# SOLAR RC BOAT 49

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## Abstract

The purpose of this project is to improve the usability of remote-controlled (RC) toy boats. In order to improve battery life, we implemented a switching power supply via a single-pull double-throw relay and microcontroller. We used a series of five solar cells to generate between 14 V - 25 V which corresponds to the necessary 8.7 W - 12 W to run the motor. We then used a dc-dc synchronous buck converter to step down and regulate the input voltage to 6 V. The regulated solar input connected to the normally-connected pin of the relay whereas the 9.6 V internal boat's battery connected to the normally-opened pin. Finally, we implemented signal strength detection using 2.4 GHz wifi modules to warn the user if they are driving out of range via an LED.

# Contents

# 1. Introduction

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 mounted five solar panels on the boat to provide an alternate power source in addition to the original battery. The solar power is 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 might not always be sufficient to power the motor, we used 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. Our RC boat solution addresses this signal range problem by implementing an RF detection circuit to warn the user if he/she is driving the boat out of range. The circuit senses the signal strength received from the remote controller and compares it to a minimum power threshold. If the signal strength is lower than the threshold, an LED on the remote controller alerts the user with enough time to respond to the signal and turn the boat around.

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

# 2 Design

From a high-level perspective, our design is composed of the five subsystems shown in Figure 1. The power block supplies power to our linear regulator circuits as well as our buck converter. The regulator circuits supply power to two microcontrollers and two XBee modules; the buck converter outputs a 6 V regulated voltage into a single-pull double-throw (SPDT) relay alongside a 9.6 V internal battery. The microcontrollers control the relay switch by determining if the solar power is sufficient. They also monitor communication between the two XBee modules to turn on the LED light when the signal strength between the boat and remote control is too low. We designed PCBs for the microcontrollers, power conditioning stage, and RF circuits.

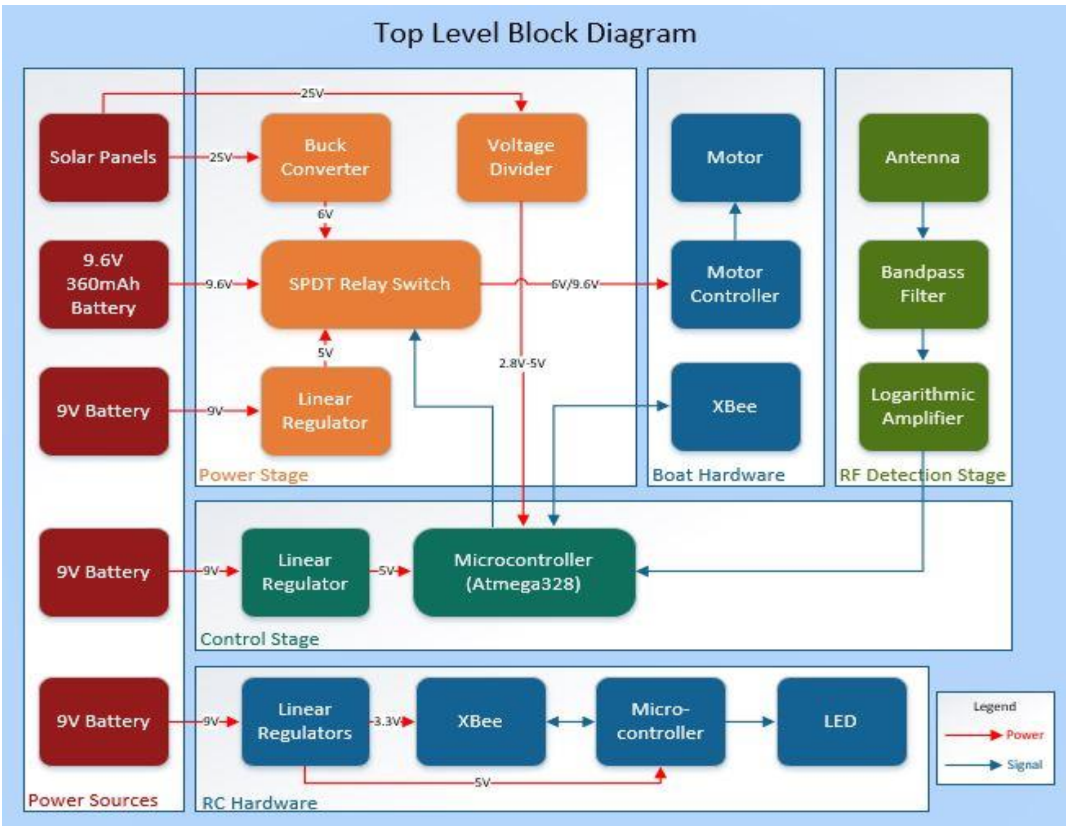


**Figure 1: Block diagram for overall system**

## 2.1 Boat Hardware

The first objective of the design process was to characterize the boat's motor and motor controller. We did this in order to integrate our design with the existing hardware without compromising the boat's integrity. We worked with a New Bright Marine RC Boat [2], shown in Figure 2.

Figure 2: New Bright Marine RC Boat

### 2.1.1 Motor Controller

The motor controller was included in our boat, and we did not alter the communication and connection between the controller and the motor. The motor controller simply connects the power source directly to the motor when given a command from the user's remote control. We determined this functionality by testing how the controller operated when connected to a DC voltage supply. We supplied a 0 to 9.6 V input to simulate the battery effects and commanded the motor to operate using the remote controller. We observed the resulting motor controller output waveform on the oscilloscope, shown in Figure 3. We measured the average value to be the DC input voltage, as expected. There were small ripples in the output waveform due to noise and the manufacturer's PCB design; the PCB had small capacitors and inductors to keep costs low since the boat does not need a precise power system. The peak-to-peak ripple during this test was 0.5 V and within our desired tolerance.

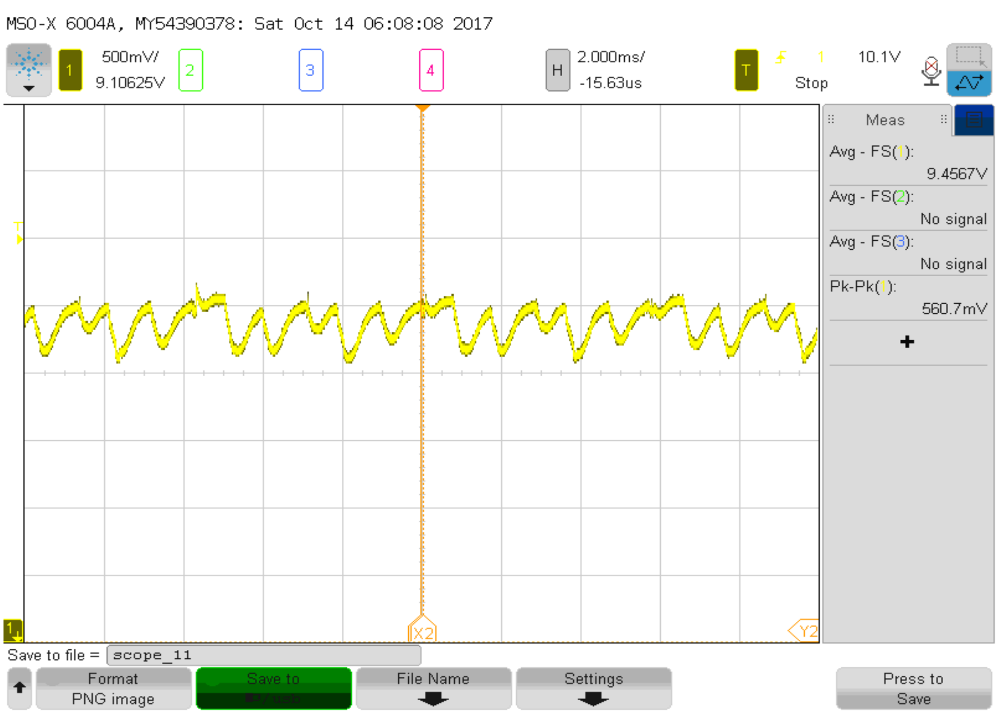


Figure 3: Motor controller output waveform with 9.5 V power supply

In order to integrate our design, we connected our power stage output to the motor controller in place of the 9.6 V internal boat battery. The motor controller will wait until it receives a signal from the user's remote controller; when it receives a signal, the motor controller will connect the power we supply in full to the motor, and it will continue to do so for as long as the user sends the signal.

### 2.1.2 Motor

We characterized the boat's motor to determine its power consumption so that we could size the solar panels accordingly. We isolated the motor, applied different voltages to it, and recorded the current draw. We performed the experiment with the boat's propeller submerged in water to get accurate current draws for the increased torque experienced by the motor as opposed to air. The motor's minimum turn-on voltage in water is 1.2 V. Using Equation 1, we calculated the power consumption for various voltage inputs, shown in Table I.

$$P = IV \tag{1}$$

We decided to operate the motor at 6 V with solar power because the boat goes reasonably fast, and is still fully functional. The reduced power makes the use of solar cells to power the motor feasible due to limited area on top of the boat. When the output power of the solar cells drops to 8.7 W, we will connect the internal 9.6 V battery to the motor. This power threshold occurs when the solar array outputs less than 14.35 V.

**Table 1: Voltage, current, and power consumption data for motor**

| Voltage (V) | Current (A) | Power (W) |
|---|---|---|
| 1 | 0.32 | 0.32 |
| 1.2 | 0.34 | 0.408 |
| 1.4 | 0.38 | 0.532 |
| 1.8 | 0.43 | 0.774 |
| 2 | 0.45 | 0.9 |
| 2.3 | 0.51 | 1.173 |
| 2.5 | 0.57 | 1.425 |
| 2.7 | 0.60 | 1.62 |
| 3 | 0.69 | 2.07 |
| 3.5 | 0.84 | 2.94 |
| 4 | 1.0 | 4 |
| 4.5 | 1.15 | 5.175 |
| 5 | 1.34 | 6.7 |
| 5.5 | 1.5 | 8.25 |
| 6 | 1.71 | 10.26 |
| 7 | 2.1 | 14.7 |
| 8 | 2.45 | 19.6 |
| 9 | 2.8 | 25.2 |
| 9.5 | 2.93 | 27.835 |

## 2.2 Power Stage

### 2.2.1 Solar Panels

We sized our solar array given the calculated power minimum of 8.7 W. We worked with ALLPOWERS solar cells [3] to capture solar energy and power the boat. The solar cells are 5 V 2.5 W mini encapsulated epoxy solar panels. Theoretically, five of these solar panels produce 12.5 W of power, and we found that the boat's motor consumes 10.26 W when run at 6 V from Table I. This means that we can use five solar cells to provide enough power to the boat for it to run at 6 V and have a power range of 8.7 W - 12.5 W. Based on our characterization of the motor, we set the minimum input voltage from the solar array to be 14.35 V corresponding to 8.7 W. At and above this voltage the boat may run off of solar energy. Below this threshold, we will switch to battery power. Figure 4 shows the solar cell's placement on the top of the boat. The top of our boat is 5.9" x 23.6," and each solar cell is 5.1" x 5.9," so we were able to mount all five panels at 45° and achieve maximum insolation.

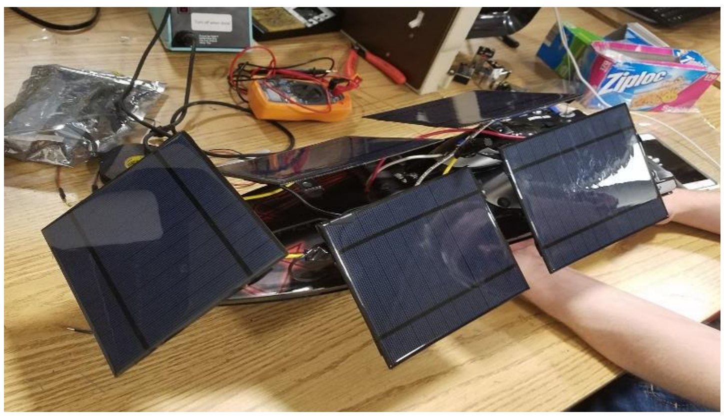


Figure 4: Solar cell placement on boat top

### 2.2.2 Buck Converter

To account for the variable input voltage from the solar cell array, we used a buck converter to step down the solar input such that a smooth and controlled DC voltage is supplied to the motor. The microcontroller allows the buck converter to be on when the input from the array is between 14.35 V - 25 V. We used a Texas Instrument LMR33630 IC to provide a 6 V +/- 0.1 V output regardless of the input. The chip is disabled by our microcontroller if the input voltage from the array falls below 14.35 V.

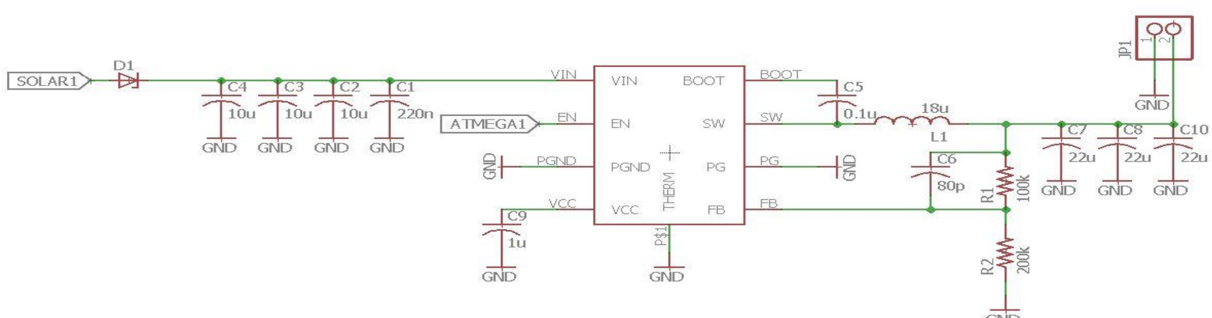


Figure 5: Buck converter circuit schematic

We implemented the LMR33630 synchronous buck converter and its peripheral components for minimal output current and voltage ripple. The circuit schematic and components are shown in Figure 5. We placed a power diode between the solar array and the LMR33630 to keep any power from traveling back to the solar array. We placed a Zener diode at the output of the regulator circuit to prevent back EMF from the motor during switching from harming our electronics. We included feedback to adjust the duty ratio such that the 6 V is maintained regardless of input. The duty ratio of a buck converter can be calculated using Equation 2.

$$D = \frac{V_{out}}{V_{in}} \tag{2}$$

We calculated a duty ratio of 28% for our ideal power output case using our input voltage to be a nominal 21.5 V; this is the average expected voltage provided by the solar array. The IC adjusts the duty ratio to meet the 6 V desired output. We used the datasheet for the LMR33630 IC [4] to determine the values of the auxiliary components. We selected the RFBT = 100 k and used Equation 3 to determine the other resistor used in the voltage divider feedback, with a 1 V reference voltage and 6 V output.

$$R_{FBB} = \frac{R_{FBT}}{\frac{V_{out}}{V_{ref}} - 1} \tag{3}$$

We sized the inductor using Equation 4. Using a switching frequency of 400 kHz, desired output current of 2 A, recommended k factor of 0.3, and input voltage of 21.5 V, we found our inductor to be 18 uH.

$$L_1 = \frac{V_{in} - V_{out}}{f_{sw} * k * I_{out}} * \frac{V_{out}}{V_{in}} \tag{4}$$

We used a 28% duty ratio, 0.5 V output voltage ripple, 0.3 k factor, and 2 A output current ripple to calculate a 32 uF minimum output filter capacitance with Equation 5. With a 20% tolerance and 10% de-rating factor we decided to use three 22 uF ceramic capacitors rated for 16 V.

$$C_{out} \geq \frac{\Delta I_{out}}{f_{sw} * \Delta V_{out} * k}\left[(1-D)(1+k) + \frac{k^2}{12}(2-D)\right] \tag{5}$$

For input capacitance, we chose to use three 10 uF ceramic capacitors rated for 50 V and a 220 nF capacitor as close to the chip input as possible as stated in the datasheet [4].

### 2.2.3 Alternate Design for Voltage Regulation

We considered two methods for solar voltage regulation: dc-dc switching converters and linear regulators. We decided to prototype each regulator but ultimately chose the buck converter topology because of its efficiency benefits. The linear regulator was more rugged and could handle large current and voltage swings, but it reduced the overall circuit complexity and was inefficient. Therefore, we decided to implement the synchronous buck converter to regulate the solar voltage to 6 V.

### 2.2.4 SPDT Relay Switch

We used an Omron 5 V SPDT relay [5] to switch between our solar and battery input to the motor controller depending on the available solar power. A 9 V battery powers this relay switch through a 5 V linear regulator [6]. Using regulated solar voltage as our default power source, we connected the regulated solar voltage and internal boat battery to the normally connected and energized inputs, respectively. We programmed the microcontroller to determine if the input voltage from the solar array is lower than the 14.35 V threshold and activate the switch if it is, as well as disable the LMR33630. When the microcontroller detects a voltage higher than the minimum 14.35V from the solar array, it will return the switch to its de-energized state. We connected the output of the relay to the motor controller. The microcontroller switches the relay as necessary to provide constant power to the motors.

## 2.3 Microcontroller

We chose the ATmega328 as our microcontroller [7]. We used a 9 V battery to provide power to the microcontroller through a 5 V linear regulator [8]. The microcontroller sampled input from the solar cells and controlled the relay switch to output either 6 V regulated solar voltage or 9.6 V internal boat battery. The microcontroller also monitored communication between the on-boat and remote controller XBee wifi modules and notified users by turning on an LED. The schematic for the microcontroller is shown in Figure 6, created based off of Arduino tutorials [9].

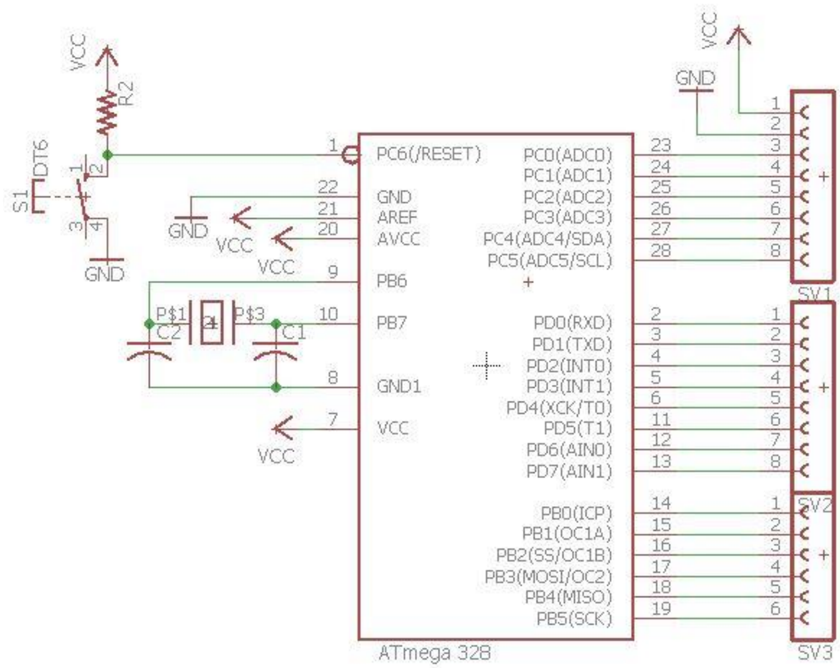


Figure 6: Microcontroller circuit schematic

## 2.4 Signal Strength Detection

The signal strength detection module detected the signal strength between the boat and the remote controller and determined if the signal level is getting too low. As the boat moves farther away, its signal strength decreases; past a threshold, this low signal strength indicates that the boat was near its operating range limit, and we notified the user to turn the boat around.

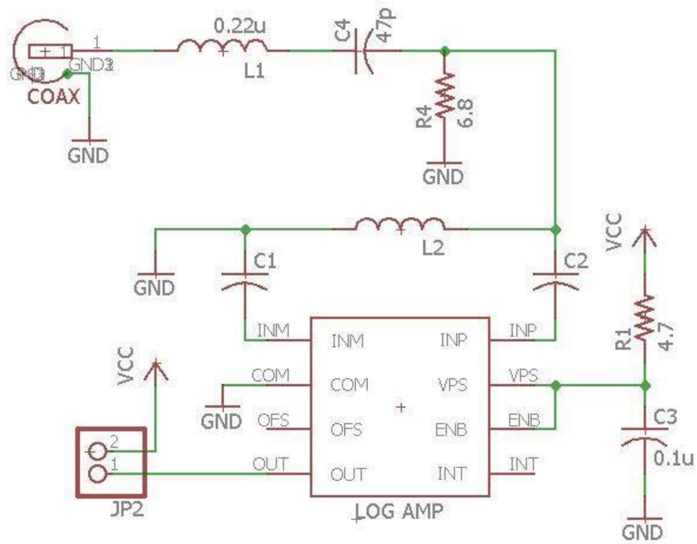


Figure 7: Signal strength detection circuit schematic

Figure 7 shows the circuit schematic for this module. We added a second antenna to the boat to capture the signal received from the remote controller. We determined that our antenna could capture the signal by connecting it to a spectrum analyzer, operating the remote controller, and observing the frequency spectrum, shown in Figure 8. The peak is at about 49.8 MHz, so we designed an RLC bandpass filter to take the signal from the antenna and filter out other frequencies and noise. We chose a bandwidth of 5 MHz, with a center frequency $f_c = 49\ MHz$. Using a standard capacitor of 47 pF, we found $R = 6.8\ \Omega$ and $L = 0.22\ \mu H$ using Equations 6 and 7. We simulated our filter in LTspice and applied an ac sweet to observe the expected behavior. The output, shown in Figure 9, was a narrow bandpass with a -3 dB bandwidth from 47 MHz to 52 MHz, centered at 49.5 MHz, as desired. The bandpass filter passed its output to an AD8307 logarithmic amplifier [10] which converts the signal power to a voltage level.

$$f_C = \frac{1}{2\pi\sqrt{LC}} \tag{6}$$

$$Q = \frac{f_c}{BW} = \frac{1}{R}\sqrt{\frac{L}{C}} \tag{7}$$

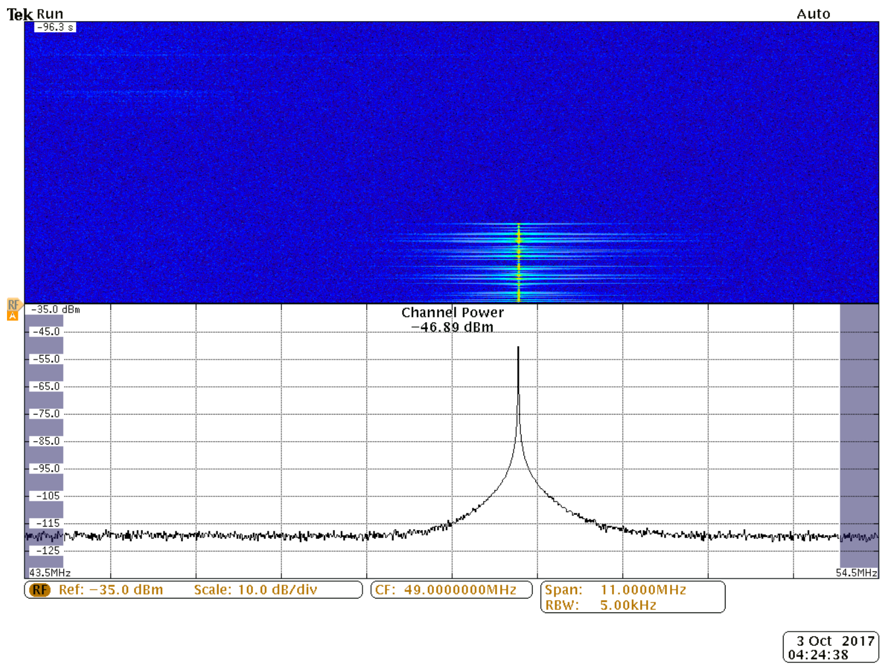


Figure 8: Frequency spectrum output from antenna

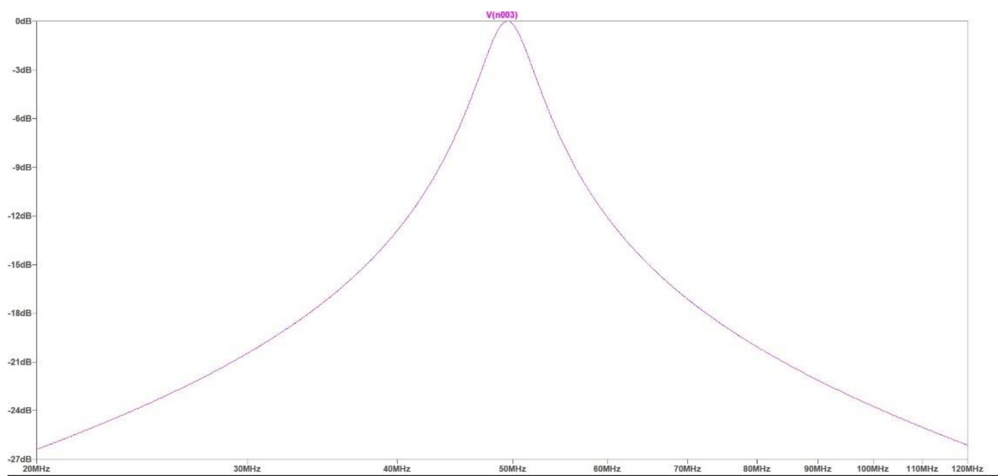


Figure 9: LTspice simulation output

### 2.4.1 XBee modules

An XBee [11] is a radio communication module by Digi that communicates with other XBees on the same channel at 2.4 GHz using the IEEE 802.15.4 Zigbee protocol. We used two XBee modules to provide an interface between the boat and user. We designed our circuit to determine the signal strength at the boat, and we needed to use that information to tell the user when the signal was too weak. We placed one XBee on the boat and a second XBee at the remote controller with the user, both controlled by their respective microcontrollers. The on-boat microcontroller took the output from the log amp $V_{out}$ and converted it back to the power level received $P_{in}$ using Equation 8 from the AD8307 datasheet [10]. The on-boat XBee sent this information to the XBee on the remote controller, which passed it along to the

RC-microcontroller. This microcontroller determined if the signal strength was too weak and turned on an indicator LED accordingly.

$$V_{out} = 25\frac{mV}{dB}(P_{in} - 84\ dBm) \tag{8}$$

### 2.4.2 Alternate Design: XBee RSSI

While testing the output of the log amp, we found that it varied only between ~0.9 V and 2 V. This small variation made it difficult to set a definitive threshold that would indicate the signal strength was too weak. There was little to no difference in $V_{out}$ when the remote controller was far from the boat and when it was simply not being used. We decided to use an alternate design involving only the two XBees. The on-boat XBee sends a data packet to the RC-XBee every 500 ms. The RC-XBee parses this data packet for received signal strength indication (RSSI) purposes [12]. It returns a hex value that corresponds to the negative power level in dBm. We passed this value to the RC-microcontroller to determine if the signal strength was too weak and turn on the indicator LED as we originally designed.

## 2.5 Additional Circuit Board

While performing component testing, we found that our microcontroller did not have a 5 V or 3.3 V direct output to provide power to the XBee and relay switch modules. We created a peripheral board, shown in Figure 10 We added a few linear regulators to this board as well as extra breakout pins for a variety of voltage inputs and grounds for smoother integration. We also included a voltage divider that enables the microcontroller to sample the solar input voltage as well as the correct footprint for the 5 V relay.

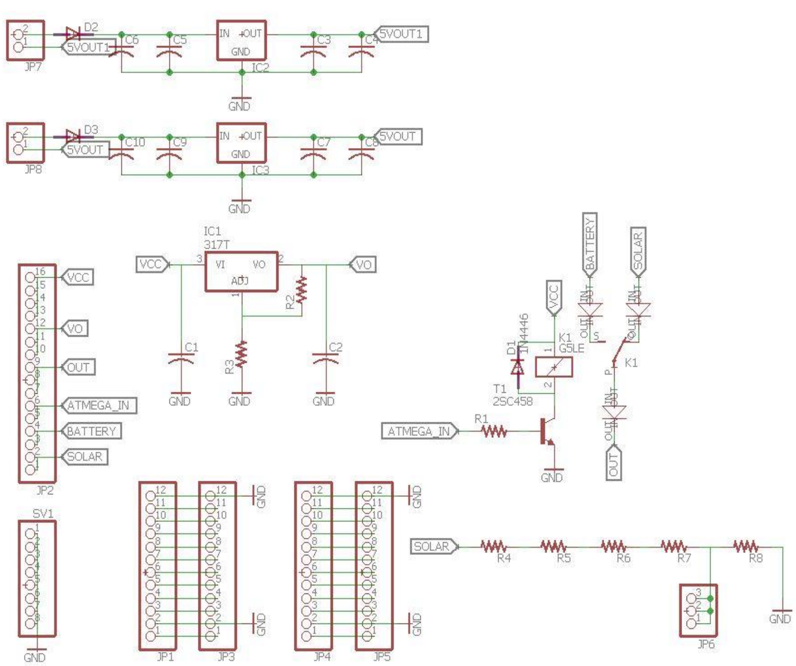


Figure 10: Peripheral board circuit schematic

# 3. Design Verification

## 3.1 Solar Cells

An important aspect of our design are the solar cells we used to power the motor. The solar cells are 5 V 2.5 W mini encapsulated epoxy solar panels. Theoretically, 5 of these solar panels produces 12.5 W of power, and our motor calculation shows that the boat's motor consumes 10.26 W when run at 6 V. We tested one of the solar cells to characterize its peak power output and I-V curve. The cell was put in direct sunlight and the voltage across varying loads was measured and the current was then calculated based on this. We then graphed current versus voltage for the solar cell to determine open circuit voltage, short circuit current, and the maximum power point during maximum insolation. The open circuit voltage for one cell is 5.53 V, the short circuit current is 0.7 A, and the peak power output is 2.4 W occurring at 4.3 V and 0.558 A. This means that the load the cell wants to see is 7.7 by dividing the voltage and current that produce maximum power using Ohm's Law. Figure 11 contains our I-V characteristic for one of the solar cells at maximum solar insolation.

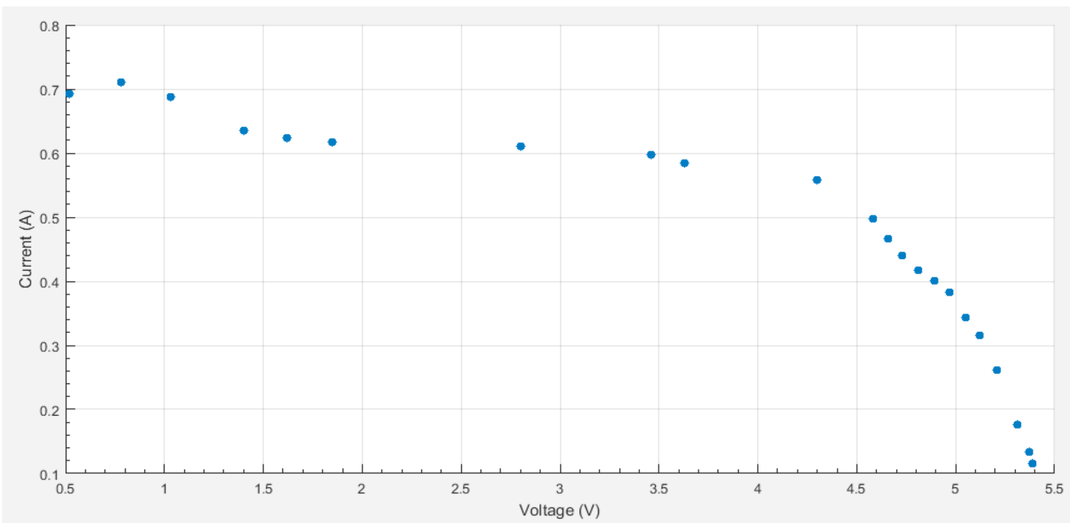


Figure 11: I-V characteristic for single Allpowers solar panel for maximum insolation

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

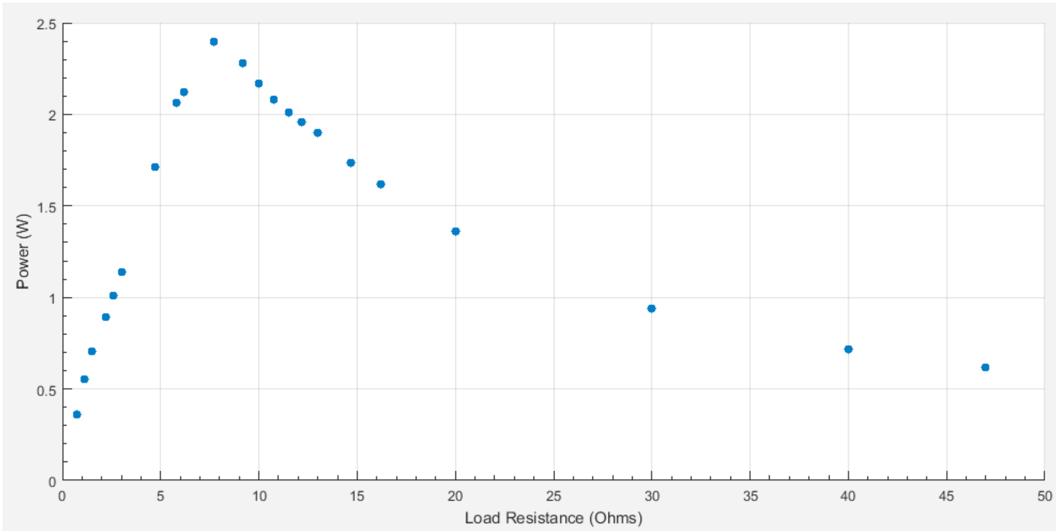


**Figure 12: Power (W) vs. Load Resistance (ohms) for single Allpowers solar cell during maximum insolation**

Our design allowed the power from the solar array to drop below 12 W since that is maximum power we can harvest under ideal maximum insolation from every panel. Our acceptable power range is between 8.7 W -12 W with the synchronous buck IC providing a constant 6 V to the motor controller and motor. This 6 V is conservative and requires only 10.3 W from the power supply since maximum insolation for each cell will not be possible at the same time. This allows our boat to operate and gives us a power window that does not result in constant switching between the internal battery and solar array.

## 3.2 SPDT Relay Switch

The relay switch was then tested in the lab using a solar lamp to excite the solar panels. The output of the solar cells was stepped down with a voltage divider and given as an analog input to our microcontroller. The 14 V - 25 V was stepped down to 2.8V - 5 V input so the microcontroller would not burn since the solar output exceeded the microcontroller's voltage rating. If the solar voltage was above the 14 V threshold then the microcontroller outputs a digital low signal and if the solar voltage is less than the threshold a digital high signal is output. The digital signal is connected to a BJT [13] since the microcontroller cannot produce enough current to close the relay. There is also a diode in parallel with the relay to provide a path for current when the contact is broken. The solar voltage is connected to the normally closed side of the relay since the solar array will be powering the motor the majority of the time. The microcontroller samples the solar voltage every 0.5 s and can then switch between the solar voltage and internal boat battery. We were able to turn the solar lamp on and off and saw on the voltmeter the 6 V regulated solar voltage when the lamp was on and the 9.6 V battery voltage when the lamp was off, verifying the integration of our microcontroller, buck regulator, and relay.

## 3.3 XBee RSSI

To verify that the two XBees communicated with each other, we used the XCTU configuration platform provided by Digi [14]. We configured the devices to communicate with only each other on their own channel. Using the serial console provided by XCTU, we confirmed that the two XBees could send and receive messages. In order to set a threshold, we first operated the XBees in transparent mode, where commands can be sent over UART. One XBee sent messages to the other every 500ms. While receiving the messages, we put the receiving XBee into command mode by sending "+++" through XCTU. Upon receiving an "OK" back from the XBee, we sent the command "ATDB" to get the negative value of the signal strength in hex. We continued to do this as we moved the receiving XBee farther from the transmitting XBee and saw that as we moved farther away, the hex values increased, as expected. Since the hex value corresponds to the negative power level, this means that a higher hex value corresponds to lower power. However, our results were not exactly consistent with the expected trend. This is because when using command mode, we only receive the RSS of the last link rather than the entire packet, so our values can be misleading.

We re-configured the XBees to be in Application Programming Interface (API) mode. In this mode, we were able to use the XBee-Arduino library to parse the RSS value from an entire data packet sent from one XBee to another. Table 2 shows the data we collected as we moved the two XBees farther away from each other. We were limited by the size of the lab, and we were unable to get too many data points. However, using our data, we decided on a threshold power level of -99 dBm. With this threshold, we tested and confirmed that our LED turned on past this threshold within the confines of the lab. The LED also turned off once the signal strength grew as me moved closer to the transmitting XBee.

**Table 2: XBee Data**

| Distance (m) | RSSI (hex) | Power (dBm) |
|---|---|---|
| 0 | 44 | -68 |
| 3.25 | 56 | -86 |
| 7.05 | 63 | -99 |
| 11.65 | 77 | -11 |

## 3.4 Boat Integration

Once we completed the integration of our individual modules, we put the PCBs in a Ziploc bag to protect them from water and placed the bag inside the boat. We mounted the five solar cells and attached a floatation device in the front end of the boat to counteract the uneven weight distribution from the solar cells and the circuitries. The fully integrated systems are shown in Figures 13 and 14 below.

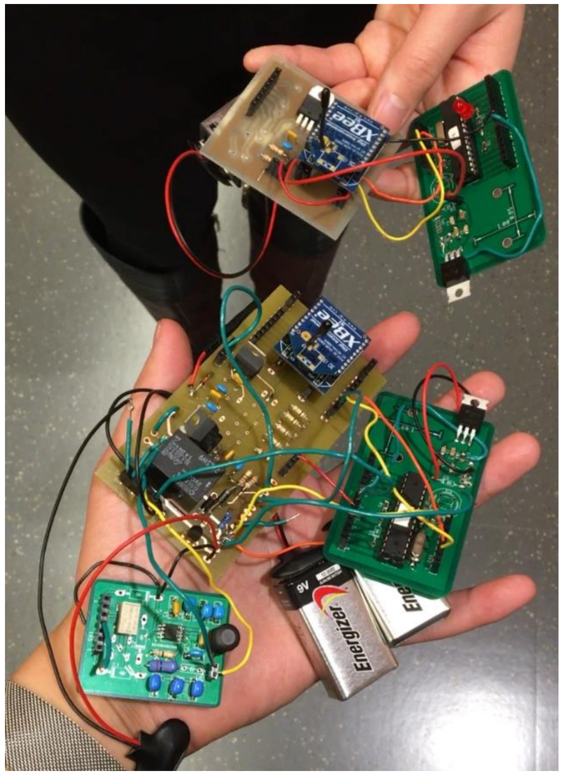


**Figure 13: Fully integrated modules**

**Figure 14: Boat fully integrated with design**

# 4. Costs

## 4.1 Parts

**Table 3: Parts Costs**

| Part | Part Number | Unit Cost | Quantity | Actual Cost |
|---|---|---|---|---|
| Programmable XBee Zigbee | XB24CZ7PITB003 | $20.73 | 2 | $41.46 |
| XBee Adapter Board | 32403PAR-ND | $5.31 | 2 | $10.62 |
| IC Logarithmic Amp 8-DIP | AD8307ANZ | $13.28 | 1 | $13.28 |
| New Bright Marine RC Boat | 6723 | $54.00 | 1 | $54.00 |
| 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 |
| IC Linear Regulator | LM7805CT | $0.95 | 2 | $1.90 |
| Coaxial connector | MM8030-2610RJ3 | $0.20 | 1 | $0.20 |
| Antenna | ANT-STUBR-433SM | $6.56 | 1 | $6.56 |
| Crystal 16.0000MHZ Series SMD | XC1251DKR-ND | $0.50 | 2 | $1.00 |
| Relay Telecom SPST | PB1248-ND | $4.73 | 2 | $9.46 |
| Elegoo Uno R3 | | $10.90 | 2 | $21.80 |
| Allpowers Solar Cells | | $7.99 | 5 | $35.97 |
| LMR33630 Synchronous Buck Converter | PLMR33630ADDA | $4.52 | 6 | $27.12 |
| SPDT Relay 10A 5V | G5LE-1 DC5 | $1.45 | 1 | $1.45 |
| Additional Passive Components | | | | $30.00 |
| **Total** | | | | **$260.22** |

## 4.2 Labor

3 * $40.00/hr * 15 hr/week * 15 weeks * 2.5 = $67,500.00

## 4.3 Total Cost of Project

**Table 4: Total Cost**

| | |
|---|---|
| Labor | $67500.00 |
| Parts | $260.22 |
| Total cost of Project | $67760.22 |

# 5. Conclusion

## 5.1 Accomplishments

Overall our project was successful. Our modules worked individually and as a whole. We took our original concepts and turned them into working prototypes over the course of three months. We fully integrated the power and communication subsystems together onto the boat without compromising its integrity. We met all our design requirements and were able to verify that our final product achieved our original goals: we successfully extended the battery life of the boat beyond the stated 15 minutes of play time, and we added an LED indicator that properly notified the user of weak signal strength from the boat.

## 5.2 Uncertainties

The signal strength detection module was the most uncertain part of our final product. Our intention in adding signal strength detection was to notify the user that the boat is near its maximum operating range. However, signal strength is not necessarily indicative of distance; signal strength does decrease as one moves farther away, but not in a linear fashion. This is due to the orientation of the antenna; as the boat moves farther away, the perceived antenna angle changes which affects how the electromagnetic wave propagates back to the remote controller. In addition, the boat would realistically be used in an outdoor environment, where obstacles between the boat and user would also affect the received signal. Therefore, when the LED lights up, it doesn't indicate a particular distance, but rather the signal strength between the boat and the user which can be affected by things other than just distance.

## 5.3 Ethical considerations

In the course of designing our project, we sought to maintain good ethical practices. We 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 [15] would be violated. The following seven points listed below relate closely to our project and we took full responsibility to closely follow them. Our project was reviewed by the teaching assistants, peers, and 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.

## 5.4 Future work

Given more time, we would change and improve upon some of our design choices. We would reselect the solar cells such that they produce more current. When integrating our power system we had trouble getting sufficient current from the solar panels and had trouble getting the propeller to turn. We could get enough current to move the rudder but the propeller required much more current and relied on a battery to get started. Therefore solar cells with large current producing capability would allow our motor to run with ease and not drastically change our initial design. The number of cells and mounting positions would change but the regulated and switching would remain the same. We would size the new solar array such that it had the same voltage range but a larger current capability. Thus we would need to change the layout of the cells on the boat such that the weight of the cells would be evenly distributed so the boat will not flip.

Our next design change would be integrating the microcontroller, power regulating and switching, and communications systems onto one PCB. This would save room inside the boat and also be cheaper to manufacture and repair. Design challenges during integration made our original PCBs not adequate since we changed some of the original circuit components. After further testing we found that we did not need as many protective diodes as we originally thought. We also found that our original relays would not be able to switch since they required a 12 V supply that we did not have on the boat. We then needed a different relay that would switch at the available 5 V and it had a different footprint which also required a BJT to take the microcontroller signal and generate enough current to switch the relay. This required us to have other PCBs made which would fit the new components and then be mated to the original PCB making for a less sleek design. Now that we have a working prototype we would be able to design a single board which could handle all our inputs, outputs, and component footprints.

The final part of our design that we would improve upon would be creating a waterproof capsule for our PCB. This would reduce the worry of water getting into the boat during operation and destroying our circuitry if the user accidentally flips the boat during operation. It would also provide a harness for the PCB so that it could not move around when the boat is in use. This capsule would mount to the inside of the boat and also make for easier installation. We believe that these simple changes to our design would decrease the cost of the production and make our design more cohesive.

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## Appendix A Requirement and Verification Table

**Table 5: System Requirements and Verifications**

| Requirement | Verification | Verification status (Y or N) |
|---|---|---|
| 1. Solar cell provides 10.3W of power with a tolerance of +/- 1W | 1. Measure output voltage and current from the solar array | Y |
| 2. Buck converter circuit provide 6V +/- 0.2V of regulated voltage from the solar panel | 2. Use a DMM to measure the average output of the regulator with a 14.35-25.35 input voltage range | Y |
| 3. Switcher circuit | 3. | |
| a. Constant power should be provided to the motor controller when switching | a. Observe a constant, non-zero voltage waveform of motor on oscilloscope | Y |
| b. Switch input to battery power when solar array output is below 14V | b. Observe switching and measure the output voltage of the relay as the voltage gradually approach and pass 14V from above 14V | Y |
| c. Switch back to solar power once solar power output increases to above 14V | c. Observe switching and measure the output voltage of the relay as the voltage gradually approach and pass 14V from below 14V | Y |
| 4. Motor controller must take our switching power sources from the relay and control the boat's motor | 4. Run the motor with our 6V solar cells output attached to it and the 9.6V internal batteries | Y |
| 5. Antenna must be able to capture 49 MHz frequency | 5. Observe peak output from the remote controller on spectrum analyzer | Y |
| 6. Bandpass filter must have 5MHz, centered around 49MHz | 6. Built RLC circuit and bread | Y |
| 7. XBee must be able to send and receive necessary signals to operate the boat | 7. Walk different distances to verify that the XCTU (XBee Configuration and Test Utility Software) demonstrates different, correlated values for different signal strength | Y |
| 8. On boat microcontroller | 8. | |
| a. Must sample appropriate voltage from the solar cell and output digital signals to the relay switch | a. Compile and upload codes onto the ATmega328 chip and connect the PCB to the control input of the relay switch via the correct pinouts. Observe the relay switch to battery output at | Y |

| | | |
|---|---|---|
| b. Must monitor communication between the two XBee wifi modules and turn up an LED when signal strength is too low | 14V and 25V solar cell power<br>b. Compile and upload codes onto the ATmega328 chip and connect the PCB to the XBee via the correct pinouts. Walk far away (10m-15m) to make sure that the LED turns on | Y |
| 9. Linear regulators<br>a. The LM317T adjustable linear regulator must output 3.1V +/- 0.3V regulated voltage<br>b. LM7805 5V linear regulators) must output 5V +/- 0.1V regulated voltage | 9.<br>a. Connect input power of 9V to the linear regulators and use a DMM to measure the outputs to be 3.1V +/- 0.3V<br>b. Connect input power of 9V to the linear regulators and use a DMM to measure the outputs to be 5V +/- 0.1V | Y<br>Y |
| 10. LED must light up when XBee wifi module signal strength is lower than -99dBm +/- 10dBm | 10. Convert the HEX value given on the XCTU display and have the light on at when the HEX value is -99dBm +/- 10dBm | Y |