RXD**
  - Received Data
  - Hop Period
  - Hop Time

Hop_Frame

Addressed Acknowledge Mode with Interface Timeout:

- **Local_RXD**
  - Packet Data
  - Wait for Hop

- **Local_TXD**
  - RF Packet

- **Remote_TXD**
  - RF Acknowledge

- **Remote_RXD**
  - Received Data
  - Interface Timeout
  - Hop Period
  - Hop Time

Hop_Frame
Addressed Acknowledge Mode with Fixed Packet Length:

Local_RXD  Packet Data  \Wait for Hop
Local_RF_TXD  RF Packet
Remote_RF_TXD  RF Acknowledge
Remote_TXD  Received Data

Hop_Frame

Broadcast Acknowledge Mode with Interface Timeout:

Local_RXD  Packet Data  \Wait for Hop
Local_RF_TXD  RF Packet
Remote_RF_TXD
Remote_TXD  Received Data  Interface Timeout  \Hop Period  \Hop Time

Hop_Frame

Broadcast Acknowledge Mode with Fixed Packet Length:

Local_RXD  Packet Data  \Wait for Hop
Local_RF_TXD  RF Packet
Remote_RF_TXD
Remote_TXD  Received Data  \Hop Period  \Hop Time

Hop_Frame
Appendix D – Aerocomm Throughput Python Scripts

Sending Computer Code
The following code describes the script running on the sending computer:

```python
#!/usr/bin/env python

import time
from datetime import datetime

import sys, os, serial, threading, getopt, md5

EXITCHARCTER = '\x04'  # ctrl+D

if os.name == 'nt':
    import msvcrt
    def getkey():
        while 1:
            if msvcrt.kbhit():
                z = msvcrt.getch()
            else:
                z = msvcrt.getch()
            if z == '\t' or z == '\x07':
                # functions keys
                msvcrt.getch()
            else:
                if z == '\n':
                    return '\n'
                return z

elif os.name == 'posix':
    import termios, sys, os
    fd = sys.stdin.fileno()
    old = termios.tcgetattr(fd)
    new = termios.tcgetattr(fd)
    new[6][termios.VMIN] = 1
    new[6][termios.VTIME] = 0
    termios.tcsetattr(fd, termios.TCSANOW, new)
    s = '
    # We'll save the characters typed and add them to the pool.
    def getkey():
        e = os.read(fd, 1)
        if e:
            sys.stdout.write(e); sys.stdout.flush()
        return e

    def elenaup_console():
        termios.tcsetattr(fd, termios.TCSADRAIN, old)
        sys.exit(0)
    # terminal modes have to be restored on exit...
else:
    raise "Sorry no implementation for your platform (%s) available." % sys.platform

CONVERT_CRLF = 2
CONVERT_CR = 1
CONVERT_LF = 0

def reader():

    ***loop forever and copy serial->console***
    print "Loopback Reader -- Online"
    output = open('received_checksum.txt', 'w')
    while 1:
        data = s.read()
        if repr_mode:
            sys.stdout.write(repr(data)[1:-1])
        else:
            output.write(data)
            output.flush()
        # sys.stdout.write(data)
        sys.stdout.flush()
```

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def writer():
    """Loop and copy console->serial until EOF character is found"""

    print "SRI Transmitter Test Program -- This Device Will Transmit"
    print "Please Select Option"
    print "1. User Defined Throughput"
    print "2. Automated Throughput Test -- Not Implemented"

    d = getkey()
    count = 0
    alpha = "abcdefgijklmnopqrstuvwxyz"

    if d == "1":
        rate_Kbps = 1.23
        print "Using %s KBps %r

            total_message = 189
            bytes_p_sec = rate_Kbps * 1024
            trans_p_sec = bytes_p_sec / total_message
            rate_value = 1 / trans_p_sec

            num_times = range(50)
            send_file = open("file_sent", "w")
            time_now = datetime.now()

            for x in num_times:
                msg = %s\n%s\n%s\n%s\n%s\n%s\n%s\n%s\n (%s,%s,%s,%s,%s,%s,%s,%s,%s)
                (alpha, alpha, alpha, alpha, alpha, alpha, alpha, alpha)
                s.write(msg)
                send_file.write(msg)
                print msg
                count += 1
                time.sleep(rate_value)
                s.write("1")
                send_file.write("1")

        if d == "2":
            print "Streaming 10 KBps"
            num_times = range(1000)
            time_now = datetime.now()

            for x in num_times:
                msg = %s\n%s\n (%s, datetime.now())
                s.write(msg)
                print msg
                count += 1
                time.sleep(.003)

            print datetime.now() - time_now

    # print 'Data File Loaded begin Transmission? (y/n)'
    # begin = getkey()
    # if begin == 'y':
    #     myfile = open('test.dat', 'r')
    #     ss = myfile.read()
    #     s.write(ss)  # send character
    # else:
    #     sys.exit(2)

    # print a short help message
    def usage():
        sys.stderr.write("""USAGE: %s [options]

Miniterm - A simple terminal program for the serial port.

options:
-p, --port=PORT: port, a number, default = 0 or a device name
-b, --baud=BAUD: baudrate, default 9600
-r, --rtscts: enable RTS/CTS flow control (default off)
-x, --xonxoff: enable software flow control (default off)
-e, --echo: enable local echo (default off)
-c, --cr: do not send CR+LF, send CR only
""")

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if __name__ == '__main__':
    #initialize with defaults
    port = 0
    baudrate = 38400
    echo = 0
    convert_outgoing = CONVERT_CRLF
    rtscts = 0
    xonxoff = 0
    repr_mode = 0

    #parse command line options
    try:
        opts, args = getopt.getopt(sys.argv[1:],
                                   "hp:sx:cr:ne:"
                                   ",help=, port=, baud=, rtscts, xonxoff, echo, cr, newline, debug"
                                   )
    except getopt.GetoptError:
        # print help information and exit:
        usage()
        sys.exit(2)

    for o, a in opts:
        if o in ("-h", "--help"):  # help text
            usage()
            sys.exit()
        elif o in ("-p", "--port"):  # specified port
            try:
                port = int(a)
            except ValueError:
                port = a
        elif o in ("-b", "--baud"):  # specified baudrate
            try:
                baudrate = int(a)
            except ValueError:
                raise ValueError, "Baudrate must be a integer number, not \%s", \% a
        elif o in ("-r", "--rtscts"): rtscts = 1
        elif o in ("-x", "--xonxoff"): xonxoff = 1
        elif o in ("-e", "--echo"): echo = 1
        elif o in ("-c", "--cr"): convert_outgoing = CONVERT_CR
        elif o in ("-n", "--newline"): convert_outgoing = CONVERT_LF
        elif o in ("-d", "--debug"): repr_mode = 1

    #open the port
    try:
        s = serial.Serial(port, baudrate, rtscts=rtscts, xonxoff=xonxoff)
    except:
        sys.stderr.write("Could not open port\n")
        sys.exit(1)
    sys.stdout.write("Serial GPS Data Transmission Simulator\n")

    #start serial->console thread
    r = threading.Thread(target=reader)
    r.setDaemon(1)
    r.start()

    #and enter console->serial loop
    writer()

print("Waiting for File")
print("Comparing Checksums")
time.sleep(1)
file_1 = open('file_sent').read()
file_2 = open('received_checksum').read()
checksum_obj = md5.new(file_1)
checksum = checksum_obj.hexdigest()
print (\"\n\")
if checksum == file_2:
    print(\"Checksum Computes Correctly\")
else:
    print(\"Data Loss Present!!!!\")
sys.stderr.write(\"\n-- exit --\"\n)

Receiving Computer Program

#!/usr/bin/env python

import sys, os, serial, threading, getopt, md5

EXITCHARCTER = '\x04' #ctrl+D

#first choose a platform dependant way to read single characters from the console
if os.name == 'nt':
    import msvirt
    def getkey():
        while 1:
            if echo:
                z = msvirt.getche()
            else:
                z = msvirt.getche()
            if z == '\03\' or z == '\xc03f':  #functions keys
                msvirt.getche()
            else:
                return z
    else:
        elif os.name == \"posix\":
            import termios, sys, os
            fd = sys.stdin.fileobj()
            old = termios.tcgetattr(fd)
            new = termios.tcgetattr(fd)
            new[6] = termios.VMIN = 1
            new[6] = termios.VTIME = 0
            termios.tcsetattr(fd, termios.TCSANOW, new)
            s = ""  # W'll save the characters typed and add them to the pool.
            def getkey():
                c = os.read(fd, 1)
                #~ c = sys.stdin.read(1)
                if echo: sys.stdout.write(c); sys.stdout.flush()
                return c
            def cleanup_console():
                termios.tcsetattr(fd, termios.TCSADFLUSH, old)
                sys.exitfunc = cleanup_console  #terminal modes have to be restored on exit...
else:
    raise "Sorry no implementation for your platform (\%s) available." % sys.platform

CONVERT_CRLF = 2
CONVERT_CR = 1
CONVERT_LF = 0

def menu():
    print "SRI Receiver Test Program -- This Device Will Receive"

    reader()
    #= threading.Thread(target=target)
    #r.setDaemon(1)
# def reader():
# "loop forever and copy serial->console"
# print "Ready to Receive Stream"
# r_file = open(R_received_file, "w")
while 1:
    data = s.read()
    if data == '2':
        r_file.flush()
        sys.exit(2)
    r_file.write(data)
    if data == '1':
        r_file.close()
        file_for_checksum = open(R_received_file, 'read')
        checksum = md5.new(file_for_checksum)
        s.write(checksum.hexdigest())
        file_len = len(file_for_checksum)
        print file_len
        s.write(file_len)
        file_length = len(file_for_checksum)
        print ('Received File Length: %d' % file_length)
        print ('Checksum Computed and Sent')
        print (*)
        reader()

sys.stdout.flush()

def writer():
# "loop and copy console->serial until EOF character is found"
while 1:
    c = getkey()
    if c == EXITCHARACTER:
        break
    # exit app
    elif c == '\n':
        # if convert_outgoing == CONVERT_CRLF:
        s.write('\n')
        # make it a CR+LF
        # if convert_outgoing == CONVERT_CR:
        s.write('\r')
        # make it a CR
        # elif convert_outgoing == CONVERT_LF:
        s.write('\n')
        # make it a LF
    else:
        s.write(c)
        # send character

# print a short help message
# def usage():
sysexec.write('MINITERM: A simple terminal program for the serial port.

options:
-p, --port=PORT: port, a number, default = 0 or a device name
-b, --baud=BAUD: baudrate, default 9600
-r, --rtscts: enable RTS/CTS flow control (default off)
-x, --xonxoff: enable hardware flow control (default off)
-c, --echo: enable local echo (default off)
-e, --kr: do not send CR+LF, send CR only
-n, --newline: do not send CR+LF, send LF only
-D, --debug: debug received data (escape nonprintable chars)

"%s" (sys.argv[1])

if __name__ == '__main__':
    # initialize with defaults
    port = 0
    baudrate = 9600
    echo = 0
    convert_outgoing = CONVERT_CRLF
    rtscts = 0
    xonxoff = 0

120
repr_mode = 0

# parse command line options
try:
    opts, args = getopt.getopt(sys.argv[1:],
        "hp:x:cr:n", ["help", "port=", "baud=", "rtscts", "xonxoff", "echo",
        "cr", "newline", "debug"]
    )
except getopt.GetoptError:
    # print help information and exit:
    usage()
    sys.exit(2)

for o, a in opts:
    if o in ("-h", "--help"):  # help text
        usage()
        sys.exit()
    elif o in ("-p", "--port"):  # specified port
        try:
            port = int(a)
        except ValueError:
            port = a
    elif o in ("-b", "--baud"):  # specified baudrate
        try:
            baudrate = int(a)
        except ValueError:
            raise ValueError, "Baudrate must be an integer number, not \%s\%s a %d" % a
    elif o in ("-r", "--rtscts"):  # rtscts = 1
        rtscts = 1
    elif o in ("-x", "--xonxoff"):  # xonxoff = 1
        xonxoff = 1
    elif o in ("-e", "--echo"):  # echo = 1
        echo = 1
    elif o in ("-c", "--cr"):  # convert_outgoing = CONVERT_CR
        convert_outgoing = CONVERT_CR
    elif o in ("-n", "--newline"):  # convert_outgoing = CONVERT_LF
        convert_outgoing = CONVERT_LF
    elif o in ("-D", "--debug"):  # repr_mode = 1
        repr_mode = 1

# open the port
try:
    s = serial.Serial(port, baudrate, rtscts=rtscts, xonxoff=xonxoff)
except:
    sys.stderr.write("Could not open port\n")
    sys.exit(1)
sys.stderr.write("--- Miniterm --- type Ctrl-D to quit\n")
# start serial->console thread
menu()
# and enter console->serial loop
writer()

sys.stderr.write("\n--- exit ---\n")

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# Appendix E – Aerocomm 900 Mhz AC4490 – 1000

## GENERAL

<table>
<thead>
<tr>
<th>Description</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 Pin Interface Connector</td>
<td>Samtec TMV-110-01-L-D-SM, mates with Samtec SMM-110-02-S-D</td>
</tr>
<tr>
<td>RF Connector</td>
<td>Telegärtner J01341C0081, mates with any manufacturer’s MMCX style plug</td>
</tr>
<tr>
<td>Antenna</td>
<td>AC4490-200: MMCX Connector or integral antenna</td>
</tr>
<tr>
<td></td>
<td>AC4490-1000: MMCX Connector</td>
</tr>
<tr>
<td>Serial Interface Data Rate</td>
<td>Baud rates from 1200 bps to 115,200 bps</td>
</tr>
<tr>
<td>Power Consumption (typical)</td>
<td><strong>Duty Cycle (TX–Transmit; RX–Receive)</strong></td>
</tr>
<tr>
<td></td>
<td>10% TX 50% TX 100% RX Pwr-Down Deep Sleep</td>
</tr>
<tr>
<td></td>
<td>AC4490-200: 36mA 68mA 106mA 30mA 19mA 5mA</td>
</tr>
<tr>
<td></td>
<td>AC4490-1000: 130mA 650mA 1300mA 30mA 19mA 5mA</td>
</tr>
<tr>
<td>Channels</td>
<td>3 Channels: Sets comprising 56 total channels</td>
</tr>
<tr>
<td>Security</td>
<td>One byte System ID, 56 bit DES encryption key</td>
</tr>
<tr>
<td>Interface Buffer Size</td>
<td>Input/Output: 256 bytes each</td>
</tr>
</tbody>
</table>

## TRANSceiver

<table>
<thead>
<tr>
<th>Description</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency Band</td>
<td>902 – 928 MHz</td>
</tr>
<tr>
<td>RF Data Rate</td>
<td>76.8kbps fixed</td>
</tr>
<tr>
<td>RF Technology</td>
<td>Frequency Hopping Spread Spectrum</td>
</tr>
<tr>
<td>Output Power</td>
<td>Conducted (no antenna)</td>
</tr>
<tr>
<td></td>
<td>EIRP (3dBi gain antenna)</td>
</tr>
<tr>
<td>AC4490-200</td>
<td>100mW typical</td>
</tr>
<tr>
<td></td>
<td>200mW typical</td>
</tr>
<tr>
<td>AC4490-1000</td>
<td>743mW typical</td>
</tr>
<tr>
<td></td>
<td>1486mW typical</td>
</tr>
<tr>
<td>Supply Voltage</td>
<td>AC4490-200: 3.3 – 5.5V ±50mV ripple</td>
</tr>
<tr>
<td></td>
<td>AC4490-1000: Pin 10: 3.3 – 5.5V ±50mV ripple</td>
</tr>
<tr>
<td></td>
<td>Pin 11: 3.3 ±3% ±100mV ripple</td>
</tr>
<tr>
<td>Sensitivity</td>
<td>-100dBm typical @ 76.8kbps RF Data Rate</td>
</tr>
<tr>
<td>Range, Line of Site (based on 3dBi gain antenna)</td>
<td>AC4400-200: 4 miles</td>
</tr>
<tr>
<td></td>
<td>AC4400-1000: 20 miles</td>
</tr>
</tbody>
</table>

## ENVIRONMENTAL

<table>
<thead>
<tr>
<th>Description</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature (Operating)</td>
<td>-40°C to 80°C</td>
</tr>
<tr>
<td>Temperature (Storage)</td>
<td>-50°C to +85°C</td>
</tr>
<tr>
<td>Humidity (non-condensing)</td>
<td>10% to 90%</td>
</tr>
</tbody>
</table>

## PHYSICAL

<table>
<thead>
<tr>
<th>Description</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dimensions</td>
<td>Transceiver with MMCX Connector: 1.05” x 1.9” x 0.20”</td>
</tr>
<tr>
<td></td>
<td>Transceiver with Integral Antenna: 1.05” x 2.05” x 0.20”</td>
</tr>
<tr>
<td>Weight</td>
<td>Less than 0.75 ounce</td>
</tr>
</tbody>
</table>
Appendix F – Aerocomm 2.4 Ghz AC5124 – 200

**GENERAL**

<table>
<thead>
<tr>
<th>Bus Interface</th>
<th>Serial (TTL Level Asynchronous) through 40 pin mini connector, AMP P/N 177886-1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Serial Interface Data Rate</td>
<td>Programmable to 882 Kbps, PC rates to 115.2 Kbps</td>
</tr>
<tr>
<td>Compliance</td>
<td>AC5124-10: US (FCC 15.247); Canada (IC); Europe (EN)</td>
</tr>
<tr>
<td></td>
<td>AC5124-200: US (FCC 15.247); Canada (IC)</td>
</tr>
<tr>
<td>Power Consumption</td>
<td>All Serial Interface Modes</td>
</tr>
<tr>
<td>Duty Cycle (TX=Transmit, RX=Receive)</td>
<td>123K</td>
</tr>
<tr>
<td></td>
<td>AC5124-10: 111mA 122mA 135mA 100mA</td>
</tr>
<tr>
<td></td>
<td>AC5124-200: 195mA 280mA 472mA 110mA</td>
</tr>
<tr>
<td></td>
<td>Interface ON/RF OFF (API Mode Only)</td>
</tr>
<tr>
<td></td>
<td>Sleep Walk (Clients in all Modes Only)</td>
</tr>
<tr>
<td></td>
<td>Deep Sleep (Servers in API/Mode Only)</td>
</tr>
<tr>
<td></td>
<td>45mA typical</td>
</tr>
<tr>
<td></td>
<td>25mA typical</td>
</tr>
<tr>
<td></td>
<td>20mA typical</td>
</tr>
<tr>
<td>Channels</td>
<td>Supports 77 non-interfering channels</td>
</tr>
<tr>
<td>Security</td>
<td>User assigned System ID. Unique IEEE addresses on each transceiver</td>
</tr>
</tbody>
</table>

**TRANSCIEVER**

| Frequency Band       | 2.402 – 2.479 GHz                                                              |
| Transceiver Type     | Frequency Hopping Spread Spectrum                                              |
| Output Power         | AC5124-10: 10mW                                                               |
|                     | AC5124-200: 20mW                                                              |
| Input Voltage        | 5V nominal ±2% ±50mV ripple                                                    |
| Sensitivity          | 30dBm                                                                          |
| RF Data Rate         | 882 Kbps                                                                       |
| Range                | AC5124-10: Can be extended with directional antenna                           |
|                     | Indoors up to 300 ft. Outdoors up to 3,000 ft.                                 |
|                     | AC5124-200: Indoors up to 500 ft. Outdoors up to 10,000 ft.                    |
| Synchronization Time | Average = 750ms; Maximum = 1.5s                                               |

**ENVIRONMENTAL**

| Temperature (Operating) | -40°C to +85°C                                                                |
| Temperature (Storage)  | -5°C to +85°C                                                                  |
| Humidity (non-condensing) | 10% to 90%                                                                 |

**PHYSICAL**

| Dimensions            | 1.65" x 2.65" x 0.20"                                                        |
| Antenna Connector     | Standard MMCX jack                                                            |
| Weight                | Less than 0.75 ounces                                                          |

**SOFTWARE**

| User Configurable Options | Host Interface Data Rate Up to 882 Kbps                                      |
|                         | Maximum bi-directional throughput Up to 176kbps                              |
|                         | Variable Packet Length Up to 2 KBytes                                         |
|                         | Serial Interface Modes (b) Transparent and (t) API                           |
|                         | Diagnostic Error Counters AP Mode                                             |
|                         | User Programmability Attempts Up to 256                                      |
Appendix G – MSP430 Code

ADC Code

//**************************************************************************************
******
// MSP-FET430P140 Demo - ADC12, Repeated Single Channel Conversions
//
// This example shows how to perform repeated conversions on a single channel
// using "repeat-single-channel" mode. AVcc is used for the reference and
// repeated conversions are performed on Channel A0. Each conversion result
// is moved to an 8-element array called results[]. Test by applying a
// voltage to channel A0, then running. To view the conversion results, open a
// watch window and view 'results.'
//
//
//   MSP430F149
//     ---------------
//     |               |
//     |      A0 (P6.0)<---- Vin
//     |               |
//
//
// M.Mitchell
// Texas Instruments, Inc
// January, 2002
// Built with IAR Embedded Workbench Version: 1.25A
// December 2003
// Updated for IAR Embedded Workbench Version: 2.21B
//
// Modified by Chris Hamman for SRI International
// February 2005
//**************************************************************************************
******

#include "msp430x16x.h" // Standard Equations

#define Num_of_Results 12

static unsigned int Nadc[Num_of_Results]; //Nadc is digital output of converter
static double Vin[Num_of_Results];
static double Vdivider[Num_of_Results];
static int HoldFlag; //Flag Indicates if Voltage has been Shut Down
// -->Need to Add Capacitors to Circuit to Filter Noise!!!!!!!(Check out Vref Later)
//Apply Voltage Divided to P6.0 and 3.3 Reference Voltage to AVcc Pin
//ADC will convert values between 0 and 3.3 Volts See pg 17-17 for wiring guide
//see page 17-4 for Conversion Calculation
static const double Vrplus = 3.286; // Positive Reference Voltage
static const double Vrminus = 0.0; // 0 Volt Negative Reference
static const double QuantLevel = 4095; //Quantization Level- 2^12 for 12 bit converter
static const double Resistor1 = 11*1000; //Top Resistor Value Connected to Vin on Voltage Divider Circuit (Ohms)
static const double Resistor2 = (3)*1000; //Bottom Resistor Value Connected to Vin on Voltage Divider Circuit (Ohms)
static const double Thresh1 = 11.70;
static const double Thresh2 = 12.10;

void main(void)
{
    WDTCTL = WDTPW+WDTHOLD; // Stop watchdog timer
    P6SEL |= 0x02; // Enable A/D channel A1
    ADC12CTL0 = ADC12ON+SHT0_8+MSC ; // Turn on ADC12, set sampling time
    ADC12CTL1 = SHP+CONSEQ_2; // Use sampling timer, set mode
    ADC12IE = 0x01; // Enable ADC12IFG.0
    ADC12CTL0 |= ENC; // Enable conversions
    _EINT(); // Enable interrupts
    ADC12CTL0 |= ADC12SC; // Start conversion
    _BIS_SR(LPM0_bits); // Enter LPM0

    HoldFlag = 1; //Set Flag Before Checking Processor
}

#pragma vector=ADC_VECTOR
__interrupt void ADC12ISR (void)
{
    static unsigned int index = 0;

    Nadc[index] = ADC12MEM0; // Results are Stored as Hex Equivalent to a base conversion
    //Perform Calculation to See What Value Should be on Vout of Voltage Divider
    Vdivider[index] = (((Nadc[index]/QuantLevel) * (Vrplus - Vrminus)) + Vrminus); //Vin is applied voltage
    //Perform Calculation to See What Vin Value of Voltage Divider is on Load
    index = (index+1)%Num_of_Results; // Increment results index, modulo

    Vin[index] = Vdivider[index]*((Resistor1+Resistor2)/(Resistor2));
if(Vdivider[index] <= 2.50714) //Send Pulse for 'delay' seconds to Port 1 to turn on relay 
    {
        P1DIR |= 0x01;                       // Set P1.0 to output direction
        P1OUT = 0x00;   //Voltage Has Gone Below Threshold, Turn off Base Voltage on Mosfet
        HoldFlag = 0;   //Processor Needs to Wait Until 12.10 Voltage Threshold Is reached
    }

//Voltage Has been below 11.70, Continue to Wait Until Voltage reaches 12.1

if(Vdivider[index]>=2.5928) //Voltage Is now above Threshold, Reconnect Power
    {
        HoldFlag=1;  //Set Hold Flag To Continue to Power Threshold Voltage
        P1DIR |= 0x01;                       // Set P1.0 to output direction
        P1OUT = 0x01;                       //Output Voltage of Base Pin On
    }

}
#include <msp430x16x.h>

#include "msp430x16x.h"

unsigned int received0, received1;

void main(void)
{
    WDTCTL = WDTPW + WDTHOLD;  // Stop Watch Dog Timer
    P3SEL |= 0xF0;  // P3.4,5 = USART0 TXD/RXD & P3.6,7 = USART1 TXD/RXD
    ME1 |= UTXE0 + URXE0;  // Enable USART0 TXD/RXD
    ME2 |= UTXE1 + URXE1;  // Enable USART1 TXD/RXD
    UCTL0 |= CHAR;  // 8-bit character (USART0)
    UCTL1 |= CHAR;  // 8-bit character (USART1)
    UTCTL0 |= SSEL0;  // UCLK = ACLK (USART0)
    UTCTL1 |= SSEL0;  // UCLK = ACLK (USART1)
    UBR00 = 0x03;  // 32k/9600 - 3.41 (USART0)
    UBR10 = 0x00;  // Modulation
    UBR01 = 0x03;  // 32k/9600 - 3.41 (USART1)
    UBR11 = 0x00;  // Modulation
    UMCCTL0 = 0x55;  // Modulation
    UMCCTL1 = 0x55;  // Modulation
    UCTL0 &= ~SWRST;  // Initialize USART0 state machine (USART0)
    UCTL1 &= ~SWRST;  // Initialize USART state machine (USART1)
IE1 |= URXIE0 + UTXIE0; // Enable USART0 RX/TX interrupt
IE2 |= URXIE1 + UTXIE1; // Enable USART1 RX/TX interrupt

_BIS_SR(LPM3_bits + GIE); // Enter LPM3 w/ interrupt
}

#pragma vector=UART0RX_VECTOR // Compiler specific command
__interrupt void usart0_rx (void) // Interrupt program
{
  if((RXERR & U0RCTL) == 0x01) // Test to ensure that received data is valid
    {                           // If it is not valid...
      received0 = RXBUF0;       // RXBUF0 read to set buffer clear flag
      received0 = 0x00;         // Invalid data received, move null character into
      received0
    }
  else                        // Otherwise data is valid
    received0 = RXBUF0;       // RXBUF0 is read into received0
  IE1 &= ~URXIE0;            // Disable the RX interrupt until this character has been
  transmmitted
  IE2 |= UTXIE1;             // Enable the USART1 Transmit interrupt

}

#pragma vector=UART1RX_VECTOR
__interrupt void usart1_rx (void)
{
  if((RXERR & U1RCTL) == 0x01) // Test to ensure that received data is valid
    {                           // If it is not valid...
      received1 = RXBUF1;       // RXBUF1 read to set buffer clear flag
      received1 = 0x00;         // Invalid data received, move null character into
      received0
    }
  else                        // Otherwise data is valid
    received1 = RXBUF1;       // RXBUF1 is read into received1
  IE2 &= ~URXIE1;            // Disable the Receive interrupt until this character has
  been transmmitted
  IE1 |= UTXIE0;             // Enable the USART0 Transmit interrupt

}

#pragma vector=UART0TX_VECTOR
__interrupt void usart0_Tx (void)
{
  TXBUF0 = received1;        // Transmit character received from USART1
  IE2 |= URXIE1;             // Re-enable the Receive interrupt on USART1
  IE1 &= ~UTXIE0;            // Disable the this Transmit interrupt
```c
#pragma vector=UART1TX_VECTOR
__interrupt void usart1_Tx (void)
{
    TXBUF1 = received0;  // Transmit character received from USART0
    IE1 |= URXIE0;      // Re-enable the Receive interrupt on USART0
    IE2 &= ~UTXIE1;     // Disable the this Transmit interrupt
}

I2CEEPROM
/**************************************************************************/
/* The following code demonstrates how to use the I2C bus to read         */
/* from memory and write to it. This code is designed for the 24AA512      */
/* EEPROM. However, the routines in the accompanying file, I2Croutines,    */
/* can easily be modified to interface to any memory device.              */
/*                                                                      */
/* developed with IAR Embedded Workbench V2.21                          */
/*                                                                      */
/* Texas Instruments Deutschland GmbH                                    */
/* Christian Hernitscheck                                                 */
/* July 2004                                                             */
/* Modified by: Sean Candlish                                            */
/* SRI International                                                     */
/* February 2005                                                         */
/**************************************************************************/

#include "msp430x16x.h"

/****- external functions of file "I2Croutines.c"-----------------------*/
extern void InitI2C(void);
extern void EEPROM_ByteWrite(unsigned int Address,unsigned char Data);
extern unsigned char EEPROM_RandomRead(unsigned int Address);
extern unsigned char EEPROM_CurrentAddressRead(void);
extern void EEPROM_AckPolling(void);

/****- external functions of file "I2Croutines.c"-----------------------*/
void main(void)
{
    volatile unsigned char Data[18] = "Now for the output";
    volatile unsigned char var1[18] = "This is some input";
    unsigned int saver = 0x0000;

```
unsigned int i;

WDTCTL = WDTPW+WDTHOLD;    // disable Watchdog
P1DIR = 0xFF;               // termination of unused pins
P2DIR = 0xFF;
P3DIR = 0xF5;
P4DIR = 0xFF;
P5DIR = 0xFF;
P6DIR = 0xFF;

InitI2C();                      // Initialize I2C module
__EINT();

for(i = 0; i < 18; i++)        // Write each byte to memory in turn
{
    EEPROM_ByteWrite(saver,Data[i]);    // Write the current byte to the EEPROM
    EEPROM_AckPolling();                // Wait for EEPROM write cycle completion
    saver++;
}

var1[0] = EEPROM_RandomRead(0x0000);   // Read the data at the first memory
                                       // location of the EEPROM &
                                       // Store it in var1[0]

for(i = 1; i < 18; i++)                   // Read each subsequent memory location &
    var1[i] = EEPROM_CurrentAddressRead();  // store it in the next element of var1
    // var1 initially held "This is some input", it now contains
    // the data stored on the EEPROM "Now for the output"

while (1);

I2C_Routines

#include "msp430x16x.h"
#define SlaveAddress 0x50;

int PtrTransmit;
unsigned char I2CBuffer[3];

/*-----------------------------------------------*/
void InitI2C(void)
// Description:
//   Initialization of the I2C Module
{}
P3SEL = 0x0A; // select module function for the used I2C pins
P3DIR &= ~0x0A;

// Recommended initialisation steps of the I2C module:
U0CTL &= ~I2CEN; // (1) clear I2CEN bit
   // (2) Re-configure the I2C module with I2CEN=0
U0CTL = I2C+SYNC+MST; // I2C Master Mode, 7-bit addressing,
   // no DMA, no feedback, I2CEN=0
I2CTCTL = I2CTRX+I2CSSEL_2; // byte mode, repeat mode, clock source = SMCLK,
   // transmit mode
I2CSA = SlaveAddress; // define Slave Address
   // In this case the Slave Address defines the
   // control byte that is sent to the EEPROM.
I2COA = 0x01A5; // own address.
I2CPSC = 0x00; // I2C clock = clock source/1
I2CSCLH = 0x03; // SCL high period = 5*I2C clock
I2CSCLL = 0x03; // SCL low period = 5*I2C clock
U0CTL |= I2CEN; // (3) set I2CEN via software
}

/*-----------------------------------------------*/
void I2CWriteInit(void)
// Description:
//   Initialization of the I2C Module for Write operation.
{}
U0CTL |= MST; // define Master Mode
I2CTCTL |= I2CTRX; // I2CTRX=1 => Transmit Mode (R/W bit = 0)
I2CIFG &= ~TXRDYIFG;
I2CIE = TXRDYIE; // enable Transmit ready interrupt
}

/*-----------------------------------------------*/
void I2CReadInit(void)
// Description:
//   Initialization of the I2C Module for Read operation.
void EEPROM_ByteWrite(unsigned int Address, unsigned char Data)
// Description:
//   Byte Write Operation. The communication via the I2C bus with an EEPROM
//   (2465) is realized. A data byte is written into a user defined address.
{
    unsigned char adr_hi;
    unsigned char adr_lo;

    while (I2CDCTL&I2CBUSY); // wait until I2C module has finished all operations

    adr_hi = Address >> 8;       // calculate high byte
    adr_lo = Address & 0xFF;      // and low byte of address

    I2CBuffer[2] = adr_hi;       // store single bytes that have to be sent
    I2CBuffer[0] = Data;
    PtrTransmit = 2;             // set I2CBuffer Pointer

    I2CWriteInit();
    I2CNDAT = 3;                  // 1 control byte + 3 bytes should be transmitted
    I2CTCTL |= I2CSTT+I2CSTP;     // start and stop condition generation
    //      => I2C communication is started

    while ((~I2CIFG)&ARDYIFG);  // wait untill transmission is finished
    return I2CBuffer[0];
}
/**---------------------------------------------------------------------------*/

unsigned char EEPROM_RandomRead(unsigned int Address)
// Description:
// Random Read Operation. Data is read from the EEPROM. The EEPROM
// address is defined with the parameter Address.
{
    unsigned char adr_hi;
    unsigned char adr_lo;

    while (I2CDCTL&I2CBUSY);  // wait until I2C module has finished all operations

    adr_hi = Address >> 8;       // calculate high byte
    adr_lo = Address & 0xFF;     // and low byte of address

    I2CBuffer[1] = adr_hi;       // store single bytes that have to be sent
    I2CBuffer[0] = adr_lo;       // in the I2CBuffer.
    PtrTransmit = 1;             // set I2CBuffer Pointer

    I2CWriteInit();
    I2CNDAT = 2;                 // 1 control byte + 2 bytes should be transmitted
    I2CIFG &= ~ARDYIFG;          // clear Access ready interrupt flag
    I2CTCTL |= I2CSTT;           // start condition generation
    // => I2C communication is started
    while ((~I2CIFG)&ARDYIFG);   // wait untill transmission is finished
    I2CReadInit();
    I2CNDAT = 1;                 // 1 byte should be received

    I2CIFG &= ~ARDYIFG;          // clear Access ready interrupt flag
    I2CTCTL |= I2CSTT+I2CSTP;    // start receiving and finally generate
    // re-start and stop condition
    while ((~I2CIFG)&ARDYIFG);   // wait untill transmission is finished
    return I2CBuffer[0];
}

/*---------------------------------------------------------------------------*/

void EEPROM_AckPolling(void)
// Description:
// Acknowledge Polling. The EEPROM will not acknowledge if a write cycle is
// in progress. It can be used to determine when a write cycle is completed.
{
    unsigned int count;
    while (I2CDCTL&I2CBUSY); // wait until I2C module has finished all operations
    P5OUT ^= 0x10;       // clear I2CEN bit => necessary to re-configure I2C module
    U0CTL &= ~I2CEN;    // transmission is software controlled
    count=0;
    while (I2CTCTL&I2CSTP);  // wait until I2C module has finished all operations
}
U0CTL |= I2CEN;       // enable I2C module
I2CIFG = NACKIFG;      // set NACKIFG
while (NACKIFG & I2CIFG)
{
    I2CIFG=0x00;        // clear I2C interrupt flags
    U0CTL |= MST;       // define Master Mode
    I2CTCTL |= I2CTRX;   // I2CTRX=1 => Transmit Mode (R/W bit = 0)
    I2CTCTL |= I2CSTT;  // start condition is generated
    while (I2CTCTL&I2CSTT); // wait till I2CSTT bit was cleared
    I2CTCTL |= I2CSTP;  // stop condition is generated after slave address was sent
    // => I2C communication is started
    while (I2CDCTL&I2CBUSY); // wait till stop bit is reset
    count=count+1;
P5OUT ^= 0x10;
}
U0CTL &= ~I2CEN;       // clear I2CEN bit => necessary to re-configure I2C module
I2CTCTL &= ~I2CRM;     // transmission is by the I2C module
U0CTL |= I2CEN;       // enable I2C module

return;
}

/*---------------------------------------------------------------------------*/
/*  Interrupt Service Routines                                              */
/*     Note that the Compiler version is checked in the following code and   */
/*     depending of the Compiler Version the correct Interrupt Service       */
/*     Routine definition is used.                                           */
#if __VER__ < 200
    interrupt [USART0TX_VECTOR] void ISR_I2C(void)
#else
    #pragma vector=USART0TX_VECTOR
    __interrupt void ISR_I2C(void)
#endif

// Description:
//  Byte Write Operation. The communication via the I2C bus with an EEPROM
{
    switch (I2CIV)
    {
    case I2CIV_AL:    /* I2C interrupt vector: Arbitration lost (ALIFG) */
                        break;
    case I2CIV_NACK:  /* I2C interrupt vector: No acknowledge (NACKIFG) */
                        break;
    case I2CIV_OA:    /* I2C interrupt vector: Own address (OAIFG) */
                        break;
    case I2CIV_ARDY:  /* I2C interrupt vector: Access ready (ARDYIFG) */
                        break;
    }
case I2CIV_RXRDY:  /* I2C interrupt vector: Receive ready (RXRDYIFG) */
    I2CBuffer[0]=I2CDRB;  // store received data in buffer
    break;

case I2CIV_TXRDY:  /* I2C interrupt vector: Transmit ready (TXRDYIFG) */
    I2CDRB = I2CBuffer[PtrTransmit];
    PtrTransmit = PtrTransmit-1;
    if (PtrTransmit<0)
    {
        I2CIE &= ~TXRDYIE;  // disable interrupts
    }
    break;

case I2CIV_GC:      /* I2C interrupt vector: General call (GCIFG) */
    break;

case I2CIV_STT:     /* I2C interrupt vector: Start condition (STTIFG) */
    break;
}
}

UART 0

/*****************************************************************************/
******
//  MSP-FET430P169 - UART 9600 Full-Duplex Transceiver, 32K ACLK
//
//  Description: UART0 loops back whatever whatever it receives on its RX pin
//  Normal mode is low power mode (LPM3), with activity only during RX and
//  TX ISR's. The TX ISR indicates the UART is ready to send another character.
//  The RX ISR indicates the UART has received a character. At 9600 baud, a full
//  character is tranceived ~1ms.
//  The data received on UART0 is transmitted from UART1, and the data received on
//  UART1
//  is transmitted from UART0 to allow full-duplex communication between two devices
//  ACLK = UCLK1 = LFXT1 = 32768
//  Baud rate divider with 32768hz XTAL @9600 = 32768Hz/9600 = 3.41 (000Dh 4Ah )
// //*An external watch crystal is required on XIN XOUT for ACLK*//
//
//
//  MSP430F169
//  -----------------
//    |              XIN|-
//    |                 | 32KHz
//    |             XOUT|-
//    |                 | /\
//    |              RST|--
//    |
//    |
//    |
//    |
//    |
//    |
```c
#include <msp430x16x.h>

unsigned int recived;

void main(void)
{
    WDTCTL = WDTPW + WDTHOLD; // Stop WDT
    P3SEL |= 0x30; // P3.4,5 = USART0 TXD/RXD
    ME1 |= UTXE0 + URXE0; // Enable USART0 TXD/RXD
   UCTL0 |= CHAR; // 8-bit character
    UTCTL0 |= SSEL0; // UCLK = ACLK
    UBR00 = 0x03; // 32K/9600 - 3.41
    UBR10 = 0x00; //
    UMCTL0 = 0x55; // Modulation
    UCTL0 &= ~SWRST; // Initialize USART state machine
    IE1 |= URXIE0 + UTXIE0; // Enable USART0 RX/TX interrupt

    _BIS_SR(LPM3_bits + GIE); // Enter LPM3 w/ interrupt
}

#pragma vector=UART0RX_VECTOR
__interrupt void usart0_rx (void)
{
    if((RXERR & U0RCTL) == 0x01)
    {
        recived = RXBUF0;
        recived = 0x00;
    }
    else
        recived = RXBUF0; // RXBUF0 to TXBUF0
```
IE1 &= ~URXIE0;
IE1 |= UTXIE0;

#pragma vector=UART0TX_VECTOR
__interrupt void usart0_Tx (void)
{
    TXBUF0 = received; // Transmit character
    IE1 |= URXIE0;
    IE1 &= ~UTXIE0;

}
#include <msp430x16x.h>
unsigned int received = 0x57;

void main(void)
{
  WDTCTL = WDTPW + WDTHOLD; // Stop WDT
  P3SEL |= 0xC0; // P3.6,7 = USART1 TXD/RXD
  ME2 |= UTXE1 + URXE1; // Enable USART1 TXD/RXD
  UCTL1 |= CHAR; // 8-bit character
  UCTL1 |= SSEL0; // UCLK = ACLK
  UBR01 = 0x03; // 32k/9600 - 3.41
  UBR11 = 0x00; //
  UMCTL1 = 0x55; // Modulation
  UCTL1 &= ~SWRST; // Initialize USART state machine
  IE2 |= URXIE1 + UTXIE1; // Enable USART1 RX/TX interrupt

  _BIS_SR(LPM3_bits + GIE); // Enter LPM3 w/ interrupt
}

#pragma vector=UART1RX_VECTOR
__interrupt void usart1_rx (void)
{
  if((RXERR & U1RCTL) == 0x01)
  {
    received = RXBUF1;
    received = 0x00;
  }
  else
    received = RXBUF1; // RXBUF1 to TXBUF1
  IE2 &= ~URXIE1;
  IE2 |= UTXIE1;
}
#pragma vector=UART1TX_VECTOR
__interrupt void usart1_Tx (void)
{
    TXBUF1 = received;              // Transmit character
    IE2 |= URXIE1;
    IE2 &= ~UTXIE1;
}

Notes on Model -
The potential Battery Status in Watts is also filled in. To generate this value an assumed 130 Ah battery was used which would draw approximately 120 Watts / Day. Power available from sunlight was calculated using the BP 3125 Solar Panel, and the watts generated were added to the Battery throughout the course of 1 year. Insolation values are given as W/m² and were generated from NASA²⁴ calculated at the top of the Atmosphere at the Sondrestrom geographic coordinates (77° N, 67° W). The angle was calculated highest point off the horizon throughout the day. Cloud cover was generated from the Sondrestrom Axis 2100 Network Camera pointed at the sky and took a picture every hour every day throughout the 2004 year.

<table>
<thead>
<tr>
<th>Date</th>
<th>Sunrise</th>
<th>Sunset</th>
<th>Sunlight Hours</th>
<th>(W/m²) Angle</th>
<th>% Cloud Cover</th>
<th>Solar Panel Watts hours / Day</th>
<th>Battery Status Watts Temperature</th>
<th>% Capacitance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>11:22</td>
<td>13:33</td>
<td>2.18333</td>
<td>0</td>
<td>0</td>
<td>1494</td>
<td>-21</td>
<td>55</td>
</tr>
<tr>
<td>2</td>
<td>11:19</td>
<td>13:37</td>
<td>2.3</td>
<td>0.001</td>
<td>100</td>
<td>0</td>
<td>1374</td>
<td>-22</td>
</tr>
<tr>
<td>3</td>
<td>11:16</td>
<td>13:40</td>
<td>2.4</td>
<td>0.002</td>
<td>90</td>
<td>0.0042</td>
<td>1254.0042</td>
<td>-19</td>
</tr>
<tr>
<td>4</td>
<td>11:13</td>
<td>13:44</td>
<td>2.51667</td>
<td>0.004</td>
<td>85</td>
<td>0.01387</td>
<td>1134.01807</td>
<td>-9</td>
</tr>
<tr>
<td>5</td>
<td>11:10</td>
<td>13:48</td>
<td>2.63333</td>
<td>0.005</td>
<td>90</td>
<td>0.01659</td>
<td>1014.03466</td>
<td>4</td>
</tr>
<tr>
<td>6</td>
<td>11:07</td>
<td>13:52</td>
<td>2.75</td>
<td>0.007</td>
<td>90</td>
<td>0.02599</td>
<td>894.060651</td>
<td>4</td>
</tr>
<tr>
<td>7</td>
<td>11:04</td>
<td>13:57</td>
<td>2.88333</td>
<td>0.008</td>
<td>10</td>
<td>0.34514</td>
<td>774.405786</td>
<td>-1</td>
</tr>
<tr>
<td>8</td>
<td>11:00</td>
<td>14:01</td>
<td>3.01667</td>
<td>0.01</td>
<td>0</td>
<td>0.53848</td>
<td>654.944261</td>
<td>-4</td>
</tr>
<tr>
<td>9</td>
<td>10:57</td>
<td>14:05</td>
<td>3.13333</td>
<td>0.012</td>
<td>50</td>
<td>0.35916</td>
<td>468</td>
<td>-12</td>
</tr>
<tr>
<td>10</td>
<td>10:53</td>
<td>14:09</td>
<td>3.26667</td>
<td>0.014</td>
<td>100</td>
<td>0</td>
<td>468</td>
<td>-15</td>
</tr>
<tr>
<td>11</td>
<td>10:50</td>
<td>14:14</td>
<td>3.4</td>
<td>0.016</td>
<td>100</td>
<td>0</td>
<td>468</td>
<td>-14</td>
</tr>
<tr>
<td>12</td>
<td>10:46</td>
<td>14:18</td>
<td>3.53333</td>
<td>0.018</td>
<td>98</td>
<td>0.03055</td>
<td>468</td>
<td>-18</td>
</tr>
</tbody>
</table>

… A complete listing of this data can be located within the attached CD ROM
Appendix I - Kangerlaussauq 7 Year Wind Averages

Notes on Data –

This data was collected at 3 meters at the Kangerlaussauq airport near to where current deployment of 9 node system\(^5\)\(^0\). These averages are taken over the course of 24 hours and do not reflect the highest potential wind speed for the day.

<table>
<thead>
<tr>
<th>Date</th>
<th>Year 1</th>
<th>Year 2</th>
<th>Year 3</th>
<th>Year 4</th>
<th>Year 5</th>
<th>Year 6</th>
<th>Year 7</th>
<th>Average (mph)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-Jan</td>
<td>8</td>
<td>4</td>
<td>10</td>
<td>8</td>
<td>13</td>
<td>7</td>
<td>15</td>
<td>9.3</td>
</tr>
<tr>
<td>2-Jan</td>
<td>7</td>
<td>8</td>
<td>17</td>
<td>11</td>
<td>12</td>
<td>7</td>
<td>10</td>
<td>10.3</td>
</tr>
<tr>
<td>3-Jan</td>
<td>9</td>
<td>9</td>
<td>16</td>
<td>10</td>
<td>8</td>
<td>5</td>
<td>22</td>
<td>11.3</td>
</tr>
<tr>
<td>4-Jan</td>
<td>10</td>
<td>8</td>
<td>19</td>
<td>14</td>
<td>7</td>
<td>6</td>
<td>8</td>
<td>10.3</td>
</tr>
<tr>
<td>5-Jan</td>
<td>4</td>
<td>9</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>13</td>
<td>10</td>
<td>8.1</td>
</tr>
<tr>
<td>6-Jan</td>
<td>14</td>
<td>5</td>
<td>13</td>
<td>5</td>
<td>21</td>
<td>10</td>
<td>4</td>
<td>10.3</td>
</tr>
<tr>
<td>7-Jan</td>
<td>12</td>
<td>7</td>
<td>12</td>
<td>5</td>
<td>13</td>
<td>6</td>
<td>6</td>
<td>8.7</td>
</tr>
<tr>
<td>8-Jan</td>
<td>6</td>
<td>9</td>
<td>10</td>
<td>14</td>
<td>11</td>
<td>4</td>
<td>5</td>
<td>8.4</td>
</tr>
<tr>
<td>9-Jan</td>
<td>7</td>
<td>10</td>
<td>5</td>
<td>10</td>
<td>20</td>
<td>7</td>
<td>8</td>
<td>9.6</td>
</tr>
<tr>
<td>10-Jan</td>
<td>5</td>
<td>6</td>
<td>6</td>
<td>9</td>
<td>13</td>
<td>7</td>
<td>6</td>
<td>7.4</td>
</tr>
<tr>
<td>11-Jan</td>
<td>6</td>
<td>6</td>
<td>7</td>
<td>12</td>
<td>9</td>
<td>8</td>
<td>7</td>
<td>7.9</td>
</tr>
<tr>
<td>12-Jan</td>
<td>13</td>
<td>9</td>
<td>3</td>
<td>13</td>
<td>12</td>
<td>8</td>
<td>9</td>
<td>9.6</td>
</tr>
<tr>
<td>13-Jan</td>
<td>14</td>
<td>5</td>
<td>8</td>
<td>16</td>
<td>7</td>
<td>6</td>
<td>5</td>
<td>8.7</td>
</tr>
<tr>
<td>14-Jan</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>5</td>
<td>7</td>
<td>7</td>
<td>8</td>
<td>6.9</td>
</tr>
<tr>
<td>15-Jan</td>
<td>8</td>
<td>7</td>
<td>10</td>
<td>9</td>
<td>5</td>
<td>8</td>
<td>12</td>
<td>8.4</td>
</tr>
<tr>
<td>16-Jan</td>
<td>6</td>
<td>8</td>
<td>8</td>
<td>6</td>
<td>9</td>
<td>6</td>
<td>9</td>
<td>7.4</td>
</tr>
<tr>
<td>17-Jan</td>
<td>10</td>
<td>5</td>
<td>5</td>
<td>6</td>
<td>9</td>
<td>6</td>
<td>13</td>
<td>7.7</td>
</tr>
<tr>
<td>18-Jan</td>
<td>13</td>
<td>6</td>
<td>8</td>
<td>7</td>
<td>10</td>
<td>8</td>
<td>11</td>
<td>9.0</td>
</tr>
<tr>
<td>19-Jan</td>
<td>9</td>
<td>7</td>
<td>5</td>
<td>10</td>
<td>12</td>
<td>19</td>
<td>18</td>
<td>11.4</td>
</tr>
<tr>
<td>20-Jan</td>
<td>5</td>
<td>8</td>
<td>5</td>
<td>13</td>
<td>10</td>
<td>10</td>
<td>17</td>
<td>9.7</td>
</tr>
</tbody>
</table>

... A complete listing of these files is located in the attached CD ROM
Appendix J – Evaluation Gel Cell vs. AGM

The two viable options developed in the Technical Research were Gel Cell and Absorbed Glass Mat (AGM). Both technologies adequately fulfill the constraint of at -40°C and both self discharge rates are similar at the lower temperatures; however the AGM technology provides the most efficient use of power. The bulk charge of a Gel Cell is strictly limited to the C/20 in the bulk phase to prevent damage, while the AGM has none and accepts a wide range of current at any voltage over the terminal potential. This flexibility of the AGM allows a shorter recharge cycle and is vital when conditions only allow short periods of limited power as seen in the recharge efficiency. When comparing the recharge efficiency of both the Gel Cell and AGM batteries, under ideal conditions the Gel Cell recharge efficiency is optimally rated for 90%, while the AGM worst case recharge is 96%.55

Another design constraint analyzed is best illustrated by the depth of discharge comparison graph below.

Figure 54: Performance Comparison during different depth of discharge cycles.56

Personal Communications with Concorde manufacturers indicated that AGM batteries deep cycle discharge should not exceed 30% or damage to the battery may occur. Both batteries are deep cycle, however as shown in the figure above an AGM operates for approximately twice as many deep discharge cycles as a Gel Cell (at 30% Depth of Discharge).
Appendix K – Voltage vs. State of Charge

Voltage and State of Charge
In order to control the power system, the relationship between Voltage and Depth of Discharge was analyzed. It was indicated in personal Communications with Concorde manufacturers that their AGM mirrors the relationship developed for standard 12 Volt lead acid batteries. The table below was generated for a standard 12 Volt lead acid battery, and served as the standard the prototype AGM was tested against. The table marks two areas, one in yellow and one in red. The battery should be discharged within the yellow area greater than 30% of full capacity to prevent potential damage which is marked in red.

<table>
<thead>
<tr>
<th>State of Charge</th>
<th>12 Volt battery</th>
<th>Volts per Cell</th>
</tr>
</thead>
<tbody>
<tr>
<td>100%</td>
<td>12.70</td>
<td>2.12</td>
</tr>
<tr>
<td>95%</td>
<td>12.60</td>
<td>2.1</td>
</tr>
<tr>
<td>90%</td>
<td>12.50</td>
<td>2.08</td>
</tr>
<tr>
<td>85%</td>
<td>12.46</td>
<td>2.075</td>
</tr>
<tr>
<td>80%</td>
<td>12.42</td>
<td>2.07</td>
</tr>
<tr>
<td>75%</td>
<td>12.37</td>
<td>2.06</td>
</tr>
<tr>
<td>70%</td>
<td>12.32</td>
<td>2.05</td>
</tr>
<tr>
<td>65%</td>
<td>12.26</td>
<td>2.04</td>
</tr>
<tr>
<td>60%</td>
<td>12.20</td>
<td>2.03</td>
</tr>
<tr>
<td>55%</td>
<td>12.13</td>
<td>2.02</td>
</tr>
<tr>
<td>50%</td>
<td>12.06</td>
<td>2.01</td>
</tr>
<tr>
<td>45%</td>
<td>11.98</td>
<td>1.99</td>
</tr>
<tr>
<td>40%</td>
<td>11.93</td>
<td>1.98</td>
</tr>
<tr>
<td>35%</td>
<td>11.825</td>
<td>1.97</td>
</tr>
<tr>
<td>30%</td>
<td>11.75</td>
<td>1.96</td>
</tr>
<tr>
<td>25%</td>
<td>11.66</td>
<td>1.945</td>
</tr>
<tr>
<td>20%</td>
<td>11.58</td>
<td>1.93</td>
</tr>
<tr>
<td>10%</td>
<td>11.31</td>
<td>1.89</td>
</tr>
<tr>
<td>5%</td>
<td>10.95</td>
<td>1.8</td>
</tr>
<tr>
<td>0</td>
<td>10.50</td>
<td>1.75</td>
</tr>
</tbody>
</table>
Appendix L - BP Solar Datasheets

### BP 350

50 Watt Photovoltaic Module

#### High-efficiency photovoltaic module using silicon nitride multicrystalline silicon cells.

#### Performance
- Rated power ($P_{max}$): 50W
- Nominal voltage: 12V
- Limited Warranty: 25 years

#### Configuration
- BP 350U: Clear universal frame and standard J-box

#### Electrical Characteristics

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>BP 350</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum power ($P_{max}$)</td>
<td>50W</td>
</tr>
<tr>
<td>Voltage at $P_{max}$ ($V_{mp}$)</td>
<td>17.5V</td>
</tr>
<tr>
<td>Current at $P_{max}$ ($I_{mp}$)</td>
<td>2.9A</td>
</tr>
<tr>
<td>Warranted minimum $P_{max}$</td>
<td>45W</td>
</tr>
<tr>
<td>Short-circuit current ($I_{sc}$)</td>
<td>3.17A</td>
</tr>
<tr>
<td>Open-circuit voltage ($V_{oc}$)</td>
<td>21.8V</td>
</tr>
<tr>
<td>Temperature coefficient of $I_{sc}$</td>
<td>(0.005±0.01)%/°C</td>
</tr>
<tr>
<td>Temperature coefficient of $V_{oc}$</td>
<td>-80±10%/°C</td>
</tr>
<tr>
<td>Maximum power at STC ($P_{max-STC}$)</td>
<td>45W</td>
</tr>
<tr>
<td>Maximum series fuse rating</td>
<td>20A</td>
</tr>
<tr>
<td>Maximum system voltage</td>
<td>800V (U.S. NEC &amp; IEC 61215 rating), 1000V (TÜV Rheinland rating)</td>
</tr>
</tbody>
</table>

#### Mechanical Characteristics

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Length: 839mm (33&quot;)</th>
<th>Width: 537mm (21.1&quot;)</th>
<th>Depth: 50mm (1.97&quot;)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight</td>
<td>8.0 kg (13.2 pounds)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solar Cells</td>
<td>72 cells (42mm x 125mm) in a 4x18 matrix connected in 2 parallel strings of 36 in series</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Junction Box</td>
<td>U-Version junction box with 6-terminal connection block; IP 54, accepts PG 13.5, M20, 1/4 inch conduit, or cable fittings accepting 6-12mm diameter cable. Terminals accept 2.5 to 10mm² (8 to 14 AWG) wire.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diodes</td>
<td>One 9A, 46V Schottky by-pass diode included</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Construction</td>
<td>Front: High-transmission 3mm (0.12&quot;) tempered glass; Back: Tedlar; Encapsulant: EVA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frame</td>
<td>Clear anodized aluminum alloy type 6063T6 Universal frame, Color: silver</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1. Module Warranty: 25-year limited warranty of 80% power output; 12-year limited warranty of 90% power output; 5-year limited warranty of materials and workmanship. See your local representative for full terms of these warranties.
2. These data represent the performance of typical BP 350 products, and are based on measurements made in accordance with ASTM E1036 (corrected to DGC 67C.)
3. During the stabilization process that occurs during the first few months of deployment, module power may decrease by up to 3% from typical $P_{max}$. 
Quality and Safety

ESTI Module power measurements calibrated to World Radiometric Reference through ESTI (European Solar Test Installation at Ispra, Italy)

- Manufactured in ISO 9001-certified factories, conforms to European Community Directives 89/336/EEC, 73/23/EEC, 95/68/EEC; certified to IEC 61215
- Framed modules certified by TUV Rheinland as Safety Class II (IEC 60364) equipment for use in systems up to 1000 VDC
- Listed by Underwriter's Laboratories for electrical and fire safety (Class C fire rating)
- Approved by Factory Mutual Research in NEC Class 1, Division 2, Groups C & D hazardous locations (U)

Qualification Test Parameters

- Temperature cycling range: -40°C to +85°C (-40°F to 165°F)
- Humidity freeze, damp heat: 85% RH
- Static load front and back (e.g. wind): 50psi (3400 pascals)
- Front loading (e.g. snow): 113psf (5400 pascals)
- Hallstone impact: 25mm (1 inch) at 23 m/s (52mph)

Module Diagram

Dimensions in brackets are in inches. Unbracketed dimensions are in millimeters. Overall tolerances ±3mm (1/8")

Included with each module: self-tapping grounding screw, instruction sheet, and warranty document.

Note: This publication summarizes product warranty and specifications, which are subject to change without notice. Additional information may be found on our web site: www.bpsolar.com
High-efficiency photovoltaic module using silicon nitride multicrystalline silicon cells.

Performance
- Rated power ($P_{max}$) 125W
- Power tolerance ± 5%
- Nominal voltage 12V
- Limited Warranty 25 years

Configuration
- S BP 3125S Clear universal frame with LoPro J-Box and polarized Multicontact (MC) connectors
- U BP 3125U Clear universal frame and standard J-Box

Electrical Characteristics
- Maximum power ($P_{max}$) 125W
- Voltage at $P_{max}$ ($V_{max}$) 17.8V
- Current at $P_{max}$ ($I_{max}$) 7.1A
- Warranted maximum $P_{max}$ 118.75W
- Short-circuit current ($I_{sc}$) 7.64A
- Open-circuit voltage ($V_{oc}$) 22.1V
- Temperature coefficient of $I_{sc}$ (0.065 ± 0.015) %/°C
- Temperature coefficient of $V_{oc}$ (-0.4 ± 0.05) %/°C
- Temperature coefficient of power (-0.5 ± 0.05) %/°C
- NOCT (Air 20°C, Sun 0.8kW/m², wind 1m/s) 47 ± 2°C
- Maximum series fuse rating 15A (S), 20A (U)
- Maximum system voltage 600V (US NEC rating)
- 1000V (IEC 61215 rating)

Mechanical Characteristics
- Dimensions S, U: Length: 1510mm (59.4") Width: 674mm (26.5") Depth: 50mm (1.97"
- Weight S, U: 12.0 kg (26.5 pounds)
- Solar Cells S, U: 36 cells (157mm x 157mm) in a 4x9 matrix connected in series
- Output Cables S: 8x4 AWG# 12 (4mm²) cable with polarized weatherproof DC rated
- Multicontact connectors; asymmetrical lengths - 800mm (-) and 800mm (+)
- Junction Box U: U-Version junction box with 6-terminal connection block; IP 54, accepts PG 13.5, M20, 1/8" inch conduit, or cable fittings accepting 8-12mm diameter cable. Terminals accept 2.5 to 10mm² (8 to 14 AWG) wire.
- Diodes S, U: IntegraBus™ technology includes Schottky bypass diodes integrated into the printed circuit board bus.
- Construction S, U: Front: High-transmission 3mm (1/8th inch) tempered glass; Back: Tedlar; Encapsulant: EVA
- Frame S, U: Clear anodized aluminum alloy type 6063T6 Universal frame; Color: silver

1. Module Warranty: 25-year limited warranty of 80% power output; 12-year limited warranty of 90% power output; 8-year limited warranty of materials and workmanship. See your local representative for full terms of these warranties.
2. These data represent the performance of typical BP 3125 products, and are based on measurements made in accordance with ASTM E1608 corrected to SRQ/GCTC.
3. During the stabilization process that occurs during the first few months of deployment, module power may decrease by up to 3% from typical $P_{max}$.
Quality and Safety

Assignment of Classes, Models, and Certifications

- Module power measurements calibrated to World Radiometric Reference through ESTI (European Solar Test Installation at Isola, Italy)
- Listed by Underwriter's Laboratories for electrical and fire safety (Class C fire rating)
- Approved by Factory Mutual Research in NEC Class 1, Division 2, Groups C & D hazardous locations (UL)

Qualification Test Parameters

- Temperature cycling range: -40°C to +85°C (-40°F to 185°F)
- Humidity freeze, damp heat: 85% RH
- Static load front and back (e.g., wind): 2,400 pa (50psf)
- Front loading (e.g., snow): 5,400 pa (113psf)
- Hallstone impact: 25mm Ø 1 inch at 23 m/s (52mph)

Module Diagram

Dimensions in brackets are in inches. Unbracketed dimensions are in millimeters. Overall tolerances ±3mm (1/8")

Included with each module: self-tapping grounding screw, instruction sheet, and warranty document.

Note: This publication summarizes product warranty and specifications, which are subject to change without notice. Additional information may be found on our web site: www.bpsolar.com
SOLAR BOOST™ 2000E
MAXIMUM POWER POINT TRACKING PHOTOVOLTAIC CHARGE CONTROLLER

• Patented MPPT technology increases charge current up to 30% or more!

• 12 Volt / 25 Amp rating supports wide range of applications

• Multi-stage stage PWM charge control improves battery performance & life

• Electronic current limit prevents overload or nuisance fuse blow

• LCD digital display monitors PV charge performance

• Durable powder coat finish & conformal coated electronics resist corrosion

• Available temperature compensation further improves battery performance & life

• Fully protected against excess current, temperature, transient voltage & polarity

• Full 36 month limited warranty, optional extended coverage available

Get Improved Performance From Your Solar Modules and Batteries

The Ultimate Photovoltaic Charge Controller...
Increases Charge Current Up To 30% Or More!

Patented Maximum Power Point Tracking (MPPT) technology allows Solar Boost 2000E to increase charge current up to 30% or more compared to conventional charge controllers. Don't waste money by throwing PV power away! Get the power you paid for with a Solar Boost charge controller.

The Solar Boost 2000E provides a precision Multi-stage Pulse Width Modulation (PWM) charge control system to ensure the battery is properly and fully charged, resulting in enhanced battery performance with less battery maintenance. An equalize function is also included to periodically condition liquid electrolyte lead-acid batteries.

A built-in LCD digital display monitors solar charge performance. The display shows battery voltage, solar panel current and output charge current. You can actually see current boost working by knowing the difference between solar panel current and output charge current. A charge status LED indicates the present charge mode, and shows when the battery has become fully charged.

Manufactured by Blue Sky Energy Inc. and offered by a large network of quality distributors and dealers. Call us today for information or a dealer near you.

Contact us today for more information
Visit our web site: www.blueskyenergyinc.com
email: sales@blueskyenergyinc.com
(800) 493-7877 • or (760) 597-1642 • fax (760) 597-1731
2596 Fortune Way, Suite K • Vista, CA 92081 • USA

Covered under US Patent 6,111,391
How Do Solar Boost™ Controllers Increase Charge Current?

Solar Boost controllers increase charge current by operating the PV module in a manner that allows the module to produce all the power it is capable of. A conventional charge controller simply connects the module to the battery when the battery is discharged. When the 75W module in this example is connected directly to a battery charging at 12 volts its power production is artificially limited to about 53 watts. This wastes a whopping 22 watts or nearly 30% of the available power.

Patented MPPT technology used in Solar Boost controllers operates in a very different fashion. The Solar Boost controller continually calculates the module's maximum power voltage, in this case 17 volts. It then operates the module at its maximum power voltage to extract maximum power. The higher power extracted from the module is then provided to the battery in the form of increased charge current. In conditions where extra PV power is not available, Solar Boost controllers will operate as a conventional controller with very low voltage drop. The actual charge current increase you will see varies primarily with module temperature and battery voltage. In comfortable temperatures, current increase typically varies between 10 to 25%, with 30% or more easily achieved with a discharged battery and cooler temperatures. What you can be sure of is that Solar Boost charge controllers will deliver the highest charge current possible for a given set of operating conditions.

<table>
<thead>
<tr>
<th>SPECIFICATIONS</th>
<th>Solar Boost 2000E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Output Current Rating</td>
<td>25 Amp Maximum</td>
</tr>
<tr>
<td>Nominal System Voltage</td>
<td>12 VDC</td>
</tr>
<tr>
<td>PV Open Circuit Voltage</td>
<td>30 VDC Maximum</td>
</tr>
<tr>
<td>Standby Power Consumption</td>
<td>0.7mA Typical</td>
</tr>
<tr>
<td>Charge On Power Consumption</td>
<td></td>
</tr>
<tr>
<td>Charge Algorithm</td>
<td>Fully automatic two stage charge, Bulk &amp; Constant Voltage. A third manually actuated Equalize charge function is included to periodically condition lead-acid batteries.</td>
</tr>
<tr>
<td>Charge Voltage Setpoint Range</td>
<td>13 – 16VDC (14.0VDC initial factory setting)</td>
</tr>
<tr>
<td>Equalization Voltage</td>
<td>Charge voltage setting +1.2VDC</td>
</tr>
<tr>
<td>Temperature Compensation</td>
<td>Optional temperature sensor adjusts charge voltage setpoint based on measured battery temperature. Field selectable slope, -5.0mV/°C/cell (lead-acid), or -2.0mV/°C/cell (NiCd)</td>
</tr>
<tr>
<td>Power Conversion Efficiency</td>
<td>95% @ 15 Amp Output</td>
</tr>
<tr>
<td>Panel Dimensions</td>
<td>4 5/8&quot;H x 6 5/8&quot;W x 1 7/8&quot;D (11.75cm x 16.19cm x 4.76cm)</td>
</tr>
<tr>
<td>Construction</td>
<td>Open frame construction with conformal coated electronics visible from rear. Designed to mount into a rectangular surface cutout. Optional conduit ready surface mount box available.</td>
</tr>
<tr>
<td>Front Panel Displays</td>
<td>LCD digital display shows PV module input current, output charge current and battery voltage. Charge status LED shows present charge mode and battery state of charge.</td>
</tr>
<tr>
<td>Digital Display Range/Accuracy</td>
<td>Voltmeter, 19.99VDC ±0.10% F.S. Ammeter, 26.0A ±0.75% F.S.</td>
</tr>
<tr>
<td>Specified Temperature Range</td>
<td>0 to +40°C (Extended range -40 to +50°C, will operate but may not meet spec.)</td>
</tr>
</tbody>
</table>

**Available From**

**Part Numbers & Shipping Weight**

<table>
<thead>
<tr>
<th>Part Number</th>
<th>Description</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>SB2000E</td>
<td></td>
<td>0.91kg</td>
</tr>
<tr>
<td>SB2000E wall mount box</td>
<td>720-0011-01</td>
<td>2 lbs</td>
</tr>
<tr>
<td>Battery Temp. sensor, 20' cable</td>
<td>930-0022-20</td>
<td>1 lbs</td>
</tr>
</tbody>
</table>

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800-460-7677 • 760-697-1652 • Fax 760-697-1731
www.blueskyenergyinc.com
Appendix N - Concorde SunXtender Datasheets

Notes – Both the prototyped PVX 490T and the recommended PVX 1080T are included within this section.

<table>
<thead>
<tr>
<th>Part Number</th>
<th>Overall Dimensions</th>
<th>Capacity Ampere Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>L in (mm)</td>
<td>W in (mm)</td>
</tr>
<tr>
<td>PVX-340T</td>
<td>12</td>
<td>7.71 (196)</td>
</tr>
<tr>
<td>PVX-420T</td>
<td>12</td>
<td>7.71 (196)</td>
</tr>
<tr>
<td>PVX-490T</td>
<td>12</td>
<td>8.99 (228)</td>
</tr>
<tr>
<td>PVX-560T</td>
<td>12</td>
<td>8.99 (228)</td>
</tr>
<tr>
<td>PVX-690T</td>
<td>12</td>
<td>10.22 (260)</td>
</tr>
<tr>
<td>PVX-840T</td>
<td>12</td>
<td>10.22 (260)</td>
</tr>
<tr>
<td>PVX-1080T</td>
<td>12</td>
<td>12.90 (328)</td>
</tr>
<tr>
<td>PVX-1040T</td>
<td>12</td>
<td>12.03 (306)</td>
</tr>
<tr>
<td>PVX-890T</td>
<td>12</td>
<td>12.90 (328)</td>
</tr>
<tr>
<td>PVX-2120L</td>
<td>12</td>
<td>20.75 (528)</td>
</tr>
<tr>
<td>PVX-2580L</td>
<td>12</td>
<td>20.72 (526)</td>
</tr>
<tr>
<td>PVX-1380T</td>
<td>6</td>
<td>10.22 (260)</td>
</tr>
<tr>
<td>PVX-1680T</td>
<td>6</td>
<td>10.22 (260)</td>
</tr>
<tr>
<td>PVX-1780T</td>
<td>6</td>
<td>12.90 (328)</td>
</tr>
<tr>
<td>PVX-2080T</td>
<td>6</td>
<td>12.03 (306)</td>
</tr>
<tr>
<td>PVX-2160T</td>
<td>6</td>
<td>12.90 (328)</td>
</tr>
<tr>
<td>PVX-2240L</td>
<td>6</td>
<td>10.27 (261)</td>
</tr>
</tbody>
</table>

Concorde SunXtender PVX Battery Series—
Concorde Sunxtender batteries are designed for deep cycle / back-up power for solar electric photovoltaic applications.

PVX Series batteries from Concorde use AGM or absorbed glass mat technology, making their charge retention about five to ten times better than flooded/vented type batteries. Concorde sunxtender AGM battery series deliver and absorb higher rates of amperage than any other sealed battery during discharging and charging.

**SUN-EXTENDER® BATTERY DESIGN FEATURES**

Copper Alloy Terminals for improved electrical connections.

No exposed lead terminals. This change was incorporated to improve environmental safety and health.

Threaded insert terminals are recessed to prevent short circuits across battery connections.¹

New cover is flat top design. No protruding or exposed vent valves.¹
Built in lifting handles, except PVX-490T, PVX-560T, and PVX-2240L.

Reinforced container walls to reduce bulging.

High Impact Strength Copolymer Polypropylene Case and Cover.

Completely Sealed Valve Regulated Construction.

Immobilized Electrolyte Non-Spillable.

Maintenance Free Design Never Requires Watering.

Absorbed Glass Mat (AGM) Micro-porous Glass Separators retain electrolyte.

Flame Arresting Pressure Regulated Safety Valves.

UL Recognized Systems Component.

Positive Plates - Proprietary Lead Calcium Alloy- Negatives Plates - Lead Calcium.

Low Self Discharge Rate Approximately 1 % per month at 25 C (77 F).

Operate over a Wide Range of Temperatures from -40 C (-40 F) to +72 C (+160 F).

Classified as "Non-Spillable Battery" for Transport.

Most Part Numbers comply with DOT HMR49, Non-Hazardous Materials.
1 SRI Center for Geospace Studies. January 2005
http://www.sri.com/esd/cgs/

2 SRI International. The Sondrestrom Research Facility. January 2005

http://transport.sri.com/AMISR/Sections/Introduction


5 The University of Colorado. Global Positioning Overview. January 2005
http://www.colorado.edu/geography/gcraft/notes/gps/gps_f.html

6 Personal Communication Todd Valentic


9 Northern Arizona Wind and Sun. Photovoltaics Information. February 2005
http://www.windsun.com/images/Batt_temperature1.gif

10 Northern Arizona Wind and Sun. AGM Frequently asked Questions. January 2005
http://www.windsun.com/Batteries/Battery_FAQ.htm#AGM,%20or%20Absorbed%20Glass%20Mat%20Batteries

http://www.windsun.com/Batteries/Battery_FAQ.htm#AGM,%20or%20Absorbed%20Glass%20Mat%20Batteries


http://www.oksolar.com/battery/gel.html


http://www.solar4power.com/pdf/concorde-things-that-work.pdf


17 WASA. Observations for Ice Sheet History. February 2005
http://www.phys.uu.nl/~wwwimau/research/ice_climate/gofish.pdf

18 Personal communication with Paul Tregong

19 Personal Communication with Roy Stehle


36 http://www.its.bldrdoc.gov/fs-1037/images/nettopoc.gif


