Solar RC Boat 49

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ECE 445 Design Document - Fall 2017

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Contents

1 Introduction

1.1 Objective

Typical RC boats have terrible battery life and long charge times (10 minutes of use for 1.5 hours of charge [1]). This is incredibly frustrating because the boat is charging out of the water and cannot be used the majority of the time. To provide longer playtime, we plan to mount four solar panels on the boat to provide an alternate power source in addition to the original battery. The solar power will be used as the main power source for the boat's motor, theoretically providing an infinite amount of playtime so long as solar energy is available. Since solar energy will not always be sufficient to power the motor, we will use battery power as a backup. The boat's motor will always be connected to a power source, and we will switch between solar and battery power, depending on the amount of solar energy available.

Along with poor battery life, RC boats also have a very limited signal radius for control, and the boat is often driven out of range of the controller. This is a problem because it is difficult to get the boat back once the signal is lost. We will expand on our RC boat solution by addressing this signal range problem. We will implement an RF detection circuit to warn the user if he is driving the boat out of range. The circuit will sense the signal strength received from the remote controller; once that signal reaches a minimum power threshold, we will alert the user with enough time to respond to the signal and turn the boat around. The user will be warned via an LED on the controller indicating poor signal strength.

These two enhancements will allow for longer use of the boat since the battery life will be extended, and the user will be warned of poor signal so the boat stays within range. Thus, our objective is to innovate the RC boat to allow for longer playtime and signal detection.

1.2 Background

RC boats are commonly bought for recreational purposes because they are fun and easy to use as well as affordable. Typically, these toy boats are available from around $30 [1] to $80 [2]. The cheaper boats are generally slower and have a smaller operating radius of around thirty meters. The more expensive boats can go up to 18 mph with a remote control distance of up to 150 meters. Regardless of the price, however, typical boats only allow for around ten minutes of playtime on a fully-charged battery, and the batteries themselves take at least an hour to charge completely, sometimes up to two hours. This minimal playtime is the greatest complaint for any type of RC boat [1]; users often seek to purchase multiple batteries so that they can extend their playtime by using them one after another [2].

RC boats are generally used in a pool, on a lake, or on a pond. Although their operating ranges are specified, users usually cannot determine if the boat is about to go out of range by simply looking at how far away the boat is on the water. This is very inconvenient if the boat is accidentally driven at top-speed out of range. It becomes difficult, especially on a lake or a pond, to retrieve the boat once it can no longer respond to the remote controller.

Our design will address both of these problems to allow for longer playtime and feedback to the user about the range and power of the boat's signal.

1.3 High-Level Requirements List

- Motor must receive sufficient power from solar cells to operate as it normally would on battery power.
- Voltage comparator will determine when to switch between battery power and solar power to provide consistent and continuous operation when solar energy is insufficient.
- User will be notified via LED added to controller that the boat is within approximately 5 meters of going out of range.

2 Design

From a high-level perspective, our design is composed of five subsystems, shown in Figure 1. We will have a power block that supplies power to our communication control as well as our power regulating circuit. The regulator circuit will supply power to the motor controller and motor. The communication control subsystem includes the communication hardware that determines if the boat is going out of range and when we need to warn the user. We will design a PCB that contains the power and RF subsystems, along with the microcontroller that determines their behaviors.

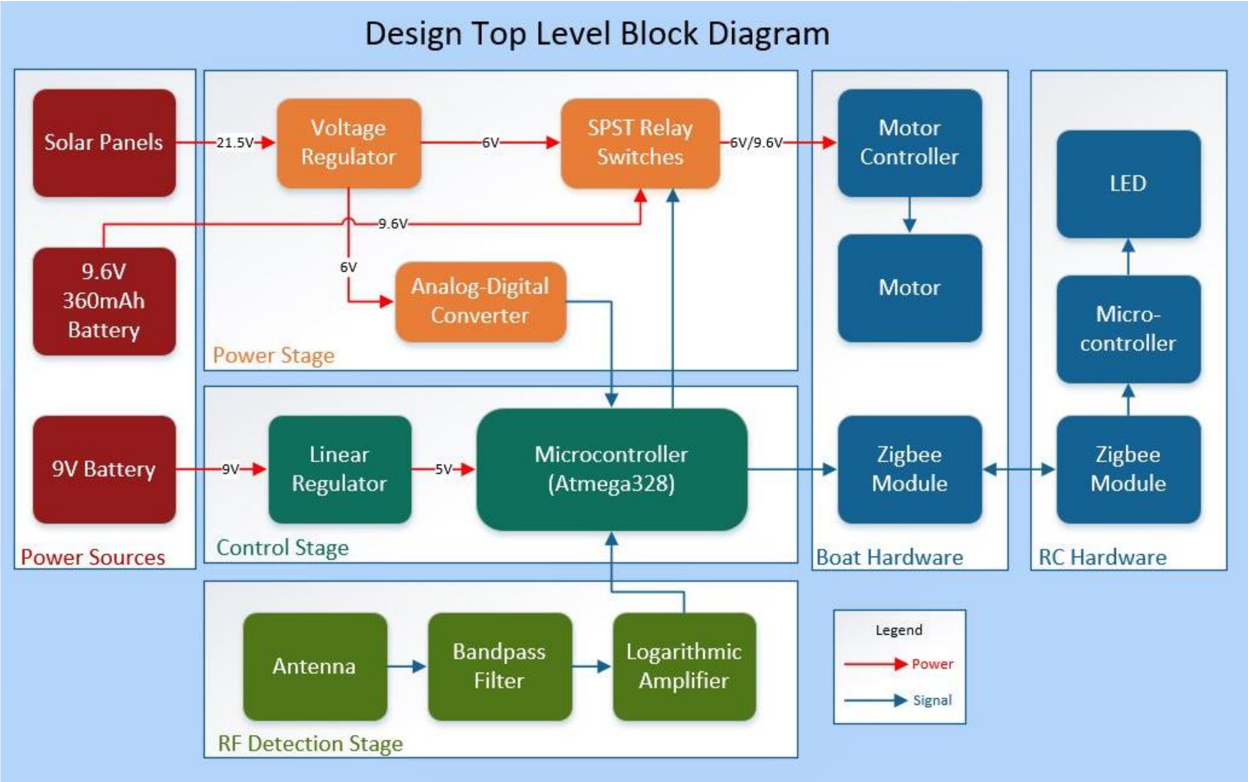

Figure 1. Block Diagram for Overall System

2.1 Power Supplies

Our design consists of three power sources that will be used to power the boat, motor, and our circuitry. We do not plan to use the solar panels or the boat's internal battery to power our own circuitry; instead, we will provide power to our microcontroller and circuitry using an external battery.

2.1.1 Solar Panels

We plan to work with a New Bright Marine RC Boat [3] and ALLPOWERS solar cells [4] to capture solar energy and power the boat. The solar cells are 5V 2.5W mini encapsulated epoxy solar panels. Theoretically, 5 of these solar panels produces 12.5W of power, and we found that the boat's motor consumes 10.26W when run at 6V. This means that we can use five solar cells to provide enough power to the boat for it to run at 6V. Based on our characterization of the motor, we will set 4.5V as the minimum voltage the boat may run on using solar energy. Below this threshold, we will switch to battery power.

Requirement	Verification
Must provide 10.3W of power with a tolerance of +/- 1W.	a. Measure the output voltage of the solar array b. Calculate the equivalent load resistance to be 7.7Ω c. Use Ohm's Law to calculate the current to be 0.558A .

2.1.2 9.6V 450mAh Battery

The New Bright Marine RC boat has a rechargeable 9.6V 450mAh battery that lasts for 15 minutes on a full charge. When our solar power drops below 5W we will first connect the battery to the motor controller and then disconnect the solar power so that we deliver seamless power to the motor controller. Once solar power is above the threshold again, we will connect it to the motor controller and then disconnect the battery. We will also implement a circuit protection diode scheme to block back EMF produced from switching between power sources from destroying our circuitry. The minimum turn on voltage for the boat motor is 1.2V. We chose to operate the boat at 6V Our boat has been ordered and we need to characterize its motor as well as our solar panels to determine the minimum power the boat needs to maintain adequate speed before switching between battery and solar power. Once we have that data, we will be able to select a power threshold.

Requirement	Verification
The boat must operate longer than 15 minutes when using both solar power and its battery.	a. Power the motor using solar cell on a sunny day b. Switch power from solar cells to 9.6V battery c. Run boat for an additional 15 minutes using the 9.6V battery

2.1.3 9V Battery

Our solar energy and the boat's internal battery will only power the boat's motor; therefore, we will use an external 9V battery to power our microcontroller and circuitry. A 9V battery is considered dead when its voltage is 5.4V and below. Therefore, we will verify that our 9V battery does not get below 5.4V during the playtime of the boat.

Requirement	**Verification**
A signal LED must notify the user when the 9V battery runs below 7.2V	a. Attach Battery to a digital multimeter and a 100 ohm resistor b. Discharge battery at 20mA to 7.2V c. Connect LED to the battery to light up when the battery is below 7.2V

2.2 Regulator Circuit

The regulator circuit will determine which power source will supply the motor, using solar power as its default. If the solar energy falls below a certain threshold (i.e. it gets cloudy), we will switch to providing battery power until sufficient solar energy returns (i.e. clouds go away). When the solar energy is sufficient, the internal battery will then be disconnected, and the solar energy will supply power to the boat motor again. Figure 2 shows the schematic for our power module.

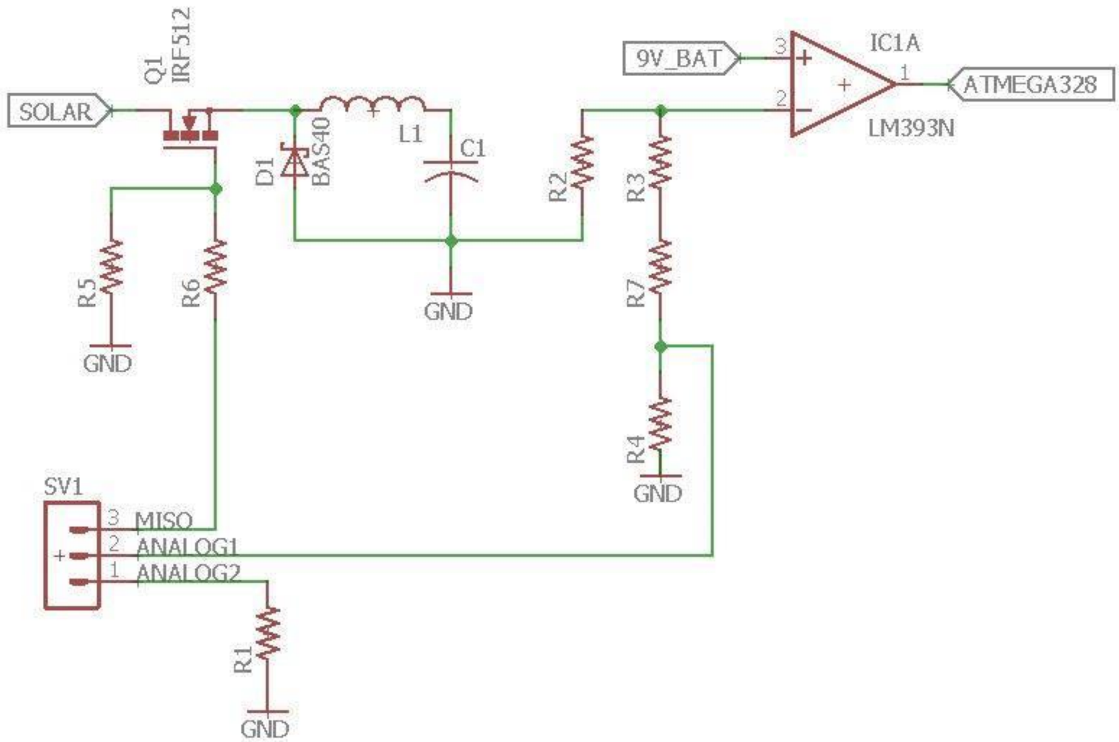

Figure 2: Power Stage Schematic

2.2.1 Voltage Regulator

The voltage regulator will take the energy from the solar panels as an input, and the circuit will boost/buck the voltage such that a smooth and controlled DC voltage is supplied to the motor. We will implement the boost/buck converter on our PCB. We have characterized our motor and solar panels to find that five solar panels will provide enough power to run the motor at 6V. Although this is less than the voltage provided by the boat battery, we chose this based on our available resources and testing capabilities. The characterization of the motors showed that it would be difficult to run the boat at above 6V in a confined laboratory space.

Requirement	**Verification**
Provide 6V +/- 0.2V of regulated voltage from the solar panels	a. Attach oscilloscope to the output of the regulator b. Measure the output of the regulator to be 6V +/- 0.2V consistently

2.2.2 SPST Relay Switch

The regulated solar voltage and internal boat battery will each be connected to a SPST relay switch [5], which will be controlled by the microcontroller. The microcontroller use data from the ADC to determine if the regulated voltage from the solar panels is above our 4.5V threshold. The microcontroller will then switch the relays as necessary to provide constant power to the motors. We will use the regulated solar voltage as our default power source.

Requirement	**Verification**
1. One power source must be connected before the other power source is removed to ensure continuous power is supplied to the motor 2. If output of voltage regulator falls below 4.5V, must switch to battery power 3. If battery power is used, but solar power returns to sufficient voltage level, must switch back to solar power	1. Verification for Item 1: a. Program microcontroller to switch one relay at a time b. Observe voltage waveform of motor on oscilloscope c. Waveform must remain nonzero when switching between battery and solar power 2. Verification for Item 2: a. Program microcontroller to compare regulated solar voltage to 4.5V threshold b. Measure voltage across motor on oscilloscope to be 9.6V 3. Verification for Item 3: a. Program microcontroller to check output of voltage regulator continuously b. Measure voltage across motor on oscilloscope to be above 4.5V

2.2.3 Analog-Digital Converter

The analog-to-digital converter (ADC) will convert the output of the voltage comparator into digital data to pass to the on-boat microcontroller. We plan to use a Maxim Integrated 8-bit analog to digital converter with a sampling rate of 25kS/s [6].

2.3 Boat Hardware

We will be working with the existing hardware that comes with the boat. We will need to integrate our design with this hardware without compromising the boat's integrity. Figure 3 shows the boat we will be working with.

Figure 3: New Bright Marine RC Boat

2.3.1 Motor Controller

The motor controller will be included in the boat that we purchase. We do not plan to alter the communication and connection between the controller and the motor. Once the boat arrives we will characterize the motor controller by varying the boat throttle and recording the voltage signals it sends to the motors.

Requirement	**Verification**
The motor controller must take our switching	a. Run motor under solar panels of 6V

power sources and control the boat's motor.	b. Run motor original battery of 9.6V

2.3.2 Motor

The boat's motor was isolated and different voltages were applied to it and the current draw was recorded. This experiment was done with the boat's propeller submerged in water so we could get accurate current draws for the increased torque experienced by the motor as opposed to air. The boat motor's minimum turn on voltage is 1.2V. We decided to operate the motor at 6V with solar power because the boat goes reasonably fast and the power savings makes the use of solar cells to power the motor feasible. The boat will be fully functional with 6V supplied to the motor. When the output power of the solar cells drops to 5W (half of the desired output) the internal 9.6V battery will be connected to the motor. This threshold occurs when the boat motor is supplied 4.5V.

Requirement	**Verification**
The motor must be able to propel the boat forward at at least 10km/hr.	a. Go to a lake or pond on a sunny day b. Measure a 10m distance along the shore c. Perform three timed trials to determine how long it takes for the boat to travel 10m d. Calculate speed from distance and time

2.4 RF Detection Stage

The purpose of the RF Detection circuit is to detect the strength of the signal received from the remote controller and determine if it is above a certain threshold. We will use a bandpass filter and a log amplifier to condition the signal before it is passed to the microcontroller. The microcontroller will then determine if the signal is getting too weak and control communication between two Zigbees to notify the user that the boat should be turned around. Figure 4 shows the schematic of our RF Detection module. We based the schematic off of information from the datasheet of the log amplifier [7].

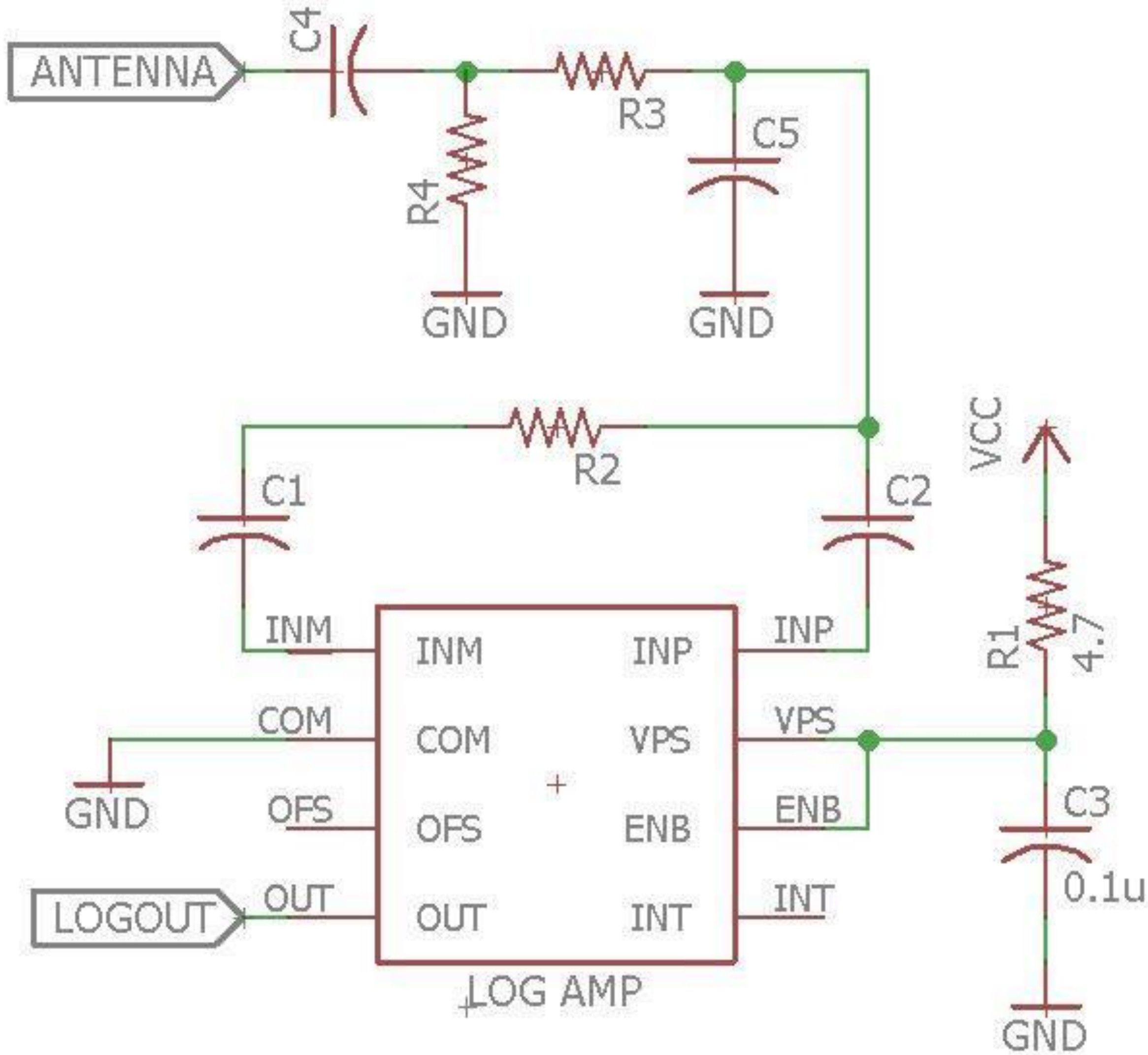

Figure 4: RF Detection Stage Schematic

2.4.1 Antenna

The antenna on the boat will sense the signal received from the remote controller and send it through the bandpass filter where any noise picked up by the antenna will be discarded.

Requirement	**Verification**
Must be able to capture 49MHz	a. Connect antenna to spectrum analyzer

	b. Set center frequency to 49MHz with span of 10kHz c. Operate remote controller near antenna d. Observe peak from remote controller on spectrum analyzer

2.4.2 Bandpass Filter

The bandpass filter will filter out other frequencies and noise captured by the antenna. We want a bandwidth of 10 MHz, centered around 49 MHz. This means our lower cutoff frequency $f_L = 44\, MHz$ and our upper cutoff frequency $f_H = 54\, MHz$. We designed our bandpass filter as a simple RC circuit, shown in Figure 4; we chose our resistors $R3 = R4 = 1k\Omega$, and can solve for capacitors C4 and C5:

$$C4 = 1/(2\pi * R3 * f_L) = 1/(2\pi * 1000 * 44 * 10^6) = 3.62pF \qquad (1)$$

$$C5 = 1/(2\pi * R4 * f_H) = 1/(2\pi * 1000 * 54 * 10^6) = 2.95pF \qquad (2)$$

Requirement	**Verification**
1. Bandwidth must be 10MHz, centered around 49MHz	a. Build RC circuit on breadboard using components with values found in Equations 1 and 2 b. Use frequency spectrum captured by antenna as input c. Observe output of bandpass filter on oscilloscope to determine if bandwidth is appropriate

2.4.3 Logarithmic Amplifier

The logarithmic amplifier will be used for receiver signal strength indication. It will take the output of the bandpass filter and convert the signal level to decibel form to pass to the on-boat microcontroller. We'll be using the AD8307 log amplifier, which has a 92 dBm range [7].

2.4.4 On-Boat Zigbee Module

The Zigbee module on the boat will communicates with a second Zigbee module on the remote controller. The on-boat Zigbee will be controlled by the on-boat microcontroller to communicate with the controller Zigbee. The Zigbees will communicate at 2.4GHz using the IEEE 802.15.4 standard. We will use Digi XBee Zigbees [8].

2.5 Control Stage

This module will control the relay switch for the power stage as well as the communication between the two Zigbees for the RF Detection stage.

2.5.1 On-Boat Microcontroller

The microcontroller we have chosen is ATmega328p [9]. It will be powered by the 9V battery. For the power stage, it will control the relay switches based on the output of the voltage comparator. For the RF detection stage, it will determine if the boat is near its maximum range based on the output from the log amplifier. It will also handle communication between the on-boat Zigbee and the controller Zigbee. The schematic for the microcontroller is shown in Figure 5, created based off of Arduino tutorials [10].

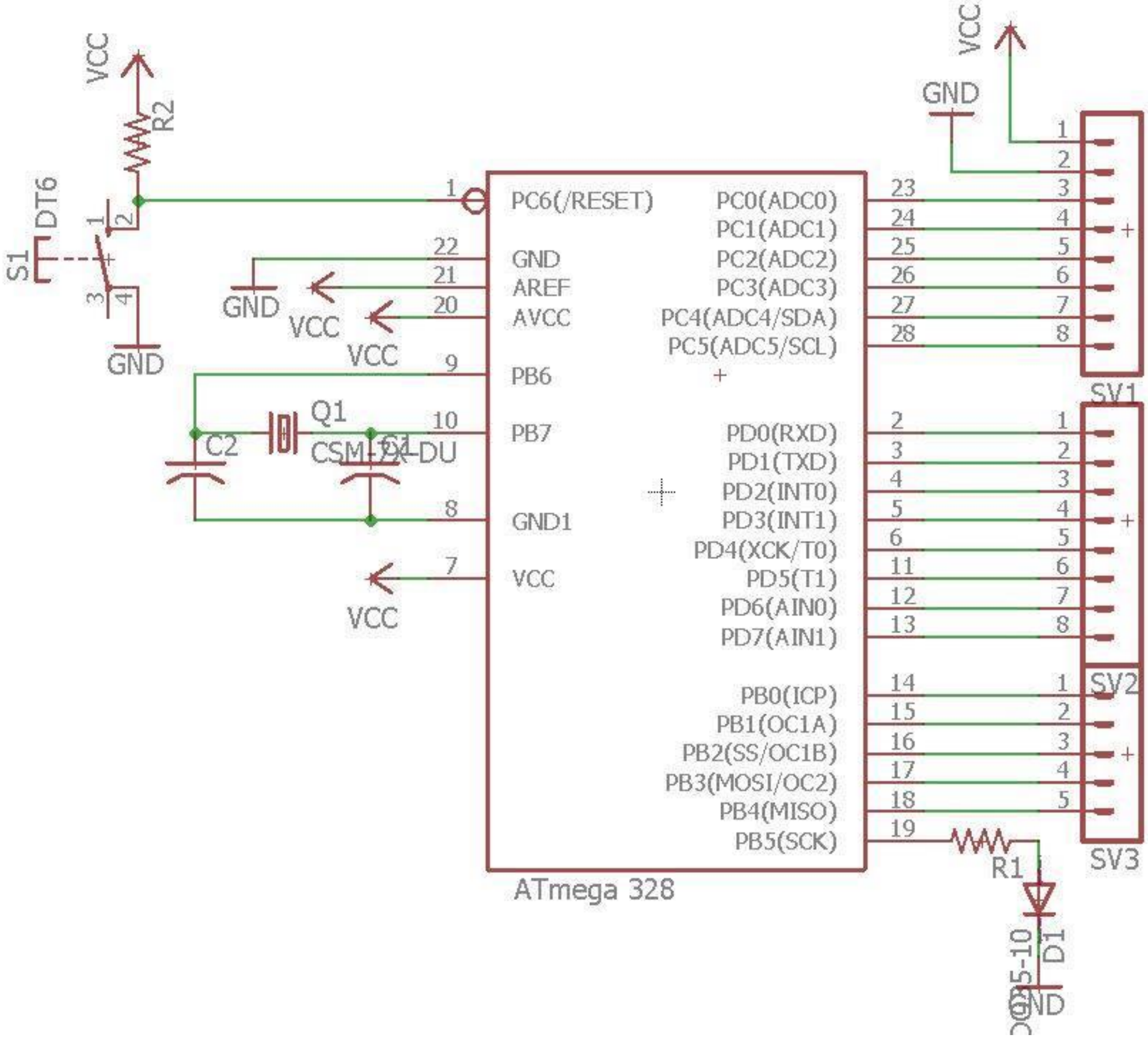

Figure 5: Microcontroller Schematic

2.5.2 Linear Regulator

The ATmega328 microcontroller operates at 5V, so there will be a linear regulator to step down the voltage from the battery to 5V. We need to be careful with the current because the linear regulator will melt with current that is too high. We will use an ON Semiconductor 5 V linear regulator IC [11]; using its datasheet, we created the schematic for the regulator, shown in Figure 6.

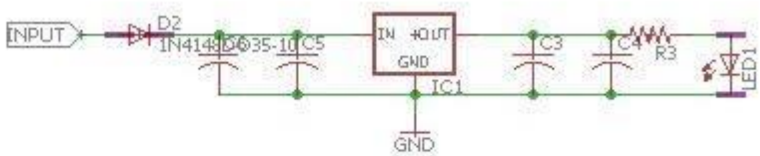

Figure 6: Linear Regulator Schematic

Requirement	**Verification**
Must take 9V +/- 1.8V and provide constant 5V +/- 0.2V	a. Attach oscilloscope the output of the linear regulator b. Measure the voltage of the output is 5V +/- 0.2V

2.6 RC Hardware

The boat comes with a remote control that we will modify in order to communicate with the circuitry we add to the boat. We do not plan to alter the actual control of the motor.

2.6.1 RC Zigbee Module

The Zigbee module on the remote controller will communicate with the on-boat Zigbee. The Zigbees will communicate at 2.4GHz. The RC Zigbee module will feed information to a second microcontroller on the remote controller.

2.6.2 RC Microcontroller

There will be a microcontroller on the remote controller to enable or disable an LED based on the data received from the Zigbee.

2.6.3 LED

We will modify the remote controller to include an LED. Its purpose is to notify the user that the boat will soon be out of range and should be turned around. For the purposes of the demonstration, the senior design lab allows the user to be 8-10m away from the boat, so we will show the functionality of this feature with a 7 meter threshold.

Requirement	Verification
1. LED must light up when the boat is 7m away from the remote control	1. Verification process: a. Connect antenna to spectrum analyzer, with center frequency set to 49MHz and span of 10kHz. b. Measure signal strength (dBm) from remote control at 1m intervals for 10m c. Determine appropriate signal strength threshold that corresponds to approximately 7m d. Program RC-microcontroller to control functionality of LED based on this threshold e. Check that LED turns on when remote controller is farther than 7m from boat

2.7 Tolerance Analysis

An important aspect of our design are the solar cells we will use to power the motor. The solar cells are 5V 2.5W mini encapsulated epoxy solar panels. Theoretically, 5 of these solar panels produces 12.5W of power, and our motor calculation shows that the boat's motor consumes 10.26W when run at 6V. We tested one of the solar cells to characterize its peak power output and IV curve. The cell was put in direct sunlight and the voltage across varying loads was measured and the current was then calculated based off of this. We then graphed current versus voltage for the solar cell to determine open circuit voltage, short circuit current, and the maximum power point. The open circuit voltage for one cell is 5.53V, the short circuit current is 0.7A, and the peak power output is 2.4W occurring at 4.3V and 0.558A. This means that the load the cell wants to see is 7.7Ω using Ohm's Law. Figure 7 contains our I-V characteristic for one of the solar cells.

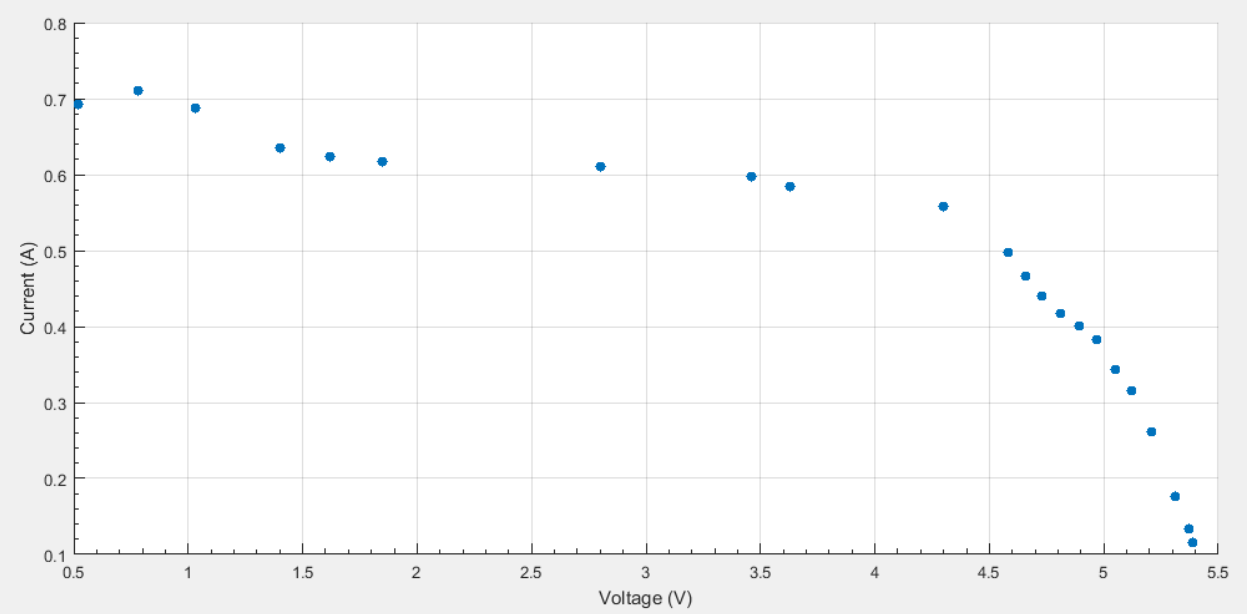

Figure 7: I-V Characteristic for Single Allpowers Solar Panel

The power at each data point taken during the solar cell characterization was calculated and plotted against load resistance used in Figure 8. This allows us to visualize the maximum output power of the cell under a given load. The maximum power output by the cell was 2.4W which is 0.1W less than the theoretical output. This means that we can generate 12W of power with our solar array.

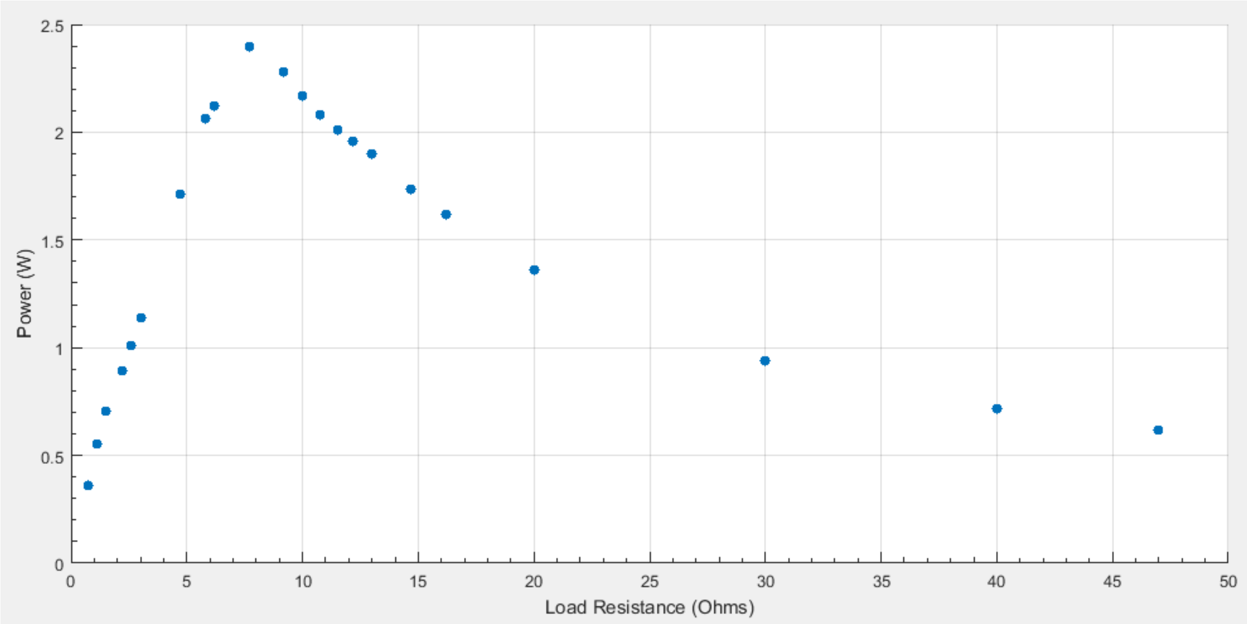

Figure 8: Power (W) vs. Load Resistance (Ω) for Single Allpower Solar Cell

According to Figure 8, maximum power output happens at 4.30V and 0.558A with a load resistance seen by the solar panel of 7.7Ω. This allows us to produce 2.4W of power from each solar cell and 12W from our 5-cell array.

Another essential aspect of our design is ensuring that the motors can run smoothly with the power that we supply from the solar panels. We have characterized the motor by isolating it from the rest of the boat circuitry and have applied different voltages across it while measuring the current draw. This test was done with the boat's propeller submerged in water since a larger torque will need to be produced by the boat to move in water than in air. This larger torque results in a larger current draw and larger overall power consumption. The turn-on voltage for the motor is between 1-1.2V. A summary of the currents and voltages from the test are summarized in Table I.

Voltage (V)	Current (A)
1	0.32
1.2	0.34
1.4	0.38

1.8	0.43
2	0.45
2.3	0.51
2.5	0.57
2.7	0.60
3	0.69
3.5	0.84
4	1.0
4.5	1.15
5	1.34
5.5	1.5
6	1.71
7	2.1
8	2.45
9	2.8
9.5	2.93

Table I. Voltage and Current Values of Motor Test

We have determined to run the motor at 6V when the solar cells are powering the motor because that results in a power need of 10.26W. This power need makes using solar cells to power the motor feasible since we can theoretically generate 12W of power with full sun exposure since each cell produces 2.4W and we have 5 cells. We have determined the peak power output of the solar cells by extrapolating the results from the solar cell test and Figure 7 and Figure 8. We have selected a lower motor power than our theoretical maximum solar cell production because we recognize that we will not be able to produce maximum power at all times due to shading of the cells. We have also calculated the resistance the cell needs to see as 7.7Ω using Figure 7 and Figure 8 along with Ohm's Law. Therefore, we will calculate the equivalent resistance that the solar panel array sees and then add resistors in parallel or series so that the array sees this resistance and maximum power can be extracted.

Our solar cell array will be connected in series to our regulating buck converter circuit. We will get a total voltage from the series combination of 21.5V since each cell will produce approximately 4.3V under maximum power conditions. We will have feedback from the buck converter circuit and our microcontroller will be able to adjust the duty ratio such that the 6V is maintained. However, when the solar power results in a power of 5W we will disconnect the solar cells and instead use the internal boat battery to power the motors until sufficient solar power returns. The duty ratio of a buck converter can be calculated using

$$D = \frac{Vout}{Vin} \tag{3}$$

We get an initial duty ratio of 28% for our ideal power output case using our input voltage to be 21.5V and output voltage to be 6V. The duty ratio will be changed by the microcontroller to meet the 6V output desire fed to the motor controller and to the motor. We can approximate the inductor size using

$$L \geq \frac{D(1-D)Vin}{fsw*\Delta i} \tag{4}$$

With the duty ratio, input voltage, switching frequency, and ripple current. We will operate our converter with a frequency of 150 kHz. We will then design our inductor around our ideal power output data with a current ripple of 0.3A, input voltage of 21.5V, and duty ratio of 28%. This results in an inductor value greater than or equal to $96\mu H$. We then will be able to approximate the capacitor size using

$$C \geq \frac{\Delta i}{8fsw*\Delta v} \tag{5}$$

With the switching frequency of 150kHz, current ripple of 0.3A, and output voltage ripple of 0.2V. This results in a capacitance greater than or equal to $1.25\mu F$.We plan to meet with Prof. Banerjee to discuss these first order estimations of inductance and capacitance and will further refine our design by simulating our circuit in LTspice once we have talked with Prof. Banerjee.

3 Cost

3.1 Labor

The cost of labor is estimated to be $36/hour at 15 hours/week for 16 weeks per person. With 3 people, the total cost of labor becomes:

$$3 * \$36/hr * 15\ hr/week * 16\ weeks * 2.5 = \$64{,}800$$

3.2 Parts

Part	**Part Number**	**Unit Price**	**Quantity**	**Cost**
Programmable XBee Zigbee	XB24CZ7PITB003	$20.73	2	$41.46
IC Logarithmic Amp 8-DIP	AD8307ANZ	$13.28	1	$13.28
New Bright Marine RC Boat	6723	$54	1	$54
Microcontroller	ATMEGA328P-PU	$2.18	2	$4.36
28-DIP Socket	ED281DT	$0.33	2	$0.66
8-DIP Socket	A 08-LC-TT	$0.19	2	$0.38
SPST Relay	1462041-6	$4.73	2	$9.46
IC Linear Regulator	LM7805CT	$0.95	1	$0.95
Passive Components				$10.00
Coaxial connector	MM8030-2610RJ3	$0.20	1	$0.20
Antenna	ANT-STUBR-433SM	$6.56	1	$6.56
Allpowers Solar Cells		$7.99	5	$35.97
Total				**$177.28**

3.3 Total Cost of Project

Labor	$64,800
Parts	$177.28
Total Cost of Project	**$64,977.28**

4 Schedule

Week	**Task**	**Delegation**
9/11/17	Decide on project and get approval	All
9/18/17	Complete project proposal	All
10/2/17	Complete design document Complete schematic design Characterize motor Characterize antenna Meet with Prof. Banerjee to talk about power circuitry	All Zhendong Robert Nisa Robert
10/9/17	Order hardware components Complete buck converter design Mount solar panels on boat	Nisa Robert All
10/16/17	Finalize on PCB components/parts choices Test RF Circuit design, adjust as needed	Zhendong / Robert Nisa
10/23/17	Complete and submit first draft of PCB Work on microcontroller protocols - communicating with Zigbees, controlling switches, checking thresholds	Zhendong Nisa

10/30/17	Complete individual progress report, test that PCB works with motor and motor controller	All
11/6/17	Complete and submit final draft of PCB, if needed Test and debug all modules	Zhendong All
11/13/17	Further testing and debugging	All
11/20/17	Thanksgiving break, begin presentation prep	All
11/27/17	Sign up for demo and presentation Mock demo, prepare for final demonstration and presentation	Nisa All
12/4/17	Demonstrate project, prepare final paper	All
12/11/17	Presentation, turn in final paper	All

5 Ethics and Safety

5.1 Safety

There are a few safety concerns with our RC boat project since we are manipulating the boat's power module. We must be highly cautious when taking apart the boat for modification; we need to maintain the battery integrity and make sure that the internal power circuitry remains protected. This is especially important because we will be doing a variety of testing in wet environments. Maintaining a protected power module is the most beneficial to the boat as well as the team members.

Although the voltage and current running through the circuitry are typically not life threatening, it could still dissipate a large amount of heat if the circuit is short circuited. This could cause burns if skin is in contact with the module, or possibly damage the boat if key components are compromised. We must be careful when handling the boat, especially when we are testing our circuitry near water. We will conduct frequent testing of our power module, especially the battery to ensure the main sources of power do not become hazards. Additionally, a first aid burn kit should be ready at hand in case such an incident occurs. With all these in mind, we would minimize the potential dangers and damages from happening in our design process.

5.2 Ethics

In the course of designing our project, we aim to maintain good ethical practices. We have discussed extensively with our teaching assistant to ensure uniqueness of our project by comparing to previous and current senior design groups. At the same time, we made sure that none of the IEEE Code of Ethics [12] would be violated. The following seven points listed below relate closely to our project and we take responsibility to closely follow them. Our project has been reviewed by the teaching assistants, peers, as well as professors. All resources used in this document have been properly cited.

1. To accept responsibility in making decisions consistent with the safety, health, and welfare of the public, and to disclose promptly factors that might endanger the public or the environment. The design specifications will check for the safety of the public, and all potentially dangerous items will be disclosed to the public below in the safety statement.
3. To be honest and realistic in stating claims or estimates based on available data. All the above claims, such as the battery life, will be based on accurate calculations and have been disclosed in this document.
5. To improve the understanding of technology; its appropriate application, and potential consequences. The goal of our product is to provide a safe base for utilizing the capabilities of PSoC, and to further improve other people's' knowledge of the product.
6. To maintain and improve our technical competence and to undertake technological tasks for others only if qualified by training or experience, or after full disclosure of pertinent limitations. Design for this product has been undertaken with caution, and only done after understanding of the design.
7. To seek, accept, and offer honest criticism of technical work, to acknowledge and correct errors, and to credit properly the contributions of others This project has been reviewed by the Teaching Assistants, Professors, and our peers in the Senior Design class, as well as Cypress Semiconductors, our project's sponsor. All resources that have been used in this document have been cited.

References

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