Modular Swimming Pace Aid

ECE445: Senior Design

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1 Introduction

1.1 Statement of Purpose

This project was chosen because presently there are no devices that allow swimmers to visually follow a specific lap pace. As such, there is a high demand for a low cost underwater swim pace aid and we are excited to design a product that would meet this demand. The project focuses on the modularity of the device to make it easy to transport, assemble, and maintain.

1.2 Objectives

1.2.1 Features:

- LED panels can withstand the pressure of water up to a depth of 2.5 meters
- LED lap pace adapts to the number of panels connected in the system
- LED lap pace will range between 8 and 45 seconds, in 0.5 second increments
- Panels can be spaced up to 1.5 meters apart underwater
- Wireless setup, requiring no wiring by the user
- High intensity (6500 mcd) green LED provide visual queue
- Modular design to fit any pool
- Wireless communication between modules
- Wireless communication between modules and controller
- Battery lifetime of 1 year at 10 hours of operation per week

1.2.2 Benefits:

- Cost adaptable to pool size
- Electric shock is prevented by housing the batteries within each panel
- Visual system for clear indication of pace to swimmer
- Simple controller, allowing real time control of the pace
- Wireless control of the LED pace in real time from outside of the pool

Design

1.3 Overall Design and Control Explanation

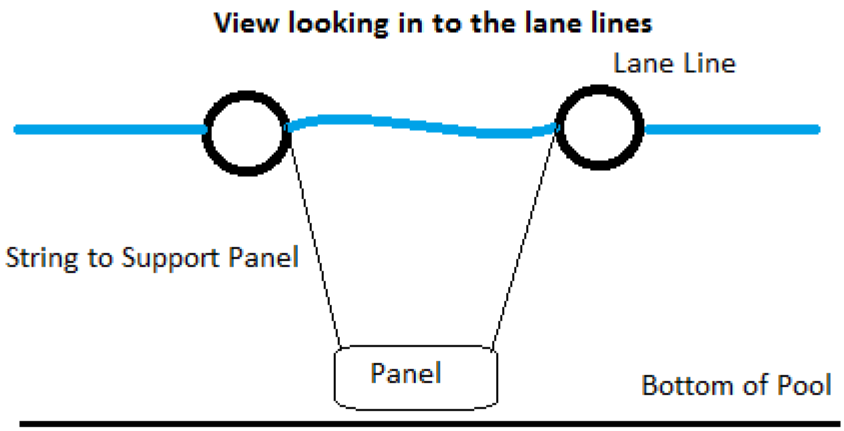

Figure 1. Underwater Depiction of Layout.

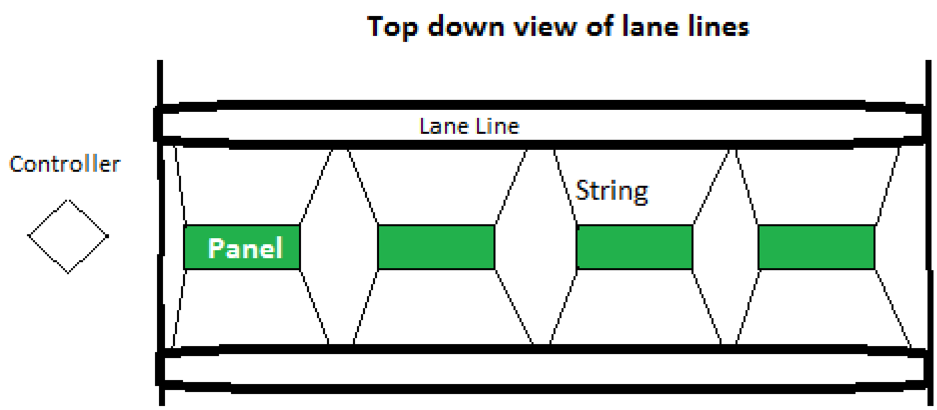

Figure 2. Top Down Depiction of Layout.

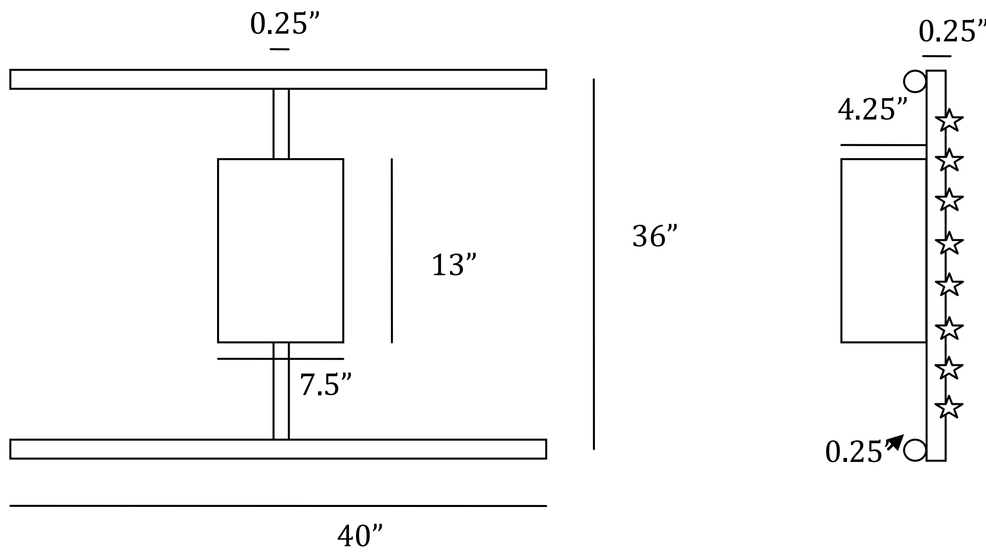

Figure 3. Underwater Module Drawing.

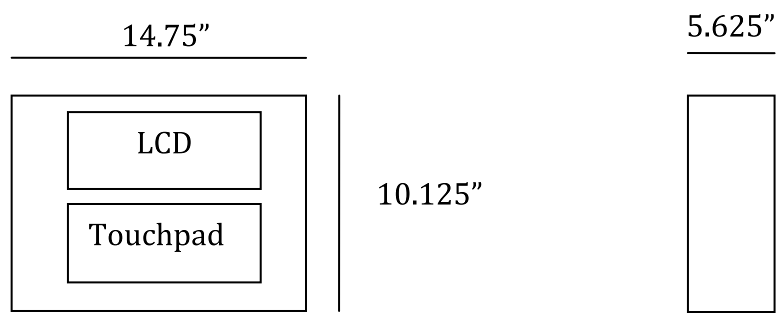

Figure 4. Main Controller Drawing

1.4 *Block Diagram*

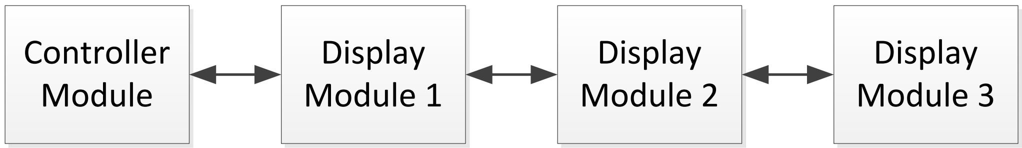

Figure 5: Top level block diagram

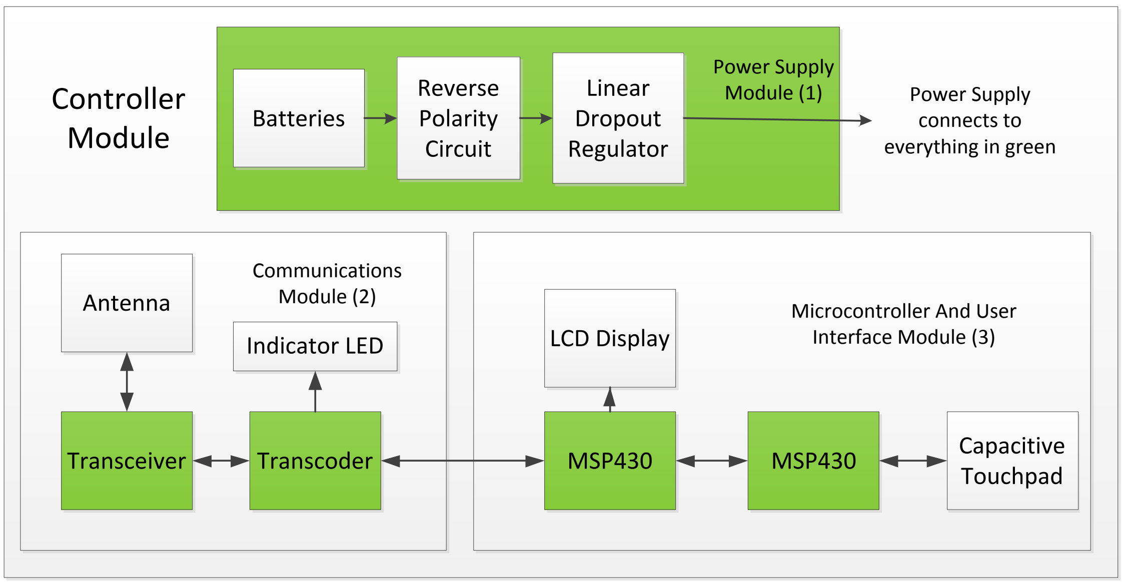

Figure 6: Controller module block diagram. (*) indicates the schematic number corresponding to the module.

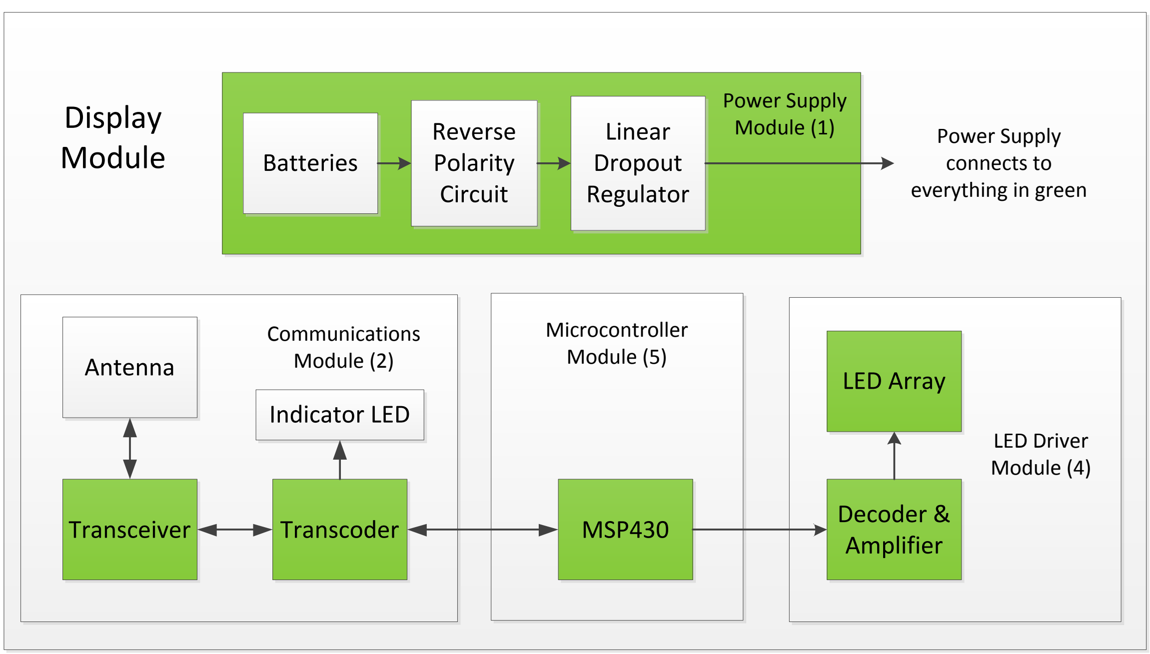

Figure 7: Display module block diagram. (*) indicates the schematic number corresponding to the module.

1.5 Block Descriptions

1.5.1 Overall Summary:

The display module has a lot of responsibility as soon as it is started up. When this module is switched on, it will broadcast to the controller module to request being added to the system. When this is completed, the controller will have the unique address to this panel and the panel will receive information on what number in the string of display modules it is, what module is in front of it in the string, and whether or not it is first in the string. Once the panel has been successfully loaded into the system, it will sit idle until it receives a command from its neighboring panels. There are three commands that a given panel can receive:

1. Timing Functionality Mode
2. Test Synchronization Mode
3. Add Panel to Modular String Mode

The timing functionality mode is when the user sets the pace on the controller and initiates the system to light up according to the desired pace. For example, one of the packets that a panel receives will tell it the pace at which the LEDs have to light up. Since the panels can identify who sent the recent packets, they can then know who to contact next in the modular string.

The test synchronization mode simply allows the user to initiate a test that will make sure all the panels are successfully communicating with each other in the water. This will ensure that the system is successfully setup and the user can proceeded and run the timing functionality mode.

The add panel to modular string mode will allow a panel to receive communication from the controller such that the panel's next pointer can be updated to point to a new panel in the string. Figure 8 on the next page shows how a panel would join the system.

The controller module has the ability to initiate these three functionalities. Figure 9 on the next page shows what the layout of the LCD display will be for the controller. The capacitive touchpad will be able to traverse the screen such that the user can select the desired functionality. The timing functionality can be controlled by selecting the start button to start the system at the current set time. The user can then change this time by selecting the up and down buttons and then commit this new set time to the system by selecting the update system time button. The test synchronization mode icon will initiate the test synchronization mode. In this mode, the controller will broadcast to the first panel in the string and then wait for the system to propagate the signal to the end of the string and back to the controller. This will help assure the user that his system is fully responsive. The add panel to system icon puts the controller in receive mode and waits to accept any new panel trying to join the system. The controller will then add this panel to the system and send back relevant information to the panel. The controller will now contact the panel previous to the new panel; reference Figure 8 on adding a panel to the system.

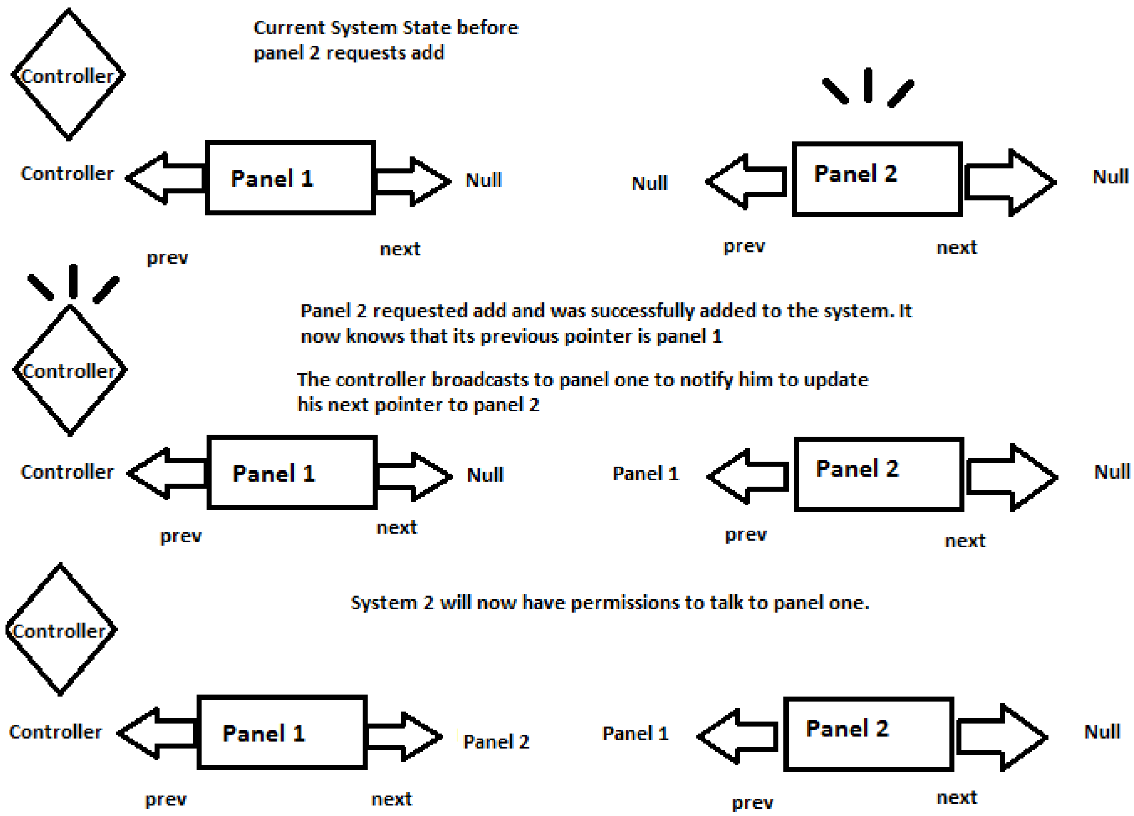

Figure 8: This is an example of a panel being added to the system

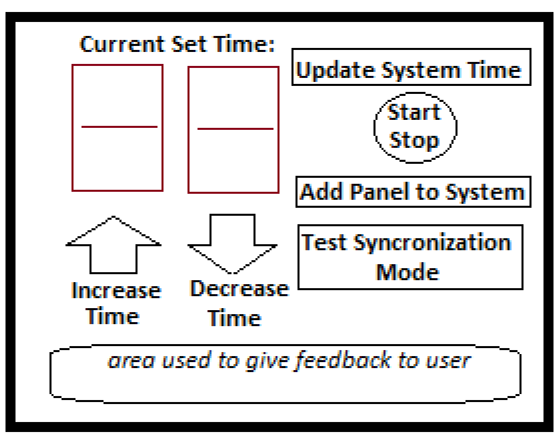

Figure 9: This is how the LCD display is going to be laid out.

1.5.2 Display Module Block Descriptions

1.5.2.1 Case Design:

The case for the underwater display bocks is designed to be accessible, waterproof, and clear to let the LEDs shine through. The main unit will be large enough to house the circuit boards and wireless devices. This main unit will require an access lid that has a waterproof seal. There will be a clear one meter long pipe connected to the top that will house all of the LEDs. The LEDs will be connected to wires that travel through the tube into the main box and connect to the circuit. This will also rest on two cross pipes that connect to the lane lines through the use of twine and a breakaway clips. The breakaway clips ensure that if someone becomes entangled in the twine, the twin easily detaches from the lane lines. The overall system will have an on/off switch as well as an easily accessible battery compartment.

1.5.2.2 Microcontroller Module:

The microcontroller in the display module will be an MSP 430. The module receives a 3.3V DC voltage supply from the power supply module. The microcontroller will do all of the processing in this block. It will communicate to the communications module serially through four of the digital IO pins. It will also pass information to a decoder to control the LED circuit through the use of four of the digital IO pins. The processing that the MSP 430 will do includes processing communication data and determining when to light up the LEDs. This keeps the total processing done in the display modules at a minimum.

1.5.2.3 Power Supply Module:

The power supply will provide power for all components in the system. The voltage source will consist of 3 C batteries wired in series, providing 4.5 V DC. The power supply will have reverse voltage protection in the form of a MOSFET reverse voltage protection circuit. Calculations, shown in the power supply simulations section, indicate that a MOSFET reverse polarity protection circuit is 99.99% efficient, while a typical diode circuit is 84.44% efficient. Moreover, the MOSFET circuit only consumes 3mV when conducting, while a diode circuit would consume on the order of 700 mV. The rectified voltage is sent to power the LED module, providing it with 4.997V voltage source.

A low dropout regulator (LDO) will be used to step down the 4.997V rectified voltage to 3V in order to provide power for the microcontroller and communications modules. At any point in time, the LDO is processing less than 2% of the total power being consumed by the system. Therefore, the inefficiency of the LDO does not degrade the efficiency of the system appreciably.

1.5.2.4 Communications Module:

In the communications module, we are going to use a series of Linx products to support our wireless interfacing. We are using the 315 MHz ANT-315-CW-HD antennas from Linx for our wireless connectivity. The Linx transceiver is the TRM-315-LT to transmit and receive data from the antenna and then his information is related to a Linx transcoder LICAL-TRC-MT which will keep track of what addresses are allowed in interface with the panel and to initialize the system such that each panel will have a unique address. The FCC requires that if you receive a signal, that you have an LED to blink to reflect this. The transcoder had a confirm pin that will allows us to comply with this standard.

The transceiver will receive a 3V voltage supply from the power supply drawing a maximum of 20mA. This transceiver does not have an internal voltage regulator, so we want to have a circuit to keep the noise less than 20mV. This can be done with a 10 ohm resistor in series with the supply followed by a 10 µF tantalum capacitor from VCC to ground. This circuit will help ensure that receiver sensitivity has been eliminated.

The transcoder will receive a 3V voltage supply from the power supply drawing a maximum current of 25mA. The transcoder will connect to the MSP430 through 4 Digital I/O pins. This will allow the microcontroller to change the mode of operation of the transcoder and transceiver based on the current state of the system.

1.5.2.5 LED Driver Module:

The LED module will consist of 10 independent circuits, with each circuit receiving one control signal from the decoder. Each circuit will have an amplifying stage that will convert the control signal from the microcontroller to a signal powerful enough to drive the row of LED's. BJT's will be used as the amplifiers and act as current sources for the LED's. As a result, no current limiting resistors will need to be used, increasing the efficiency of the system.

Each row of LED's will have 2 LED's and the rows will be spaced 10 cm apart. For the LED's, we will be using 6500 mcd green LED's. These LED's output 9.55 lumens, comparable to the minimum lumen output of high power commercial flashlights. The choice of LED color is significant because water absorbs much more light in the infrared side of the spectrum than the ultraviolet.

1.5.3 Controller Module Descriptions

1.5.3.1 Case Design:

The case for the main controller was designed to simply house all the components. This will be a simple clear plastic box with a lid to prevent splashes from the pool from entering the box. The box will have to be opened to turn on the system, change the pace, or replace the batteries. Each of these items will be easily accessible by simply opening the top of the box.

1.5.3.2 Microcontroller and User Interface Module:

This module will do all the computation on the controller. It two consists of two MSP430 units which will communicate to each other through a serial connection using the RX & TX pins. One of the MSP430 units will connect to the capacitive touchpad to provide user input. This takes up most of the pins except the RX & TX ones on the MSP430. It communicates using a parallel stream of data. The other MSP 430 connects to the Nokia 5110 LCD panel through the use of four pins including a serial input, clock, chip enable, and reset. The second MSP430 also connects to the wireless module through h four digital IO pins. This unit will be programmed to display system information and relay changes to the underwater display modules.

1.5.3.3 Power Supply Module:

See Power Module in section 1.5.2.3.

1.5.3.4 Communications Module:

See Communications Module in section 1.5.2.4.

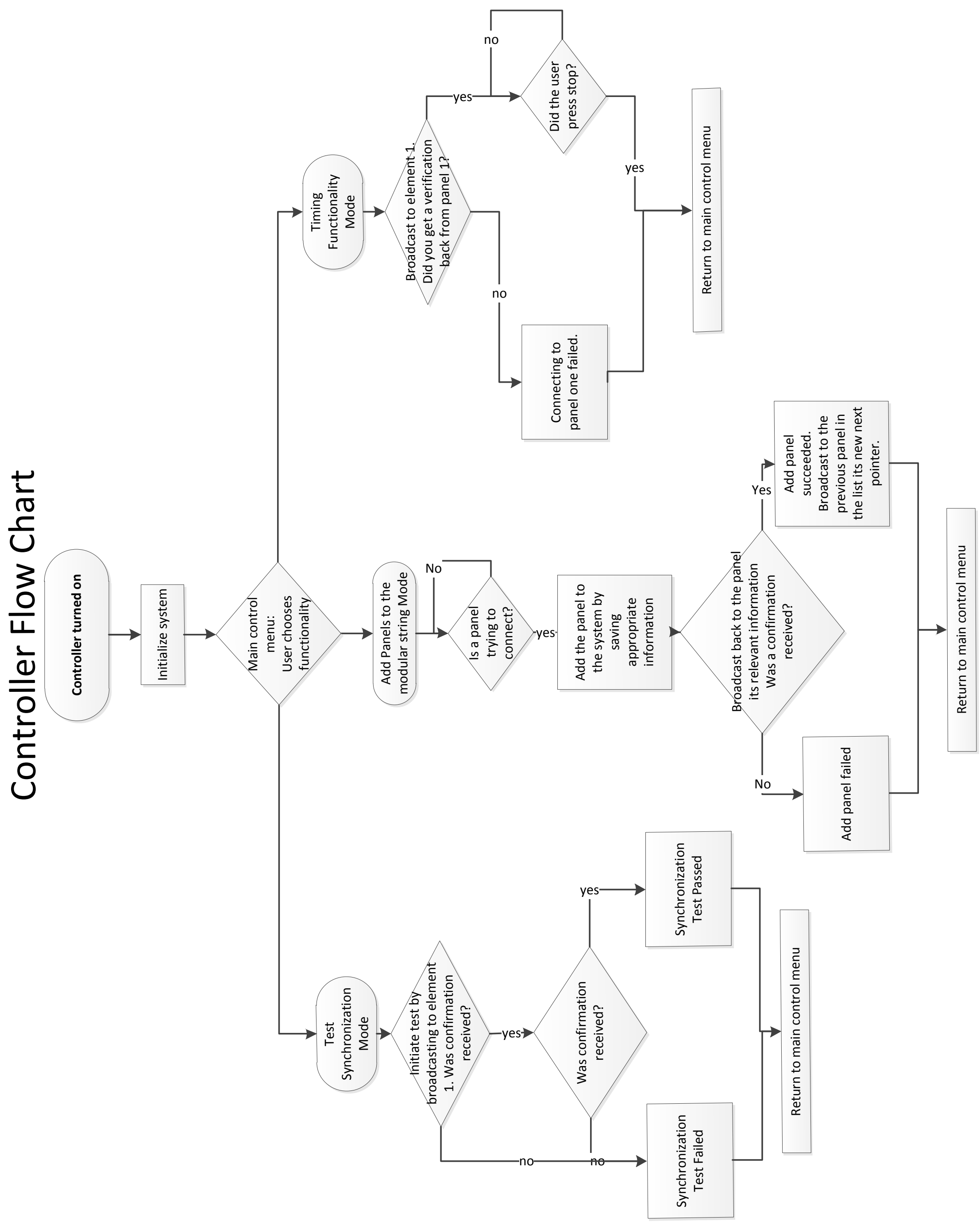

Figure 10: Controller Flow Chart

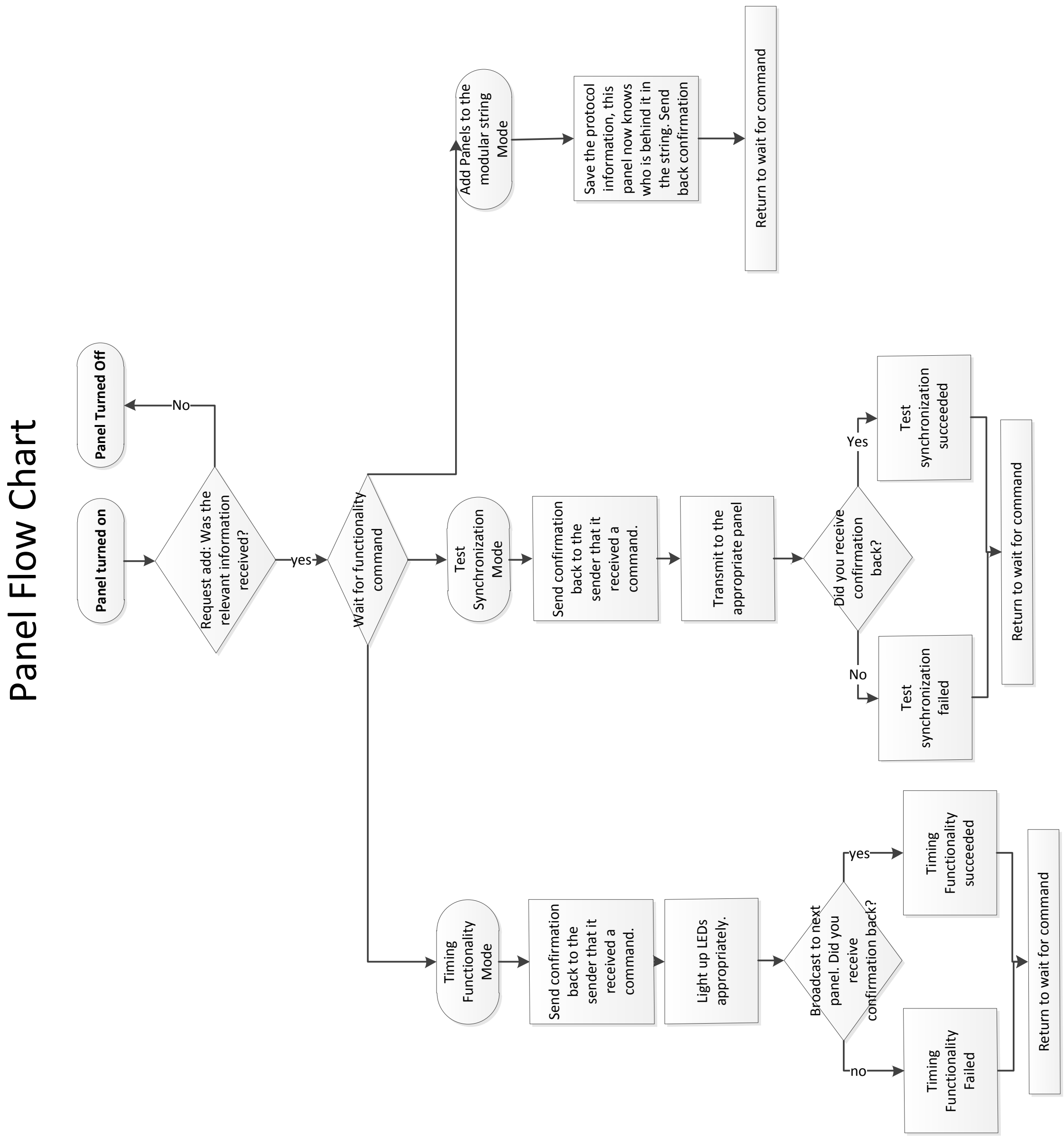

Figure 11: Panel Flow Chart

1.6 Schematic of Overall System

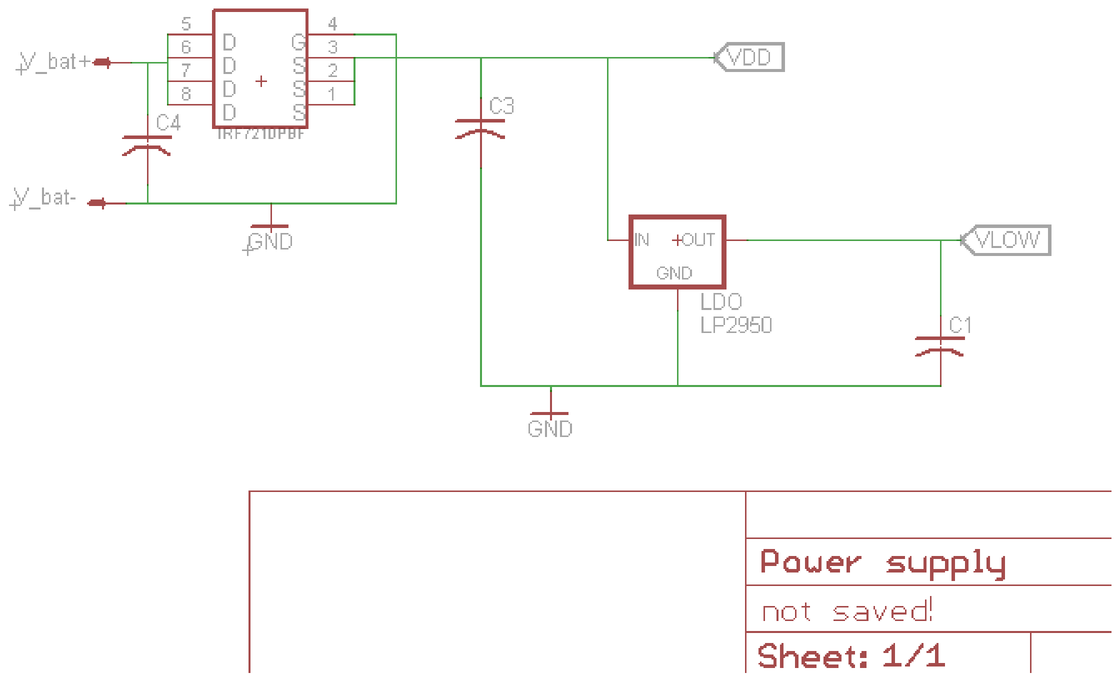

Figure 12: Schematic (1), Power supply module

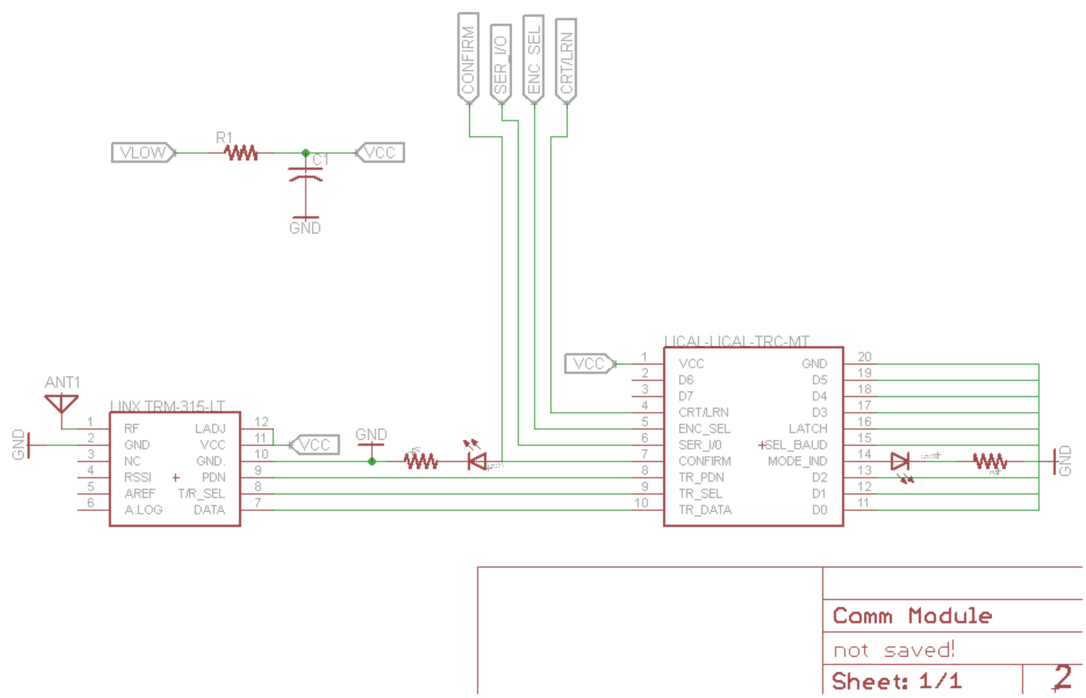

Figure 13: Schematic (2), Communications Module

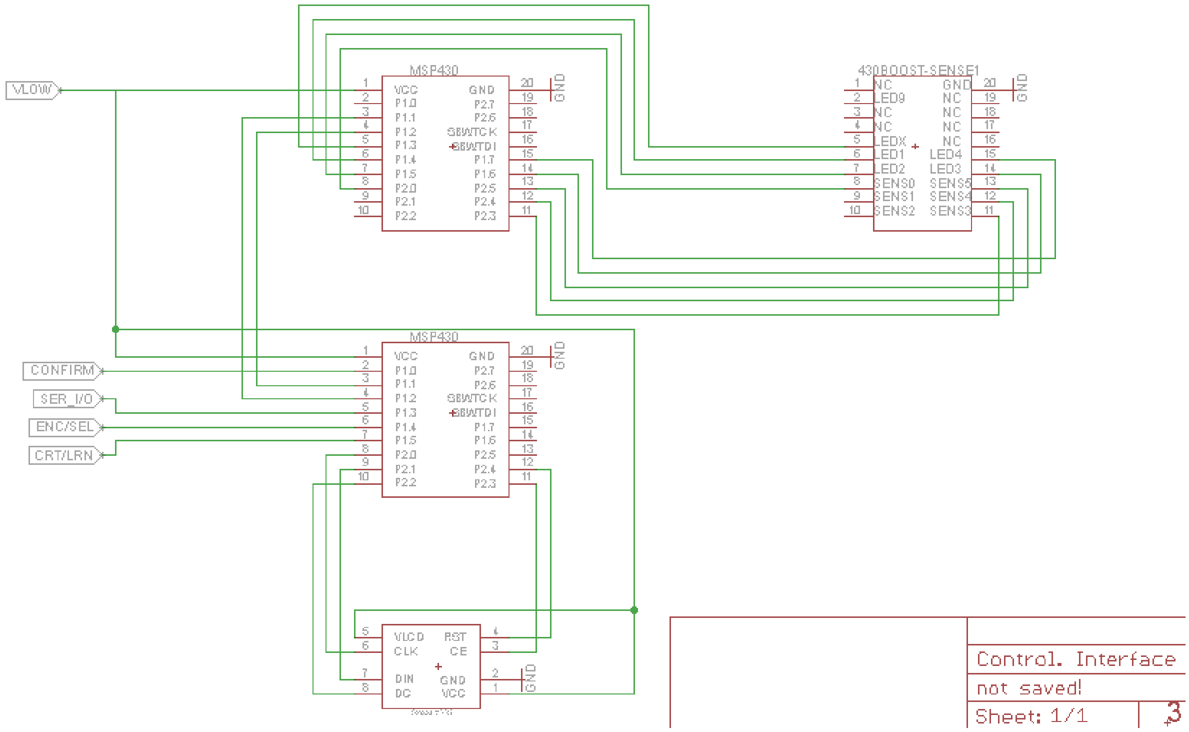

Figure 14: Schematic (3), Microcontroller and user interface module

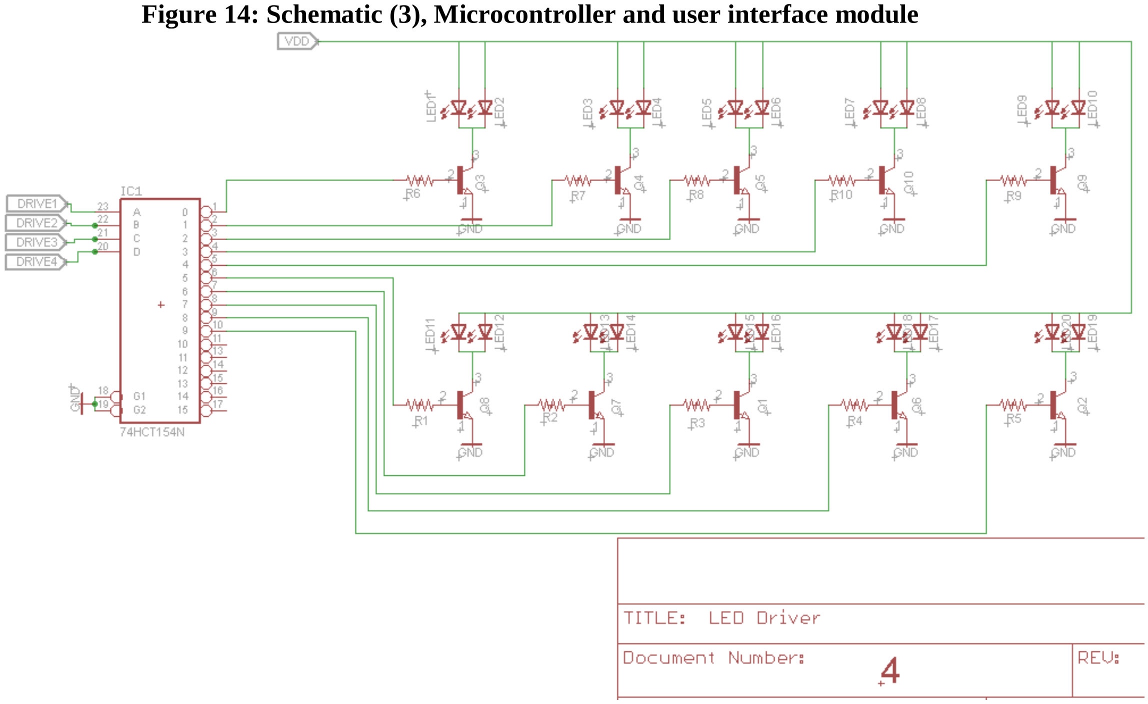

Figure 15: Schematic (4), LED module

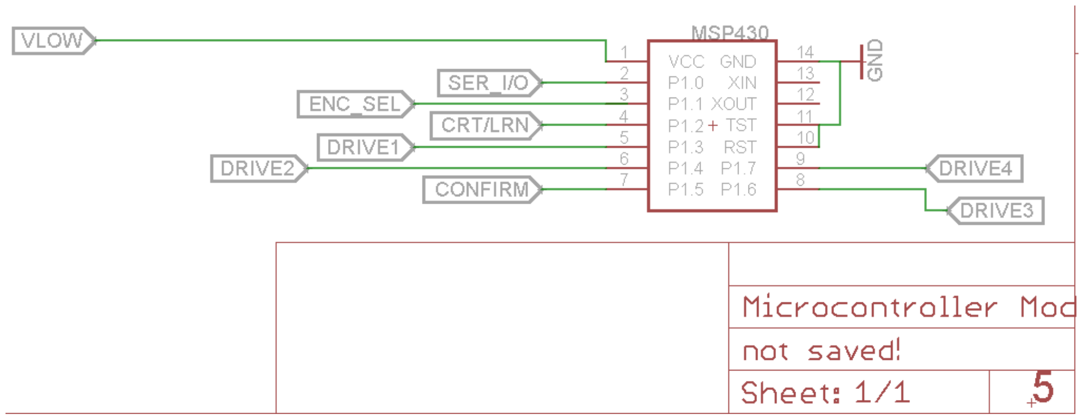

Figure 16: Schematic (5), Microcontroller module

1.7 Performance Requirements

The system has several performance requirements. These requirements are listed here.

- Maintain realized pace within 2% of set pace.
- Underwater modules can communicate at a distance greater than 1.5 meters.
- The battery life of the system needs to exceed 1 year at a usage rate of 10 hours per week.

These metrics can be tested once the device is completed. The pace accuracy will be checked by measuring the time it takes to complete several laps and ensure the time taken is within 2% of the time it would have ideally taken. The communication can be verified through a trial of spacing the modules at different distances and check to ensure communication still works. The battery life can be confirmed by measuring the power used while the system runs and comparing it to available energy in the batteries.

1.8 Simulations

1.8.1 Power Supply:

The power supply consists of two components: reverse polarity protection and a linear dropout voltage regulator. A diagram of the reverse polarity protection circuit is shown in Figure 17: Reverse polarity protection circuit diagramFigure 17. [3]

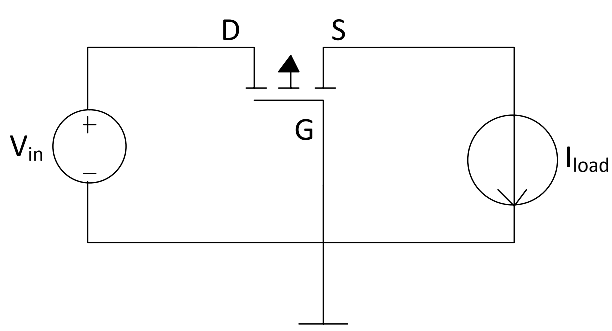

Figure 17: Reverse polarity protection circuit diagram

The circuit can be analyzed as follows. V_{in} may only take on two values: 4.5V and -4.5V, since the voltage source (in our case the batteries) is either wired correctly or backwards. If the voltage source is correctly installed, V_d, the drain voltage of the MOSFET, is 4.5 V. Assuming that the MOSFET is on, the source voltage would initially be:

$$V_s = V_d - V_{bd}$$

Equation 1

where V_{bd} is the forward voltage of the MOSFET's body diode. For the IRF7210PBF, V_{bd} = 1.2 V. Therefore, V_s = 3.3 V. Since the gate of the MOSFET is grounded, the following holds:

$$V_{gs} = -V_s$$

Equation 2

Therefore, V_{gs} = -3.3 V. For a PMOS, the transistor is on if:

$$V_{gs} < V_{th}$$

Equation 3

V_{th} = -0.6 V for the IRF7210PBF. Since V_{gs} meets the requirement given in Equation 3, the transistor must be on. The resistance of the channel between drain and source of the IRF7210PBF when it is conducting is 7 mΩ, meaning that the MOSFET acts almost as a wire when turned on. As a result, the body diode is actually bypassed. The voltage at the source can now be determined from:

$$V_s = V_d - I_{load} * R_{ds,on}$$

Equation 4

I_{load} is difficult to calculate exactly, since the current drawn by the microprocessor module and communication module varies with time. Nevertheless, I_{load} is largely dominated by the current drawn from the LED module. At any specific time, there is only one row of LED's being lit up, which require 20 mA each. The microcontroller and communication modules each require currents on the order of 200 µA during active mode operation. Therefore, using Equation 4, V_s = 4.4997 V.

The efficiency of the reverse polarity protection circuit when V_s = 4.5 can now be calculated using:

$$\%efficiency = \frac{V_s}{V_d}$$

Equation 5

Therefore, the reverse polarity protection circuit is 99.99%.

To verify that the circuit in Figure 17 protects against reverse polarity inputs, it must be analyzed for the case when V_{in} = -4.5 V. Assuming that the transistor is on and using Equation 1, V_s = -5.7 V. Using Equation 2, V_{gs} = 5.7 V, which does not meet the condition in Equation 3. Therefore, the assumption that that transistor is on is wrong. Since the transistor is off, I_{load} = 0 and the load is protected from reverse current.

The reverse polarity protection behavior of the circuit in Figure 17 is verified by PSPICE simulation. The circuit used during simulation is shown in Figure 18

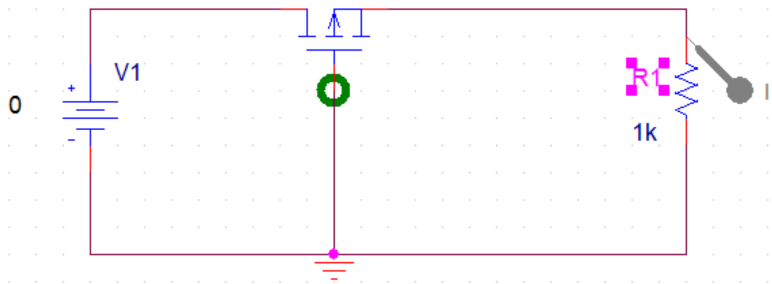

Figure 18: Reverse polarity protection circuit PSPICE simulation diagram

Figure 19 is a plot of the current through the resistor in Figure 18 as a function of the supply voltage V_1. Figure 19 confirms that the reverse polarity protection circuit blocks negative voltage.

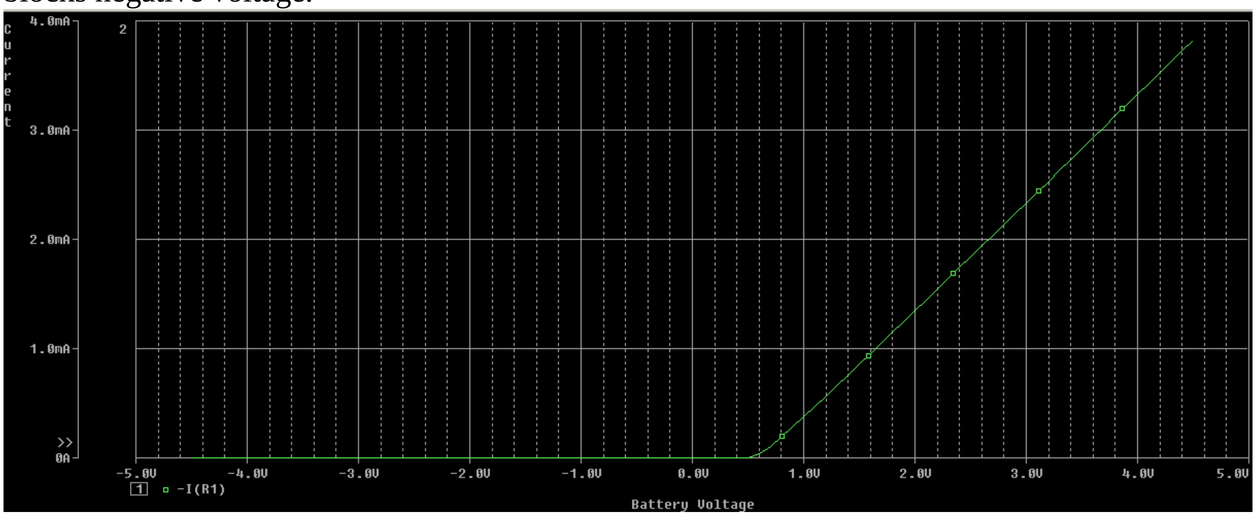

Figure 19: Reverse polarity circuit simulation

The efficiency of the reverse polarity protection circuit was verified using the diagram shown in Figure 20, where the MOSFET has been biased at 40 mA to simulate normal operating behavior.

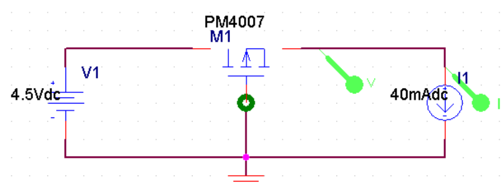

Figure 20: Biased reverse polarity protection circuit PSPICE model

Figure 21 shows the simulation results for Figure 20, confirming that the steady state rectified voltage is 4.495V.

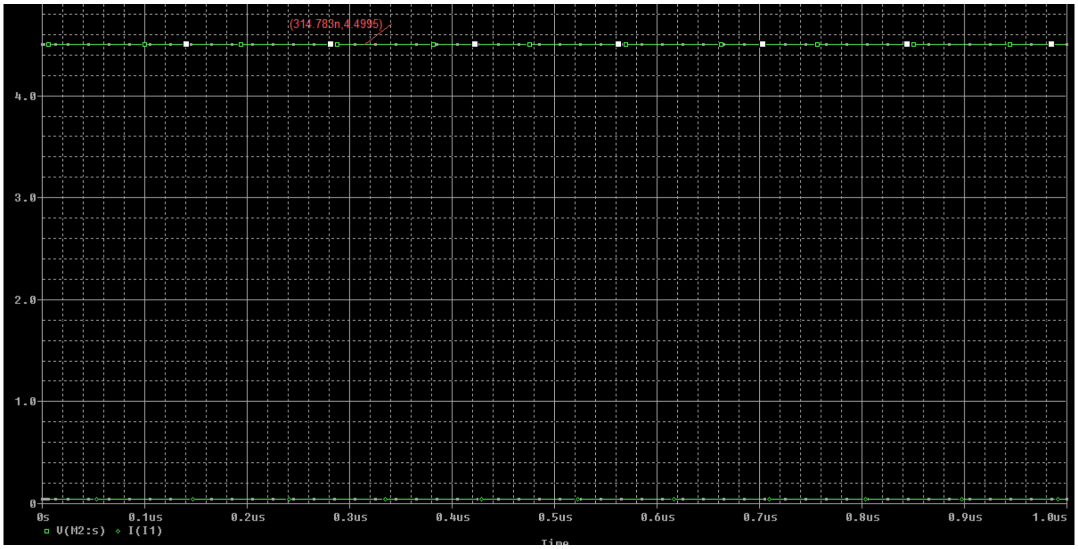

Figure 21: Simulation showing voltage drop over MOSFET in reverse polarity protection circuit at 40 mA bias point.

The efficiency of the rectifying circuit can now be calculated, from Equation 5, as 99.89%.

We will omit an analysis of the efficiency of the LDO regulator used to supply power to the microcontroller and communication modules because the power consumed by these modules is miniscule compared the LED module. For comparison, the LED module consumes 2.43 W while the microcontroller and communication modules consume a combined 2.62 mW, or less than 2% of the total power consumed by the system.

We now present a calculation of the system's battery life. The calculation is based on the following assumption:

- Each battery holds 10500 mWh
- The system is used 5 times per week for 2 hours
- The pool is 50m long, so each module is active for 1/50 of the total time the system is in use

$$Lifetime(years) = \frac{E_{battery}(Wh) * efficiency}{losses(W) * 52(\frac{weeks}{year}) * 10(\frac{hours}{week}) * \frac{1}{50}}$$

Equation 6

Using Equation 6, the theoretical lifetime of the system is 1.22 years.

1.8.2 LED Driving Circuit:

Figure 22 shows the PSPICE simulation diagram for the LED driving circuit. The LED's are modeled with simple diodes. [1]

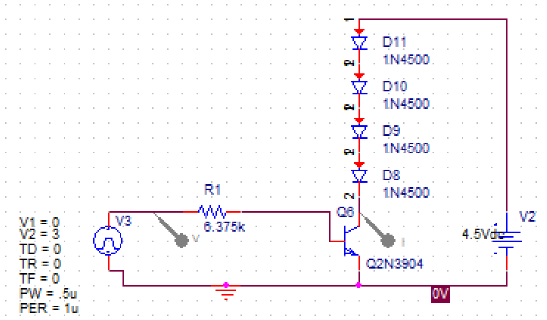

Figure 22: LED driving circuit PSPICE simulation diagram

The circuit may be analyzed as follows. For the BJT to be conducting, V_{BE}, the base-emitter voltage, must satisfy the following requirement:

$$V_{BE} = V_{BE,sat}$$

Equation 7

where $V_{BE,sat}$ = 0.75 V for the 2N3904G BJT being used. If the input voltage, V_3, is 0V, $V_{BE} < V_{BE,sat}$, the condition in Equation 7 is not met, and the BJT does not conduct, leaving the LED's off. When V_3 = 3V, the transistor is assumed to be on (verified later), and the base current, I_B, can be calculated using Equation 8:

$$I_B = \frac{V_3 - V_{BE}}{R_1}$$

Equation 8

Therefore, I_B = 352.9 µA. The collector current, I_C, can now be calculated using the following, assuming the BJT is in the active mode:

$$I_C = \beta I_B$$

Equation 9

where β is the DC current gain of the BJT, which in this case is equal to 100 according the BJT datasheet. Using Equation 9, we get that I_C = 35.3 mA, which is very close to the desired collector current of 40 mA. Finally, we can check that the BJT is in active mode by making sure the following holds:

$$V_{CE} > V_{CE,sat}$$

Equation 10

In our case, we know that, by design, when the diodes in Figure 22 are biased at 40 mA, the voltage drop over them is 3.3 V. Thus, $V_{CE} = 4.5 – 3.3 = 1.2 \text{ V} > V_{CE,sat}$, proving that BJT is in the active mode. The simulation results, shown in Figure 23 confirm this analysis. At an input voltage of 3V, I_C = 43.7 mA, which is the current needed to drive the LED's.

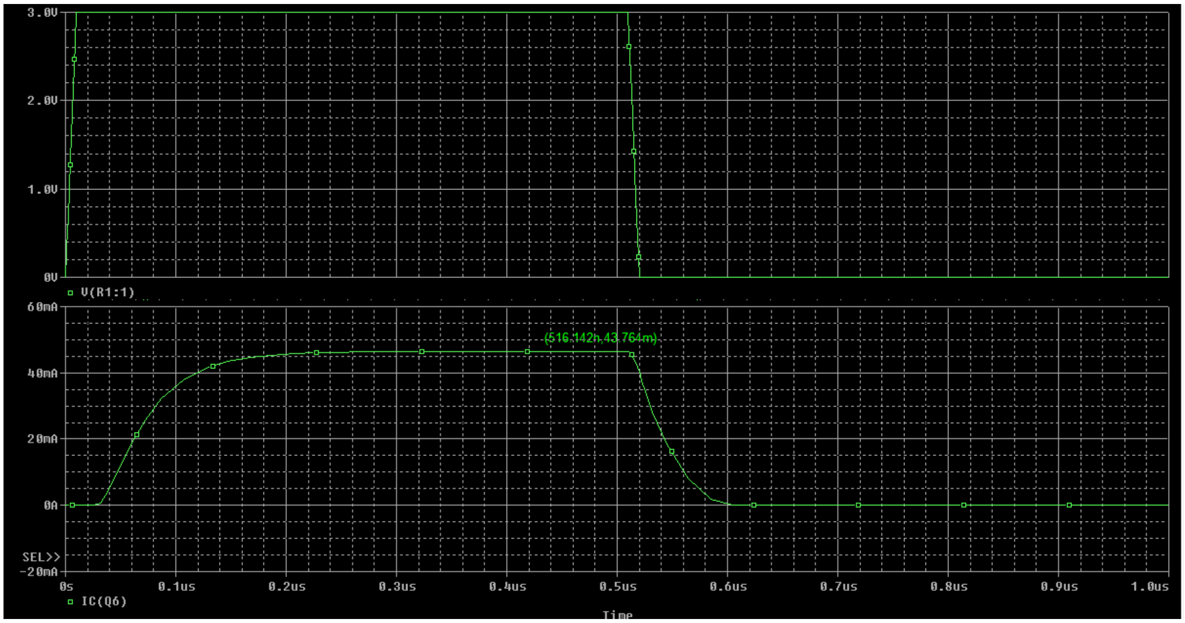

Figure 23: Simlation Results of LED driving circuit

The power consumption of the LED driver circuit can be calculated with:

$$P_{lost} = I_B^2 * R_1 + V_2 * I_C$$

Equation 11

The power loss, during active operation, is 2.43W.

1.9 Special Circuit

Special circuit not required.

2 Verification

2.1 Testing Procedures

2.1.1 Power Circuit

Requirement	Verification
Negative voltage protection a) Reverse current when supply is connected backwards is less than 150 µA b) Forward current when supply is connected with correct polarity is not clipped	a) Supply (-4.5V) from a power supply to the input of the power circuit. Measure the current at the output of the power circuit using a multi-meter. The magnitude of the current should be less than 150 µA b) Connect a power supply to the input of the power circuit. Set the power supply to deliver 2V and use a multi-meter to measure the current at the output of the power circuit. Increase the input voltage to 4.5V while measuring the output current. The output current should increase without being clipped in the for the given range of input voltages.
The power circuit provides a 4.49V DC voltage source. a) Supply voltage is maintained at 4.49V for output current in the range of 1-30 mA	a) Supply positive 4.5V DC from a power supply to the power circuit. Connect a 150 Ω resistor from V_{DD} to ground and measure the current across the resistor using a multi-meter. Increase the resistance at the in increments of 100 Ω up to 500 Ω while observing the voltage and current at the V_{DD} node. If the circuit is properly operating, the voltage should be 4.49 V while the current varies from 1-30 mA.
The power circuit provides a 3.3V DC voltage source a) Supply voltage is maintained at 3 V for output current in the range of 1-20 mA	b) Supply positive 4.5V DC from a power supply to the power circuit. Connect a 165 Ω resistor from V_{LOW} to ground and measure the current across the resistor using a multi-meter. Increase the resistance in increments of 500 Ω up to 3300 Ω while observing the voltage and current. If the circuit is properly operating, the voltage should be 3.3

	while the current varies from 1-20 mA.
The power supply is at least 80% efficient	Supply 4.5 V DC from a power supply to the power circuit. Read the power supply output current and voltage from the power supply to calculate the input power. Measure the voltage and current at the output of the power circuit. Current can be measured by connecting a 1 Ω resistor to the output of the power circuit and measuring the voltage over it. Calculate the output power. Calculate efficiency by calculating P_{OUT}/P_{IN}.

2.1.2 Wireless Communication

Requirement	Verification
MSP 430 & Evaluation Board Communication - Transmit	Set up wireless communication with an MSP 430 and ensure communication with an evaluation board using LEDs to confirm. The MSP 430 is powered via USB. a) Connect an oscilloscope to the data line of one evaluation board. b) Program with msp430 to transmit at the baud rate of evaluation boards c) Test by sending a square wave d) The square wave should appear on oscilloscope, if not check circuit connections and code
MSP 430 & Evaluation Board Communication – Receive	Set up wireless communication with an MSP 430 and ensure communication with an evaluation board using LEDs to confirm. The MSP 430 is powered via USB. a) Connect an oscilloscope to the data line of one evaluation board. b) Program with msp430 to receive at the baud rate of evaluation boards c) Hook up the msp430 to the data line on one of the transcoders d) Test by pushing the transmit button on one of the transcoders such that the data will be received by the msp430 on the other end e) The msp430, if coded properly

	should enter a receive mode. f) save sender information and view the data in code composer.
Dual MSP 430 Communication	At this point we want to build two separate circuits as shown in the schematics for the communication modules. a) Wire up circuits appropriately b) Setup one circuit as a pure receive circuit c) Setup another as a pure transmit d) Send a square wave, verify on oscilloscope e) Check code/connections if the pulse is not observed
Dual Initialization & Network Generation	Using the startup methodology, get two MSP 430s to automatically recognize each other and communicate, using LEDs to confirm. The MSP 430s are powered via USB. a) Program msp430 to initialize system such that it broadcasts its relevant information for 5 seconds upon turn on state. b) Enter receive mode, and verify the controller is broadcasting back relevant information c) Verify by viewing registers via code composer to see that the unique 24 bit address of each wireless module in being saved
Multibody Initialization & Network Generation	Using all 4 modules, ensure automatic wireless initialization and communication. At this point all module can connect with the controller and receive data from the controller. Now this test will ensure that the modules have permissions to communicate with each other a) Program each module such that it will operate in a mode where they will just continually ping each other. b) With all four communication modules wired up, turn on one at a time so that the controller circuitry

	will assign them a position. c) Check circuit diagram, to ensure proper configuration and code. Utilize code composer to analyze each msp430's register contents
Data Update & Transmission	Now that all the modules can communicate with each other, use the controller module with wireless setup, ensure that it can adjust pace of other units by timing LED display rates. a) Ensure proper setup of LED circuitry. b) Force the modules into a set mode: this mode will allow the panels to light up the LEDs based on a predefined pattern. Once all rows have been illuminated, the panels will contact their next neighbor to light their LEDs accordingly. c) Check programming and proper system initialization.

2.1.3 Controller Module

Requirement	Verification
MSP 430 & LCD Functionality	Only connect the LCD with the MSP 430, write characters and images to the screen. Use USB to power the MSP 430. a) Ensure LCD is connected to the correct pins on the MSP 430. b) Connect the MSP 430 to USB for power and programming. c) Program the MSP 430 to display pixel on the screen. d) Program the MSP 430 to display a single character on the screen. e) Program the MSP 430 to display a string of characters.
MSP 430 & Touchpad	Only connect Touchpad with the MSP 430, get LEDs to light up and respond to touch. The MSP 430 is powered via USB. a) Connect the touchpad to the MSP 430. b) Connect the MSP 430 to USB for power and programming. c) Program the touchpad such that the LEDs on the touchpad blink.

	d) Program the touchpad such that the LEDs blink only when the touchpad is in used. e) Program the touchpad such that each LED blinks for a certain input into the touchpad.
MSP 430, Touchpad, and Cross Communication	At this point, the touchpad works fully with LCD display and 'Data Update and Transmission' tests have been completed. Combine the wireless and LCD/touchpad to ensure parts work together. The MSP 430s are powered via USB. a) Change mode functionalities and ensure that we are getting the proper output. b) Any issues, resort to code composer to debug and ensure circuit connects are solid. Verify circuit initialization as well
Power Source	Check the voltage source for proper operation. V_{DD} node should be at 4.49V and V_{LOW} node should be at 3.3V. If these specifications are not met, refer to the power circuit testing procedure described above.
Controller Module Test	Connect the power circuit, the MSP 430s, touchpad, and LCD. a) Connect all parts as described in the schematic. b) Program the device using the USB cable. c) Ensure that the touchpad can update information within the system. d) Ensure the LCD is displaying the correct system information. e) Ensure the wireless communication is working between the controller and a display unit.

2.1.4 Display Module

Requirement	Verification
LED's light up a) LED's must light up when a 3 V control signal is sent.	a) First connect a power supply to the LED driving circuitry. The power supply should be connected from

b) LED's should be operating at a 20 mA bias point, with a 5% tolerance.	the V_{DD} node to ground and set to 4.5V. Use another power supply to set the input signals to the decoder (DRIVE1,DRIVE2,DRIVE3,DRIVE4) to (3V, 0V, 0V, 0V). Observe the 1st row of LED's to check for LED illumination b) Measure the current through the LED's using a multi-meter for the operating conditions specified in (a). The current must be 20 mA, with a 5% tolerance.
Power Supply	Check the voltage source for proper operation. V_{DD} node should be at 4.49V and V_{LOW} node should be at 3.3V. If these specifications are not met, refer to the power circuit testing procedure described above.
MSP 430 with LED Circuit	Connect the LED circuit to the MSP 430. The MSP 430 is powered via USB. a) Connect the LED circuit to the MSP 430. b) Connect the MSP 430 to the USB for power and programming. c) Send test signals to the LED circuit to ensure functionality. d) If LEDs not working, hook up MSP 430-to-LED wires to oscilloscope and ensure proper signaling.
MSP 430 with Wireless	Connect the wireless device to the MSP 430. The MSP 430s are powered via USB. Ensure the device is capable of connecting wirelessly. If it fails to connect, refer to wireless testing procedures described above.
Display Module Test	Add in the power circuit to the MSP 430, LED, and Wireless circuit to ensure full subsystem functionality. a) Connect all parts as described in the schematic. b) Program the device using the USB cable. c) Ensure the LEDs are capable of lighting up. d) Ensure the device is communicating wirelessly.

2.1.5 System

Requirement	Verification
Individual Module Functionality	Construct and test each individual module as specified above. a) Test the power circuit as described above. b) Test the wireless communication as described above. c) Test the controller module as described above. d) Test the display module as described above.
Pace Testing & Timing Constraints	Using the control module, adjust pace and measure timing to ensure full system works. The pace will also be measured to ensure within 2% accuracy. a) Set up the system outside of water. b) Turn on the controller module c) Turn on each display module d) Set the pace using the touchpad e) Time how long it takes to complete a lap. f) Confirm results with set pace. g) Modify code if expected pace does not match realized pace.
Power Requirements	Measure power usage over a long period of time to determine system lifetime. The energy available divided by the power consumption must be greater than 10.9 days (1 year @ 10 hours/week) a) Set up system with voltmeter & ammeter between the power supply and rest of circuit. b) Measure voltage and current over time. c) Determine power used over course of an hour. d) Determine available energy from battery specifications. e) Ensure there is enough energy for 10.9 days of continuous operation.
Waterproofing	Ensure that device housing is waterproof by submerging housing without circuits and checking for leaks. a) Seal up display modules without electronics inside.

	b) Place underwater. c) Remove after 5 minutes. d) Check for evidence of water inside the container. e) If no water, the system is waterproofed.
Visibility	Ensure lights are visible underwater by placing device at bottom of pool and visually inspecting. a) Place waterproofed display module inside pool. b) Enter pool. c) Check to see if light is visible while swimming past.
Modularity	Ensure system works with 1, 2, and 3 modules in use. a) Turn on controller module b) Turn on one display module. c) Ensure the display module works by setting a pace and measuring the time it takes. d) Turn on a second display module. e) Ensure the display modules works by setting a pace and measuring the time it takes. f) Turn on the third display module. g) Ensure the display modules works by setting a pace and measuring the time it takes.
Communication Distance	Ensure modules can communicate at a distance of at least 1.5 meters by separating modules underwater and checking for communication. a) Turn on controller module. b) Turn on display modules. c) Place display modules in pool at distance of 1 meter apart. d) Set a pace and ensure system is able to communicate and LEDs light up. e) Separate the display modules up to 1.5 meters. f) Change the pace of the system and ensure the display modules change by manually timing the system. g) Continue to increase the distance between the modules and adjusting

	the pace to determine max communication distance.

2.2 Tolerance Analysis

The most important part of this project is maintaining a reliable and accurate pace during operation. The pace is set by user input into the control module and realized in the display modules. The display modules will then light up in accordance to the set pace. The goal of this project is to have a pace error tolerance within 2% of the set pace. This means that over the course of an hour of continual usage, the realized pace and the set pace vary by no more than 2%. This means that if the pace is set for 25 seconds for a 50 meter swim, the actual pace shown in the pool is restricted to between 24.5 seconds and 25.5 seconds for the 50 meter swim. The error can be determined by setting a pace and measuring the time taken to complete a large number of laps for the given length. Then ensure the measured time is within 2% of the desired time. The test will be done over a full hour to minimize measurement errors.

2.3 Ethical Issues

We will ensure that we abide to the following standards from the IEEE Code of Ethics:

3. to be honest and realistic in stating claims or estimates based on available data;

Working with underwater communications, we will not falsify the actually ranges of the panels between each other underwater. Extensive testing with the final design in the environment in which the product is going to be placed will be done.

Our product will be utilizing batteries for its power supply so we will provide accurate calculations to show the end user the rate at which these batteries have to be replaced.

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;

Our product covers all most all of the disciplines of ECE, from communications to photo diodes to power. We are applying our knowledge that we have learned thus far in our studies. In addition to this, we will be reaching out to other sources and continuing to develop our knowledge of ECE. We will always give credit where credit is due, and cite our sources via the IEEE citation style.

7. to seek, accept, and offer honest criticism of technical work, to acknowledge and correct errors, and to credit properly the contributions of others;

Working in a group of three on this project, we all abide to this IEEE code of ethics by critiquing each others work such that the best possible product comes to fruition. In addition to this, we will put forth our best possible effort towards our goals.

9. to avoid injuring others, their property, reputation, or employment by false or malicious action;

Working in an environment full of water, electric shock and shorting of circuits quickly comes to mind. We will ensure that there is no possibility of water coming in contact with the circuitry. Also, the underwater system will be using twine to connect to the panels to the lane line, we will ensure that there is a safety mechanism such that if a swimmer gets caught in the twine, he will not be incapacitated and can resurface with ease.

In addition to the IEEE code of ethics, we must comply with the FCC Standards for the RF frequency that we are operating at:

FCC Standards: Section 15.231 …"The prohibition against data transmissions does not preclude the use of recognition codes. Those codes are used to identify the sensor that is activated or to identify the particular component as being part of the system."… [2]

The sole purpose of all data transmissions in our system is to initiate a function to a target address.

Section 15.231 (continued) … The following conditions shall be met to comply with the provisions for this periodic operation:

(1) A manually operated transmitter shall employ a switch that will automatically deactivate the transmitter within not more than 5 seconds of being released. (2) A transmitter activated automatically shall cease transmission within 5 seconds after activation.

For panel to panel and panel to controller interaction, we will ensure that our system will always stop broadcasting after 5 seconds no matter how the broadcast is initiated.

In addition to the previous FCC standards, we will also have a confirmation LED on the transmitting device that will reflect that the targeted device received the signal.

3 Cost and Schedule

3.1 Cost Analysis

3.1.1 Labor

Name	Hourly Rate	Total Hours Invested	Total = Hourly Rate x 2.5 x Total Hours Invested
Michael Chan	$35.00	150	$13,125
Igor Fedorov	$35.00	150	$13,125
Ryan Cook	$35.00	150	$13,125
Total		450	$39,375

3.1.2 Parts

Part	Part Number	Unit Cost	Quantity	Total
LED's	WP7113ZGC	0.42	30	12.60
MOSFET's	IRF7210PBF	0.78	19	14.82
BJT's	2N3904G	0.06	10	0.60
PCB's		33.00	4	132.00
Resistors	RN60D6341FB14	0.31	20	6.20
Capacitors	C2012Y5V1A106Z	0.02	6	0.12
Linear Regulator	MCP1700T-3302E/TT	0.43	4	1.72
LCD	Nokia 5110	10.00	1	10.00
Capacitive Touchpad	430BOOST-SENSE1	10.00	1	10.00
MSP430 Launchpad	MSP-EXP430G2	4.30	5	21.50
Linx Transceivers	TRM-315-LT	15.00	4	60.00
Linx Transcoders	LICAL-TRC-MT	5.00	4	20.00
Linx Antenna	ANT-315-CW-HD	8.00	4	32.00
Batteries	C	0.67	12	8.00
Circuit Housing	Animal Crackers	15.00	3	45.00
PVC Piping	10' x 3/8"	10.00	6	60.00
Controller Housing	Container Store Shoe Box	2.00	1	2.00

3.1.3 Grand Total

Section	**Total**
Labor	$39,375
Parts	$436.56
Total	**$39,811.56**

3.2 Schedule

Week	Task	Responsibility
2/6	Finalize and hand in proposal	Ryan
	Design reverse polarity and amplifier circuits	Igor
	Research 315MHz frequency functionality in pool via evaluation boards	Michael
2/13	Conduct PSPICE simulations of reverse polarity and amplifier circuits	Igor
	Design Review	Ryan
	Layout communications module	Michael
2/20	Layout PCB boards for display, controller modules. Order parts for amplifier, power supply circuits	Igor
	Program Touchpad & Touchpad	Ryan
	Two Wireless Devices Detecting Each Other via evaluation boards and msp430	Michael
2/27	Assemble power supply and amplifier circuits for testing	Igor
	Program & Test both Touchpad & LCD	Ryan
	Work on coding based on the decision diagram for the two evaluation boards/have a wired up circuit to replace at least one evaluation board	Michael
3/5	Test and debug power supply	Igor
	Build control box & display box. Test for leaks.	Ryan
	Complete coding for panels. Construct the 3rd circuit and work with Ryan to make sure all the panels are communicating properly with controller	Michael
3/12	Have power supply/amplifier circuits fully tested, order PCB boards	Igor
	Program Visualization on MSP430	Ryan
	Test system in waterproof container	Michael
3/19	Assemble PCBs for controller and display modules	Igor
	Mock Up Demo	Ryan
	Time for modifications to code/system	Michael
3/26	Completion of modules	Igor
	Tolerance analysis	Ryan
	Verification of specifications	Michael
4/2	Fix remaining issues	Igor

4/9	Ensure completion	Ryan
4/16	Prepare Demo	Michael
	Prepare Presentation	Igor
	Prepare Paper	Ryan
4/23	Demo	Michael
5/1	Presentation	Igor
	Final Paper	Ryan
	Check In Supplies	Michael

References

1. Sedra, K. Smith. *Microelectronic Circuits*, 6th ed., Oxford: Oxford University Press, 2010, p. 257,379.
2. FCC Part-15 Rules: Unlicensed RF Devices. [Online]. Available. http://www.arrl.org/part-15-radio-frequency-devices
3. P-FET Reverse Voltage Polarity Protection Tutorial. [Online]. Available. http://www.youtube.com/watch?v=IrB-FPcv1Dc