Water quality Autonomous Robot

Senior Design I

Group #24

Fall 2013

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1.0 Executive Summary

After going through many ideas during the first two weeks of the fall semester the group decided to create a project that would sample water quality data in bodies of water. The primary motivation came from group member, Irina Bouzina, when she was telling us about the recent problems that some children and teenagers ran into when swimming in warm bodies of water. According the article she read, a brain-eating amoeba was present in the water without anybody knowing until it had entered the teenager. With this motivation we decided to create a project that will sample water quality in large bodies of water. Though there isn’t a specific sensor that can tell us if the brain-eating amoeba is present in the water, we believe that with the different measurements taken of the water it can give the user a general idea if the water is safe to enter. This data can be used by many people varying from outdoor enthusiasts to scientists researching aquatic life.

The general functionality of the will be a boat that can autonomously move to a specified GPS coordinate and take various water quality measurements. We plan to take five water quality measurements which are temperature, pH, Oxidation Reduction Potential (ORP), Dissolved Oxygen (D.O.) and conductivity. Once the boat has arrived to the GPS coordinates it will sample the water and transmit the water quality data wirelessly back to a PC onshore. To accomplish autonomous motion, the boat will be equipped with a GPS module and GPS compass. The GPS module will get the coordinates of the boat and will send them to the navigation microcontroller. The microcontroller will then compare those coordinates with the user inputted coordinates. If the two coordinates differ then the microcontroller will turn on the motor and move the rudder via a servo to the correct angle so that the boat can travel to its waypoint. The compass will be used to get a better heading than the GPS module can provide. We also plan to power the entire project using solar power. The boat will be equipped with batteries that can be recharged from PV cells that will be mounted to the top of the boats hull to gather sunlight. Using PV cells is a great opportunity to make the project self-sustaining and environmentally friendly.

To finance this project we will be sponsored by Duke Energy. From previous years Duke Energy has sponsored groups from \$1500-\$4000. With this financial backing we are able to purchase high quality sensors that can measure water quality accurately. Even with this sponsorship we still plan to make this as budget friendly as possible. If we are able to make this project low cost, we hope that other hobbyist will be able to follow these steps and build similar projects that are on a budget.

2.0 Project Description

2.1 General Description

Water quality Autonomous Robot (W.A.R.) will be an autonomous, solar-powered, robotic boat that will take various measurements of water quality and transmit them back to an on shore receiver. A user will be able to input a series of GPS coordinates and the boat will autonomously move to each location, measure water quality and transmit data before moving to the next location and repeating. This will be accomplished by using the on board servo rudder, motor, and propeller. The boat will contain batteries that will be recharged by solar panels that are also on the boat. The batteries will be used to power all the components of the robot. The robot will be waterproof and be mounted on pre-made RC boat platform.

To determine the water quality, W.A.R. will be equipped with five scientific grade sensors and corresponding circuits. These sensors and circuits will calculate temperature in degrees Celsius, pH levels on a 0 -14 scale, water conductivity, dissolved oxygen, and oxidation reduction potential (ORP). These five sensors and circuits will give us a good overall picture of the water quality in the body of freshwater. The microcontroller on the robot will receive input data from the sensors and circuits and will transmit this data wirelessly to an on-shore device.

2.2 Project Motivation and Goals

The state of Florida is not only surrounded by water on three sides, but also contains more than 30,000 lakes that cover a little more than 3 million acres of land. Water is an essential requirement of life for many different species. Unlike other species, humans also use water for recreational and leisurely activities. There are many water sports, competitive races and other activities that exist in today's society. Of course, humans do not have complete control over the water and they must share with the other natural inhabitants. Most of these other inhabitants can be relatively harmless but some can be very dangerous to the human body. Perhaps the most frightening of all is the brain-eating amoeba, called Naegleria Fowleri. While not a widespread epidemic, this particular amoeba has a very high mortality rate and is especially dangerous to younger children.

On August 3rd, 2013 a little 12 year old boy contracted Naegleria Fowleri, by swimming in a closed freshwater body of water. This amoeba thrives in warm waters and hot springs, often leaving people weary and discouraged about swimming in freshwater lakes and fully enjoying their warm weather summer. However, by precisely measuring the water temperature we are able to take the proper preventative measures in tracking this amoeba. When the temperature reaches near 25 °C/77F the amoeba becomes active and begins to reproduce.

The goal of this senior design project is to make it easier for any outdoor enthusiast to test the water for safe and comfortable conditions. We will achieve this by measuring the water temperature, as well as pH levels, conductivity, dissolved oxygen and the oxygen reduction potential of the water. The user of the W.A.R. will be able to stay safely on shore while inputting a series of GPS coordinates to maneuver the W.A.R. to take samples in different areas of the fresh water body. The W.A.R. will then wirelessly transmit the gathered data to a portable display the user has on shore. Creating this system will help scientists and outdoor enthusiasts gather precise data on anybody of freshwater. Instead of having people go in the water and find out that it is unsafe or uncomfortable for use when it is too late.

2.2.1 Future Goals

A great thing about our project is that we can continuously add more and more features to it in the future. A feature that the team discussed if we had enough time to implement was integration with Android devices and Google Maps. Currently we plan on having the user enter GPS coordinates to a microcontroller from a PC using a USB to FTDI cable. In the future we could implement a way for the user to take out their Android device, open Google Maps and select where W.A.R. would need to go. The Android device would communicate with the microcontroller using Bluetooth and the integration of Google Maps would be achieved by using the open Google Maps API.

Another feature that we would like to add in the future would be a live video stream from W.A.R. to the onshore PC. Having a live video stream would be beneficial to the user if the water quality testing was happening outside the line of sight. With the live stream the user can see where W.A.R. is and how the surrounding environment could be changing the water quality. To implement a live video stream we would need to upgrade our wireless connection to something with a higher data right. Wi-Fi would be ideal here since it has high data rate and can support long distances.

A last feature that would prove useful to our project could be data transmission to a server. Currently we only plan on transmitting water quality data to an onshore PC. If we could upload the water quality data in real time to a server then other people who are interesting the water quality can see the data without being next to the onshore computer. Also having a direct upload to the server can be useful because we can create a large database of water quality data.

2.3 Specifications and Requirements

2.3.1 List of Requirements

Based off of our team meetings below are the minimum system requirements for W.A.R. These requirements will be a general outline for completion of the design. During testing we will confirm that each of these minimum requirements are working and part of the design. Below in Table 2.3.1.A is a list of general requirements for our project.

Req. ID	**Requirement Text**
W-001	W.A.R. shall be able to transmit data within 800 meters of the main receiver tower.
W-002	W.A.R. subsystems shall operate off lithium ion batteries which are connected to solar panels.
W-003	W.A.R. sensors shall operate off their connection to the PCB through BNC connectors.
W-004	W.A.R. navigation system shall operate off lithium ion batteries which are connected to solar panels.
W-005	W.A.R. shall measure water temperature with an error no greater than ± 1°C.
W-006	W.A.R. shall measure dissolved oxygen with a range 20 mg/L.
W-007	W.A.R. shall measure pH levels of freshwater on a scale of 0-14.
W-008	W.A.R. shall measure Oxidation Reduction Potential with a range of ± 2000 mV.
W-009	W.A.R. shall measure Water Conductivity in micro Siemens.
W-010	The dimension of the BB shall be at most 3x1x1 ft.
W-011	The sensors W.A.R. shall be connected to one microcontroller.
W-012	W.A.R. shall wirelessly transmit data to a PC on shore.
W-013	W.A.R. shall have one main microcontroller to for navigation and movement.
W-014	W.A.R. shall be able to stay in water indefinitely.
W-015	W.A.R. shall be optimized for freshwater use only.

Table 2.3.1.A Requirements Table

2.3.2 Physical Description

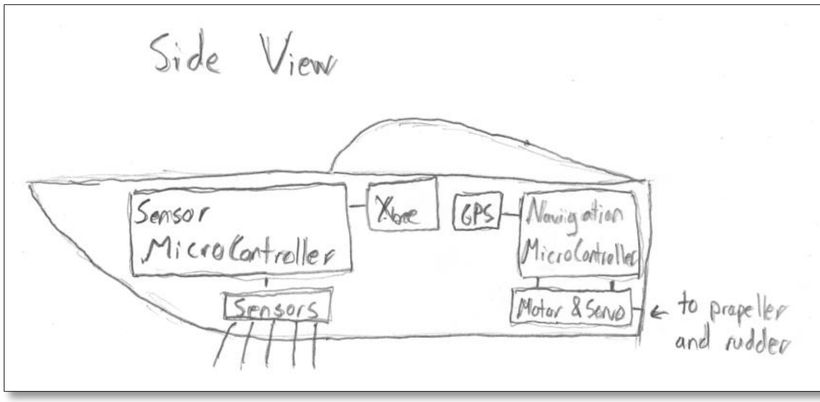


Figure 2.3.2.A Rough Design Drawing of a Side View of W.A.R.

For the robot to move through the water, we will be using a pre-made RC boat platform. The boats length will be no longer than three ft. and its width no wider than one ft. It will have the form of a speed boat so it can traverse through the water easily. The body of the boat, the electronics, sensors, motors, and servos will not exceed 10 pounds. All the electronic components on the boat will be water resistant and will not fail due to small amounts of water. All electronics will be housed inside the boat hull and we will have access to these electronics with a hatch on top of the boat. The storage of the electronics is shown in Figure 2.3.2.A.

On top of the RC boat platform we will place our solar panels on it as shown by our rough draft drawing in Figure 2.3.2.B. We will need to ensure that the solar panels are protected from the water when the boat is moving. Any wiring coming from the solar panels will be shielded and have no open ends to ensure no electronics are damaged.

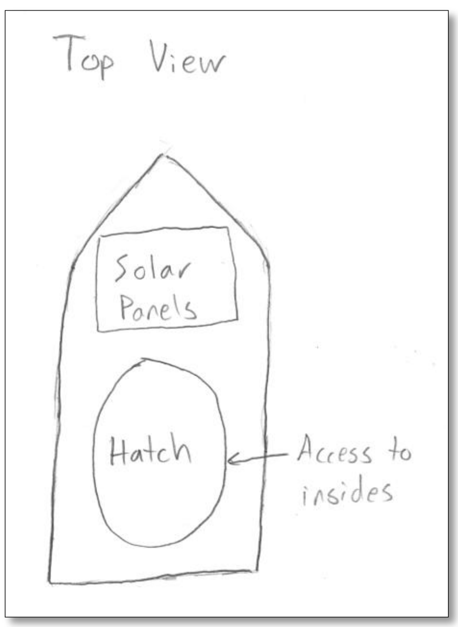


Figure 2.3.2.B Top View of the Boat Platform

The rear of the RC boat will hold our motor and servo to control the rudder. Figure 2.3.2.C shows a design drawing when we started planning this project.

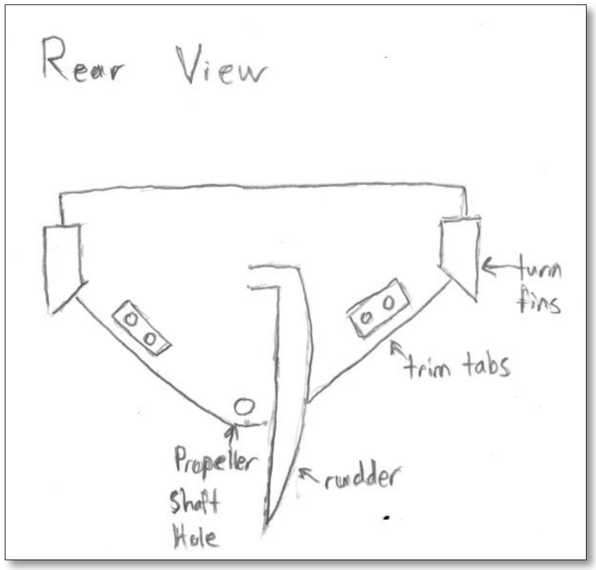


Figure 2.3.2.C Rear View of the Boat Platform

2.3.3 Electrical Hardware

The entire boat will be powered by solar energy. The PV cells will be horizontally mounted on top of the boat and connected in a parallel and series composition. In order to prevent any sort of discharge or backflow of current, which would cause the battery to discharge when the solar panel is not providing energy, a diode configuration or some other discharge prevention mechanism will be set on the wire(s) leading to the battery pack. A charge controller will be connected between the solar panels and the battery to prevent any sort of battery overcharge damage.

The set of rechargeable batteries, or battery pack, will be able to charge and supply 5V to the first system and 3.3V to the second system. The first system will contain the sensors, motors, and microcontroller. The second system contains the communication system. The solar panel will continually charge the battery pack, as the boat is running off the same rechargeable battery pack.

The battery supply connections will all be made on a custom made PCB. The power requirements for each of the two systems is different, therefore each will most likely have different DC to DC converters and/or circuit configurations.

2.3.4 Internal Software

The software on the navigation microcontroller will take a series of GPS coordinates from the user and determine the location that the boat will navigate to. The input from user will be a

UART standard with possibly 8 bits of data. With this data the software on the navigation microcontroller will calculate the offset, position the rudder and power the motor. This configuration for movement shall have a response time under three seconds.

The software on the sensor microcontroller will receive UART communication from the sensors one at a time by using a multiplexer. Each sensor shall have a response time of less than 3 seconds so the total time to calculate the water quality shall be no more than 15 seconds. The sensor microcontroller will poll each water quality circuit for a set amount of time. Once that time has expired a multiplexer will select the next water quality data the microcontroller will send to our wireless transmitter.

2.3.5 External Software

The software on the receiving device will be able to receive data in UART standard up to 8 bits and convert it into readable data for the user. The external software used will be open source terminal software that can read serial data. The open source terminal software should allow the user to create logs of the water quality so we can make an archive of data.

The user will be able to send simple commands to the boat from the on shore display as well. These commands will be no longer than eight bits and include, travel to the inputted GPS coordinates, measure water quality, transmit data, and return to shore. “Shore” will be a static GPS coordinate that the microcontroller will store upon initial launch.

2.3.6 Mechanical Hardware

The mechanical hardware on the boat robot will consist of the motor, the rudder and servos. The boat robot will utilize a pre-made RC motor and rudder. These will be connect to the navigation microcontroller and along with the internal software and user inputted GPS coordinates will steer the boat to the intended destination. All the mechanical hardware will be powered by our own hand crafted power supply. The power supply will use photovoltaic cells to charge lithium ion batteries which in turn will ensure that the boat will be able to stay on the water for extended periods of time.

2.4 Group Dynamics

2.4.1 Division of Labor

There are three members in Group 24 of the fall 2013 Senior Design for Computer and Electrical Engineers class. These people are Irina Bouzina, EE, Dennis Figueras, CpE and Joey Yuen, CpE. Irina will be responsible for the boat’s power supply subsystem, using PV cells to power the various components of the boat. The PV cells will be used to charge a rechargeable battery that will then power the PCBs on the boat. Dennis will be responsible for the boat’s autonomous movement using GPS coordinates. The GPS will send the coordinates to the GPS and calculate the distance and direction the boat will need to travel. Joey will be responsible for the boat’s water quality sensors and wireless data transmission. The water quality data will be sent to a microcontroller and then transmitted wirelessly to an onshore PC. All three members will work together on microcontroller programming, subsystem integration, and PCB design. Table 2.4.1.A specifically breaks down, what each group member will be doing.

Irina	Dennis	Joey
PV Cell Layout	Autonomous Movement	Sensor Measurement
Power Generation	GPS	Wireless Data Transmission
Power Distribution		
Microcontroller Programming		
Design Integration		

Table 2.4.1.A Each Group Members Responsibility of the W.A.R. Project

Figure 2.4.1.1 is a block diagram that demonstrates the amount of work each group member is doing with respect to the entire project.

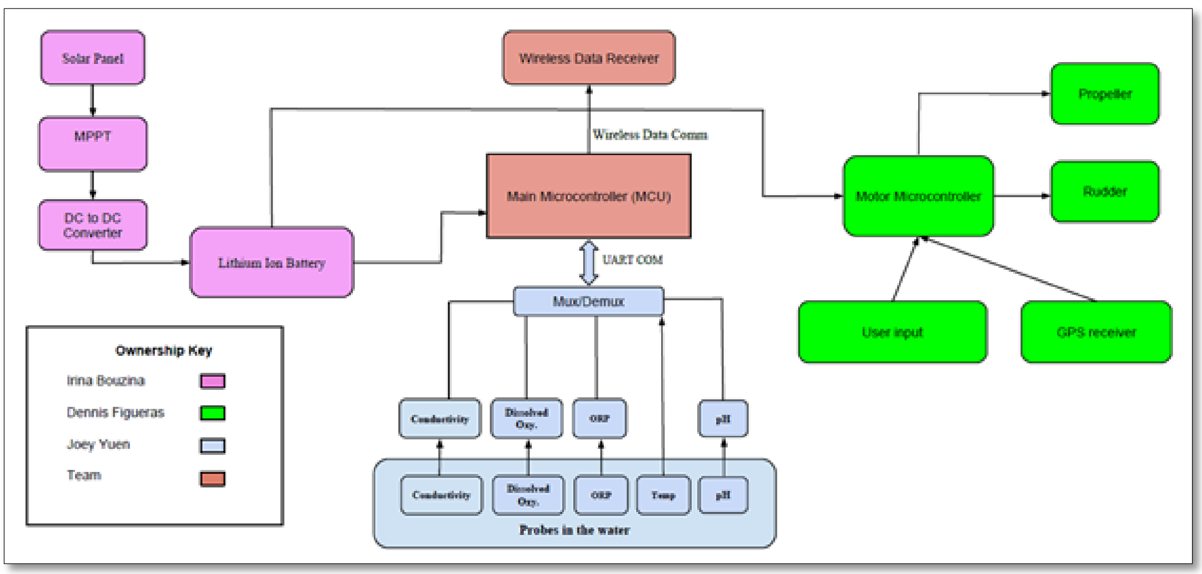


Figure 2.4.1.A Flow Chart with each Group Members Responsibility

2.4.2 Project Schedule

A project schedule is assigned to help the group realize the amount of design work that needs to be accomplished during the first semester of Senior Design and the amount of work that will be needed to actually implement the design itself during the second semester of Senior Design. Each group member is tentatively responsible for their own section of the project (the work distribution is shown in the block diagram in Figure 2.2 in the next section) and to follow the project schedule start and finish dates. The two semester long Senior Design schedule for the W.A.R. project, is displayed in the Figure 1.4.1 below. Though the dates below are well defined the group will not necessarily have to follow it to the exact day. We expect there will be holdups and complications throughout this project due to the fact we are all entry level engineers designing our first full project.

	Task Name	Duration	Start	Finish
0	**Senior Design Project Plan**	**157 days**	**Mon 9/23/13**	**Tue 4/29/14**
1	Research PV Cells and Wireless transmission	7 days	Mon 9/23/13	Tue 10/1/13
2	Research Microcontrollers/Motor	7 days	Mon 9/23/13	Tue 10/1/13
3	Research Water Quality Probes	7 days	Mon 9/23/13	Tue 10/1/13
4	Meeting to consolidate research/outline Design Paper/Sponsors	1 day	Wed 10/2/13	Wed 10/2/13
5	Begin Design Paper/Continue Research	7 days	Thu 10/3/13	Fri 10/11/13
6	Meeting for Design Paper	1 day	Sat 10/12/13	Sat 10/12/13
7	Continuation of Design Paper/Research	7 days	Sun 10/13/13	Mon 10/21/13
8	Learn Eagle PCB Software	7 days	Mon 10/14/13	Tue 10/22/13
9	Design Solar Panel/Power Management	21 days	Sat 10/19/13	Fri 11/15/13
10	Design Navigation/Control system	21 days	Sat 10/19/13	Fri 11/15/13
11	Design Water Quality System	21 days	Sat 10/19/13	Fri 11/15/13
12	Finish and refine Design Paper	7 days	Sat 11/16/13	Sat 11/23/13
13	Finalize Parts list and order parts for SD2	2 days	Mon 11/25/13	Tue 11/26/13
14				
15	Winter Break	19 days	Wed 12/11/13	Sat 1/4/14
16				
17	Begin SD2/Take inventory of ordered parts	1 day	Mon 1/6/14	Mon 1/6/14
18	Design Software/Test	21 days	Tue 1/7/14	Tue 2/4/14
19	Prototype Solar Panel	14 days	Fri 1/24/14	Wed 2/12/14
20	Prototype Navigation/Control System	14 days	Fri 1/24/14	Wed 2/12/14
21	Prototype Water Quality System	14 days	Fri 1/24/14	Wed 2/12/14
22	Test/Debug Solar Panel	21 days	Thu 2/13/14	Thu 3/13/14
23	Test/Debug Navigation/Control System	21 days	Thu 2/13/14	Thu 3/13/14
24	Test/Debug Water Quality System	21 days	Thu 2/13/14	Thu 3/13/14
25	Integrate whole system	14 days	Sat 3/15/14	Wed 4/2/14
26	Test whole system	15 days	Thu 4/3/14	Wed 4/23/14
27	Finalize Documentation/Presentation	9 days	Sat 4/12/14	Wed 4/23/14
28	Presentation	5 days	Wed 4/23/14	Tue 4/29/14

Figure 1.4.1 W.A.R. Project Schedule

2.4.3 Initial Project Budget

The estimated project budget is generated after the general design of the W.A.R. project is conducted. Each part, its quantity, and cost, is demonstrated in the Table 2.4.3.A. The total cost of the project sums up to be approximately $1148.00.

Part	Cost Per Unit	Quantity	Total Cost
Scientific Grade pH Sensor -------------------------------- pH Circuit	$60 ------------------------ $28	1	$88
Field Ready Temperature Sensor	$18	1	$18
Dissolved Oxygen Sensor ----------------- D.O Circuit	$160 ------------------------ $33.00	1	$193
Oxidation Reduction Potential Sensor -------------------------------- ORP Circuit	$90.00 ------------------------- $28.00	1	$118.00
Conductivity Sensor -------------------------------- Conductivity Circuit	$105.00 ------------------------- $43	1	$148.00
Microcontroller (specific model TBD)	$15.00	2	$30.00

Microcontroller Development Board	$50.00	1	$50.00
GPS unit	$20.00	1	$20.00
1-to-8 MUX - 74HCT4051	$1.00	5	$5.00
Diode	Free*	4	$0.00
PV Cells	$146.00 + $40(Shipping)	1	$186
Lithium-Ion Battery	$45.00	1	$45
MPPT	$12.00	1	$12.00
AC to DC Power Converter	$40.00	1	$40.00
Breadboard	$10.00	1	$10.00
Wiring	$10.00	1	$10.00
PCB Manufacturing	$50.00	1	$50.00
Rudder	$10.00	1	$10.00
Rudder Servo	$20.00	1	$20.00
Propeller	$5.00	1	$5.00
Motor	$10.00	1	$10.00
Robot Frame/Platform	$80.00	1	$80.00
Total Cost of Buoy Bot			**$1148.00**

Table 2.4.3.A - Initial Projected Costs Table

3.0 Research

3.1 Existing Projects and Products

3.1.1 Commercial Designs

No existing commercial products have been found for this project. There have been a few noncommercial ones but none available to be purchased by the general populace. The noncommercial projects are generally from other universities or hobby groups. There are however many companies that create water quality measurement devices that are handheld. These handheld devices can measure many different measurements like W.A.R. does.

3.1.2 Other Designs

In April of 2010, a group from the University of Oulu made a water quality measuring robot boat. Similarly to our design they used a pre made RC boat platform, with a GPS receiver. However their boat could only measure and transmit the water temperature. This project will be very similar but will expand on their boats capabilities by adding more water quality measuring functionality such as conductivity, dissolved oxygen, oxidation reduction potential and pH levels. The W.A.R. will be able to take in a series of GPS coordinates and save them in the microcontroller for future use. The robot can be programed to follow the saved path on a daily basis so that the user does not have to manually enter the coordinates every day.

3.2 Relevant Technology

3.2.1 Temperature Sensor

To accurately measure the water temperature it's important to consider the proper temperature calibration of the sensor itself. It's vital to make sure that the chosen temperature sensor covers the following range of temperatures: 60 to 90 degrees Fahrenheit (1). The data for average for water temperature is displayed in Figure 3.2.1.A below.

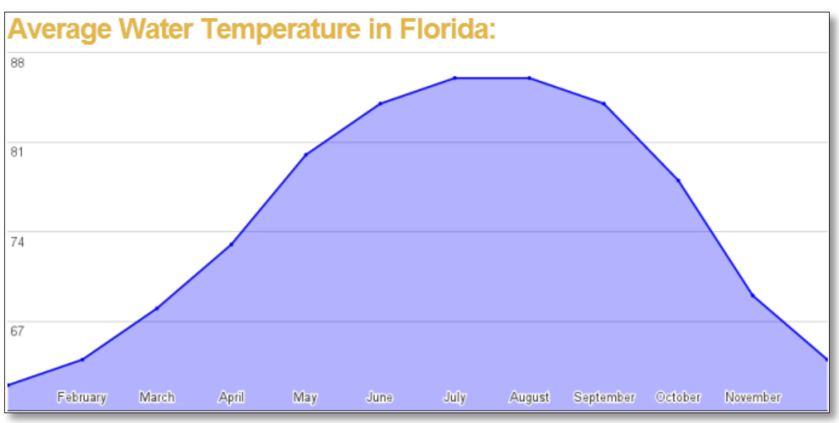


Figure 3.2.1.A: Average Water Temperature (F) in FL Graph
Pending Permission from Water Temperature

Also, the total power that is derived from the solar cells will be distributed to all of the components, so it’s important to conserve the power and pick the components that require the least amount of energy. Proper measures have to be taken to prevent any leaking current draw in between the times that the sensor is not testing any water. That is usually achieved with some diode configuration that prevents any excess power withdraw.

3.2.2 Conductivity Sensor

The conductivity is an important measurement because it indirectly measures the Total Dissolved Solids (TDS) in the water. A normal body of water will have a constant range of conductivity under regular conditions. Therefore significant changes in the conductivity will let the user of the W.A.R. know that there may be pollutants in the water.

The sensor should be able to send data to our microcontroller in a unit called Siemen. To send the data the sensor will be connected from a BNC connector to our conductivity circuit. From there the circuit will decipher the data and then send it to our microcontroller. The data will be transmitted through RS-232 format. The sensor uses the RX so it will know when to take the conductivity of water and the TX line to transmit the data to the conductivity sensor.
There are many factors in choosing the conductivity sensor. The one we choose to be on our boat will have to be designed for freshwater use, be accurate enough up to micro Siemens and be light weight so it will not weigh down our boat.

3.2.3 pH Sensor

The pH is another measurement that is important in determining water quality. We want a measurement of pH because it is one of the most common measurements that can determine if the water is acidic. Due to acid rain and other pollutants a natural body of water that can sustain life at 6.5-8 pH can drop to 5 or lower. At levels 5 or below organisms such as fish and aquatic plants cannot survive. Figure 3.2.3.A shows what pH level acid rain and other acids that pollute bodies of water. It also shows at what pH level aquatic life will be affected.

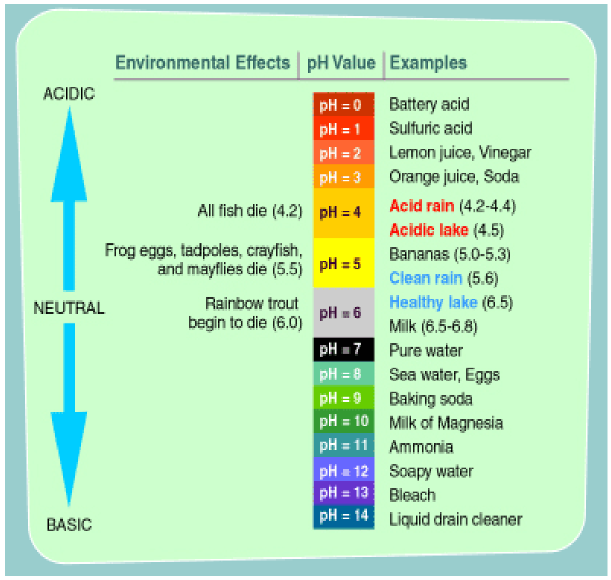


Figure 3.2.3.A pH Table

Our sensor for pH will be similar to our conductivity sensor. It will connect to a pH circuit through a BNC connector. From there the pH will be determined from the circuit and sent to our main microcontroller. The data will be transmitted through RS-232 format exactly the same as the conductivity sensor.

3.2.4 Dissolved Oxygen Sensor

Another measurement that W.A.R. will taking is dissolved oxygen. Dissolved oxygen measures the amount of gaseous oxygen in a solution. The oxygen enters the water from the air, aeration of the water (movement in the water) and waste from aquatic plants through photosynthesis. A very important factor that determines the dissolved oxygen levels is the temperature of the water. As the temperature of the water increase the oxygen level continues to decrease and vice versa as shown in Figure 3.2.4.A.

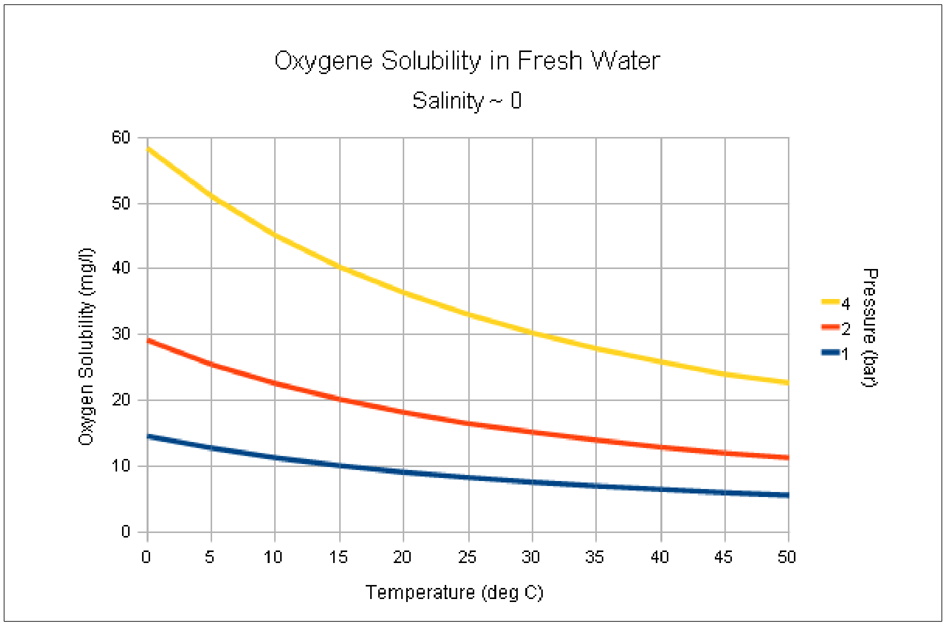


Figure 3.2.4.A Oxygen Concentration in Water vs. Temperature

It is an important factor in water quality because oxygen is important for all life forms to live. If a body of water has a low concentration of dissolved oxygen then organisms will begin to die off which could lead to bacteria and other toxins may enter the water.

Like our other sensors the dissolved oxygen will be connected to a dissolved oxygen sensors through a BNC connector. The circuit will calculate the dissolved oxygen in the water and then transmit the data to our microcontroller. The data will be transmitted through a RS-232 line on the microcontroller.

3.2.5 Oxidation-Reduction Potential (ORP) Sensor

Oxidation-reduction potential measures the ability for a body of water to break down waste, such as dead animals and plants. ORP is an important measurement in water quality because it can determine how well bacteria are decomposing the dead tissue in the water. ORP is related to dissolved oxygen in the fact that both measurements can tell scientists if there are pollutants in the water. The sensor for our design should be similar to the other sensors using a BNC connector to the ORP sensor and transmits data through a RS-232 line with the microcontroller.

3.2.6 GPS Module

For this project, a GPS receiver will be needed for the boat robot. The receiver should be able to report the current longitude and latitude of the boat with an error no greater than three meters. The GPS module will be connected to the navigation microcontroller which will then compare the boat's current location to the user inputted GPS coordinates. If the two locations do not match, the microcontroller will turn on the boats motor and steer towards the intended location. The navigation microcontroller shall be able to receiver user inputted coordinates from up to 1000 meters away.

GPS receivers can communicate with microcontrollers in various ways but the most common is via serial port, using the NMEA protocol for transmitting. The NMEA protocol is based on strings. Figure 3.2.6.A shows an example of NMEA transmitting protocol that is commonly used to connect a GPS receiver to a microcontroller.

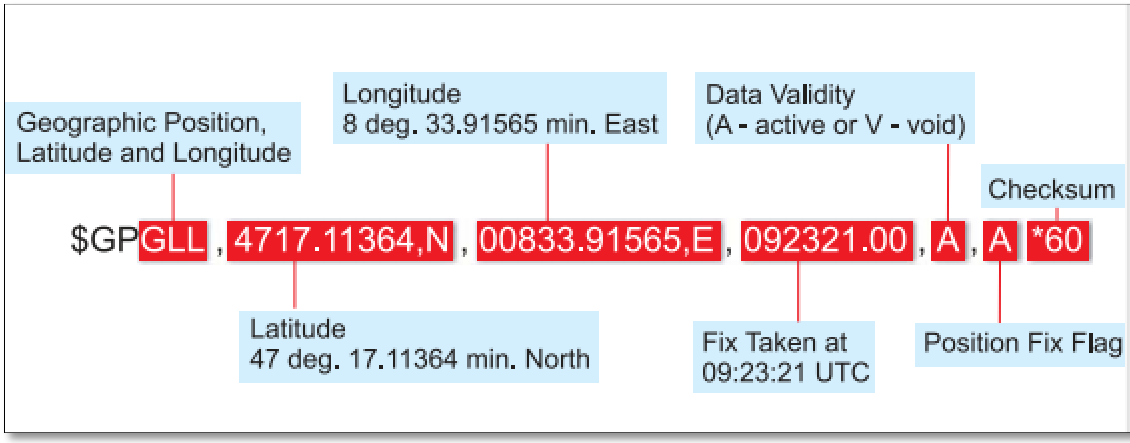


Figure 3.2.6.A NMEA Example

To connect the GPS to the microcontroller it is necessary to provide two lines, RX and TX. The RX line is used for sending data from a GPS receiver to the microcontroller, while the TX line is used for sending commands from the microcontroller to the GPS receiver. Most GPS receivers require a power supply of around 3V, since other parts on the boat will require more voltage, it will be necessary to use a voltage level translator.

The GPS signal contains three different bits of information. These are as follows: a pseudo random code, almanac data and ephemeris data. The pseudo random code is an I. D. code that identifies which satellite is transmitting the information. Almanac data is data that describes the orbital courses of the satellites. Every satellite will broadcast almanac data for every other satellite. The GPS receiver uses this data to determine which satellites are the closest. It can then determine which satellites it should track. With Almanac data the receiver can concentrate on the satellites it can see and ignore the ones that are too far or out of line of sight. Ephemeris data is data that tells the GPS receiver where each GPS satellite should be at any time throughout the day. Each satellite will broadcast its own ephemeris data showing the orbital information for that satellite only. Because ephemeris data is very precise orbital and clock correction data necessary for precise positioning, its validity is much shorter. It is broadcast in three six second blocks repeated every 30 seconds. The data is considered valid for up to 4 hours but different manufacturers consider it valid for different periods with some treating it as stale after only 2 hours.

There are many factors that need to be taken into account before selecting a GPS receiver. These factors are size, update rate, power requirements, number of channels, and accuracy. Most GPS receivers are very small, so size should not be a problem. The boat will have plenty of space but the smaller the better. The standard update rate is 1Hz (once per second) which will be more than enough for this project. Depending on the microcontroller that is picked, the update rate might have to be staggered so that the microcontroller is not overwhelmed with NMEA sentences. GPS receiver use around 30mA at 3.3V, this needs to be taken into account during the power supply construction. Number of channels affects the time it takes the GPS receiver to first find which satellites to connect to, 12 or 14 channels should work just fine for tracking. Most GPS have an accuracy of about +/- 10 meters. This would not be ideal, as a gap of 10 meters could cause the W.A.R. to crash onto shore. Some GPS have an accuracy of +/- 3 meters and are relatively inexpensive. These would work for the W.A.R. however there exists another method to raise the GPs accuracy even further.

This method is called differential GPS (DGPS) and is used to obtain a much higher accuracy than just using a regular GPS by itself. Essentially, DGPS requires an additional receiver to be fixed at a known location nearby. Coordinates obtained by the fixed stationary receiver are used to correct the coordinates recorded by the moving unit. Under the ideal conditions and best implementation, an accuracy of 10 centimeters can be achieved using DGPS. An example picture of DGPS is shown in figure 3.2.6.B below.

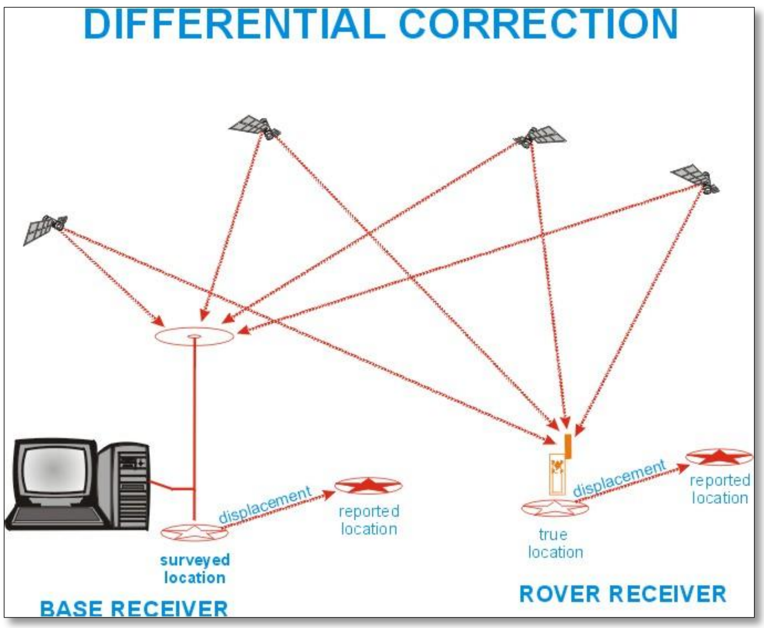


Figure 3.2.6.B Differential GPS Example

3.2.7 Wireless Data Transmission Module

To transmit the water quality data, we researched Bluetooth, WLAN, and ZigBee options. With a Bluetooth module we can use a transmit data with extremely low power usage. The new Bluetooth 4.0 standard (Bluetooth LE) can transmit data up to 50 meters and using up to 20 mA. Compared to a Classic Bluetooth which can transmit data up to 100 meters and using up to 30 mA. Due to the different classes of Bluetooth we can have low power transmission that won't drain out batteries. Some downsides of using Bluetooth are the range we can transmit data. Using Bluetooth LE, the module can only transmit data 50 meters (160 feet) away. Classic Bluetooth doubles the transmission range to 100 meters (330 feet). Another downside of Bluetooth is the bandwidth channel that Bluetooth uses. Currently Bluetooth has a bit rate of ~2.1 Mbps.

For the WLAN (Wi-Fi) option, we can increase the transmission range. With the IEEE 802.11n protocol we can transmit data outdoors with a max range of 250 meters (820 feet). This allows us to sample water quality on large bodies of water without worrying about losing connection and data corruption. Another upside to Wi-Fi is the transfer rate. Depending on which 802.11 protocol is used the bandwidth can vary from 11 Mbps (802.11b) to 600Mbps (802.11n). A downside of using WLAN though is that it has fairly high power consumption. As you increase the distance the data must travel the power consumption will also increase to get the data to the receiver. Depending on the distance and obstacles in the area the power to transmit data can vary.

The last option we research is the ZigBee standard based off the IEEE 802.15.4 standard. ZigBee is a great option for us because it is fairly easy to use and can create small personal area networks (PANs) using very little power. A typical ZigBee standard module has a max range of 100 meters which is not sufficient for our design. But an adoption of the ZigBee standard is XBee modules which are the most popular form of point-to-point data transmission. These XBee modules keep the same standard as ZigBee but improve on many factors like range and power consumption. The XBee modules can transmit data from 100 meters to 4000 meters which is great for our design. The XBee modules are also easy to setup for communication as the transmitter and receivers only need to know the other modules serial number and PAN ID to transmit/receive data. A downside the XBee modules though is the bandwidth and power consumption. The highest bandwidth it can support is 250Kbps considerably lower compared to Bluetooth and Wi-Fi. For the power consumption it can vary depending on which module we purchase but for our design we plan on using a module that can transmit at least 1500 meters which will require about 215mA at 3.3V. Table 3.2.7.A shows all three wireless options and their technologies.

Properties	Bluetooth	WLAN (Wi-Fi)	ZigBee (XBee)
Range(max)	100 meters	820 meters	1500 meters
Network Topology	Ad-hoc, small networks	Point to hub	Ad-hoc, peer to peer, or mesh
Power Consumption	Low	High	Low
Frequency	2.4 GHz	2.4 / 5 GHz	2.4 GHz
Bandwidth	Low (~2.1 Mbps)	High (~11 Mbps; dependent on which 802.11x protocol)	Low (250 Kbps)
Cost	Cheap	Expensive	Expensive

Table 3.2.7.A Wireless Technology Comparison

3.2.8 Photovoltaic (PV) cells

(1)
Monocrystalline - Typically, the top layer of the cell has a slight negative charge and the rest of the monocrystalline cell has a positive electrical charge. The cell is usually connected to a base called the backplane, which is typically made of metal and is useful when physically reinforcing the cell and providing electrical contact at the bottom. The cells are cut from a single silicon crystal ingot. To make the ingot, silicon is purified, melted and crystallized. The ingot is then sliced into thin wafers that are then cut to make individual cells. The cells are very fragile and must be mounted in a rigid secure frame to protect them and prevent them from breaking. They are the most efficient but the most expensive out of all different photovoltaic cells. Monocrystalline cells have one solid color throughout the cell, usually black or blue. It’s important to note that temperature does affect the voltage of each individual cell.

Polycrystalline - The cells are cut from a block of silicon that, unlike monocrystalline cells, has a large number of crystals in the silicon block. Similar to the monocrystalline cells they are fragile and need to be mounted to a rigid protective frame. Polycrystalline cells have a random pattern of crystal borders instead of a solid color, like the monocrystalline cells.

Ribbon - The cells are manufactured by growing a ribbon from molten silicon instead of an ingot. The ribbon silicon cells possess an anti-reflective coating that gives them a prismatic rainbow appearance. All three types of referenced cells: monocrystalline, polycrystalline, and ribbon possess a distinct crystal structure.

Amorphous - The cell is produced by placing several very thin layers of vaporized non-crystalline silicon are placed on a wide surface. The surface that the silicon is deposited on is usually glass, plastic, or metal. The thin layer of silicon is flexible, therefore if placed on a flexible surface such as plastic it has the potential to be a flexible solar cell. Amorphous cells are the least expensive and least efficient. The amorphous cells are considered least efficient because they possess less than half efficiency of the amorphous, ribbon, and polycrystalline cells. One important thing to note is that their power output decreases dramatically, about 15%, over the first few months of initial exposure; however, after that period the power output stabilizes to a particular value. Most specifications sheets indicate a power output that is achieved after the stabilization period. The cells are typically made up in long rectangular sizes called strip cells. The strip cells connected in series make up modules.

Connection of Cells - Most cells produce a voltage of about half a volt, independent of the size of the surface area of the cell. However, the current does depend on the surface area of the cell: the larger the cell the more current it will produce. The cells and their electrical components are sealed between a top layer of glass or clear plastic and the lower level of plastic or/and metal. A set of these laid out cells is usually attached by an outer frame that increases mechanical stability. Each of these sealed cells is called a module. To provide adequate output voltage or current, the cells on a panel are connected in different ways called an array. To increase the output voltage the cells are connected in series and to increase the output current the cells are connected in parallel.

Reflectors and Concentrators - To increase the amount of solar energy that is hitting the solar panel reflectors and/or concentrators are often used as an aid in addition to photovoltaic cells to focus the sunlight to a specific area. Reflectors are a good way to save money because they are much less expensive than photovoltaic cells. An important aspect to take into consideration when using reflectors is that they can often block direct sunlight if not properly positioned. In addition to that, reflectors work best when direct sunlight is being focused to the reflector, therefore cloudy weather is a problem while using them. The physical dynamics of the reflectors themselves cause a wind loading resistance that becomes problematic in a portable design. Concentrators contain lenses or parabolic reflectors that focus light from a larger area, sunlight from the sun, to a smaller area, the photovoltaic cell. Unlike reflectors, concentrators have are relatively expensive cost with respect to the photovoltaic cells, and also increase the temperature of the modules which unless cooled properly, delivers lower output voltage.

3.2.9 Rechargeable Battery

A battery is composed of many individual cells. A cell is considered the smallest unit in a battery that is capable of generating voltage. The cells are composed of plates and insulators. The plates have two opposite polarities, and are composed of the conductive grid and active material. A pair of positive and negative polarity plates are held together, covering a separator, a type of insulator. The electrolyte is a source of free electrons, which are waiting to be liberated by a chemical reaction. A conductive charge escape path is created using grids and electrodes, which are part of each other due to the conductive welding process.

Lead Acid Battery- In a lead acid battery the electrodes and grids are made from lead. A chemical additive, usually calcium, is added to the battery to give it mechanical strength. The active material is a special formulation that varies with every battery manufacturer, of lead oxides. The electrolyte in a lead acid battery is sulfuric acid. The advantages of a lead acid battery include: chemistry has been proven to work for over 140 years, they come in various sizes, available in sealed maintenance free form, and are mass produced. In addition to that, they provide the best value of power per kilowatt-hour, have the longest life cycle, and are the leading recycled battery. Low maintenance, there is no memory and no electrolyte fill. A strong disadvantage of a lead acid battery is that it is one of the heaviest of batteries. The battery accepts a very heavy initial charge quickly, however once the battery hits about 70-80% charging capacity, the electricity being forced in will eventually begin to decompose the battery. This process is called gassing and it can permanently damage the cells. Also, it allows a limited a limited number of full discharge cycles. Best suited for standby applications that require only occasional deep discharges.

Aluminum Air Fuel Cell - The fuel cell consists of an aluminum alloy anode which is placed in a saline or alkaline electrolyte that then reacts with oxygen. The chemical reaction that produces energy comes from the aluminum oxidizing, hence the name "Aluminum Air". A standard aluminum air battery cell consists of aluminum alloy plates and a cathode which is coupled by an electrolyte. The oxygen is sparingly served to the cathode as it is required. When the aluminum alloy is consumed during the electrochemical reaction, a new plate is then inserted and the chemical reaction resumes. Aluminum Air fuel cell is considered to be 75 times more energy dense than lithium ion cells, which makes it less heavy and more portable. Disadvantage: difficult to find one for purchase online and the ones available are significantly more expensive.

Lithium Ion - A low maintenance battery that has no memory and no scheduled cycling is required to prolong the battery's life. This battery contains high energy density. The self-discharge is less than half when compared to the nickel-cadmium. A disadvantage of the lithium ion battery is that it is fragile and would require a protection circuit that would limit the voltage and current to maintain safe operation. The maximum charge and discharge current is limited on most packs to 1C and 2C. It is more expensive than most rechargeable batteries. Also, there is no official established recycling system for lithium ion batteries.

Nickel Cadmium - Uses nickel oxide and metallic cadmium as electrodes. Has been in commercial use since the 1950's. Nickel Cadmium battery is a low maintenance sealed battery that does not expel any gasses and achieves full charge quickly. In addition to that it has a long lasting storage life and is able to last over 500 charge/discharge cycles. It is able to operate for a large temperature spectrum, -40 to 60 degrees Celsius, and maintains good performance after a long storage period. Usually encased in a metal casing, which ensures ruggedness. It is about five times more expensive than lead acid batteries. The nickel cadmium battery material is very toxic and the recycling system for this battery is very limited. Also, if left inactive for some time it might be necessary to recharge it before use because it is prone to self-discharge.

Nickel Metal Hydride - Higher energy density than the Nickel Cadmium, however its life cycle is dramatically reduced. Heavy load and high temperature degrades the batteries life cycle. During charge, Nickel Metal Hydride generates a significant amount of heat and requires longer charge time than the Nickel Cadmium. Strong disadvantage: this battery requires full discharge to prevent crystalline formation. Environmental benefit: contains no toxic materials. Often found in mobile phones and laptops.

Lithium Polymer - Have three things that make them perfect for RC vehicles. They are lightweight and can be made into almost any shape and size. They have a large capacity meaning that they hold a lot of power in little packages and they have a very high discharge rate to power even the most demanding motor. However, they are more expensive than other rechargeable batteries; they don't last as long and can burst or catch fire if mistreated. Over the years, safety has been improved for these batteries and they've become more resistant to overcharge and embody smaller probability of electrolyte leakage.

Nickel Zinc - Similar to the Nickel Cadmium battery because both use an alkaline electrolyte and a nickel electrode, however they differ in voltage. Some of the Nickel Zinc cells are available in AA cells. Low cost with respect to other batteries. Provides higher output and a practical, -20 to 50 degrees Celsius, temperature range. Nickel Zinc battery does not contain any toxic materials and has various recycling programs.

Sodium Sulfur - Contains a sodium anode and sulfur cathode. The sodium and sulfur must both be a liquid and the electrolyte must be at a temperature (very hot between 400-700 degrees Celsius) at which it can work as an ionic conductor. A common structure for the Sodium Sulfur cell is two concentric tubes. The inner tube contains one electrode and the outer tube contains aluminum which has the other electrode. It's important to note that the cells are completely enclosed and do not emit any gases. The cells must be at their operating temperatures otherwise the startup time of the battery is severely extended. Sodium Sulfur battery has a limited shelf life that ranges from 2-5 years. A common failure of this battery is due to electrical shorts which are caused by the corrosion of the insulators. Once the insulators begin to corrode, the battery begins to self - discharge.

3.2.10 Maximum Powerpoint Tracking

A photovoltaic cell will produce maximum current when (ideally) there is no resistance in the circuit. Therefore the maximum current would be passing through a short circuit, and containing zero voltage: this point is demonstrated in Figure 3.1 below. Maximum voltage, also called the open circuit voltage, occurs when there is a break in the circuit. The open circuit is essentially infinitely resistant and not allowing any current to pass through. The power output relationship is directly dependent on the voltage and current, confirmed by equation P=IV. Hence, the maximum power point is where the maximum current and maximum voltage point intersect. This point is called Maximum Power Point on the graph in Figure 3.2.10.A below.
(1)

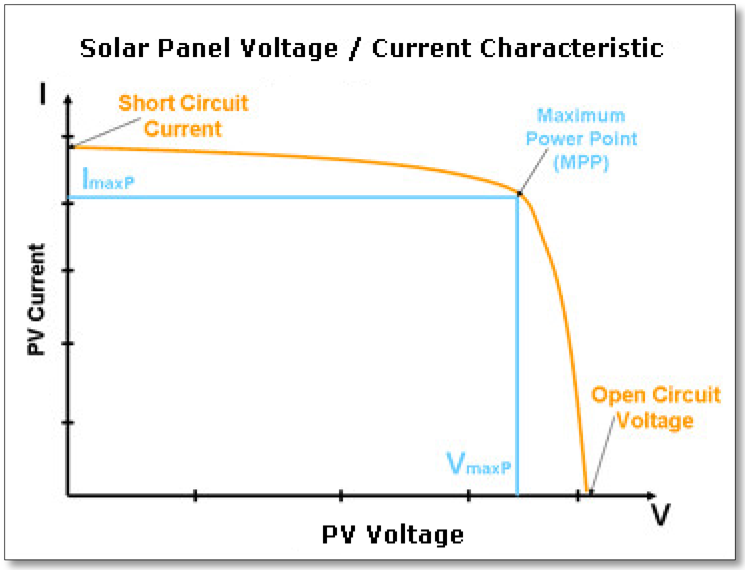


Figure 3.2.10.A: How the MPPT finds the Maximum Power Point

3.2.11 Microcontrollers

The brains of W.A.R. will be from our microcontrollers. We will use two microcontrollers, one of which will be responsible for the navigation/movement of W.A.R. and the other will receive/transmit the water quality data. The criteria we used in selecting the correct microcontroller was low power consumption, architecture, development, and ease of compatibility with the water sensors. The two microcontrollers that we researched are shown below in Table 3.2.11.A with a general description of each microcontroller.

Microcontroller	MSP430G2553	Atmega328P
Speed	16 MHz	16 MHz
Data Bus	16-bit RISC	8-bit RISC
RAM	512B	2KB
Storage	16KB	32KB
Digital I/O Channels	8	14
Analog I/O Channels	8	6

Table 3.2.11.A

Power Consumption

Many microcontrollers in today's market are designed to be ultra-low power consumption. We want to focus on using a microcontroller that uses low power due to the fact that our entire system will be powered by solar panels connected to rechargeable batteries. Two very popular microcontrollers that are used in the industry and hobbyist community that focus on low power consumption are Texas Instruments MSP430 and the Atmel Atmega328P. Currently the MSP430 power consumption is one of the best in the industry using only 230µA in active mode and 0.5µA in an idle state. The Atmega328P though using more power is still a very lower power microcontroller using 0.2mA in active mode and 0.75µA in a power-saving mode. To make it easier for the engineers to implement a low power system each of these microcontrollers have several low power modes of operation. These low power modes operate by turn off different features that made not be necessary for the task the engineering is using the microcontroller for.

Architecture

When it comes to which architecture to use we need to look at RISC vs. CISC and 8-bit or 16-bit instructions. The choice of determining which instruction set to use, reduced instruction set computing (RISC) versus complex instruction set computing (CISC), should play a small factor in terms of designing W.A.R. Most microcontrollers on the market today use RISC due to the fact that they are programmer friendly by allowing the use of high-level programming languages, use less transistors due to the fact they don't have complex instruction decoders, and are low power. As for 8-bit or 16-bit instruction size, either of these will work for our design since do not need high processing power or performance.

Development

For designing W.A.R. we will need a development board for the microcontroller. Both Texas Instruments MSP430 and Atmel Atmega328P have cheap development board for industry and hobbyists. The MSP430 has the MSP430 Launchpad which features on-board emulation for programming, push buttons and LEDS, along with other connectors for development. The Atmega328P has the Atmel AVR Dragon for development, but a better and cheaper option for developing the Atmega328P is the open-source microcontroller the Arduino Uno.

The Arduino Uno features multiple digital and analog input and output pins, USB connection, reset button, LEDs and more. One big advantage of the Arduino Uno for development is the huge online Arduino community that continues to grow. With such a large community there is a plethora of information for engineers to help them with their designs. Using the Arduino also allows us to use the extensive Arduino libraries to integrate components with the Atmega328P.The benefit of both MSP430 Launchpad and Arduino Uno is that both development boards are low cost. The MSP430 retails for $9.99 and the Arduino Uno retails for $29.99.

Compatibility

The last criterion in selecting our microcontroller is the ease of compatibility to the water quality circuits. Both the Texas Instruments MSP430 and Atmel Atmega328P can support the water quality circuits because all it needs is a TTL RS-232 line for communications. Both microcontrollers have one UART line which is sufficient for our design as we will be using a multiplexer to connect each water quality circuit. An advantage with the Atmega328P though is that it is used on the Arduino Uno which has direct support from the manufacturer of the water quality sensor circuits due to the large hobbyist community supporting the Arduino.

3.2.12 Autonomous Motor Control

The W.A.R. will move autonomously after the user has inputted a GPS coordinate or series of GPS coordinates for the robot to follow. These coordinates will be transmitted wirelessly via a method to be further discussed. The navigation microcontroller will then turn on the motor and turn the rudder to the appropriate position. The navigation microcontroller will also regularly receive GPS latitude and longitude coordinates from the GPS receiver that is on the boat. It will then compare the two coordinates and continue to move the boat until the two coordinates match.

In order to make the W.A.R. move we will need to use an RC servo. An RC servo is used to convert an electrical signal into polar or linear movement. The vast majority of RC servos are composed with the same blocks. The controller circuit**:** This is the "brain" of the Servo. This circuit is responsible to read the user's input signal and translate it into a motor revolution in such a way, that the drive shaft will be rotated to the desired position. The feedback potentiometer**:** The shaft of the potentiometer is attached to the drive shaft of the servo. When the drive shaft rotates, so does the potentiometer. In that way, each and every rotation angle of the drive shaft, corresponds to a different resistance of the potentiometer. By reading the potentiometers' resistance, the controller is able to know the exact angle of the drive shaft of the servo. The motor**:** This is usually a small high speed DC motor controlled by a H-bridge circuit attached to the servos' controller. The gearbox**:** The gearbox will drive the motor's revolution to the drive shaft. Also, the rpm will be significantly reduced and the torque will be increased. The torque is one of the main characteristics of RC servos. The drive shaft**:** When all of the above operate in perfect harmony, the drive shaft will be rotated with accuracy to the user's requested angle. Below is a block diagram of a standard RC servo.

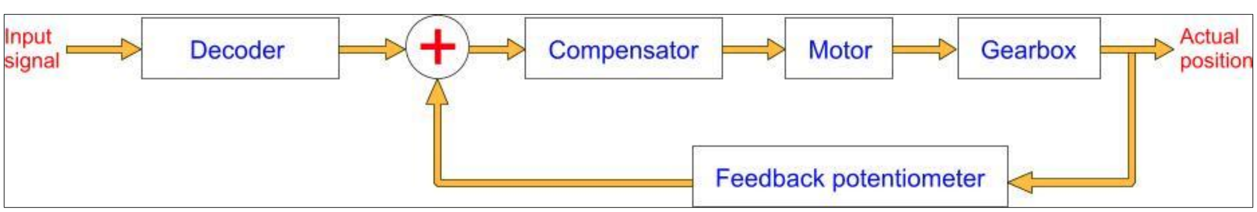


Figure 3.2.12.A - Block Diagram of RC Servo

However, some modifications will have to be made in order for the servo to work with our microcontroller and not a remote. All servos come with three wires: A ground which is usually brown or black, red which is for power and is typically between 4.8V and 6V, and an orange/white/yellow which is the signal wire and typically between 3V to 5V. While the red and black wires provide power for the servo, the signal wire is used to command the servo. The idea is send an ordinary logic square wave at a specific wavelength and the servo gets a particular angle. To replicate what the RC receiver does, the microcontroller must bring high a digital port, wait between 1 to 2 milliseconds then bring low the same digital port. This cycle should happen about every 20 milliseconds.

The W.A.R. is not required to move very fast as it will be weighed down by the PV cells, batteries and other electronics that will be placed on it. However, it still has to be able to move and not be pushed aside by any disruptions in the water. There are many RC motors that will satisfy this need.

However, before the motor can be selected, there are some terms that need to be defined, particularly the different types of motors, and the relevant units:

- **540 motors -** are the most common motor size for 1/12 and 1/10- scale electric vehicles.

- **550 motors -** are a slightly longer version of the 540 motor which is capable of delivering more torque and power without suffering from power loss.

- **Brushed motors -** utilize brushes rubbing against a commutator to transfer electrical current to create rotation

- **Brushless motors -** utilize a permanent magnet on the rotor and a series of coils to generate rotation. Brushless motor are more efficient than brushed motors and have no components can be worn down.

- **Closed end bell motors -** are brushed motors that are not designed to be readily serviced. They tend to have shorter life spans compared to open end bell motors due to the fact that they commutator and brushes cannot be easily cleaned or replaced.

- **Hand wound modified motors** - feature an armature that has the windings wound around the stack by hand. This provides a much tighter, more consistent and more efficient armature than machine wining and provides better overall performance.

To select the motor best suited for a hull it is important to know the hull size and amount of cells planned to be used. Size of hull will determine the size of motor needed to push the weight. Cell count will determine the wind (Kv) of motor needed. Hulls from 20"/55cm – 34"/86cm typically will use a 540 size motor 36mm Diameter by 50-75mm length Hulls from 34"/86cm – 40"/102cm + typically will use a motor with a diameter around or over 42mm and a length of over 65mm. To determine the best suited Kv for a motor, the cell count planned to be used is needed. Following this chart will provide a wide-ranging base for proper Kv selection. Kv is the rating of performance for brushless motors. The higher the Kv rating of a motor the faster it will be. Kv refers to the number of RPM a motor will produce for each volt of power input to it. For example, a 1000 Kv motor would produce roughly 6500 rpm at 6.5 volts.

LiPo Cell	Kv Range
2 cell LiPo	3000-5500Kv
3 cell LiPo	2000-3500kv
4 cell LiPo	1350-2700Kv
6 cell LiPo	900-1800Kv
8 cell LiPo	675-1350Kv
10 cell LiPo	550-1100Kv
12 cell LiPo	450-900Kv

Table 3.2.12.A - Shows Optimal LiPo Cells for a Specific Kv Rating

3.2.13 Robot Platform

For this project, some sort of platform is needed to house all the components of the robots. The platform must have room for all components while still being able to float. The platform shall be waterproof or made waterproof through outside means. This biggest difficulty in choosing a robot platform will be ensuring that platform will be able to stay afloat when all the components are integrated such as the power supply, PV cells and microcontrollers. Due to time and other constraints, it was decided that a pre-built platform would be used for this project. There are plenty of hobby stores/RC boat enthusiasts who would be able to provide an adequate platform can be obtained.

A three foot long RC boat frame would be perfect for this project. RC boats of this length are generally around $50 to $80 dollar depending on if they are used or not and if a motor/rudder is included. Ideally the boat frame that is ultimately chosen will be waterproof or easily made waterproof. While the sensors and circuitry should not fail when near water or exposed to small amount of water, the less water in the boat the better. Also, ideally the boat frame will require as few modifications as possible for this project. In other words the design of the frame should be as simple and efficient as possible. The frame will most likely look like the RC boat frame shown below in Figure 3.2.13.A.

Figure 3.2.13.A Shows the Boat Platform

3.2.15 74HCT4051 Serial Mux/Demux

We will be using two 74HCT4051 multiplexer to connect the water quality sensors and XBee Pro to the microcontroller. One HCT4051 will be used to connect all the RX pins to the microcontroller and the other HCT4051 will be used to connect the TX pins. This configuration will allow the microcontroller to communicate in both directions to all the water quality circuits and the XBee Pro. A more detailed schematic of this connection will be covered in the Project Hardware and Software Design details portion of the report. Below in Figure 3.2.15.A we show the pin layout of the HCT4051 and how the connection could be made.

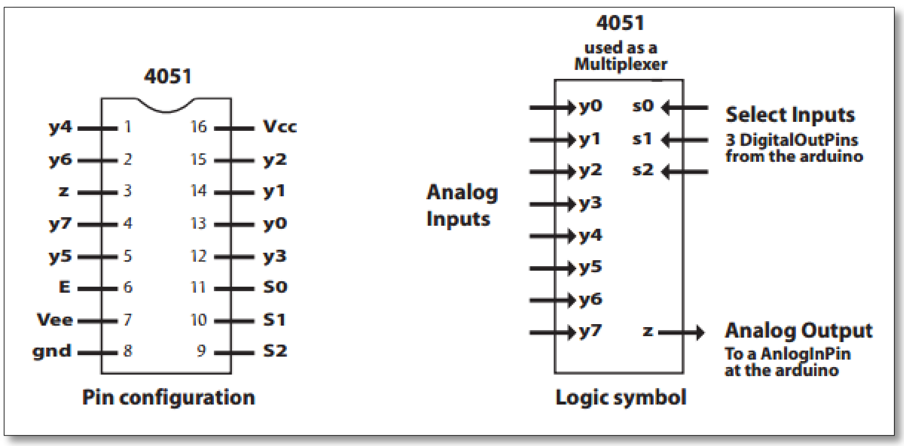


Figure 3.2.15.A HCT4051 Pin Layout and Logic Symbol

3.2.16 Power Supply

<u>AC-DC Power Converter</u>

Most power supplies are designed to convert from high AC voltages to low DC voltages, which are generally suitable for electronic devices to use. To build an AC to DC converter, its process will be broken down into four different parts, as shown in Figure 3.2.16.A below.

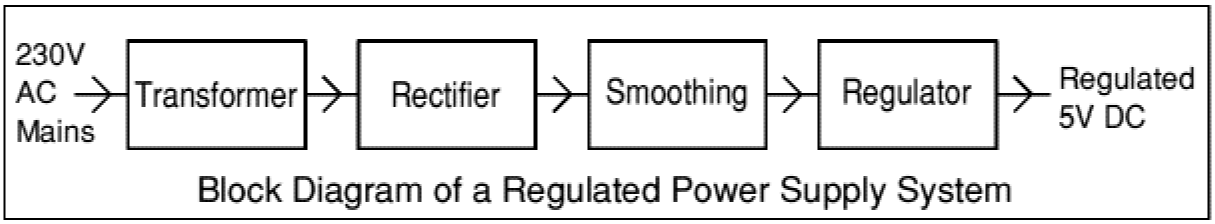


Figure 3.2.16.A Power supply that converts AC to DC

The first block labeled “Transformer” is responsible for either taking the high solar generated voltage and stepping it down to a lower AC voltage, or taking a low solar generated voltage and stepping it up to a higher AC voltage, both with very little power loss.
The second block labeled “Rectifier” is responsible for converting the AC to DC. There are several ways to construct a rectifier. First way involves building a bridge rectifier. The second way involves only two diodes (as opposed to four in the previous configuration). However, this configuration requires a center tap transformer which reduces power efficiency. Since diodes are relatively cheap, it’s more practical and power efficient to use the bridge rectifier configuration.

The following block is called “Smoothing” which acts like a reservoir that is accessed when the supplied DC voltage from the rectifier is falling. The smoothing effect is achieved by connecting an electrolytic capacitor to the output of the rectifier. The last block is called the “Regulator” which represents the voltage regulator. The voltage regulator is responsible for maintaining a constant voltage level. An adjustable voltage regulator typically ranges from 1.2 to 37 DC volts. An important aspect to consider with the voltage regulator is whether or not to use the heat sink. If there is load to the regulators, then it will draw a load current that must flow through the regulator therefore heating it up. The extent to which the load current heats up the voltage regulator determines whether or not the heat sink option on the regulator is used.

<u>DC-DC converter</u>

A DC to DC power converter regulates the voltage prior to charging the battery, and it is also capable of being a step up or step down converter. A step up converter would increase the input voltage and generate a higher output, whereas the step down converter would have the input voltage decreased therefore generating a lower output, relative to the input. The W.A.R. design contains two DC to DC step up voltage regulators. The first step up voltage regulator will convert 3.7 volts to 5 volts, which will power the a microcontroller, motors, and the water sensors. The second step up voltage regulator will convert 3.0 volts to 3.3 volts and will power the XBee Pro communication system.

The considered DC to DC converters for the first system are compared in the Table 3.2.16.A below.

Part Model	LM4510	LTC3525
Manufacturer	Texas Instruments	Linear Technology
Input	2.7V to 5.5V ● 18V@80mA from 3.2V ● 5V@280mA from 3.2V	-0.3V to 6V ● 3V@65mA from 1V ● 3.3V@60mA from 1V ● 3.3V@140mA from 1.8V ● 5V@175mA from 3V
Output	5V and 18V	Fixed Voltages: 3V, 3.3V, or 5V
Shutdown Current	0.002μA	Less than 1μA
Peak Efficiency	85%	95%
Layout	10-Pin 3mm	6-Pin 1mm

Table 3.2.16.A DC-DC Power Converter for First System Comparison

The two DC to DC step up converters that would suit the best for the W.A.R. project are the LM4510 and LTC3525 parts, which are compared in the Table 3.2.16.1 above. Both of the step up converters convert the desired voltage input to 5 volts, which is the exact amount needed to power the two PCBs. The LTC3525, however, has a couple of additional input ranges which would make the solar panel design (which generates the DC power) more flexible. LM4510 has one of the lowest shut down currents among many step up converters, including the LTC3525, which will be not essential but overall beneficial for the W.A.R. design. The high peak efficiency percentage and smaller dimension of the Linear Technology LTC3525 step up converter makes it more favorable than the Texas Instrument LM4510 step up converter. However, overall circuit protection is extremely important and the LM4510 offers a true shutdown function that ensures input and output isolation and a thermal shutdown protection which would shut down the device if it exceeded 302 degrees Fahrenheit.

The DC to DC step up converters considered for the second system, will power the XBee Pro Communication System. The selected by TI WEBENCH software step up voltage regulators are plotted on the Efficiency vs. Size plot in Figure 3.2.16.B below.

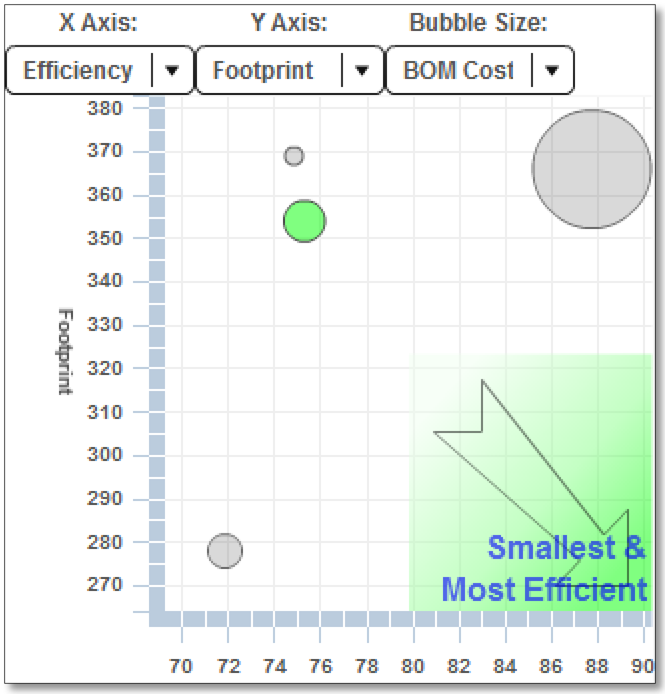


Figure 3.2.16.B: WEBENCH Plot Demonstrating the Applicable Step Up Converters

Both of the components the LM3478 and the LM25118 fit the requirement to power the XBee Pro which is displayed in Table 3.2.16.C below.

Vin Min	3V
Vin Max	10V
Vout	3.3V
Iout	0.215A

Table 3.2.16.C: Requirements for the XBee Pro Communications

Each of the step up converters are compared in the Table 3.2.16.D below.

Part Model	LM3478	LM25118
Manufacturer	Texas Instruments	Texas Instruments
Efficiency	75%	88%
BOM Cost	$2.36	$3.12
BOM Size for Application	354mm^2	366mm^2
I-out Max	20A	20A

Table 3.2.16.D: *DC-DC Power Converter for Second System Comparison*

Both of the components have available WEBENCH tools such as: Circuit Calculator, Electrical Simulation, and Schematic Export, which will be useful while implementing the testing protocol and troubleshooting. When comparing the LM3478 component with the LM25118, it is apparent that the higher the desired efficiency percentage the higher the cost of the component, hence the $0.76 difference for 13% efficiency. However, after reviewing the specification sheets for both of them its apparent that the LM25118 component is much more complex in design therefore the size for all of the additional materials needed to create a step up voltage regulator is slightly larger (in area). To be more specific, the difference in BOM size for the step up voltage regulator application is $12mm^2$.

3.2.17 Charge Controller

A charge controller is essential especially if the battery is charged with solar energy. If the battery continues to charge after it is already full, it can potentially become damaged harming it's performance. A charge controller will prevent the battery from being overcharged, as well as not allowing any current to drain out of the battery while it's not being charged. It's important to make sure that the input current to the charge controller does not exceed what the controller can handle. A charge controller can either be built from scratch or bought ready to use. To build a charge controller from scratch a printed circuit board would need to be built or ordered through a manufacturer.

The charging voltage of a battery is temperature dependent. Hence, the colder the temperature the higher the charging voltage needs to be. If the charge controller was built from scratch a temperature sensor would need to install or the user could manually adjust the controllers activation point. If the battery is mostly warm and well sheltered, small temperature changes won't affect the charging voltage. The overall potential cost to build a charge controller from scratch is “less than $20.”

Already manufactured lithium ion battery charge controllers are compared in Table 3.2.17.A below.

Part Model	LM3420	LTC4050
Manufacturer	Texas Instruments	Linear Technology
Input	4.2V	4.5V - 10V
Current Detection Output	N/A	C/10
Operating Temperature	-40 to 257 degrees Fahrenheit	-40 to 185 degrees Fahrenheit
Battery Drain Current	0.1µA	5µA
Layout	5-Pin 3.2 x 3.2mm	10-Pin 3.0 x 3.0mm

Table 3.2.17.A Compares the LM3420 and LTC4040 Charge Controllers

The Texas Instruments LM3420 lithium ion battery charge controller comes in three different fixed voltage charging options: 4.2, 8.2, 12.6, 16.8V. The absolute maximum input voltage the TI charge controller is able to accept is 20V, and the maximum output current it is able to generate is 20mA. Its operating temperature ranges from -40 to 257 degrees Fahrenheit, which certainly can handle some of the hotter outdoor temperatures that W.A.R. would be placed in. However, when all of the electronics would be placed in a small tight space, heat could potentially become an issue, therefore testing and measuring the maximum internal temperature of all of the electronics turned on is essential. The charge controller needs to be a very compact size since all of the electronics will be stored inside the boat structure; the LM3420 is 3.2mm x 3.2mm which is certainly compact enough to fit inside the structure.

The Linear Technology LTC4050 lithium ion battery charge controller is able to power a 4.1V and 4.2V battery. The charge controller voltage input is between 4.5 and 10V, the absolute maximum the controller can handle is a 12V input supply voltage. If the supply voltage is removed the charge controller automatically enters a low quiescent current sleep mode, which drops the battery drain current to 5µA. It has an internal comparator that detects the near-end-charge condition, which is C/10, while a programmable timer sets the total charge time. Once the battery is discharged, or a discharged battery is connected, the charge controller begins a new charge cycle. Also, if the battery cell voltage drops below 3.88 volts, a new charge cycle begins. The operating temperature for this charge controller varies from -40 to 185 degrees Fahrenheit. The dimensions for the controller are 3.0mm x 3.0mm. It contains a ten pin connection.

In addition to having a separate charge controller chip like the ones mentioned previously, LTC4050 and LM3420, another option is to purchase a battery with the charge controller already installed. The Tenergy Lithium Ion battery has a PCB charge controller that monitors the batteries' charge and prevents it from being overcharged. The battery and the integrated PCB design of the Tenergy battery is displayed in the Figure 3.2.17.A below.

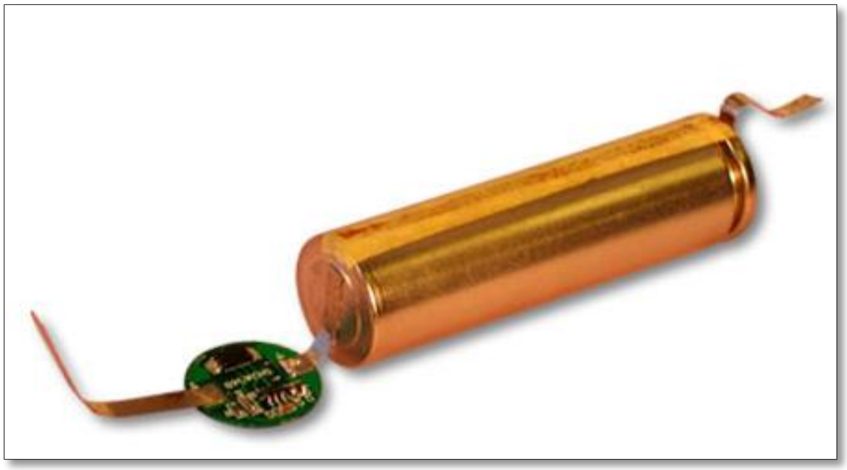


Figure 3.2.17.A Tenergy 30006 Lithium Ion Battery with a Charge Controller

The Tenergy battery is not designed to be in a battery pack. The battery specifications are displayed in the Table 3.2.17.B below.

Parameter	**Value**
Capacity	Nominal: 2600mAh Minimum 2450mAh
Dimensions	Diameter 18+/-0.2mm Height 67+/- 0.2mm
Weight	46g
Internal Impedance	180mΩ
Cycle Life	More than 500 cycles
Charge Characteristics	Current = 0.5C Voltage = 4.2V End Current = 0.01mA
Discharge Characteristics	Current = 0.5C End Voltage = 3.0V

Table 3.2.17.B Tenergy Lithium Ion Battery Specifications

If the Tenergy 30006 3.7V Lithium Ion battery was to be chosen for the W.A.R. design it would be able to power the XBee Pro communication system for at least 11 hours. Also, another Tenergy battery would be able power the motors, sensors, and the microcontroller on the second platform for at least one full day, 24 hours. The power estimations are calculated using all ideal conditions, when the design will be tested in the actual operating conditions, slightly different

results are expected. The battery will be exposed to high temperatures; therefore some loss in battery efficiency is expected.
The internal PCB protection protects the battery for under voltage at 2.5V and over voltage at 4.25V, more specifications about the PCB are displayed in the Table 3.2.17.3 below.

Parameter	**Minimum**	**Typical**	**Maximum**	**Unit**
Operation Voltage	1.5	N/A	10	V
Excess Charge Detection Voltage	4.2	4.25	4.3	V
Excess Charge Delay Time	61	77	93	mS
Excess Discharge Detection Voltage	2.437	2.5	2.563	V
Excess Discharge Delay Time	7	10	13	mS
Consuming Current	N/A	3	6	μA
Standby Current	N/A	0.3	0.6	μA

Table 3.2.17.C The Internal Charge Controller PCB Specifications

3.2.18 Capacitors

Tantalum Capacitors - Composed of a tantalum center section which is covered by tantalum peroxide. Comparing to other capacitors, these are the smallest, lightest, and the most stable. They have a relatively high volumetric efficiency, that is (capacitance*maximum_voltage)/volume. Tantalum capacitors have incredible frequency characteristics, for example they have ten times better equivalent series resistance than an aluminum electrolytic capacitor. They possess very low electrical leakage. In addition to that, these capacitors are very reliable while being used for long periods of time and do not lose their performance efficiency over time. Lastly, tantalum capacitors have a very vast operating temperature range which is between -55 to 125 degrees Centigrade.

Ceramic Capacitors - Ceramic capacitors contain no polarity, therefore minimizing circuit design errors. They also work well in areas where very low, less than 1 microfarad capacitance is needed, however when the capacitance above that is needed tantalum capacitors work best. Ceramic capacitors are able to pick up mechanical vibrations, therefore interfering with the signal and sometimes even producing a voltage. They are not constructed as a coil therefore they contain a low inductance and perform well in high frequency applications.

Aluminum Capacitors – The capacitor is composed of two aluminum foil strips, with a piece of paper that is soaked in electrolyte solution between them. They are one of the largest capacitors on the market, in terms of storage. Aluminum capacitors are able to work in voltage ranges from 10V to 100V. These capacitors have relatively high leakage rates which makes them undesirable for high frequency AC coupling applications. In addition to that, aluminum capacitors have a high tolerance range +/- 20% which makes them unreliable in applications that require precise accuracy.

3.2.19 Compass

After the GPS module gets a lock on the vehicle's coordinates, the vehicle needs to know which way it is facing so when the needed heading is calculated the vehicle can easily turn to face the waypoint and steer relatively straight there. While the GPS module does give a heading value, this only occurs when the vehicle is moving forward and it isn't very accurate when the vehicle is turning, as it is not moving forward very much at all. If a good heading is not obtained, the vehicle will not know how much to turn. The compass can be used to obtain a heading from 0-360 degrees. From this heading, the needed heading between the vehicle's location and the next waypoint can be calculated. Since the vehicle that we are using is a boat, a compass with tilt compensation will be needed to account for wind or small waves. A compass without tilt compensation will give incorrect readings. The compass will need to be mounted away from the other electronics so that neither will interfere with the other's operations. A compass module comes with a ground pin, a VCC pin, a SCL pin, and a SDA pin. These are the pins that will be used for the I2C communications in the code.

3.2.120 Electronic Speed Control

An electronic speed control (ESC) is a circuit with the purpose to vary an electric motor's speed and its direction. It can also act as a dynamic brake. ESC systems for brushed motors are very different from brushless ESC systems and therefore are not compatible. This must be taken into considerations when purchasing the motor and the ESC. ESC is normally rated according to maximum current, for example 25 Amperes. Higher ratings usually imply a larger and heavier ESC which is a factor when calculating the mass of our boat. ESC's support nickel metal hydride, lithium ion polymer and lithium iron phosphate batteries. ESC designed for boats are waterproof. This means the motor and ESC must be cooled effectively to prevent burn outs in a matter of minutes. This can be achieved by circulating water run by the motor by negative propeller vacuum near the drive shaft input. Like cars, boat ESCs can be used to brake and go in reverse.

3.3 Methods and Architecture

This section will describe a high level design of the method and architecture of our system. It will show how important parts of each subsystem will be connected and help us determine final choices of each subsystem.

3.3.1 Software

Microcontroller Programming

The main method of programming on Texas Instruments MSP430 is Code Composer Studio (CCS) integrated development environment (IDE). It is based off of the open source software framework Eclipse. The IDE includes a set of tools used to develop and debug embedded applications. CCS includes compilers for all TI processors, debuggers, simulators, and many more.

For the Atmel Atmega328P we have two options for programming the microcontroller. We can use the Arduino IDE or Atmel Studios. Both environments have built-in support for all Atmel microcontrollers and allow the user to program in ANSI-C code.

The Arduino IDE is a very simple interface which holds the text editor, text console, message area, and menu bar. It is an extremely easy to use IDE since the Arduino platform is geared towards beginner hobbyist with no technical background. To code in the Arduino IDE, the programmer creates "sketches" in the text editor. The Arduino programs are written in C or C++ and the IDE comes with a software library called "Wiring" which is an open source prototyping programming language.

An alternative IDE used to program the Atmega328P is Atmel Studios. Atmel Studios is free of charge from Atmel and used to program all their Atmel ARM Cortex M chips and Atmel AVR microcontrollers. Atmel Studios has many built in open source libraries and with over 1600 examples projects to help the engineer. Atmel Studios is based off of Microsoft Visual Studios so the interface is similar for anyone who has used the software before.

Simulation Software

To properly test and predict the electronic components that will be used for the W.A.R. design a couple of different simulation software will be used. MultiSim will be used to simulate the circuit configuration. If any Linear Technology electronic components will be used in the design, then LTSpice software will be used to simulate the components' behavior and output characteristics. If a component will be from Texas Instruments then the software WEBENCH will be used to use to simulate its behavior as well as several additional components and how their values would affect the overall circuit configuration. While looking for and selecting the various electronic power design components for the project, the WEBENCH software is able to provide a several parameter comparison to accurately select the component.

3.3.2 Hardware

Solar Panel Connections

A typical solar panel configuration has 36 silicon cells connected in series to charge a 12 volt battery. If more current needs to be generated, the cells or the power array can be connected in parallel. Each cell provides roughly about 0.5 volt in direct sunlight. A standard battery that is often used is a 12 volt battery, which usually needs about 14 volts to charge. So, (36 cells)*(0.5V) = 18 volts total produced by 36 silicon cells. About 4 volts are left over from the 18 volt energy harvest that extra voltage is for when the solar cells heat up and are no longer entirely efficient. A typical solar cell is about 0.8x1.6".
Most of the solar cells are extremely fragile and some of them are paper thin. A protective frame is essential in preserving the solar cells. The frame needs to have a rigid bottom, to make sure that the connected solar cells do not move out of place and do not crack. Also, a glass or plastic top layer will be protecting the solar panel surface against debris. A group of PV cells connected in parallel or series is referred to as a module.

A potential challenge can arise while trying to enclose the properly connected PV cells. Since the solar cells are extremely fragile, and would be extremely sensitive to water damage, extra time and emphasis must be devoted to making the module properly sealed.

Lithium Ion Battery

Temperature is a vital factor to take into account when charging a lithium ion battery. Table 3.3.2.A shows the detrimental effects of having the battery be in high temperatures. A battery located in an environment above 86 degrees Fahrenheit, is considered to be at an elevated temperature. According to Battery University, keeping a battery at full charge in high heat is more stressful than cycling.

Temperature	40% charge	100% charge	
0°C	98%	94%	**Estimated recoverable capacity when storing Li-ion for one year at various temperatures**
25°C	96%	80%	Elevated temperature hastens capacity loss. The capacity cannot be restored. Not all Li-ion systems behave the same.
40°C	85%	65%	
60°C	75%	60% (after 3 months)	

Table 3.3.2.A Shows How Temperature Affect the Charging Capacity of a Li-ion Battery

To accurately predict the power lifetime the battery can last and will need to charge, to the desired level, its charge and discharge current need to be calculated precisely. In addition to that, the capacity of the battery must be known. The current, charge or discharge, is defined by the following equation:

$$I = M*C * n$$

Where “I” is the charge or discharge current, “M” is the multiple of “C”, “C” is the value of rated capacity, and “n” is the time in hours at which “C” is declared. It’s important to note that all of the values in this equation are the ideal values, which are rarely achieved due to the inefficiencies in the discharge cycles.

To properly charge a lithium ion battery, the user must take into account the four different types of charge stages: trickle and constant current charge, constant voltage, and charge termination. Charging above 1C does not increase the overall charge time for the batter, and should be avoided because it can permanently damage the battery. The different stages of recommended charging for a lithium ion battery are displayed in the Table 3.3.2.B

Stage 1	Trickle Charge	Restores charge to deeply depleted cells. When the cell voltage falls below 3V, the cell is then charged with a maximum of 0.1C.
Stage 2	Constant Current Charge	Once the trickle charge threshold is reached, the charge current is raised to a constant charging rate, between 0.1C and 0.2 C.
Stage 3	Constant Voltage	Triggered when the cell voltage reaches 4.2V.
Stage 4	Charge Termination	Not recommended to use trickle charge method at this point due to abrupt and severe damage that can be caused to the battery due to the plating of metallic lithium.

Table 3.3.2.B Stages of Charging a Li-ion Battery

3.3.3 Sensor Calibration and Connection

Before using the sensors on our design, each sensor has to be calibrated for accuracy. As each sensor is use repeatedly and exposed to different environments their accuracy will start fall. All water quality sensor manufacturers recommend that each sensor is calibrated by dipping the sensor into known solutions and measuring their outputs. Below are steps takes to calibrate a pH sensor for accuracy.

1. Vigorously stir the sensor in a rinse solution. Remove the sensor from the rinse solution and shake of any residual solution.
2. Place the sensor in known pH solution and vigorously stir.
3. Wait for the sensor readings to stabilize and then take the reading.
4. Repeat these steps for other known pH solutions to confirm for accuracy.

After each sensor is calibrated they will be connected to their respective circuits using a BNC connector. The sensor circuit will then send the data over to our microcontroller for transmission.

Our microcontroller will then select which sensor data it will transmit by using the 1 to 8 multiplexer on our board.

Due to the similarity of each water quality sensor the calibration will be similar to the pH one above.

3.3.4 GPS/Motor Integration

In order for the W.A.R. to have autonomous motion a GPS module must be integrated with the navigation microcontroller. The first task is to determine where the target point is relative to the boat. A vector to the waypoint can be calculated by subtracting the boat's position from the waypoint position. The representation of the GPS position will be latitude and longitude given in degrees, minutes and thousandths of minutes. The latitude and longitude coordinate can each be represented as a single floating point value. However, it would be easier to separate the coordinates into its three corresponding parts. The subtraction logic will be as follows: 1. Calculate the difference in thousandths of minutes term. If result is negative, add 1000 and subtract 1 from the minute term. 2. Calculate the difference in minutes term. If the result is negative, add 60 and subtract 1 from the degree term. 3. Calculate the difference in the degree terms. If the result is negative, add either 90 for latitude or 360 for longitude and set a sign flag. 4. Finally, combine the result from the three previous operations into one term. Once the required vector has been calculated it is up to the servo to steer the boat in the right direction until the coordinates of the boat equal that of the target waypoint. A relatively small error tolerance will be allowed and will not make a big difference for when the robot is out in a pond or lake.

The GPS module has several pins that must be connected to the navigation microcontroller. A description of the pins and their locations are shown below in Figure 3.3.4.A.

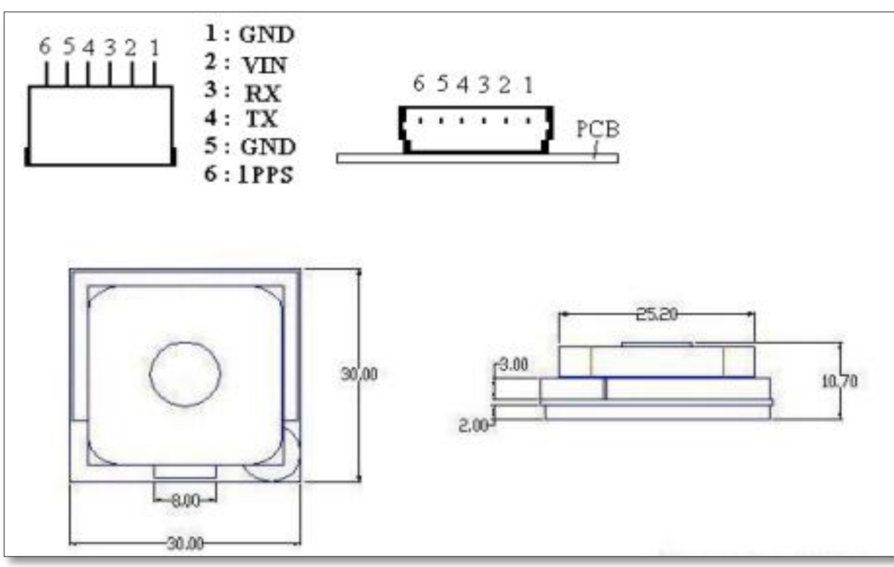


Figure 3.3.4.A - Pin Assignment for EM-406A

Pin Description:

VIN (DC power input) - this is the main Dc supply which should be about 4.5V to 6.5V DC input power.
TX - This is the main transmitting channel for outputting navigation and measurement of data to the user written software.
RX - This is the main receiving channel for receiving software commands to the engine board from the user written software.
GND - This provides the ground for the engine board.
IPPS - This pin provides one pulse per second output from the engine board that is synchronized to GPS time.

3.3.5 Protection against Electrostatic Discharge

Making sure to follow proper procedures while handling sensitive power modules and integrated circuits is essential. Electrostatic discharge can cause temporary damage by reducing its performance or even permanent failure in a power module or integrated circuit. Permanent damage can be done by ESD destroying a semiconductor junction or a connected metallization. Temporary or slight damage might not be visible at first, however the sensitivity of the circuit could be drastically affected which could cause eventual failure. Especially since electronic components are progressively decreasing in size, the ESD damage is more frequent than ever. ESD is the transfer of static energy between two objects at different potentials. MOSFET and IGBT power modules are among the components that are sensitive to ESD because the thickness of the gate isolation only amounts to ten nanometers, according to. The extent of how sensitive a component is depends on the input capacitance value. Therefore, the lower the capacitance is the higher the ESD risk. Also, humidity has an effect on ESD transfer: with higher humidity the component becomes less susceptible to ESD damage.

ESD most often occurs when any conductor, such as a human body, discharges to an ESD sensitive device. To prevent ESD damage, by grounding all bodies within one meter of the ESD sensitive component so that the electrostatic charge is able to escape. Another option for preventing ESD is to work on a conductive package, in which often the electronic components are already shipped in. The conductive sheet absorbs any ESD, preventing it to getting in the ESD sensitive component. The second method of working on the conductive sheet, is most likely what we will be using while assembling electronic components. Also, to prevent ESD damage an electrostatic field meter can be used to detect the static charges in the area.
Table 3.3.5.A shows the different ESD classifications, for different models, and their voltage ranges. This table is vital in providing the necessary emphasis on how important it is to take all necessary ESD precautions to prevent damage to the electronic components.

ESD Model	ESD Classification	Voltage Range
Human Body Model (HBM)	0	0V – 249V
	1A	250V – 499V
	1B	500V – 1999V
	1C	1000 – 1999V
	2	2000 – 3999V
	3A	4000 – 7999V
	3B	>= 8000V
Machine Model (MM)	M1	0V – 100V
	M2	101V – 200V
	M3	201V – 400V
	M4	401V – 800V
	M5	>800V
Charged Device Model (CDM)	C1	0V – 124V
	C2	125V – 249V
	C3	250V – 499V
	C4	500V – 999V
	C5	1,000V – 1,499V
	C6	1,500V – 2,999V
	C7	>= 3,000V

Table 3.3.5.A: Shows ESD Classifications and Voltage Range for Each ESD Model

3.4 Final Design Choices

3.4.1 Final choice for battery

The battery that was chosen for the W.A.R. design is two 3.7 volt lithium ion batteries. The lithium ion battery has several benefits to it, which are crucial in making W.A.R. successful. The battery is lightweight and is sold in various compact sizes especially when compared to the nickel cadmium battery. Because W.A.R. will be afloat on a lake, the amount of weight that the boat can support needs to be extremely conservative, hence, lithium ion battery alone on that fact is ideal for this design. Also, it has a minimal amount of self-discharge and the rest of the self-discharge will be taken care of by the charge controller. The lithium ion battery has no charge memory effect, which would typically cause a battery to hold less charge. One drawback of using this battery is the cost. It is one of the most expensive rechargeable battery choices, however when it is compared with all of the other benefits this battery holds it is clear that this is the battery for W.A.R.

3.4.2 Final choice for microcontroller

For our design we decided to choose the Atmel Atmega328P. We decided to use the Atmel Atmega328P as our microcontroller because of three reasons.

1. First, the group decided that we wanted to learn a new microcontroller and its architecture. In our classes we were mainly taught how program Texas Instruments MSP430. We all wanted to learn something new so we can be versatile in the industry.
2. Secondly the group wanted to use the Arduino IDE/software libraries and take advantage of the huge Arduino community that could help along the way with our design.
3. Lastly we chose to use the Atmega328P because the water sensors that we chose have direct support with the Arduino which is distinct advantage when it comes to designing our project.

3.4.3 Final Choice on Wireless Technology

From our research we believe that ZigBee (XBee) will be the best fit for our design, specifically we chose an XBee Pro Series 1 due to high data range. Reasons why we chose the XBee modules was for it long range and ease of use. If our project is put into a scenario where its range from the laptop can span over a huge lake then we want to make sure that we can still transmit water quality data. We also really liked how easy it was to set up the communication between W.A.R. and the PC. All we would need to do is configure each XBee module with the others serial number and PAN ID and they should be able to communicate. Below are specifications of the XBee Pro module we chose:

XBee Pro U.FL Series 1

- Outdoor RF line-of-sight Range: 1 Mile
- Power Consumption: 215mA @ 3.3V
- Frequency: 2.4 GHz
- Transmission Power: 60 mW
- Antenna: External/U.FL

Since our XBee Pro will not come with a built in antenna but comes with a U.FL connector, we will purchase an external antenna. We chose to go with an XBee Pro with an external antenna so we can get the best connection to our PC onshore. We will purchase a U.FL to SMA cable and then connect a 2.4 GHz RP-SMA antenna. This should allow us to get the best range compared to having a built in antenna that will have interference since it will be inside the RC boat.

3.4.4 Final Choice of Water Quality Sensors

For our sensors we decided to go with sensors from Atlas-Scientific. We chose to go with sensors from Atlas-Scientific because their sensors and embedded circuits have direct support with the Atmega328P. From our research, other water quality sensors made by other companies do not have hobbyist support and may not be able to connect to the water quality circuits. These water quality sensors are more geared towards scientists who have lab equipment to work from.

3.4.5 Final Choice of Water Quality Circuits

Due to the fact there are no other manufacturers of water quality circuits that are available to purchase and integrate into our design we will be purchasing these embedded circuits from Atlas-Scientific. These embedded circuits are simple to use, low powered, and will calculate the sensor data for us. The water quality circuits that we will be purchasing are:

- pH
- Oxidation Reduction Potential (ORP)
- Dissolved Oxygen (D.O.)
- Conductivity

3.4.6 Final choice for PV cells

The solar cells chosen for the W.A.R. design are the monocrystalline silicon cells. They are among the least expensive, by far and easily obtainable photovoltaic cells on the market. The ribbon photovoltaic cells are difficult to obtain individually (not in a module), which is important for our design since our PV cell layout will have to vary with the shape of the boat. Although the monocrystalline cells are extremely fragile, extra emphasis is made to enclose them properly and to purchase a few extra ones (just in case some of the cells break). Also, no reflectors or concentrators will be installed in the solar panel design because the efficiency of the solar module will not be increased significantly as it will impact the weight of the W.A.R. design. The solar cells will be attached to a firm, yet light material on the bottom and a clear plastic protection layer on top which will prevent debris damage.

3.4.7 Final for platform

Most RC boat hulls meet the criteria that we need for this project. We are putting off final selection as long as possible until we find a particularly good deal somewhere or until we are ready to start assembling the robot. RC hobby stores tend to sell the hulls for a little more than we had anticipated. Online stores tend to have sales or discounts however, and then we have to take shipping and handling into account. Ideally, a used boat hull from eBay or a similar website would be what we would settle for. Most new RC boats are streamlined speed boats that are very expensive. First we must ensure that all the components work and are integrated properly before we attach to them to the hull, so we can afford to wait on the purchasing of the platform. If nothing ideal shows up, then we will just settle for the cheapest RC hull that is approximately 2 to 3 feet long.

3.4.8 Final choice for DC to DC Step Up Converter

The chosen DC to DC step up converter for the first system is the Texas Instruments LM4510 part. This converter is the best for the W.A.R. design because it converts the necessary voltage input of 3.7 volt to a 5 volt output. It also offers an extremely low shutdown current. The converter also offers lots of flexibility with its input and output voltages, if the power intake design of the project is modified. Although, its size is slightly bigger than the other step up converter that had similar features, it’s still small enough (3mm x 3mm) to compactly fit into the boat design One of the major deciding factors in choosing the TI LM4510 step up converter is its thermal shutdown feature which would shut down the entire circuit if the converter reaches 302 degrees Fahrenheit. Since W.A.R. will already be exposed to hot outdoor temperatures, its vital for the internal electronics to be protected against heat damage.

The chosen DC to DC step up converter for the second system is the Texas Instruments LM3478 switching regulator which will be connected to be applicable as a step up voltage regulator. It is chosen because it is cheaper than the LM25118 buck boost controller and is a simpler design. A simpler design configuration indicates a smaller size dimension, and usually a cheaper alternative, which are essential qualities for the W.A.R. design.

3.4.9 Final Choice for GPS module

	20 Channel EM-406A SiRF III Receiver with Antenna	66 Channel LS20031 GPS 5Hz Receiver
Number of Channels	20(all-in-view tracking)	66 (22 Tracking, 66 acquisition)
Frequency	L1, 1575.42MHz	L1, 1575.42MHz
Sensitivity	159dBm	159dBm
Update Rate	1Hz	1Hz default, up to 10Hz
Hot Start	1s	<2s
Cold Start	42s	35s
Max Altitude	<18,000m	<18,000m
Max Velocity	<515m/s	<515m/s
Power Consumption	44mA	29mA
Power Input	4.5V - 6.5V	3V - 4.3V
Price	$39.95	$59.95

Table 3.4.9.A - Comparison the Two Considered GPS Units

We decided to go with the 20 Channel EM-406A SiRF III Receiver with Antenna over the 66 Channel LS20031 GPS 5Hz Receiver mainly because it is cheaper. The two modules are almost identical in every aspect the only difference beside the price is the power input. We are already making a voltage step up circuit for the 5V motor so if the GPS also uses 5V we can reuse our circuit instead of having to make another circuit. The SiRF III also interfaces well with the ATmega microcontrollers that we have selected for this project.

3.4.10 Final Choice for Charge Controller

The charge controller chosen for the W.A.R. design is the Texas Instruments LM3420 lithium ion battery charge controller. The 4.2V, one cell, charging controller is the best controller for the project because it is able to accept a very high voltage, up to 20 volts, which is significantly larger than the LTC4050 which accepts a maximum of 12V. Although we most likely will not utilize a voltage input range that high, it's good to have a large input voltage range because that way we have more design flexibility and design testing. The TI charge controller also offers a higher temperature tolerance than the LT charge controller, which is extremely important since all of the electronics will be in a small, tight, confined space. An important aspect to consider further in the testing phase of this experiment is the heat dissipation from all of the electric components connected together and powered on.

3.4.11 Final Choice for Motor

For the motor we decided to use the HobbyWing 2040 SL 4800kv Brushless Inrunner. This motor is priced $34.99 and has many desirable features. These include: a high Kv rating of 4800, max current of 20A, a no load current at 7.4V of 1.7A, a low internal resistance of 0.0399 ohms. The diameter is 20mm and the length is 40mm. The diameter shaft is 2.3mm and the length is 10mm. The motor weighs approximately 60 grams. Figure 3.4.10.1 shown below is the schematic of the motor.

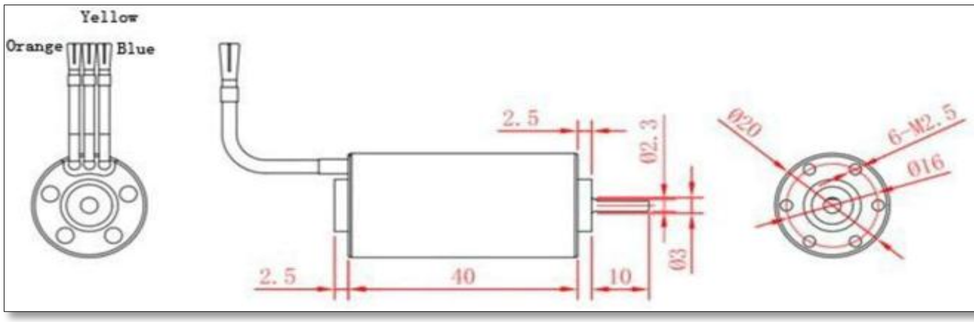


Figure 3.4.10.1 - Schematic of Brushless Inrunner Motor

3.4.12 Final Choice for Compass

The compass's main purpose is providing a better heading that what the GPS module already provides. While not absolutely necessary for our project it would be ideal to include one. Since it is not absolutely required but would be nice to include we have decided to go for a breakout board. This would make integration very easy while still providing the needed simple functionality. For the compass we decided to go with the LSM303DLMTR Breakout Board with tilt compensation. The board is a triple axis accelerometer combined with a triple axis magnetic sensor which gives all the data the microcontroller needs. The microcontroller must still calculate the tilt-compensated output. Figure 3.4.12.1 shows a schematic of the board.

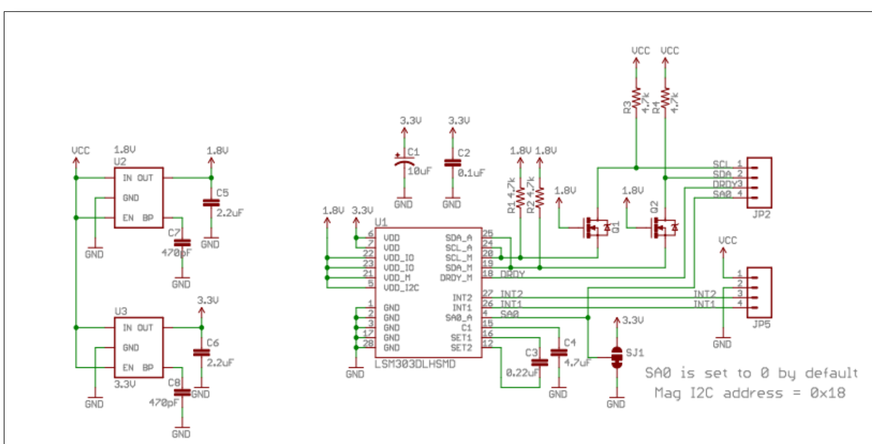


Figure 3.4.12.A shows the schematic of the LSM303DLMTR

4.0 Project Hardware and Software Design Details

4.1 Overall Design

4.1.1 Printed Circuit Boards

In our final design we plan to have four custom printed circuit boards (PCB). First PCB will be responsible for the water quality data and transmission of the data to the user. The second will be responsible for the GPS and motor control. Third and fourth PCB will be used for the DC to DC step up converter designs for each system. To create these PCBs each member of our group will learn how to use CadSoft Eagle PCB Design Software, ExpressPCB CAD software, or PCB123 Design Software. To determine which design software to use we will experiment with each software and determine which one will be easiest for use to learn but also have enough features to create our custom PCB. Once our PCB layout has been created we will send it out to get manufactured.

The first PCB will hold all components that are relevant to gathering water quality data and sending it back to a laptop. This will include a microcontroller, an XBee module, four different water quality circuits, four BNC connectors to connect the water quality sensors, two HCT4051 8-channel analog multiplexer/demultiplexer, connection to program the microcontroller, power connection. There may be more components on the PCB but the ones listed above are the main components on the PCB. Figure 4.1.1.A shows the initial layout of the PCB for the water quality subsystem.

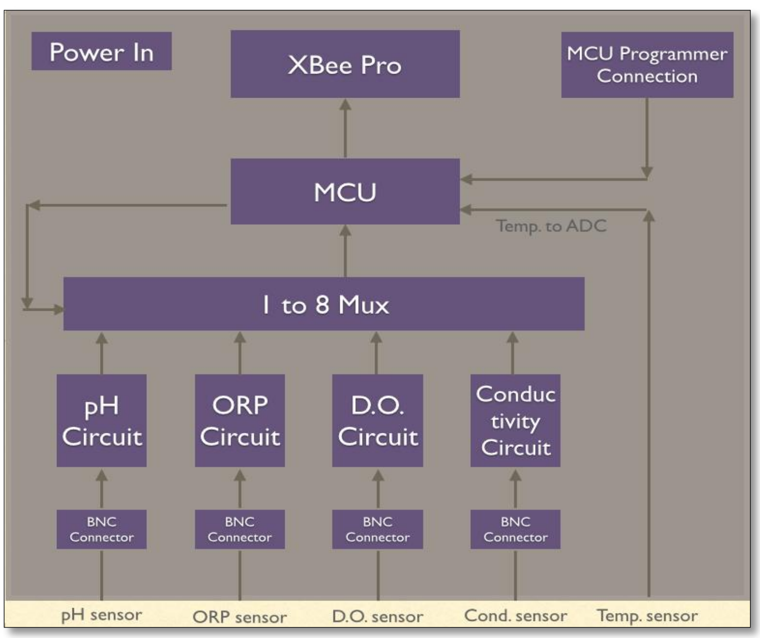


Figure 4.1.1.A Initial PCB Layout for Water Quality Subsystem

The second PCB will hold all components that are relevant movement of the boat. The PCB will include a microcontroller, a GPS module, connection to program the microcontroller, power connection and various input and output to control the motor and rudder of the boat. Figure 4.1.1.B shows the PCB layout for the navigation system for the W.A.R. project.

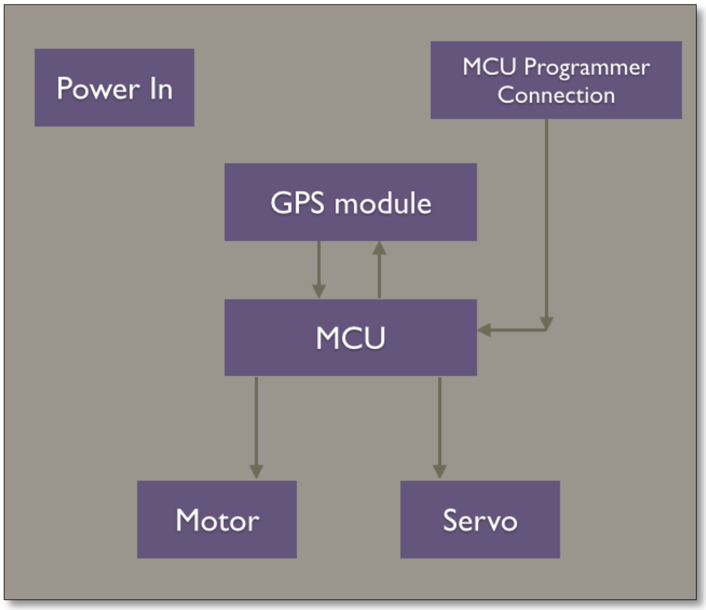


Figure 4.1.1.B Initial PCB Layout for Navigation Subsystem

The third PCB will be designed for a DC to DC step up converter that will be located in the first system. The first system is designed to deliver accurate voltage and current to the sensors, motors, and microcontrollers. The step up converter requires a specific circuit configuration design that is specific to how much current and the exact voltage the output components will be using. In addition to that the circuit will have a few passive components that will need to be included in the PCB design that will make the sturdy PCB connections that much more vital.

The fourth PCB will also be designed for a DC to DC step up converter; however this PCB is designed specifically for the second system. The second system will have different output requirements than the third PCB, that's why a separate system has to be designed. The output of the fourth PCB requires a smaller step up voltage, with respect to the third PCB, and a higher output current to power the XBee Pro communication system.

4.2 *Hardware*

4.2.1 Microcontrollers

For this design we will be using two Atmel Atmega 328P microcontrollers. One will used to gather water quality data and then transmit this data wirelessly to a computer through a XBee wireless module. The second microcontroller will be used for navigation and movement. It will take in GPS coordinates from the user and then navigate the boat to the correct position.

An Atmel Atmega 328P is a low powered 8-bit microcontroller. It has 32 kilobytes of flash, 1 kilobyte of Electrically Erasable Programmable Read Only Memory (EEPROM), 1 Universal Asynchronous Receiver/Transmitter (UART). A great benefit of this microcontroller is its use in the Arduino community and low cost.

4.2.2 XBee Pro Module

After choosing the XBee Pro as our method of wireless data transmission we designed how to integrate the module with the microcontroller. The minimum connections to have the XBee module communicating are VCC, GND, UART-TX (DOUT), and UART-RX (DIN). VCC requires a voltage of 3.3V and a current of 215mA for transmission, the max power usage during transmission will be 60mW. The UART-TX will connect to RX pin on the microcontroller and the UART-RX will connect to the TX pin. This connection will allow the XBee Pro module and the microcontroller to send data serially to each other. Figure 4.2.2.A details how the XBee Pro and our microcontroller will be connected.

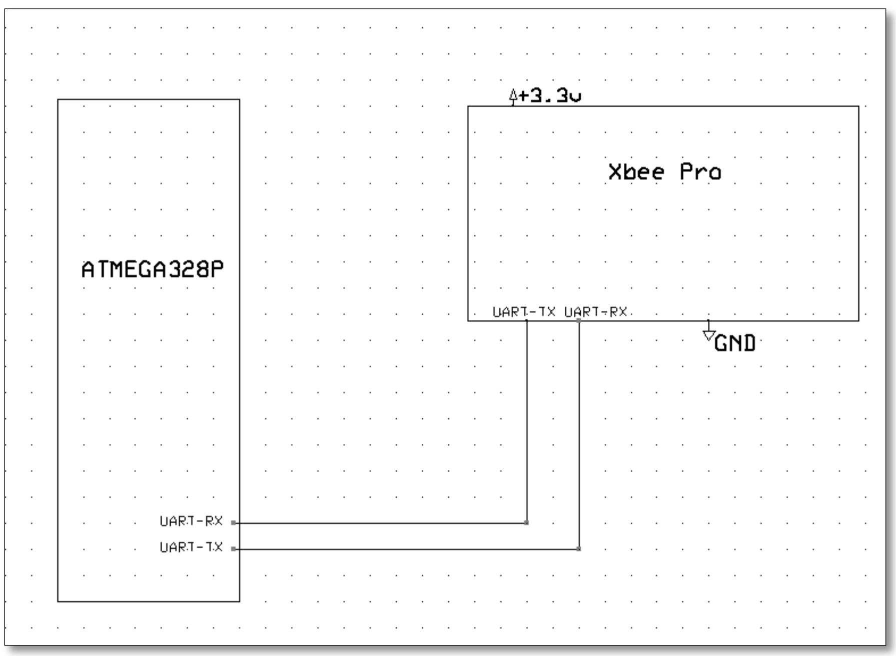


Figure 4.2.2.A XBee Pro and Atmega328P Connection

For the XBee Pro to transmit data wirelessly we will need a second XBee Pro module that will connect to our PC through a serial USB connection. This will allow the PC to receive and transmit serial data from other XBee modules.

Before the two XBee Pro can communicate with each other they will need to be configured with two identical Personal Area Network (PAN) IDs. We will discuss this further in our Software Design section of the report.

4.2.3 Sensors/Circuits

When W.A.R. is powered on it will continuously poll data from five water quality sensors. These sensors will be take turns sending data to the microcontroller one by one. Each sensor will connect to the system using a female BNC connector. On the other end of this BNC connector will have the specific water quality circuit.

pH Sensor/Circuit

The pH sensor and circuit will be purchased from Atlas-Scientific. The sensor will be laboratory grade and have an accuracy of 95% within 1 second of testing. The pH circuit will connect with the sensor allowing us to decode the sensor data into serial data that we can use. The circuit will be able to operate on 2.5-5.5V consuming anywhere from 1.89mA to 14mA depending on the activity of the circuit. Below in Table 4.2.3.A and Table 4.2.3.B, is a detailed table of these specifications.

Parameter	Min	Typical	Max
Storage Temp(Circuit)	-40° C		125° C
Storage Temp(Sensor)	1° C	25° C	35° C
VCC	2.5V	3.3V	5.5V

Table 4.2.3.A - Absolute Maximum Ratings

Parameter	5V	3.3V
LED on (Active)	14 mA	4 mA
LED off (Active)	2.3 mA	2 mA
LED on (Quiescent)	7.6 mA	3.6 mA
LED off (Quiescent)	2 mA	1.89 mA

Table 4.2.3.B - Power consumption

Once the circuit is powered on we will need to send commands to the circuit so it will know what action to take. These commands are sent serially using any Terminal software through the circuits TX and RX pins. Below, in Table 4.2.3.C, are some commands that we’ll be using

Command	Function
L1	Enable LEDs
L0	Disable LEDs
R	Take one pH reading
C	Take continuous pH readings every 378 milliseconds
X	Reset circuit to default state
Z0	Change baud rate

Table 4.2.3.C - Circuit Commands

ORP Sensor/Circuit

The ORP circuit has the exact same max voltages and power consumptions as the pH sensor. Some differences between the circuits are the commands. Due to the nature of measuring ORP the circuit will have a few commands. Below, in Table 4.2.3.D are some commands of the ORP circuit.

Command	Function
L1	Enable LEDs
L0	Disable LEDs
R	Take one pH reading
C	Take continuous pH readings every 320 milliseconds
+	Calibration: Increase ORP
-	Calibration: Decrease ORP
X	Reset circuit to default state
Z0	Change baud rate

Table 4.2.3.D – ORP Circuit Commands

Other sensors/circuits

With the rest of the sensors/circuits they all have the same max voltages and power consumption. Instead of listing more redundant data, the datasheets for each circuit and sensor can be found on the manufacturer's website.

4.2.4 HCT4051 8-channel Serial Analog Mux/Demux

We will be integrating two HCT4051 8-channel multiplexers to connect our water quality circuits and XBee Pro to the Atmega328Ps UART. Each TX pin on the water quality circuits and XBee Pro will connect to an HCT4051. This will be our transmit mux that will determine which transmit signal will be received by the microcontroller. Another HCT4051 will connect the RX pins of the water quality circuit and XBee Pro. The microcontroller will select which circuit it will want to send data to through this method. The detailed schematic of this implementation, 4.2.4.A is shown below:

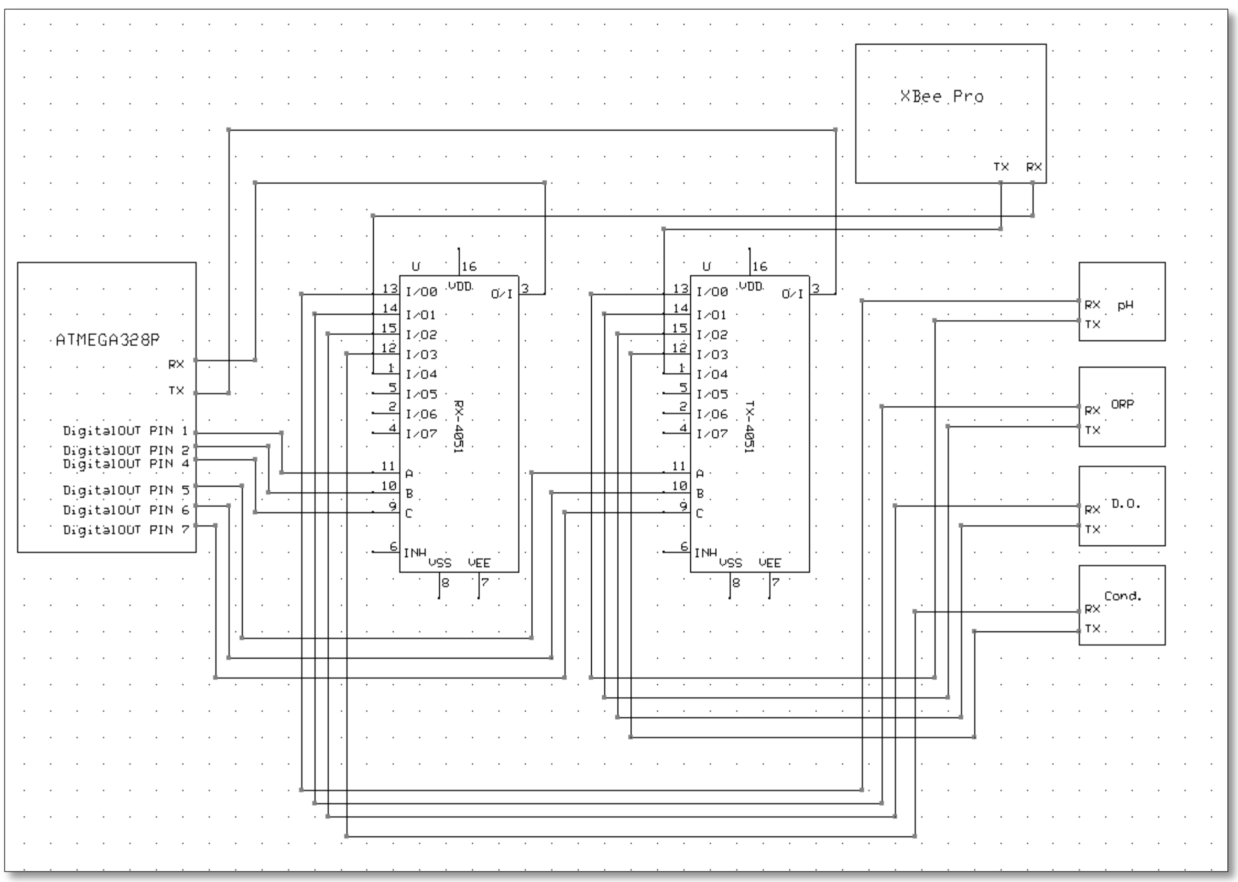


Figure 4.2.4.A Schematic of Communication between Microcontroller and the Circuits/XBee Pro

With this implementation we allow the microcontroller to be able communicate in both directions will all components in this subsystem. We will be able to send commands to the water quality circuits and receive the water quality data. With the data from the water quality circuits the microcontroller can transmit the data to the XBee Pro which then passes it on to our PC.

4.2.5 GPS Module

For this project we are using the 20 Channel EM-406A SiRF III Receiver with Antenna (EM-406A). This GPS module features the SiRF star III high performance GPS chip set with very high sensitivity (tracking: -159 dBm). It has an extremely fast TTFF (Time to First Fix) at a low signal level. It supports NMEA 0183 data protocol and has a built in patch antenna. For its main power input it requires from 4.5V to 6.5V and 44 mA of power consumption. The input for the module will be done in the NMEA protocol standard. The output of the module can be controlled and can be in the form of GGA, GLL, GSA, GSV, RMC, and VTG. GGA gives time, position and fix type data.. GLL gives latitude/longitude, UTC time of position fix and status. GSA gives the GPS receiver operating mode, satellites used in the position solution and DOP values. GSV gives the number of GPS satellites in view, satellite ID numbers, elevation, azimuth, and signal noise ratio values. RMC gives the recommended minimum data for GPS which is time, date, position, course and speed data. VTG gives course and speed information relative to the ground.

A list of all commands can be found on the GPS datasheet. However, the following four are the most notable and useful to our project: These commands are as follow:

1) Set Serial Port - This command is used to set the protocol for the GPS module. The different protocol options are as follows (SiRF Binary, NMEA, or USER1). This command is also used to set the communication parameters. These can be in baud, data bits, stop bits and parity. This command can be used to switch the module back to SiRF Binary protocol mode since this mode contains a more extensive command message set. This mode is very useful in changing the navigation parameters. When the module receives a valid message, the parameter will be stored in the battery backed SRAM and then the receiver will restart using the new parameters.

The format of the Set Serial Port command is:

$PSRF100, **<protocol>,<baud>,<DataBits>,<StopBits>,<Parity>***CKSUM<CR><LF>

<protocol>	0 = SiRF Binary, 1 = NMEA, 4 = USER1
<baud>	1200, 2400, 4800, 9600, 19200, 38400
<DataBits>	8,7. SiRF protocol is only valid f8 Data bits
<StopBits>	0,1
<Parity>	0 = None, 1 = Odd, 2 = Even

Example: Switch to SiRF Binary protocol at 9600, 8, N, 1.

$PSRF100,0,9600,8,1,0*0C<CR><LF>

The CheckSum Field is the absolute value calculated by the exclusive-OR of the 8 data bits of each character in the sentence between but excluding the “$” and the “*” characters. The hexadecimal value of the most significant and least significant 4 bits of the results are converted to two ASCII characters (0-9, A-F) for transmission. The most significant character is transmitted first.

2) Navigation Initialization - This command is used to initialize the module for a warm start by providing the current position in (X,Y,Z coordinates). The clock offset and the time must also be provided in this command. The receiver will then search for the correct satellite signals at the correct signal parameters. The more accurate the initialization parameters are the more quickly the receiver will be able to acquire a signal and thus produce a faster navigational solution. When a valid Navigation Initialization command is received, the receiver will restart using the input parameters as a basis for satellite selection and acquisition.

The format of the Navigation Initialization command is as follows:

$PSRF101,**<X>,<Y>,<Z>,<ClkOffset>,<TimeOfWeek>,<WeekNo>,<chnlCount>,<ResetCfg>**

<X>	X coordinate position (32 bit Integer)
<Y>	Y coordinate position (32 bit Integer)
<Z>	Z coordinates position (32 bit Integer)
<ClkOffset>	received in Hz, use 0 for last saved value, default 75000(INT 32)
<TimeOfWeek>	GPS time of week (Unsigned 32 bit Integer)
<WeekNo>	Week number (calculated from UTC time)
<chnlCount>	Number of channels to use 1-12. (Unsigned Byte)
<**ResetCfg>**	bit mask 0x01=hot start, 0x02, warm start, 0x04=cold start(Ubyte)

Example: Start using known position and time.

$PSRF101,-2686700,-4304200,3851624,96000,497260,921,12,3*7F

3) Query/Rate Control - This command is used to control the output of the standard NMEA message. This command is used to control the output of the standard NMEA message. This command message is also used to set up a standard NMEA message to poll once or for periodic output. Checksums may also be enabled or disabled depending on the needs of the receiving program. NMEA message settings are saved in the battery backed memory or each entry when the message is accepted.

The format of the Query/Rate Control message is:

$PSRF103,**<msg>,<mode>,<rate>,<cksumEnable>***CKSUM<CR><LF>

<msg>	0=GGA,1=GLL,2=GSA, 3=GSV,4=RMC,5=VTG
<**mode>**	0=SetRate,1=Query
<rate>	Output <rate> seconds, off=0, max=255
<**cksumEnable>**	0=disable Checksum, 1=Enable checksum

Example 1:Query the GGA message with checksum enabled

$PSRF103,00,01,00,01*25

Example 2: Enable VTG message for a 1Hz constant output with checksum enabled

$PSRF103,05,00,01,01*20

4) LLA Navigation Initialization - This command is very similar to the Navigation Initialization command in format and operation. The only difference is that the coordinates are provide in latitude, longitude and altitude. This command also requires the clock offset and time and just like command 2 it enables the receiver to search for the correct satellite signals.

The format of a LLA Navigation Initialization is as follows:

$PSRF104,**<Lat>,<Lon>,<Alt>**,<ClkOffset>,<TimeOfWeek>,<WeekNo>, <ChannelCount>, <ResetCfg>*CKSUM<CR><LF>

<Lat>	Latitude position, positive is north of the equator and negative is south. Given as signed float.
<Lon>	Longitude position, positive is east of Greenwich and negative is west of Greenwich. Given as a signed float.
<Alt>	Altitude position. Given as signed float.

The remaining parameters are exactly the same as the corresponding parameters discussed in command 2.

Example: Start using known position and time.

$PSRF104,37.3875111,-121.97232,0,96000,237759,922,12,3*37

The remaining commands for the 20 Channel EM-406A SiRF III Receiver with Antenna can be found in the module's data sheet.

Figure 4.2.5.A shows how the 20 Channel EM-406A SiRF III Receiver with Antenna (the EM-406A) is connected to the ATMEGA328P microcontroller. The ATMEGA328P needs to transmit the correct commands to the EM-406A. This is achieved by connected the microcontroller's TX pin to the GPS module's RX pin. The GPS module needs to transmit the current coordinates to the microcontroller so that the microcontroller can carry out the corresponding calculations to find out where it need travel by moving/starting the servo/motor to the correct positions.

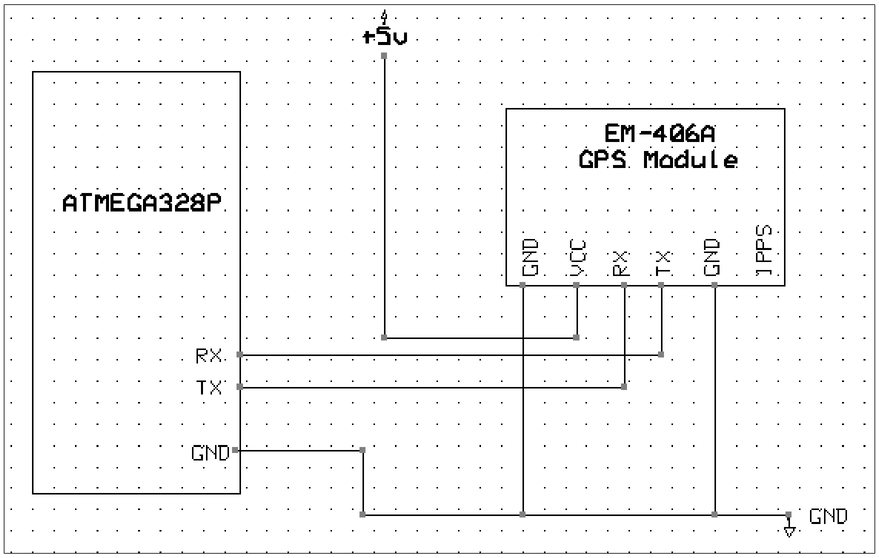


Figure 4.2.5.A The EM-406A Connections to the ATMEGA328P

4.2.6 PV Cells

Each monocrystalline solar cell generates 0.5 volt. Therefore, to power a 3.7 volt battery with a charging voltage of 3.6 volt between 7 and 8 monocrystalline solar cells would be needed. The decision to choose 8 solar cells (more than is technically needed) is made for the following reasons: the solar cells will not be operating at ultimate efficiency the entire time the battery will be charging, the perfect angle to receive sunlight at which the solar cell will generate its maximum amount of energy will not be achieved by all, if any, cells. The solar cells will be laid out on the boat platform with 8 solar cells on each side of the boat, with a custom made protection encasing. The cells in each module will connected in series, therefore generating the needed voltage with a relatively low current. The low current will provide a longer charge time, however the risk of overheating the components, which will already be hot from the sun, will be ultimately low. Each module will consist of 8 solar cells, and there will be two separate modules that power each 3.7 volt battery. The individual module connections that will be implemented in the design are displayed in Figure 4.2.6.A below.

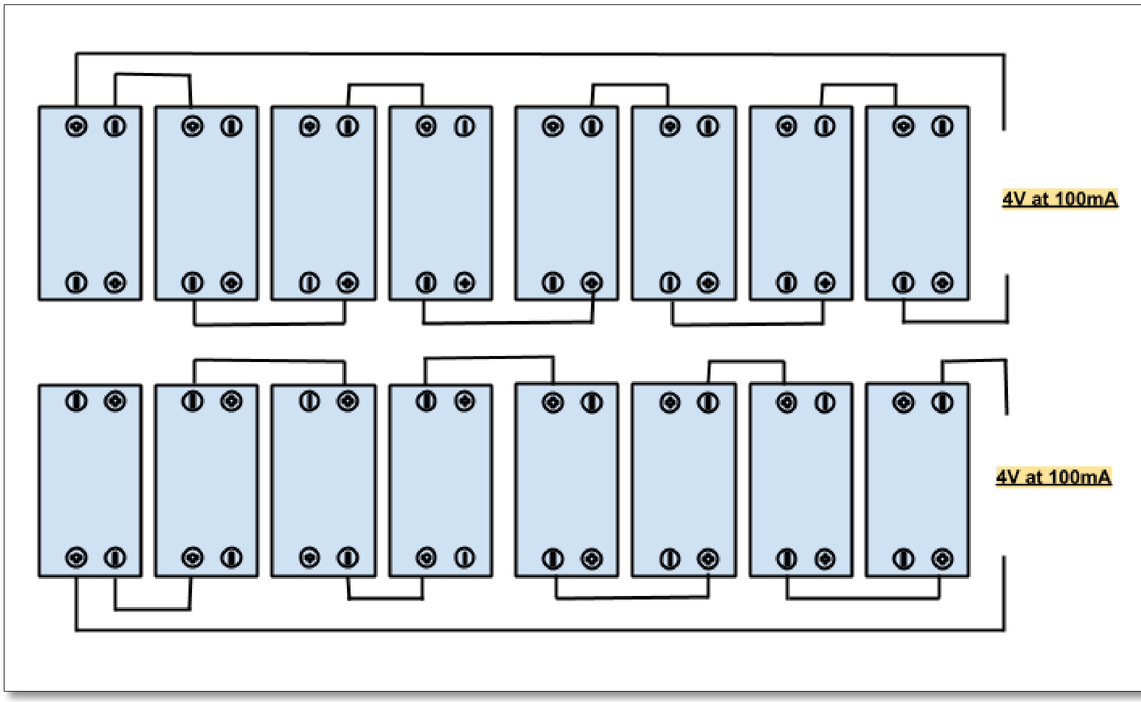


Figure 4.2.6.A Solar Cell Connections for the Two Modules

4.2.7 DC to DC Power Converter

The W.A.R. design contains two DC to DC step up voltage regulators. The first step up voltage regulator will convert 3.7 volts to 5 volts, which will power the microcontroller, motors, and the water sensors. The second step up voltage regulator will convert 3.0 volts to 3.3 volts and will power the XBee Pro communication system.
To power the first system, the microcontroller and XBee Pro communication, the design will have a Texas Instruments LM4510 Synchronous DC to DC Step Up Converter. The resistor, capacitor, and inductor values are all shown in Figure 4.2.7.A below.

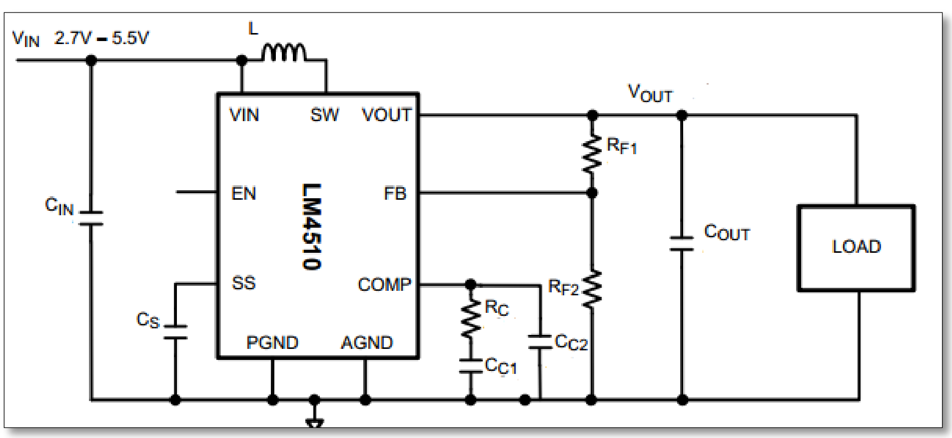


Figure 4.2.7.A LM4510 3.7V to 5V converter

In order to successfully convert 3.7 volts to 5 volts resistor, inductor, and capacitor values must be strategically selected. R_{F1} is calculated using the following formula:

$$R_{F1} = \left(\frac{V_{out}}{V_{FB}} - 1\right) * \ R_{F2} = \left(\frac{5}{Vfb} - 1\right) * 20.5 = 60.4k\Omega$$

R_{F2} is recommended to be a value between 10kΩ and 25kΩ, $R_C = 45.4k\Omega$, and $C_{C1} = 2.2nF$ by the specifications sheet of the LM4510. The input capacitor, C_{IN}, is not as vital as the output capacitor, C_{OUT}, because of the inductor presence. The suggested input and output ceramic capacitor values range between 4.7μF to 10.0μF. For the W.A.R. design C_{IN}= 4.7μF and C_{OUT} = 10μF. The output capacitor endures very large ripple currents when the switch is closed and the inductor is charging, therefore a larger value might help the stability of the output. TI suggests that if larger amount of capacitance are desired for improved line support and transient response tantalum capacitors may be used. The choice whether to use ceramic or tantalum capacitors will be made during the testing phase where we will try out both capacitors and make the final decision by how much each different type of capacitor benefits the output.

Inductor value is suggested to be between 4.7μH and 10μH. TI recommends that when choosing an inductor value it's important to note that the higher the inductor value is the lower the peak inductor current will be therefore causing less stress on the internal power of the NMOS and the lower inductor value has a smaller outline and a higher current capacity.

It's incredibly vital to know the maximum output current, $I_{OUT_{MAX}}$, to make sure to take appropriate measures in protecting the battery from being damage. To calculate the maximum output current the following formula is used.

$$I_{OUT\_MAX} = \frac{1.32 * V_{in} - 2.79}{V_{out}} = \frac{1.32 * 3.2 - 2.79}{5} = 0.2868\, mA$$

To power the second system, the XBee Pro communication, the W.A.R. design will have the LM3478 High Efficiency Low Side N Channel Controller for Switching Regulator component connected in a step up converter application configuration. The schematic for the step up voltage configuration is displayed in Figure 4.2.7.B below. The Texas Instruments WEBENCH Designer software was used to implement the exact needed parameters for this circuit.

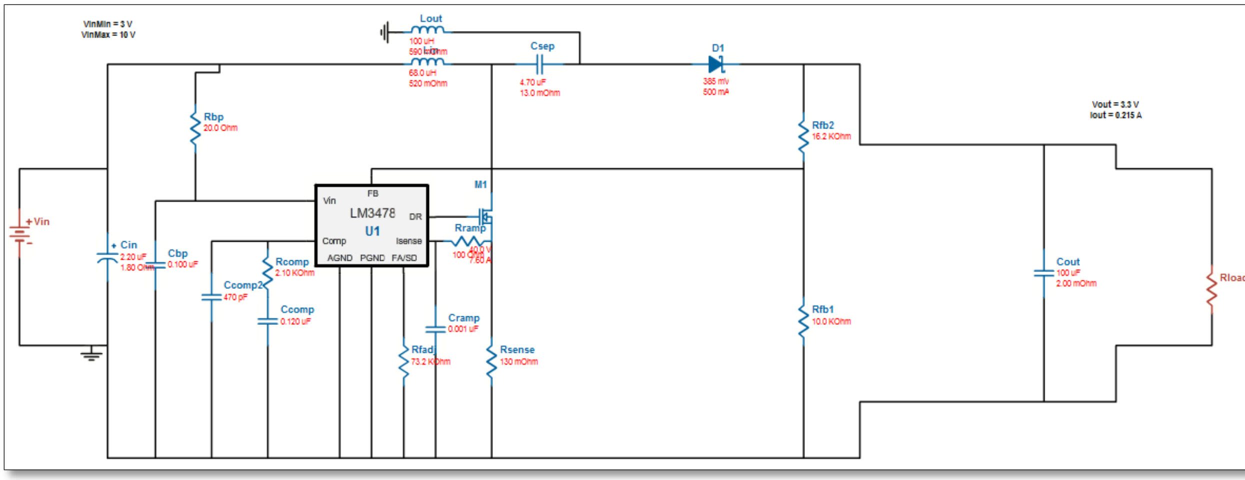


Figure 4.2.7.B: LM3478 Connected as a Step Up Voltage Regulator

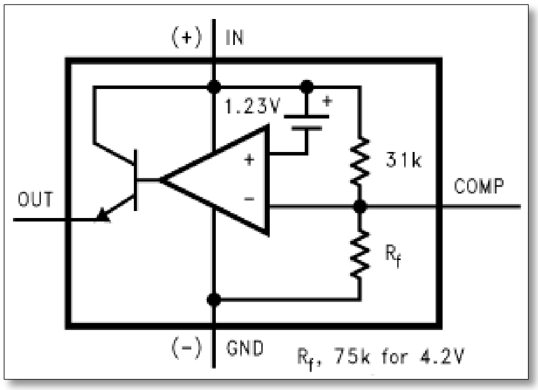
4.2.8 Lithium Ion Battery

The W.A.R. design will consist of two 5 volt lithium ion batteries that each will be connected to a charge controller that will monitor the battery and make sure that it does not over charge. One of the batteries will then be connected to the two PCB boards in parallel; each PCB will be holding either the sensors or the motors. From there on each of the PCB boards will power all of the connected components from the 5 volt battery connection. The second lithium ion battery will be connected to the XBee Pro communication device and will be in charge of supplying power to it specifically. Because the lithium ion battery is so sensitive to high temperatures, the battery will be stored in an insulated structure to help prevent lack of efficiency due to the heat caused by the sun. Styrofoam is used as the insulator from heat, because of its lightweight and easy installation. The styrofoam will be stacked on top and bottom of the battery to make sure that the least amount of heat impacts the battery. The connection cables will be guided out of the styrofoam insulation and sealant will be applied where the cables exit the styrofoam insulation to prevent heat intake.

It is suggested to not charge the lithium ion battery to full capacity, but instead to somewhere between 40-80%. When the battery is left idle, overnight, the battery will be left charged about 40%. The battery’s charge cycle will begin once the charge controller senses a specific voltage drop, once again replenishing the battery. All of the components will continually be running off the lithium ion battery, therefore continually discharging the battery.

4.2.9 Charge Controller

The Texas Instruments LM3420 lithium ion battery charge controller has a four pin configuration which is displayed in Figure 4.2.9.A and Figure 4.2.9.B. The input voltage range can be as high as 20V, which is the maximum. However, when the input is that high it is important to monitor the output current to be no more than 20mA and if needed add an external resistor to limit the output current.



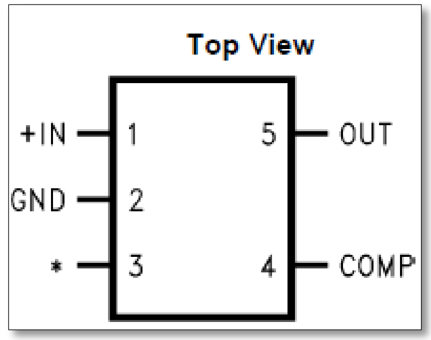


Figure 4.2.9.A Functional Diagram of LM3420 *Figure 4.2.9.B External Top View of LM3420*

Diagram in Figure 4.2.9.1 shows that for a one cell 4.2 volt charge controller a feedback resistor,R_f, with 75kΩ is required. The feedback resistor is an internal resistor that is located directly on the die.The component itself will have four connections leading into the internal electronic components, the fifth connection in Figure 4.2.9.2 marked "*" is there solely for proper heat transfer, and should be soldered in place.

For the LM3420 charge controller the input regulation, voltage is 4.2 volts with an output current 1mA. The output leakage current is a maximum of 0.1µA. It is a shunt regulator that is created to be the reference and control in an overall feedback loop of the charger, which has the regulated output voltage sensed between the "IN" pin and "GND". If the voltage in the "IN" pin is less than the input regulating voltage then the "OUT" pin has no current. However, when there is current flow out of the "OUT" pin, it is used to drive the feedback device or power device, like a linear, switching, or another type of regulator.

To design a constant current/constant voltage lithium ion battery charger the circuit in Figure 4.2.9.C must be created. An additional part LM317 voltage regulator is needed for this design. For that circuit, at the beginning of the charge cycle the charge controller doesn't output any current from the "OUT" pin, keeping Q2 off, and allowing the LM317 voltage regulator to operate as a constant current source giving 1.25 volt across the R_{LIM} resistor. The current exiting the "OUT" pin of LM317 can be calculated with the following equation:

$$I_{LIM} = \frac{1.25}{R_{LIM}}$$

The transistor Q1 provides a disconnect from the battery when the input is removed, which prevents the quiescent current from discharging the battery. Also, the diode D1 prevents the battery from discharging. Once the battery reaches the desired voltage, 8.4V for a two cell charge controller, the controller begins to regulate and start sourcing current to the base of Q2. Eventually as the battery approaches full charge the current falls to a very low value to prevent damaging the lithium ion battery.

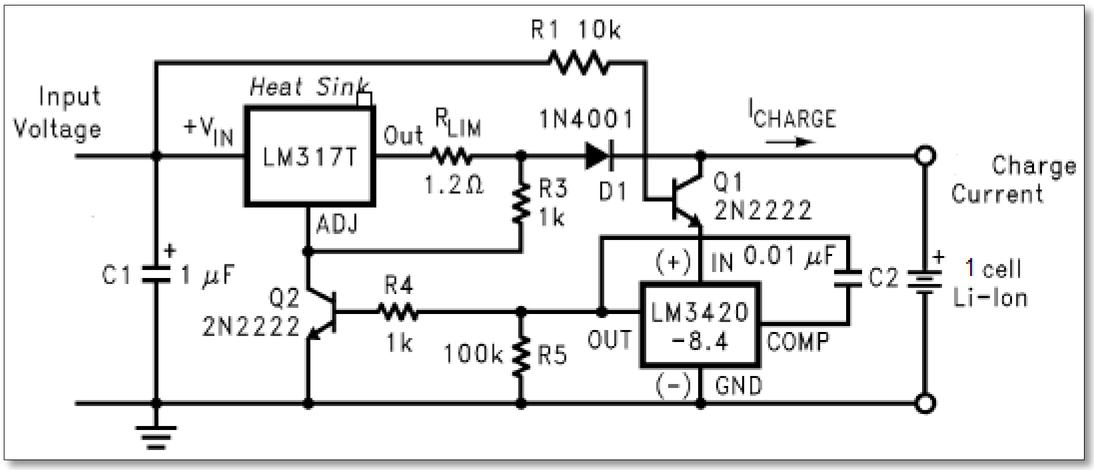


Figure 4.2.9.C Constant Current/Constant Voltage Lithium Ion Battery Charger

4.3 Software

4.3.1 Microcontrollers

For this project we will be using two Atmel Atmega328P microcontrollers. The task of the first microcontroller will be to receive water quality data from our circuits/sensors and take this data and transmit to an onshore PC. The microcontroller will be able to transmit this data to our onshore PC using an XBee Pro wireless module. In short the first microcontroller will be responsible for choosing which water quality data to receive in it RX pin by using a mux, from here the data will be send to the connected XBee Pro from the microcontrollers TX pin. Figure 4.3.1.A. demonstrates the communication between the PC and W.A.R. on a lake.

Figure 4.3.1.A Diagram of PC Communication to W.A.R. on a Lake.

The task of the second microcontroller will be to receive GPS coordinates from the user, calculate the path to those GPS coordinates, and then power/steer the boat to the correct location. The microcontroller will receive the GPS coordinates from the user using open source terminal software on the PC. The data will be sent to the microcontroller using a USB to FTDI cable that connects to the RX and TX pins of the microcontroller. With the coordinates saved in memory on the microcontroller we will calculate the distance and direction to travel. Table 4.3.1.A describes the functions that our first microcontroller will be using to gather water quality data. Some of these functions are sensor specific so we can calibrate the sensor if needed offshore.

Function Name	Description
IntializeSensors()	The microcontroller will configure the mux to select each water quality circuit and configure them. Configuration will be setting the correct baud rate and waiting for a response from the circuit.
DefaultSensors()	The microcontroller will configure the mux to select each water quality circuit and set them to their default state.
Stop()	This function will have the microcontroller configure each water quality sensor to stop all readings.
TakeReading()	The microcontroller will take a reading from each water quality circuit. The mux will be configured to select each water quality circuit for a given amount of time and have the microcontroller receive the data. This function will run continuously taking a reading from the circuits for a given time.
OnlyTemp()	Take only the temperature of the water and send the data to PC
OnlypH()	Take only the pH of the water and send the data to PC
OnlyORP()	Take only the ORP of the water and send the data to PC
OnlyDO()	Take only the DO of the water and send the data to PC
OnlyCond()	Take only the Conductivity of the water and send the data to PC
SendData()	With the data received from the water quality circuit, the microcontroller will send data to the XBee Pro for wireless transmission.
DisableLEDs()	To conserve power, the microcontroller will turn off all debug LEDs on each water quality circuit.
EnableLEDs()	For debugging, the microcontroller will turn on all debug LEDs on each water quality circuit.
CalibrateORP+()	Increase ORP for calibration purposes
CalibrateORP-()	Decrease ORP for calibration purposes
DOsaturation()	Toggles ON/OFF the percentage of D.O. saturation
CalibrateEC()	Calibrate Electrical Conductivity sensor commands

Table 4.3.1.A Sensor Function Calls

4.3.2 XBee Pro

The software to configure the XBee Pro will be X-CTU. This software is free to download by Digi International, the manufacturer all XBee modules. X-CTU will allow us to connect to both our XBee Pro modules and configure them so they will have point-to-point communication and update their firmware from Digi if needed.

The steps needed to configure the XBee Pro are listed below.

1. Connect a XBee Pro to the PC with X-CTU using a XBee USB Dongle
2. Launch the X-CTU configuration tool and select the XBee module from the the COM Port list
3. Click the "**Test/Query**" button to test the that X-CTU can connect/communicate to the XBee Pro
4. Navigate to the "**Modem Configuration**" tab in X-CTU
5. Hit the "**Read**" button to get the Modem and Function set of the XBee Pro.
6. Look at the PAN ID and check if it is the correct ID for the network. The default PAN ID will be 3332. This PAN ID must be the same for both XBee Pro modules.
7. Configure the baud rate to desired rate.
8. Hit the "**Write**" and the configuration above will be set onto the XBee Pro. A reset of the device may be required to finish the configuration.
9. **Repeat** these steps again for the second XBee Pro.

Once these steps are done, both XBee Pro modules should be able to communicate with each other.

4.3.3 Desktop Application

To record the water quality data that is being sent to the PC we will use a open source terminal software like PuTTY or Tera Term. The terminal software will display the serial data that is being sent to our XBee Pro that is connected to the PC. We will configure the terminal software to log the data so we can keep archives of water quality.

The terminal software will also allow us to transmit data to W.A.R. Since both XBee Pros will be configured to receive and transmit data, we will allow the user to determine the actions of the microcontroller/water quality circuits using the functions listed above in Table 4.3.1.1. We will also be using the terminal software to send the second microcontroller GPS coordinates. These GPS coordinates will tell the second microcontroller the distance and direction it will need to travel.

4.3.4 X/Y Movement

The movement of our robot boat will be handled by a motor spinning a propeller and a servo turning a rudder. The boat will travel to a number of predetermined waypoints before returning to the short. This will be accomplished by using the mounted GPS module and compass on the boat. Some of the needed functions are described in the table shown below. Table 4.3.4.A describes the routines that the navigation microcontroller will use to calculate it heading, and travel to its next waypoint.

Function Name	Description
readCoordinates()	This function will read in the boat's current coordinates.
convertCoordinates()	Convert read in coordinates to usable data.
assignWaypoint()	Tell the boat where to go to next.
printCoordinates()	Print to screen the boat's current coordinates.
calculateDistance()	Calculate distance between current position and destination
getHeading()	Calculate heading account for errors
getHeadingAtoB()	Calculate direction from A to B.

Table 4.3.4.A Navigation Function Calls

The printCoordinate routine will be useful for debugging to make sure that the boat is receiving correct information and travelling in the correct direction. Since the latitude and longitude is read in with a direction instead of a sign, the convertCoordinates routine will negate the coordinate terms for south latitude and west longitude so the math can done properly. The readCoordinates routine reads the current coordinates from the GPS module and save them after doing the direction to sign conversion.

The calculations required for navigation are carried out in the calculateDistance routine. This routine will use subtraction to find the required distance. The subtraction logic is as follows:
1. Calculate the difference in thousandths of minutes term. If result is negative, add 1000 and subtract 1 from the minute term. 2. Calculate the difference in minutes term. If the result is negative, add 60 and subtract 1 from the degree term. 3. Calculate the difference in the degree terms. If the result is negative, add either 90 for latitude or 360 for longitude and set a sign flag. 4. Finally, combine the result from the three previous operations into one term. Once the required vector has been calculated it is up to the servo to steer the boat in the right direction until the coordinates of the boat equal that of the target waypoint. A relatively small error tolerance will be allowed and will not make a big difference for when the robot is out in a pond or lake.

4.3.5 Servo/Rudder

Our servo needs a pulse-width modulation signal to set its position. The signal needs to be updated every 20ms and the pulse width should be around 1 to 2ms. 1ms is 0 degrees, 1.5ms is 90 degrees and 2ms is 180 degrees. These are standard values and will probably require a bit of tweaking.

Servos have three leads bundled together in one plug. The three leads are positive, ground and signal. The positive will be connected to 5V. The ground will be connected to the microcontroller's ground. The signal will be connected directly to the microcontroller's PWM signal output which is 0C1x for the ATmega328. We will be using the ATmega328 at 16MHz. First we have to calculate how many clock cycles are completed in 20 ms. The calculation is shown below:

$$16MHZ/50Hz = 320{,}000$$

This means that we need a pulse every 320,000 cycles. The problem is that the ATmega328 uses a 16 bit timer so we cannot count 320,000 cycles. We can solve this problem by using a prescaler to generate a clock for the timer. By using the prescale 8, we get:

$$320{,}000/8 = 40{,}000$$

40,000 is a value that we can count up to with our 16 bit timer. We will be using timer mode 14: "Fast PWM with ICR1 as Top". This means our timer will be counting up to ICR1 and then start counting from 0 again. So all we have to is write 40,000 to ICR1 to get our desired 20ms cycle.

The output will come from the OC1x pins so we need to enable output by selecting the "non-inverting Mode": Clear OC1A/OC1B on compare match set OC1A/OC1B at bottom.
The last value that must be calculated is the final value that will be written to OCR1x. These registers are the compare match registers. A match occurs if the timer value matches the OCR1x-value and the output is set from high to low. This value will control the pulse width of our obtained signal. Figure 4.4.2.A shown below is free software and will be used in our project with some modification. It is an example of how the timer control registers have to be set.

```
#define F_CPU 16000000UL

#include <avr/io.h>
#include <util/delay.h>

int main(void){

 TCCR1A        |= (1<<com1A1) | (1<<wgm11); // non-inverting mode for OC1A
 TCCR1B        |= (1<<wgm13) | (1<<wgm12) | (1<<cs11); // Mode 14, Prescaler 8

 ICR1        = 40000; // 320000 / 8 = 40000

 DDRB        |= (1<<pb1); // OC1A set to output

        while(1){

  OCR1A               = 2000; // set to 0° --> pulsewidth = 1ms
  _delay_ms              (1000);

  OCR1A               = 3000; // set to 90° --> pulsewdith = 1.5ms
  _delay_ms              (1000);

  OCR1A               = 4000; // set to 180° --> pulsewidth = 2ms
  _delay_ms              (1000);
        }
}
```

Figure 4.4.2.A Code to Set Control Registers for the Servo

4.4 Mechanical

4.4.1 Motor

In order to drive a three-phase motor with sinusoidal current, we must use independent voltages for each phase. The driver stage for a three-phase motor consists of three half-bridges, one for each terminal. Each half-bridge consists of two switches. The average voltage of the output can be regulated between 0V and V_{in} by applying two inverted pulse-width modulated (PWM) signal to the two switches. A low pass filter will be added to the motor control design to obtain a voltage level proportional to the duty cycle of the high side switch.

Switching devices are not able to switch on and off instantly. To fix the problem we add dead time, a small period of time where neither the high nor the low side switches are conducting for every PWM transition. We can use an 8-bit timer/counter unit to produce the two PWM outputs with different compare values. The top value will be 255. We can then set the 16-bit timer/counter in 8-bit phase correct PWM mode so we have another 8-bit timer/counter unit. In phase correct mode, one PWM cycle with a top value of 255 will have a period of 510 clock cycles. The PWM frequency as a function of CPU frequency can be calculated using the following equation:

$$f_{PWM} = f_{CPU} \div 510$$

We will need to use all three timers/counters on the ATmega since each one is able to control one half-bridge and there are three half-bridges. To ensure that the three timers are synchronized, they must each be preloaded with a value. It is important to make sure that the timers are synchronized since each one starts at a different time.

There are three steps need to calculate the compare values for the three time/counter units. The first step is obtaining the desired output value, the second step is scaling the value to the desired amplitude and the final step is to insert the dead time. The desired output value when driving a synchronous motor is a function of the motor position. We will store the output values in a lookup table to increase the performance of the application. The values will correspond to the maximum output amplitude. The value in the lookup tables must be scaled down to the desired output amplitude. The following equation shows how the output can be scaled, where d_o , the output duty cycle, is calculated by multiplying the output value obtained from the lookup table d_{table} with a scaling factor k:

$$d_o = \frac{k d_{table}}{2^n}$$

The most straightforward approach would be to store a sine wave in a lookup and use this table to generate a sine wave on each motor terminal. However, we can generate three sinusoidal line to line voltages with a phase shift of 120 degree between them which can be accomplished without producing a full sine wave for wave terminal. Table 4.4.1.A shows the lookup table that stores the terminal and line to line voltages for forward driving of the motor, while table 4.4.1.B has the values for reverse driving.

Step	A	B	C	A-B	A-C	B-C
1-2	sin(θ)	0	-sin(θ-120)	sin(θ)	sin(θ-120)	sin(θ-240)
3-4	-sin(θ-240)	sin(θ-120)	0	sin(θ)	sin(θ-120)	sin(θ-240)
5-6	0	-sin(θ)	sin(θ-240)	sin(θ)	sin(θ-120)	sin(θ-240)

Table 4.4.1.A Terminal and Line to Line Voltages, Forward Driving

Step	A	B	C	A-B	A-C	B-C
1-2	sin(θ)	-sin(θ-120)	0	-sin(θ-240)	-sin(θ-120)	-sin(θ)
3-4	-sin(θ-240)	0	sin(θ-120)	-sin(θ-240)	-sin(θ-120)	-sin(θ)
5-6	0	-in(θ-240)	-sin(θ)	-sin(θ-240)	-sin(θ-120)	-sin(θ)

Table 4.4.1.B Terminal and Line to Line Voltages, Reverse Driving

The advantages of this approach are that the maximum line to line voltage generated is higher than with the pure sine wave approach which yields higher torque and speed. Also since the terminal output is zero for a third of the time the losses due to switching are reduced.

4.4.2 Platform

All electronics will be mounted on a Delta Force 29 Fiberglass Hull. The dimension of this hull is 29 inches long by 10 inches wide. This hull is both lightweight and built for speed. It is designed as a deep Vee with a small rear pad for handling. Deep Vee also known as mono hulls are the easiest hull types to set up as opposed to the catamaran, F1 tunnel hulls, sports hydro hulls or outrigger hulls. All fast electric hulls have a hatch to access the inside. This is where the majority of the electronics will go. To properly keep water out of the hull, the hatch will be taped shut and checked for leaks in a controlled environment. Hockey tape will be used to tape the hatch shut.

On a mono hull there are several components that need to be properly placed and secured. These are the stinger or strut outdrive, the rudder with water pickup, trim tabs and turn fins. These components are described below:

The stinger houses the flex shaft and supports the prop shaft. The distance that is propeller will be set away from hull will be around 5-7% of the hull’s length. A hole will be cut for the flex shaft to exit the hull. The hole will be as far down in the bottom of the Vee as possible. The drive angle will be adjusted so that it runs parallel with the bottom of the hull as a starting point.

A rudder is necessary for steering any RC boat. The length of rudder will be around 15% of the hull's length. The rudder must also feature a water pickup system that will be used to water cool the motor. The rudder will be attached to a servo that receives input from the navigation microcontroller.

Turn fins will allow the hull to take sharp turns much more effectively as they provide a pivot point during corners. The turn fins will be placed at the highest point of the bottom surface as shown in the following figure. The fin must be perpendicular to the bottom surface. The accurate mounting diagram is displayed in Figure 4.4.3.A below.

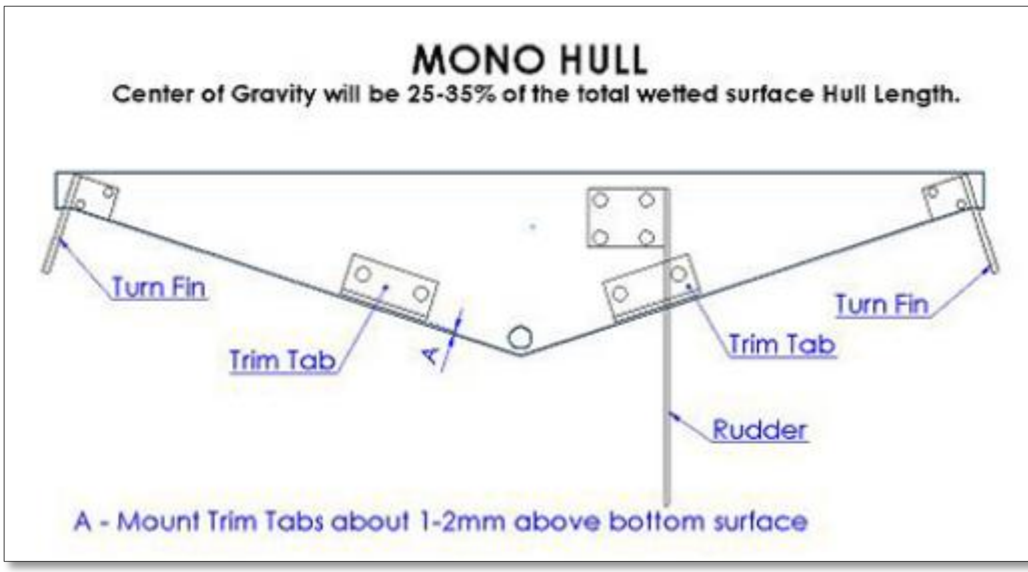


Figure 4.4.3.A - Proper Mounting of Hardware on the Boat's Hull

5.0 Design Summary of Hardware, Software, and Mechanical

5.1 Hardware

5.1.1 Overall Specifications

The list and Figure 5.1.1.A are the overall specification for W.A.R.

- W.A.R. dimension should be within 3x1x1 ft.
- It should be light enough so it can float on the surface of water.
- W.A.R. should be able to move through the water at a reasonable rate.
- W.A.R. should be easy to transport in the case testing needs to be done at other bodies of water.
- W.A.R should be powered by lithium ion batteries. These batteries will be recharged using solar panels that are on top of W.A.R.

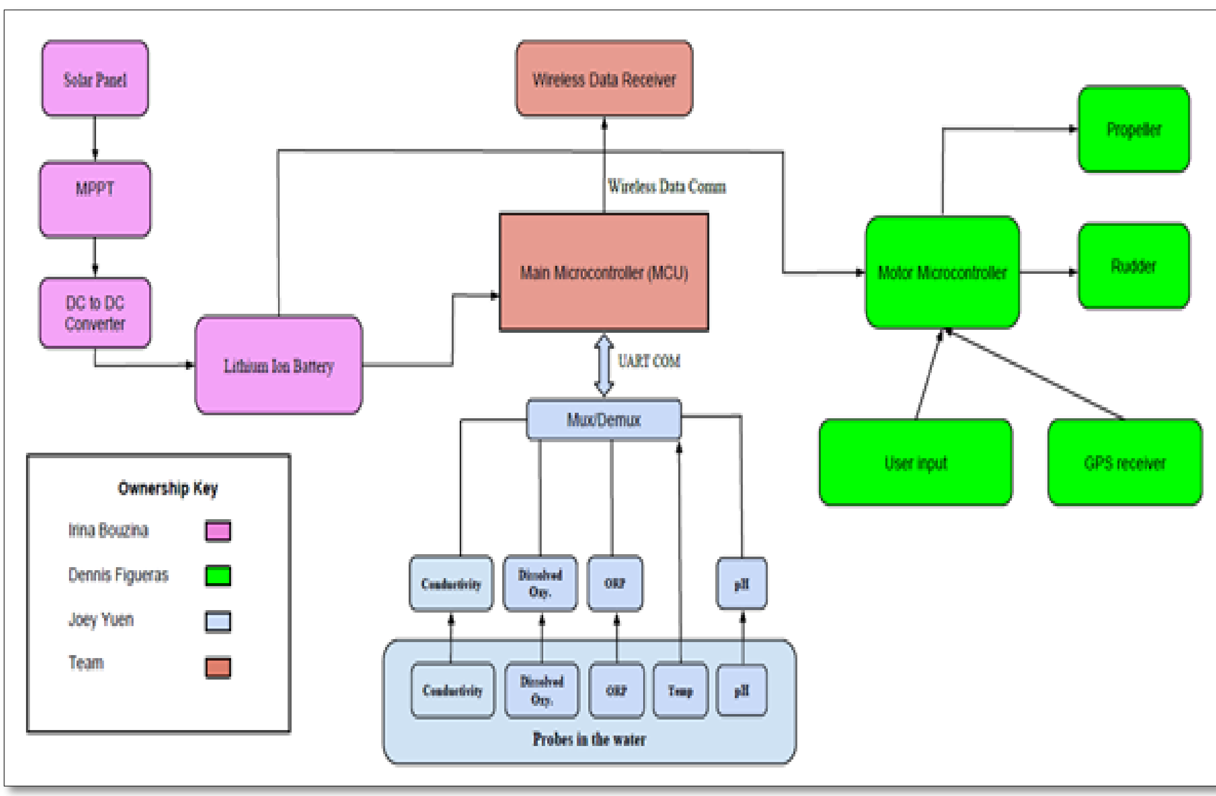


Figure 5.1.1.A Overall Hardware

5.1.2 Microcontroller

Below is a list of specification of the microcontroller we have chosen to design W.A.R. around. Currently we plan to use two of these microcontrollers in our design. One will be tasked with collecting the water quality data and transmitting it. The second microcontroller will be tasked with movement and navigation of W.A.R. using GPS. Table 5.1.2.A displayed below shows the Atmel Atmega 328P specifications.

Parameter	Value
Flash memory	32 KB
EEPROM	1 KB
CPU Frequency	16 MHz
I/O	UART - 1 SPI - 2 I2C - 1
Operating Voltage	1.8-5.5V
Active Mode Current	0.2mA
Maximum Operating Voltage	6.0V
Maximum Current Per Pin	40.0mA
Power Supply Current	0.15 - 9.0mA
Power Save Mode	0.75μA
Power Down Mode	0.1μA
Pin count	32 (23 I/O)
Price	$3.20

Table 5.1.2.A Atmel Atmega 328P Specs

5.1.3 XBee Pro

The two XBee Pros that will allow for W.A.R. to communicate to our onshore PC is shown below. We will configure each XBee Pro before attaching them to the design. Upon powering up the two XBee should be able to transmit and receive data. Table 5.1.3.A shows the Digi XBee Pro series specifications.

Parameter	Value
Max data rate	250 kbps
Operating Voltage	3.3 @ 215mA
Transmit power	60mW (+18dBm)
Frequency	2.4 GHz
Max transmission range	1 Mile(1500 ft)
I/O	8 digital I/O pins

Table 5.1.3.A Digi XBee Pro Series 1 Specs

5.1.4 Water Quality Circuits

We will have four water quality circuits connected to our PCB. There will not be a temperate circuit due to the fact that the temperature sensor will connect directly to the analog pins of the microcontroller. The microcontroller will communicate to each water quality circuit through an HCT4051 8-channel multiplexer. Each water quality circuit RX pin will be connected to a select line on the multiplexer and from there the microcontroller will choose which water quality circuit to read from.

5.1.5 Solar Cells

There will be two modules; each will be supplying energy to a lithium ion battery. Each module will consist of eight photovoltaic cells that will be connected together in series. The solar cells that will be used for the W.A.R. design are the mono-crystalline silicon cells. The cells' specifications characteristics are displayed in the Table 5.1.5.A below. It's important to note that in the specifications sheet it emphasizes that cold temperatures do not affect the silicon cell, however when the temperature is above 100 degrees Fahrenheit the temperature will begin to cause a voltage drop. The solar cells will be attached with glue to a firm, flat, lightweight-wood surface. The top of the solar panels will have a plastic panel over them, shielding them from debris and harsh weather conditions. Each of the modules will be sealed and the wires leaving the module will be sealed with sealant to prevent water escaping into the connections.

Parameter	Value
Dimensions	0.8 x 1.6”
Current	0.275 - 0.300A (full sunlight)
Current at Load	0.250-0.275A
Voltage	0.55V (full sunlight)
Voltage at Load	0.484V

Table 5.1.5.A: Specifications for a Mono-Crystalline Silicon Cell

5.1.6 Power Supply

The power system for W.A.R. will consist of two solar panel modules that will be generating solar energy to power two 3.7 volt lithium ion batteries. The block diagram describing the general power system design is displayed in Figure 5.6.1.A below. The two batteries together will be powering all of the electronics in the project. The first system that is be powered by the 3.7 volt lithium ion battery will have a DC to DC step up converter that will convert the 3.7 to 5 volts. The two PCB boards will be connected in parallel to the 5V input voltage supply pins located on each of the PCB boards. The second system will be powered from the second battery that has voltage of 3.7V, and will have an input voltage of 3.3 volts to the XBee Pro. Since the voltage from the battery will be 3.7 volts and the required input needs to be 3.3 volts a step down converter will be used to provide the necessary transition between the battery and converter and battery.

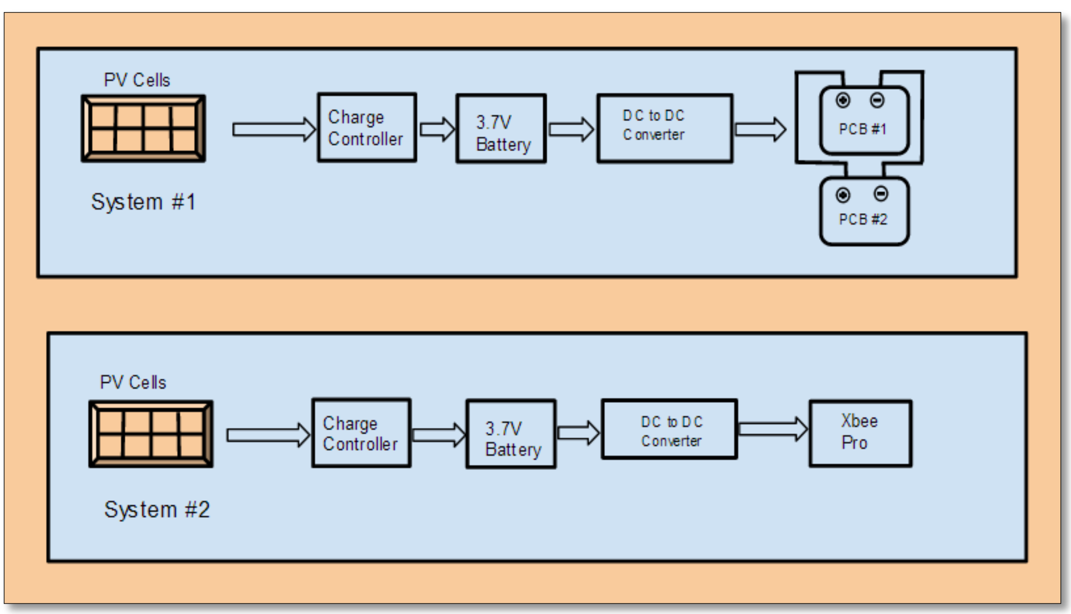


Figure 5.1.6.A Block Diagram of the W.A.R. Power System

The charge controller used for the W.A.R. design is Texas Instruments LM3420. The specifications for the charge controller are displayed in Table 5.1.6.A. below.

Parameter	**Value**
Maximum Voltage	20V
Regulation Voltage	4.2V
Maximum Output Current	20mA
Output Leakage Current	0.1μA
Output Saturation Voltage	1.2V
Power Dissipation	300mW
Operating Temperature	-40 to 257 degrees Fahrenheit
Internal Feedback Resistor	56kΩ(min) 94kΩ(max)

Table 5.1.6.A: Lithium Ion Battery Charge Controller LM3420 Specifications

The DC to DC step up converter used for the W.A.R. design for the first system is Texas Instruments LM4510. The specifications for the charge controller are displayed in Table 5.1.6.B. It is used to convert the 3.7 volts to 5 volts needed for each of the PCB boards.

Parameter	**Value**
Supply Voltage Range	2.7V to 5.5V (Operating Conditions) -0.3V (min) 6.5V (max)
Output Voltage Range	Up to 18V (Operating Conditions) -0.3V (min) 21V (max)
Switching Frequency	1.0MHz (Typical) 0.85MHz (min) 1.2MHz (max)
Junction Temperature Range	-40 to 125 degrees Celsius
Shutdown Current	0.002μA

Table 5.1.6.B: DC to DC Step Up Converter LM4510 Specifications

The DC to DC step down converter used for the second system will be the LM3478 switching regulator which will be connected in a specific configuration to satisfy the input requirement of 3.3 volts at 215mA. The specifications of the LM3478 switching regulator are displayed in the Table 5.1.6.C below.

Parameter	**Value**
Supply Voltage Range	2.97 to 40V
Output Voltage	3.3V
Switching Frequency	100kHz to 1MHz
Junction Temperature Range	-40 to 125 degrees Celsius
Shutdown Current	10μA

Table 5.1.6.C Specifications of LM3478

To ensure that the specific requirements of 3.3 volts and 215mA current were met, the Texas Instruments software WEBENCH was used to confirm that the LM3478 could provide the accurate transition between the battery and the XBee Pro component. The switching regulator will have an additional 13 components added to the circuit configuration to ensure the correct output requirements. Once the component is fully connected to the required circuit configuration using the additional thirteen components, the output and input voltage is demonstrated in Figure 5.1.6.B below using the TI WEBENCH software. The output voltage is in the color purple with its own voltage scale on the right, and the input voltage is in teal with its own voltage scale on the left.

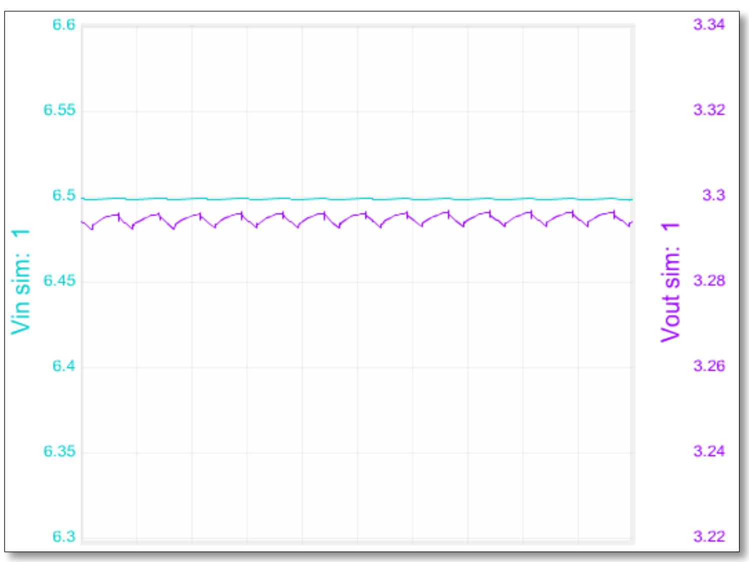


Figure 5.1.6.B Simulation Plot Displaying Input and Output Voltage of LM3478

The input and output current are displayed in Figure 5.1.6.C below. The blue waveform represents the input current and its scale is located on the right side of the plot. The red waveform represents the output current and its scale is located on the left side of the plot. While reading the plot data it's vital to consider the different scales for each of the waveforms. At first glance the input current appears to be significantly larger than the output current, however after reading each waveforms maximum and minimum peaks it's clear that the input current is smaller than the output current. Also, the output current has a very small ripple to it, which falls in the 0.215mA error range, whereas the input current varies by about 0.12mA.

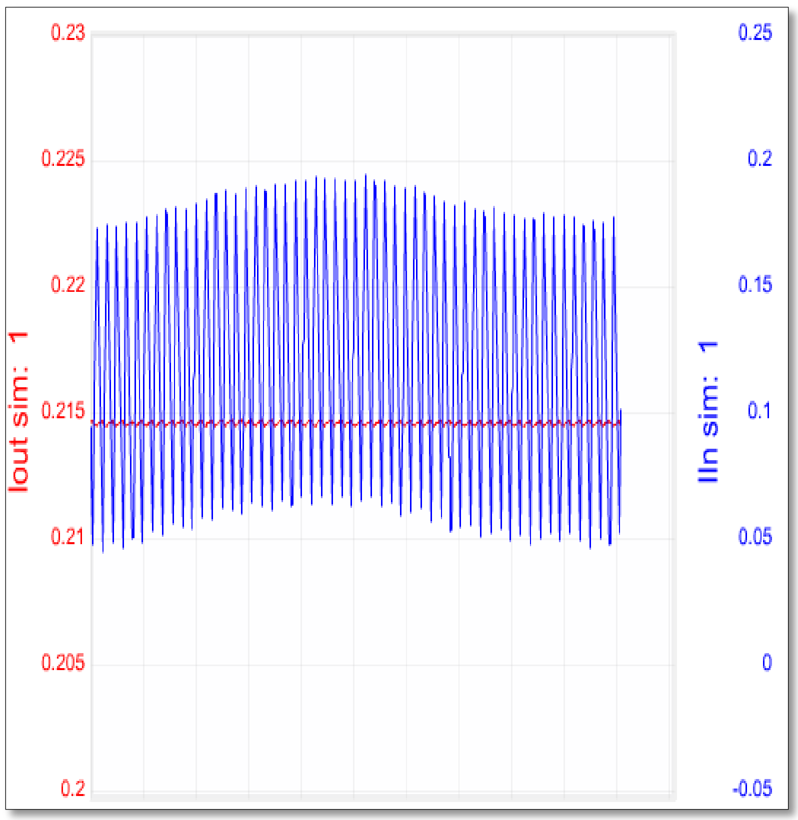


Figure 5.1.6.C Simulation Plot Displaying Input and Output Voltage of LM3478

5.1.7 GPS

The GPS module that was chosen is the 20 Channel EM-406A SiRF III Receiver with Antenna (EM-406A). The specifications for this module are shown in Table 5.1.7.A.

Parameter	Value
Number of Channels	20(all-in-view tracking)
Frequency	L1, 1575.42MHz
Sensitivity	159dBm
Update Rate	1Hz
Hot Start	1s
Cold Start	42s
Max Altitude	<18,000m
Max Velocity	<515m/s
Power Consumption	44mA
Power Input	4.5V - 6.5V
Price	$39.95

Table 5.1.7.A EM-406A Specifications

Figure 5.1.7.A shows how the EM-406A will be connected to the ATmega328P microcontroller.

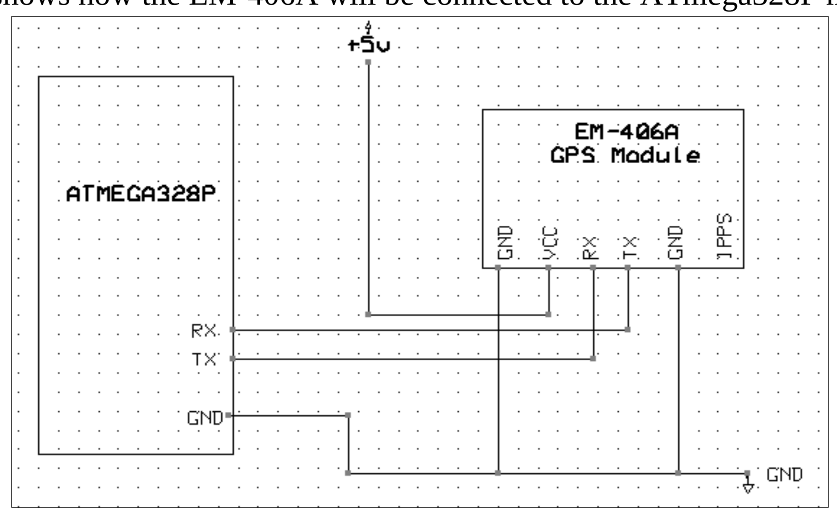


Figure 5.1.7.A Pin Connections Between EM-406A and ATMega328P

5.1.8 Motor

The motor chosen for W.A.R is the HobbyWing 2040 SL 4800kv Brushless Inrunner. The specifications for this motor are shown below in Table 5.1.8.A.

Parameter	Value
Kv	4800
Max Current	20A
No-load Current	1.7A
Resistance	0.0399 ohms
Diameter * length	20mm * 40mm
Shaft Diameter	2.3mm
Shaft Length	10mm
Weight	60g
Price	$34.99

Table 5.1.8.A Specifications for HobbyWing 2040 SL 4800kv Brushless Inrunner

Figure 5.1.8.A shows the schematic for the HobbyWing 2040 SL 4800kv Brushless Inrunner.

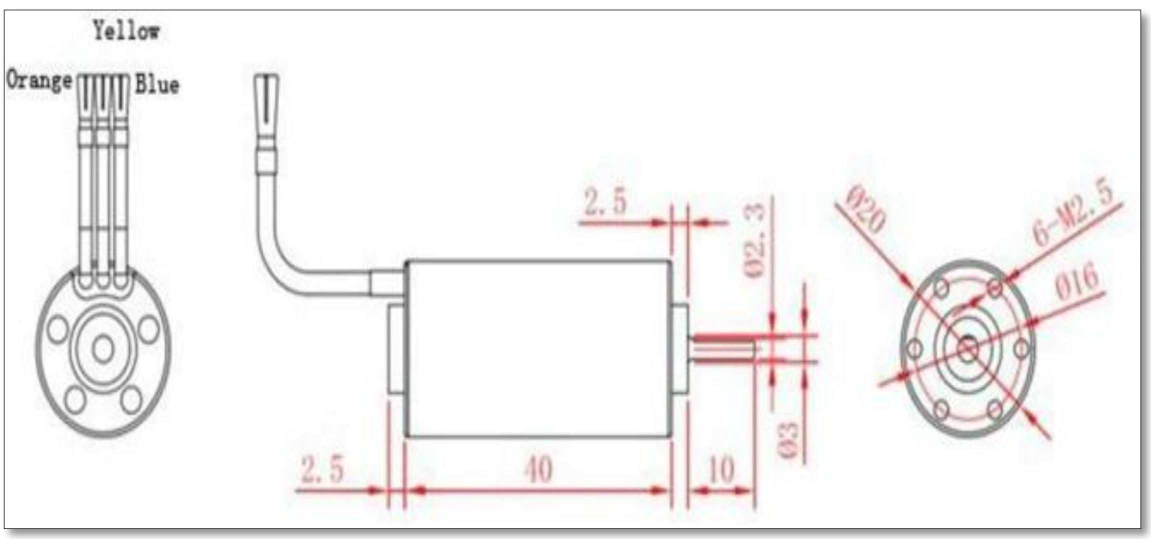


Figure 5.1.8.A Schematic for Brushless Inrunner Motor

5.1.9 GPS Compass

For the GPS compass, we decided to use the Honeywell HMC6352 which is a fully integrated compass module that combines 2-axis magneto-resistive sensors with the required analog and digital supports circuits as will the algorithms needed for heading computation. The specifications of this module are detailed below in table 5.2.9.A.

Characteristics	Conditions	Min	Typical	Max
Supply Voltage	Vsupply to GND	2.7V	3.0V	5.2V
Supply Current	Vsupply to GND Sleep Mode (Vsupply = 3.0V) Steady State (Vsupply = 3.0V) Steady State (Vsupply = 5.0V) Dynamic Peaks		1µA 1mA 2mA	10mA
Field Range	Total applied field	0.10G		0.75G
Heading Accuracy	HMC6352		2.5degRMS	
Heading Resolution			0.5deg	
Operating Temperature	Ambient	-20°C		70°C
Storage Temperature	Ambient	-55°C		125°C
Moisture Sensitivity	MAx 240°C		MSL3	
Output	Heading, Mag X, Mag Y			
Size	6.5 x 6.5 x 1.5 mm			
Weight			0.14g	

Table 5.1.9.A HMC6352 Specifications

5.2 Software

Microcontroller Programming: Each microcontroller will be programmed using the Arduino IDE. Before each Atmega328P can use the Arduino IDE we will burn the Arduino bootloader onto the chip. By using the Arduino we can use the large number of libraries that Arduino has to offer.

Microcontroller Configuration: We will have both microcontrollers programmed differently as both have different tasks. The first microcontroller will gather water quality data from the circuits. We will program the microcontroller to poll each water quality circuit for a set amount of time. The microcontroller will switch to each water quality circuit using the mux once the set amount of time has expired. Once the microcontroller receives data from the circuit it will save the byte of data and send it off to the XBee Pro which in turn will transmit this data to the onshore PC.

The second microcontroller be responsible for navigation. Once the user enters the coordinates it wants W.A.R. to travel to the microcontroller will calculate the distance and direction it must travel to. It will then power the motor and control the servo for the rudder and start the movement.

XBee Pro Configuration: The XBee Pros will not require any programming on the chip. The only software we will use on the XBee Pro will be X-CTU. X-CTU will be used to configure each XBee Pro so that they know to communicate to each other. Each XBee Pro is considered configured when their PAN ID matches the other so they are on the same network.

Desktop Application: For the water quality data to appear on the PC, we will use any open source terminal software. Since the XBee Pro connected to the PC sends the serial data through a COM port this is the easiest way. The terminal software will be configured so it will keep logs data so the user can create a water quality archive. The desktop terminal software will also be used to send GPS coordinates to the second controller using an USB to FTDI cable.

5.3 Mechanical

W.A.R will include a HobbyWing 2040 SL 4800kv Brushless Inrunner that will be connected to the navigation microcontroller (ATmega328P). The microcontroller will power the motor with 5V which will cause the boat to move forward. For steering we will use a servo that is also powered and connected to the ATmega328P. On the microcontroller’s command the servo will move the rudder to the appropriate angle so that the boat can travel to the waypoint that was inputted. The RC boat hull will need some modifications in order to sail properly. This are: the shaft hole will have to be drilled, trim tabs will be added as well as turn fins to the backside of the boat. These will aide in the steering of the boat.

6.0 Project Prototype and Coding

6.1 Robot Platform

To prototype our robot platform we will put a empty frame in a body of water and test how much weight the boat hull can handle. We will begin testing how much weight the boat can handle by gradually adding weight inside the hull. Half a pound will be added to the boat each iteration until the boat begins to take on water. When the boat starts taking in water we will record the max weight it may handle and design how much weight we can put on the boat.

6.2 Water Quality Circuit/Sensor Prototype

To prototype the water quality circuit and sensors we will build a small prototype that will output the water quality data to a PC using serial communication. This prototype will be built on a breadboard using our Arduino Uno, the water quality circuit, and the sensor. The circuit will read the data from the sensor and send the water quality to the microcontroller which will in turn output it to our PC. This simple configuration will also be used for calibrating our sensors due to the easy setup.

The connections needed for this prototype are very simple since all data will be passed using TX and RX pins. We will begin by connecting the water quality circuits RX and TX pins into the Arduino Uno digital I/O pins. In the code we will use the pins and create a software serial port from these pins. This will free up the hardware serial pins on the Arduino that will connect to the PC. This allows us full communication between the water quality circuit and the PC.

The purpose of this prototype is to proof our concept. This will allow us to work with the code necessary to start connecting multiple water quality circuits/sensors. Once we have this prototype working we can begin final design of the water quality PCB.

6.3 XBee Pro and Microcontroller Prototype

One of the more important features of our project will be the wireless communication between the PC and the Atmega328P. We will prototype this communication by sending simple character from the PC and having the Atmega328P echo the character back to the PC wirelessly. All of the communication will be sent through the two XBee Pros connected to our microcontroller and PC.

To build this prototype we will connect the microcontroller RX and TX pins to the XBee Pro DIN and DOUT pins. This will allow for serial data to be sent between the two devices. To prepare the PC all we will need is a USB to XBee explorer to connect the devices. Once everything is setup we will test the prototype by opening our open source terminal software and sending a character to our microcontroller. To acknowledge that the microcontroller received the data it will echo back the same character.

This prototype will be very beneficial to our final integration because it gives us a general base code on sending serial data back and forth from the microcontroller to the PC. Though on the final design the PC and microcontroller will not be sending back just a simple character but instead strings of data from the water quality sensors.

6.4 USB Programming

For programming the microcontroller we will purchase a 5V USB to FTDI cable. With this cable we can program the each microcontroller individually by using the proper connections. We will connect the following pins to on the microcontroller: VCC to +5V, GND to USB GND, RX to USB TX, TX to USB RX. With this setup we should be able to flash the Arduino boot loader on each microcontroller and also program/upload code from the Arduino IDE afterwards.

6.5 Multiplexer Prototype

To ensure that our communication between all the water quality circuits and the PC work we will build a simple prototype using the microcontroller and multiplexer. To accomplish this multiplexer we will connect two PCs to the multiplexer on different select lines and have the microcontroller choose which PC to communicate with.

With a PC selected we will send a character through open source terminal software and have the microcontroller echo the same character back. The microcontroller will then select the second PC and try to communicate with it.

6.6 GPS Prototype

Before integrating the GPS module into the final design of our project we will build a simple breadboard prototype. This prototype will familiarize us with the GPS and how it will work when it comes to our final design. To prototype the GPS module we will connect the microcontroller to the GPS and have the microcontroller send the current GPS coordinates to our PC. The GPS will communicate with the RX and TX pins on the microcontroller and the PC will display the coordinates using software serial connection from the USB to our Arduino Uno development board.

7.0 Project Prototype Testing

7.1 Hardware Electrical Components/Configurations

For all of the electrical components testing of the resistors, capacitors, inductor values, and power source outputs will be measured and recorded to try to eliminate as much error as possible.

Solar Cells

Before permanently connecting all of the solar cells together to as a module, each solar cell needs to be tested separately. The testing will be done to make sure that the solar cell works, and to verify its outputs in the different weather conditions and time of day. The goal of this testing is to make sure that on average there is enough sunlight to provide to the solar cells to fully charge the lithium ion battery. Each of the solar cells will be taken outside in the morning around 9am, at noon, and around 3pm to monitor its current and voltage characteristics. By looking at the minimum and maximum current and voltage output of each solar cell of all weather conditions, we will estimate approximately how much time it's going to take to fully charge the battery.

Next, the cells will be connected to form modules and a clear plastic will be used to cover the cells for protection against severe weather and debris. To view how impedance affects when all of the cells are connected together, its output voltage and current will once again be measured outside. To see how the module efficiency differs from each of the solar cells being connected, the output characteristics will be measure at the same times of the day: 9am, 12pm, and 3pm. After the testing of the solar cells is complete, the output characteristics of the module will be used to estimate the amount of time it will take to charge the battery to a desired level.

DC to DC Step Up Converter

For the first system that will have the microcontroller, motor, and sensors the testing will be done the following way: To test the DC to DC step up converter and to make sure it accurately converts a low voltage to a higher voltage several testing procedures will be done. The input pin $V_{IN,}$ will be connected to a DC power source. The input voltage will be varied and measured for the range of 2.7V to 5.5V, to make sure that the varying input range does not affect the output voltage. The output pin, $V_{OUT,}$ of LM4510, shown below in Figure 7.1.A, will be hooked up to a voltage meter and the output voltage will be measured for the varying input voltages.

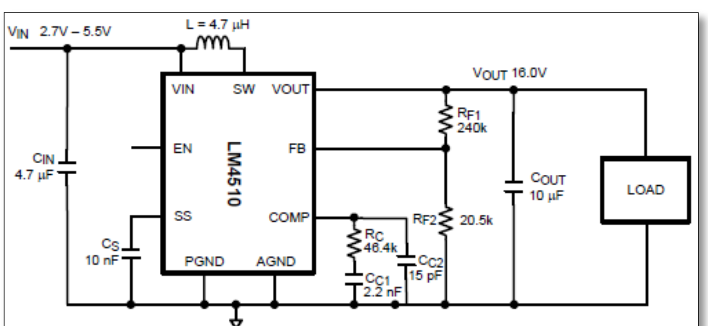


Figure 7.1.A LM4510 Circuit Configuration

For the second system which will have the XBee Pro communication system, the step up converter will be tested using the WEBENCH simulation software. The following schematic, displayed in Figure 7.1.B, will be tested for Vout and Iout characteristics.

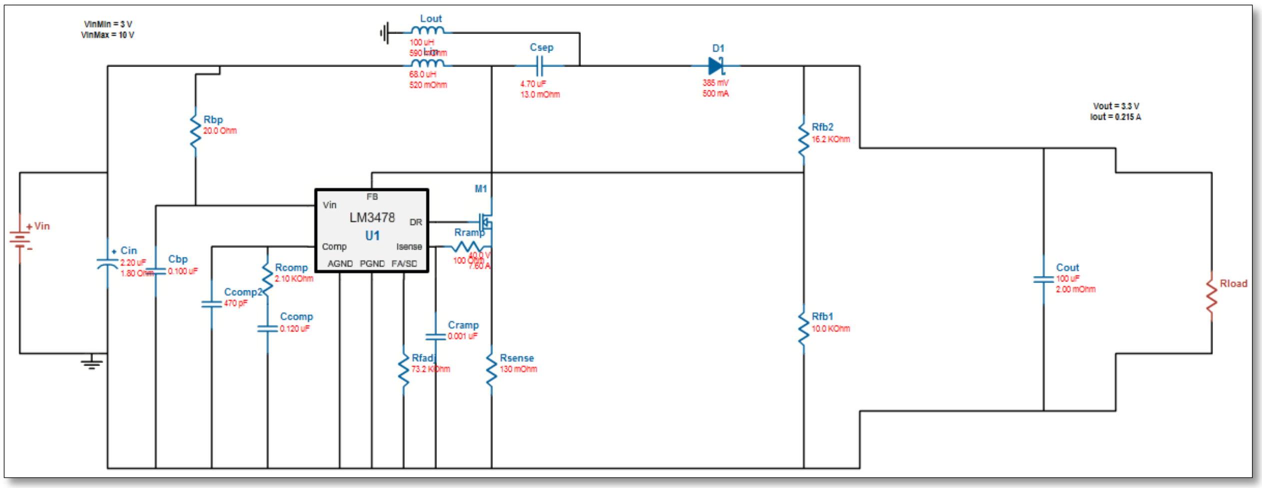


Figure 7.1.B: LM3478 Step Up Voltage Regulator Schematic

The efficiency chart for the LM3478 is displayed in Figure 7.1.C below. For powering the XBee Pro, the needed voltage is 3.3 volts at 0.215A. Looking at the chart it's clear that as the current approaches the desired amount the efficiency percentage drops. The condition for premium efficiency percentage of roughly 78% and for the input voltage of 3.0, or 3.3V in our case, circuit configuration is to have a current close to 0.1A. However, as the current approaches 0.2A the efficiency is still a desirable amount of 75%.

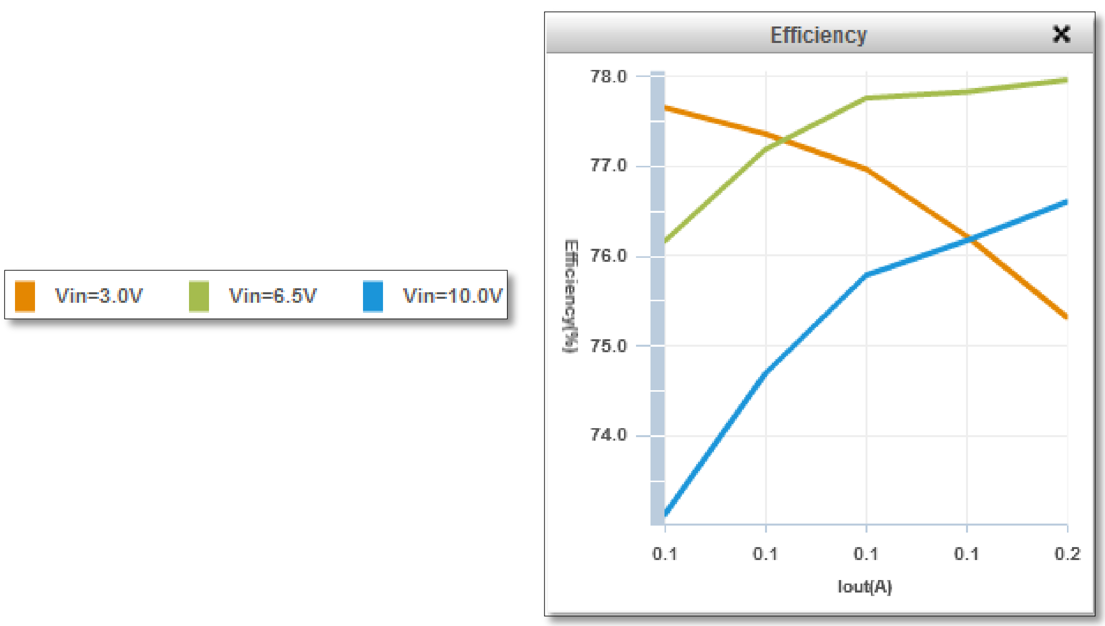


Figure 7.1.C: LM3478 Efficiency Plot

Charge Controller

Testing the charge controller is an extremely important part of the prototype testing. Throughout the testing of the lithium ion battery charge controller LM3420, it's important to take all precautions not to short or overcharge the lithium ion battery. Since the charge controller chip contains five different pins, one of them which is connected only for proper attaching reinforcement, four of them should be tested for the accurate output. Texas Instruments provides a testing circuit, which is displayed in Figure 7.1.D configuration which allows for the each of the pins to be tested with a digital multimeter. During the testing process the current and voltage of the circuit will be measured and compared to expected results. The testing of the charge controller will be done with the testing circuit located in Figure 7.1.D. The two Op-Amp output pins will each be measured for their output voltages. The current from the "OUT" pin of the LM3420 will be measured. The input voltage of the charge controller V_{REG} will also be measured.

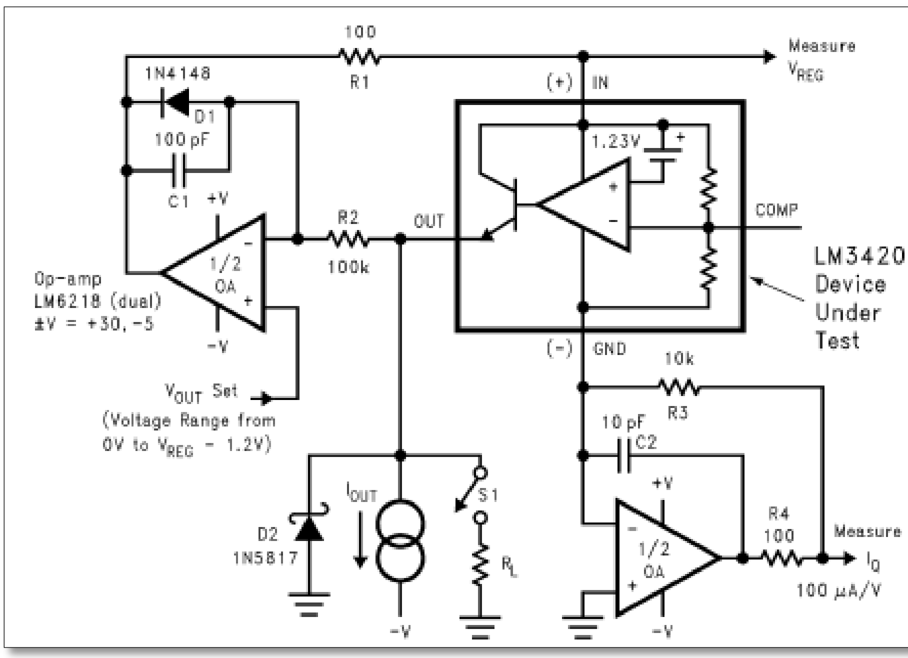


Figure 7.1.D: Li-Ion Charge Controller Testing Circuit

Lithium Ion Battery

In order to get a general idea for how long the lithium ion battery will be able to operate for, general time estimation can be done. The battery will be delivered along with its specification information. The "amp-hour" of the battery will be able to indicate its duration. The calculation will be done using one of the two following equations:

$$\frac{\#(Amp - Hours)}{\#(Amp)} = Hours$$

OR

$$\frac{(Battery\ Capacity)}{(Charger\ Current)} = Hours$$

The hours' time that is given by the equation is approximately how long it will take to recharge the battery after it has been fully discharged. The number of hours given by this equation gives the time it would take to charge the battery to about 80%. The rest of the 20%, calculation is not as predictable and can take just as much time or more to charge only that small 20%. Fortunately, it is not recommended to charge a lithium ion battery to full capacity, because that would damage the battery itself.

7.2 External Frame/Robot Platform

It is very important that the hull is waterproof and so that the inside electronics do not ever get wet. We will test for this in a tub of water by completely submerging the hull and then ensuring the insides are dry. As we are buying a quality made waterproof hull this should not be a problem. The only problem that might arise are with any modifications that we decide to do to the hull. After all the electronics are placed inside the hull, the boat must still be able to float. The motor must still be able to propel the boat forward despite the additional weight, as must he servo be able to turn the rudder in and outside of water. The boat must also be able to take sharp turns without capsizing. The speed of the boat will be regulated to avoid capsizing or losing contact with the surface of the water as the sensors must be in the water to work properly.

7.3 XBee Pro Communication Test

Below are the steps we will take test that both XBee Pro are able to communicate with each other.

1. Upon boot up both XBee Pros will check its own PAN ID and find other modules with the same ID that it can communicate with.
2. Once the XBee Pros are connected we will test the communication by sending it a character and wait for the character to be sent back.
3. If the character is sent back correctly and in a reasonable time then we can confirm that the XBee Pros are correctly communicated so the user can start taking water quality measurements.
4. If the connection is never made then each XBee Pro module must be reconfigured using the X-CTU software and checking to make sure that the PAN ID and baud rate settings are set correctly.

7.4 XBee Pro Range Testing

In order to ensure that we are able to transmit data from W.A.R. to our onshore PC we must test the range of the XBee Pro. The maximum line of sight distance of our XBee Pro will be 1500 meters. Our assumption is that the XBee Pro will be outside and have possible interference in the area so the 1500 meters may decrease. To test our devices we will acquire a USB to XBee explorer for the onshore PC and connect the second XBee Pro to our Atmega328P. Once the two XBee Pros are configured we will test their connection range by continuously sending data back and forth. As data is being sent back and forth we will increase the distance.

At any point if the data becomes corrupted or connection is terminated where no data is returned then we will determine the connection range for the XBee Pros. Due to the fact that there are many factors when transmitting data long distance we will be conservative on the distance that W.A.R. and the onshore PC can communicate.

7.5 Autonomous Motion

The testing for the W.A.R will be done in a large body of water that is particularly close to our current location, this body of water is called Lake Claire. We plan to input several different GPS coordinates and then ensure that the boat travels to them with some leeway for GPS error. Testing will be done on a clear day in spring so that the water is smooth and not rough. Commands will be sent to the navigation microcontroller which in this case is an ATmega328P through a terminal that will be positioned on the lake's shore. This terminal will most probably be a laptop. For testing purposes, we will have the boat send back what it thinks its current coordinates are. That way we can calibrate where we want it while still taking into account any GPS error in coordinates.

The goals of the testing are as follow: the boat should be able to travel successfully between waypoints, stop at each waypoint and take water samples, transmit water information to terminal before moving on to next waypoint, the boat should be able to take sharp turns, the boat should not capsize under any conditions, the boat should be able to travel in reverse, the servo should turn the rudder to the appropriate angle and the motor should spin with enough speed and torque to move the boat but not make it lose contact with the surface of the water.

7.6 GPS Function Test

To test the EM-406A GPS module we will use the SiRFdemo software provide by Falcom. The SiRFdemo can be used to access the advanced settings of the GPS receiver, check factory setting and modify them. It can also be used to restore factory defaults and verify the revision of the firmware loaded on the receiver.

To use the SiRFdemo we will connect the receiver to a PC via a USB/D89 adapter. Once the software has been run there are various navigation parameters that can be viewed in the response view window. They can be made to appear by doing a \Poll\Navigation Parameters command. The various navigation parameters are follows:

Operating Mode: defines the operating mode when optimal reception ($+ satellites) is no longer available.
Track Smoothing: will smooth the track to remove the jumps resulting from the natural inaccuracy of the GPS system, this is disabled by default.
Static Navigation: will freeze the position at very low speeds to cancel out the drifting resulting from the natural inaccuracy of the GPS.
DOP: filtering based on quality of the reception.
Power: to configure power saving trickle modes.

Most settings will remain untouched except for the static navigation; we plan to test both options in order to see which one will be better for our boat. In order to disable static navigation, a \Navigation\Static Navigation\command must be used, follow by clicking on "Disable" and then send. By calling the navigation parameters again, we can verify that the change has been recorded by the GPS.

As NMEA is the universal GPS language, after testing has been completed, we will return to that mode.
To keep the modified settings, we can do a \Action\Switch to NMEA Protocol\ command then select 4800 for the baud rate then send. To set the GPS back to its factory settings, we will do a \Action\Initialize Data Source\Factory Reset then send.

7.7 Water Quality Circuits/Sensors Calibration

To calibrate and make sure the sensors and the embedded circuits are working correctly we will assemble each water quality circuit with its respective sensor on a breadboard. The output from each water quality circuit will be output to terminal software on a PC. With each circuit and sensor connected correctly we will follow these steps to ensure correct functionality.

1. Dip the sensor into a known solution. For example, using the pH circuit/sensor, we will dip the sensor into a 7.0 pH solution.
2. Stir the sensor around the solution and wait for the measurements to appear on screen.
3. If the measurement is accurate to the solution the sensor was dipped into then we know it is calibrated correctly.
4. If the measurement is not accurate then try another calibration solution and see if the measurement is off.
5. If accuracy continues to be a problem then the sensor may need to be cleaned due to residual solutions.

7.8 Waterproofing

To ensure that the electronics in the hull of W.A.R. are not damage we will make sure no water enters W.A.R. is idle or moving. We will begin waterproofing by placing the empty hull in water and seeing if any water enters the hull. If there is a breach in the hull we plan to fill the problem area with a marine epoxy. Next we will move W.A.R. around and see if water will enter during movement. Again if water enters the hull we will determine where the problem areas are and see if we can solve the problem with the marine epoxy.

Since the solar panels need to be outside the hull to get sunlight we need to make sure the solar panels and its wiring do not get wet. To waterproof the solar panels we will wrap them in clear plastic. This clear plastic will still allow sunlight through so we can charge the batteries. Coming out of the plastic will be the wiring which we will make sure are waterproof with no open ends.

7.9 Demo Testing

Once all subsystems are integrated together we will do final demo testing on W.A.R. In this testing we will run W.A.R. as if we were end users using our product. In this test we will begin by entering GPS coordinates into our navigation microcontroller. Once the distance and directions are calculated W.A.R. will begin moving.

During the travel to the GPS coordinates the sensors will not take any measurements unless it receives commands from the onshore PC. Upon arrival to the GPS coordinates we will test the water quality commands by sending all possible commands to the water quality microcontroller. With each command entered we will log all outputs and make sure the data is consistent. Once we are done collecting the water quality data we will have W.A.R. return to the shore.To test the solar panels and the power supply for W.A.R. we will continuously run the demo tests multiple times until there is no more charge in our batteries. Once the batteries are depleted we will wait and see if the solar panels charge the batteries.

8.0 Administrative Content

8.1 Milestone Discussion

After finishing this Senior Design I paper we will be on schedule with what we originally planned in our milestone chart. During the month of December before we all leave to for winter break we will meet once more and plan what we will be purchasing our parts. During our break we all plan on researching more on each subsystem and learning the Eagle CAD PCB software. Below in Figure 8.1.A is our milestone chart again.

		Task Mode	Task Name	Duration	Start	Finish
0			**Senior Design Project Plan**	**157 days**	**Mon 9/23/13**	**Tue 4/29/14**
1			Research PV Cells and Wireless transmission	7 days	Mon 9/23/13	Tue 10/1/13
2			Research Microcontrollers/Motor	7 days	Mon 9/23/13	Tue 10/1/13
3			Research Water Quality Probes	7 days	Mon 9/23/13	Tue 10/1/13
4			Meeting to consolidate research/outline Design Paper/Sponsors	1 day	Wed 10/2/13	Wed 10/2/13
5			Begin Design Paper/Continue Research	7 days	Thu 10/3/13	Fri 10/11/13
6			Meeting for Design Paper	1 day	Sat 10/12/13	Sat 10/12/13
7			Continuation of Design Paper/Research	7 days	Sun 10/13/13	Mon 10/21/13
8			Learn Eagle PCB Software	7 days	Mon 10/14/13	Tue 10/22/13
9			Design Solar Panel/Power Management	21 days	Sat 10/19/13	Fri 11/15/13
10			Design Navigation/Control system	21 days	Sat 10/19/13	Fri 11/15/13
11			Design Water Quality System	21 days	Sat 10/19/13	Fri 11/15/13
12			Finish and refine Design Paper	7 days	Sat 11/16/13	Sat 11/23/13
13			Finalize Parts list and order parts for SD2	2 days	Mon 11/25/13	Tue 11/26/13
14						
15			Winter Break	19 days	Wed 12/11/13	Sat 1/4/14
16						
17			Begin SD2/Take inventory of ordered parts	1 day	Mon 1/6/14	Mon 1/6/14
18			Design Software/Test	21 days	Tue 1/7/14	Tue 2/4/14
19			Prototype Solar Panel	14 days	Fri 1/24/14	Wed 2/12/14
20			Prototype Navigation/Control System	14 days	Fri 1/24/14	Wed 2/12/14
21			Prototype Water Quality System	14 days	Fri 1/24/14	Wed 2/12/14
22			Test/Debug Solar Panel	21 days	Thu 2/13/14	Thu 3/13/14
23			Test/Debug Navigation/Control System	21 days	Thu 2/13/14	Thu 3/13/14
24			Test/Debug Water Quality System	21 days	Thu 2/13/14	Thu 3/13/14
25			Integrate whole system	14 days	Sat 3/15/14	Wed 4/2/14
26			Test whole system	15 days	Thu 4/3/14	Wed 4/23/14
27			Finalize Documentation/Presentation	9 days	Sat 4/12/14	Wed 4/23/14
28			Presentation	5 days	Wed 4/23/14	Tue 4/29/14

Figure 8.1.A Milestone Chart

Once spring semester start we will immediately begin to code and design W.A.R. Along with working on W.A.R. we will continually update this document as the semester continues. We hope to stay on schedule as long as we correct any problems immediately.

8.2 Finances and Budget

For this project we will be sponsored by Duke Energy. With their financial support we still plan on making this project as budget friendly as possible. After our initial documentation and research this project will cost around $1150. Unfortunately due to the price of water quality sensors the price of this project was higher than expected. Below is a more finalized budget table compared to our initial budget table earlier in our paper.

Part	Cost Per Unit	Quantity	Total Cost
Scientific Grade pH Sensor -------------------------------- pH Circuit	$60 ------------------------ $28	1	$88
Field Ready Temperature Sensor	$18	1	$18
Dissolved Oxygen Sensor ----------------- D.O Circuit	$160 ------------------------ $33.00	1	$193
Oxidation Reduction Potential Sensor -------------------------------- ORP Circuit	$90.00 ------------------------- $28.00	1	$118.00
Conductivity Sensor -------------------------------- Conductivity Circuit	$105.00 ------------------------- $43	1	$148.00
Atmel Atmega328P microcontroller	$6	2	$12.00
Arduino Uno (Atmega328P development board)	$30.00	2	$60.00
GPS unit	$39.99	1	$39.99
GPS compass	$34.95		$34.95
1-to-8 MUX - 74HCT4051	$1.00	5	$5.00
Diode	Free*	4	$0.00
PV Cells	$8.99 + $14(Shipping)	1 - Set of 25	$22.99
Lithium-Ion Battery	$7.95 +$3.33(Shipping)	3	$27.18
Step Up Converter (System 1)	$2.11	1	$2.11
Step Up Converter (System 2)	$2.36	1	$2.36
Perforated Board	$3.49	1	$3.49
Wiring	$10.00	1	$10.00
PCB Manufacturing	$50.00	1	$50.00
Rudder	$10.00	1	$10.00
Rudder Servo	$20.00	1	$20.00
Propeller	$5.00	1	$5.00
Motor	$34.99	1	$34.99

Robot Frame/Platform	$80.00	1	$100.00
Total Cost of Buoy Bot			**$1005.06**

Table 8.1.A – Updated Projected Costs

8.2.1 Sponsorship

The W.A.R. University of Central Florida Senior Design Project is entirely funded by Duke Energy. Having the project be entirely funded by Duke Energy had made it easier on the group to focus more on the technical aspect of the design project, and worry less on the having to provide the funds themselves. In addition to that, because the project was sponsored by Duke Energy the W.A.R. heroes were able to select precise equipment, such as the sensors, to make sure that their data was extremely accurate. The W.A.R. heroes are incredibly thankful for Duke Energy providing them sponsorship on their Senior Design Project.

Appendix A: Works Cited

APHA. 1992. *Standard methods for the examination of water and wastewater.* 18th ed. American Public Health Association, Washington, DC. River Watch Network. 1992. Total alkalinity and pH field and laboratory procedures (based on University of Massachusetts Acid Rain Monitoring Project). July 1.

APHA. 1992. *Standard methods for the examination of water and wastewater.* 18th ed. American Public Health Association, Washington, DC.

Hach Company. 1992. *Hach water analysis handbook.* 2nd ed. Loveland, CO.

Mississippi Headwaters River Watch. 1991. *Water quality procedures.* Mississippi Headwaters Board. March.

Donovan, John. "Bluetooth Goes Ultra-Low-Power - Wireless Solutions | DigiKey Technology Zones." *Bluetooth Goes Ultra-Low-Power - Wireless Solutions | DigiKey Technology Zones*. N.p., n.d. Web. 15 Sept. 2013. <http://www.digikey.com/us/en/techzone/wireless/resources/articles/bluetooth-goes-ultra-low-power.html>.

"Different Types of Photovoltaic Systems." *Different Types of Photovoltaic Systems*. N.p., n.d. Web. 10 Sept. 2013. <http://www.polarpowerinc.com/info/operation20/operation23.htm>.

"Is Lithium-ion the Ideal Battery?" *Advantages & Limitations of the Lithium-ion Battery*. N.p., n.d. Web. 10 Oct. 2013. <http://batteryuniversity.com/learn/article/is_lithium_ion_the_ideal_battery>.

"Lead Acid Batteries - Battery Council International." *Lead Acid Batteries - Battery Council International*. N.p., n.d. Web. 10 Oct. 2013. <http://batterycouncil.org/?page=Lead_Acid_Batteries>.

Ness, Tomek. "Arduino Playground - 4051." *Arduino Playground - 4051*. N.p., n.d. Web. 17 Sept. 2013. <http://playground.arduino.cc/learning/4051>.

"MSP430G2553(ACTIVE)MSP430G2x53, MSP430G2x13 Mixed Signal Microcontroller." *MSP430 Ultra-Low Power 16-bit MCUs*. N.p., n.d. Web. 18 Sept. 2013. <http://www.ti.com/product/msp430g2553>.

"ATmega328P." *ATmega328P*. N.p., n.d. Web. 18 Sept. 2013. <http://www.atmel.com/devices/atmega328p.aspx>.

Hewes, John. "Power Supplies." *Power Supplies*. N.p., n.d. Web. 24 Sept. 2013. <http://electronicsclub.info/powersupplies.htm>.

Byers, TJ. "Build a Solar Battery Charge Controller." *Mother Earth News*. N.p., n.d. Web. 24 Sept. 2013. <http://www.motherearthnews.com/diy/solar-battery-charge-controller.aspx>.

"How to Prolong Lithium-based Batteries." - *Battery University*. N.p., n.d. Web. 20 Oct. 2013. <http://batteryuniversity.com/learn/article/how_to_prolong_lithium_based_batteries>.

"MikroElektronika." *MikroElektronika - Development Tools, Compilers, Books*. N.p., 2009. Web. 15 Oct. 2013. <http://www.mikroe.com/downloads/get/640/en_article_c_avr_04_09.pdf>.

"GPS Tracking Comparisons." *SparkFun Electronics*. N.p., n.d. Web. 15 Oct. 2013. <https://www.sparkfun.com/tutorials/169>.

McCabe, Patrick. "Fundamentals of a GPS guided Vehicle" *Let's Make Robots! | Let's Make Robots!* N.p., May 2010. Web. 17 Oct. 2013. <http://letsmakerobots.com/node/19554>.

Von Epping hoven, Ralph. "How to Install a Steering Servo." *Offshore Electrics*. N.p., n.d. Web. 23 Nov. 2013. <http://www.offshoreelectrics.com/info-pages/install-sterring-servo.php>.

Elia. "ATmega Servo Tutorial." *Elias Electronics Blog*. N.p., 04 Nov. 2011. Web. 26 Nov. 2013. <http://eliaselectronics.com/atmega-servo-tutorial/>.

"Three Phase Permanent Magnet Motor." *Atmel Corporation - Microcontrollers, 32-bit, and Touch Solutions*. Atmel Corporation, n.d. Web. 13 Nov. 2013. <http://www.atmel.com/Images/doc8010.pdf>.

Gironi, David. "Controlling DC Motor Speed and Direction with AVR Atmega." *Davide Gironi: Controlling DC Motor Speed and Direction with AVR Atmega*. N.p., 06 Mar. 2013. Web. 01 Dec. 2013. <http://davidegironi.blogspot.com/2013/03/controlling-dc-motor-speed-and_6.html>.

"Propeller." *Radio Control Info*. N.p., n.d. Web. 24 Sept. 2013. <http://www.radiocontrolinfo.com/ElectricBoat/propeller.php>.

"Motor." *Brushless Motor Electric Boat Selection, How to Choose / Pick a Suitable Brushless Motor*. N.p., n.d. Web. 22 Sept. 2013. <http://www.radiocontrolinfo.com/ElectricBoat/motor.php>.

"Hull." *RC Electric Boat Hulls, Catamaran, Tunnel, Hydro, Outrigger, Mono, Hatch, Hatch Tape*. N.p., n.d. Web. 24 Sept. 2013. <http://www.radiocontrolinfo.com/ElectricBoat/hull.php>.

"Boat Guided by GPS Example." *Acroname Robotics*. N.p., n.d. Web. 07 Oct. 2013. <http://www.acroname.com/examples/10071/10071.html>.

Drain, John. "RC Servos and What They Do." *PT Boat Servo's*. N.p., 2006. Web. 08 Nov. 2013. <http://www.pt-boat.com/electric/Servo.html>.

Molle, Harald. "Ardupilot Goes into the Water." *DIY Drones*. N.p., 30 Mar. 2010. Web. 17 Nov. 2013. <http://diydrones.ning.com/profiles/blogs/ardupilot-goes-into-the-water>

Appendix B: Letters of Copyright Use

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Figure 3.2.3.A

http://www.epa.gov/acidrain/education/site_students/phscale.html
http://www.epa.gov/students/faq.html

Frequently Asked Questions

Need an answer to a question? Check out the FAQs below.
If you do not find the answer to your question, please submit your question to us here.

- **Students**
- **Teachers**
- **Environmental Education**
- **Resources**

Some of the sites listed on this page are not on the EPA Web site. Please see our disclaimer information EXIT Disclaimer

Students

I need more information on environmental issues for a homework assignment, where should I look?

You can see various environmental subjects in our homework resources area.

I'm looking for pictures of the environment to use for a school project?

All the images on the EPA website are public domain and may be used by students.

Figure 3.2.4.A

http://www.engineeringtoolbox.com/oxygen-solubility-water-d_841.html
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Figure 3.2.6.A

Permission Pending

http://www.mikroe.com/downloads/get/640/en_article_c_avr_04_09.pdf

Subject: Permission to Use Diagram

Name: Dennis Figueras

Email: dennis_fs@hotmail.com

Country: UNITED STATES

Message:

Hello,

My name is Dennis Figueras, a senior at UCF, currently working on a senior design project with two other members. We are making a GPS guided robot and would like your permission to use the NMEA example diagram in our report. This diagram is found at

http://www.mikroe.com/downloads/get/640/en_article_c_avr_04_09.pdf

Thank you in advance for your time.

-Dennis

Figure 3.2.10.A

http://bama.ua.edu/~bwbuckley/projects/mppt.html

---------- Forwarded message ----------
From: **Bryan Buckley** <bryanwbuckley@gmail.com>
Date: Sat, Nov 2, 2013 at 12:37 PM
Subject: Re: Permission to use an image
To: Irina Bouzina <irinabouzina@gmail.com>

I appreciate you asking.

Yes, you may use it. Please add a link to the project page on the image.

On Nov 2, 2013 8:49 AM, "Irina Bouzina" <irinabouzina@gmail.com> wrote:

> Hello Bryan,
> My name is Irina Bouzina and I am a student of University of Central Florida studying electrical engineering. I was wondering if I could have your permission on using one of your images (the PV Current vs PV Voltage plot) from your website for my senior design project paper.
>
> Please let me know if you approve my group and I to use your image.
> Thank you.
>
> Irina Bouzina
> Electrical Engineer
> IEEE UCF Branch - Industry Chair
> University of Central Florida
> (386) 682 - 9975 | irinabouzina@gmail.com

Figure 3.2.15.A

http://playground.arduino.cc/learning/4051

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Figure 3.2.16.A

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---------- Forwarded message ----------
From: **John** <john@electronicsclub.info>
Date: Sat, Nov 2, 2013 at 1:14 PM
Subject: Re: Permission to use an image
To: Irina Bouzina <irinabouzina@gmail.com>

Hello Irina

Yes, that's fine, you have my permission. Please credit my website electronicsclub.info as the source of the image. Thank you for asking.

Regards

John Hewes
electronicsclub.info

On 2 Nov 2013, at 16:44, Irina Bouzina <irinabouzina@gmail.com> wrote:

> Hello, my name is Irina Bouzina and I am a student of University of Central Florida studying electrical engineering. I was wondering if I could have your permission on using one of your images from your website, the power supply page, for my senior design project paper.
>
> Please let me know if you approve my group and I to use your image.
> Thank you.
>
> **Irina Bouzina**
> Electrical Engineer
> IEEE UCF Branch - Industry Chair
> University of Central Florida
> (386) 682 - 9975 | irinabouzina@gmail.com

Figure 3.2.17.A

Permission Pending

Figure 3.4.10.A

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Figure 4.2.7.A

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Figure 7.1.C

Figure 7.1.D

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