MODULAR SWIMMING PACE AID

By

Michael Chan
Ryan Cook
Igor Fedorov

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TA: Ryan May

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Abstract

The motivation for this project is to provide a training aid for swimmers to follow a certain pace while swimming. A number of interconnected LED display modules indicate the pace set by the swimming coach to the swimmer by lighting up successive LEDs in a wave fashion. The swim coach is able to control the displays wirelessly from the controller, which allows for changing the pace of the LED displays in 0.5 second intervals in real time. The displays can be submerged in up to 2.5 meters of water. Successive LED displays are spaced evenly throughout the pool and strung from the lane lines.

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1 Introduction

1.1 Project Overview

In today's market, there is demand for a training aid product that will give swimmers real time feedback about their pace. In addition, coaches want to be able to adjust the pace of this system in real time such that they can influence the pace at which the swimmer is swimming.

Our design meets this basic demand while tackling a number of other issues: from cost to modularity to adaptability. Figure 11-1 and Figure 11-2 in *Appendix E*, which show the system layout in a swimming pool, showcase the modularity of the design. Each panel communicates with each other panel through wireless devices and the swim coach can interact with the system from a wireless device outside the pool. This design can also adapt to any pool profile because the panels are strung from the lane lines. Our design can adapt to any pool size because the consumer can purchase as many panels as desired and the timing system automatically adapts. Cost is reduced by placing display panels every other meter in the pool, thus reducing the amount of material needed to span the pool. Figure 7-4 and Figure 7-5 in *Appendix A* show the dimensions of the system. The compact dimensions of our system make it extremely portable.

1.2 Overall Summary

The display module, which can be seen by Figure 13-11 in *Appendix G*, has many responsibilities as soon as it is powered up. When the display module is switched on, it broadcasts to the controller module to request being added to the system. When this is completed, the controller has the unique address to the display module. In addition, the display module receives information from the controller regarding its place in the string of display modules, what module is in front of it in the string, and whether or not it is first module in the string. Once a module has been successfully loaded into the system, it sits 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* allows the user to set the pace on the controller and then initiates the system to light up according to the desired pace.

The *test synchronization mode* allows the user to initiate a test to check that all the modules are successfully communicating with each other in the water. The synchronization test ensures that the system is successfully set up and ready to run the timing functionality mode. The *test synchronization mode* also counts the number of panels in the system and returns that information to the controller.

The *add panel to modular string mode* allows the controller or a panel to know who their neighbors are.

The controller module has the ability to initiate the three modes above. A capacitive touchpad and LCD allow users to traverse the system and select the desired functionality. Every time the user enters the timing functionality, the system runs the synchronization test to count how many modules are in the system. After this is complete, the user can set the length of the pool (in meters) as well as the pace. The first time that the desired pace is committed, a buzzer sounds to signal the swimmer to begin swimming. The user can then press the middle button on the touchpad at any time to update the pace.

2 Display and Controller Block Diagram Summary

A detailed block diagram of the display module is shown in *Appendix A,* Figure 7-3. The following is a description of the design.

2.1 Display Module Block Diagram Description

2.1.1 Microcontroller Module

The circuit for the microcontroller module is shown in *Appendix B*, Figure 8-6. The microcontroller module consists of a single MSP 430. The module receives a 3V DC voltage supply from the power supply module. The microcontroller interfaces with the communications module serially through four digital IO pins. The microcontroller also uses digital IO pins to send four control signals to the LED module. The microcontroller must process communication data and determine when to light up the LED's.

2.1.2 Power Supply Module

The circuit for the power supply module is shown in *Appendix B,* Figure 8-4*.* The power supply provides power for all components in the system. The voltage source consists of three C batteries wired in series, providing 4.5 V DC. The power supply has reverse voltage protection in the form of a MOSFET reverse voltage protection circuit. The efficiency of a MOSFET reverse polarity protection circuit can be calculated using:

$$\%efficiency = \frac{V_d - I_{load} * R_{ds,on}}{V_d}$$

Equation 1

where V_d is the MOSFET drain voltage (4.5 V), I_{load} is the current drawn by the entire circuit (approximately 100 mA), $R_{ds,on}$ is the on-resistance of the MOSFET (0.01 Ω for the IRF7210 being used). Equation 1 indicates that a MOSFET reverse polarity protection circuit is 99.99% efficient, while a typical diode circuit is 84.44% efficient. The voltage drop over the MOSFET circuit is given by:

$$Voltage\ drop = I_{load} * R_{ds,on}$$

Equation 2

Therefore, the MOSFET circuit only consumes 1mV when conducting, while a diode circuit would consume on the order of 700 mV. The clipped voltage is sent to power the LED module, providing it with a 4.499V voltage source. The simulation results in *Appendix C,* Figure 9-1 and Figure 9-2 confirm that the voltage drop over the MOSFET reverse polarity protection circuit is less than 1 mV and that negative input voltages are in fact blocked.

A low dropout regulator (LDO) is used to step down the 4.497V rectified voltage to 3V in order to provide power for the microcontroller and communications modules. Several different alternative regulators were considered in place of the LDO. The trade-off between a linear regulator like, an LDO, and a switching regulator, like a buck-boost converter, is that the linear regulator is much simpler than the switching regulator while the switching regulator is much more efficient. An LDO was finally chosen because we did not want to add more layers of complexity to the design than needed.

2.1.3 Communications Module

The circuit for the communications module is shown in *Appendix B,* Figure 8-5. The communications module uses 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. We are also using the TRM-315-LT Linx transceiver, which is used to transmit and receive data from the antenna. The transceiver data is fed through a bidirectional multiplexor into the microcontroller module. The bidirectional multiplexor that we are using is a quad 2:1 bidirectional multiplexor (CD4053B), where the MSP 430 controls the select line. The MSP430 TX and RX pins are the data-in lines for the multiplexor. This allows the MSP430 to have the TX pin fed into the data line of the transceiver when it is in transmit mode and the RX pin fed into the data line of the transceiver when the transceiver is in receive mode.

The transceiver receives 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. Noise reduction was accomplished using a low pass filter, implemented by placing a 10 ohm resistor in series with the supply followed by a 10 µF tantalum capacitor from the supply to ground.

2.1.4 LED Driver Module

The circuit for the LED Driver Module is shown in *Appendix B,* Figure 8-7. The LED module consists of 10 independent circuits, with each circuit receiving one control signal from the decoder. Each circuit has an amplifying stage that converts the control signal from the microcontroller to a signal powerful enough to drive the row of LED's. BJT's are used as the amplifiers and act as current sources for the LED's. As a result, no current limiting resistors are needed, increasing the efficiency of the system.

Each row of LED's has 2 LED's and the rows are spaced 10 cm apart. For the LED's, we used 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.

2.2 Controller Module Block Diagram Description

A detailed block diagram of the controller module is shown in *Appendix A*, Figure 7-2. The following is a description of the design.

2.2.1 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 TX pin. 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 four digital IO pins. This unit will be programmed to display system information and relay changes to the underwater display modules. Also, this msp430 will be tied to two multiplexors. The bidirectional multiplexor is described in section 2.2.3. The multiplexor in the user interface module is a quad 2:1 multiplexor (SN74LS157N). This is used to switch between the capacitive touchpad and communications module. This essentially allows us to listen for a panel trying to contact the controller or take user input from the touchpad.

2.2.2 Power Supply Module

See Power Module in section 2.1.2.

2.2.3 Communications Module

See Communications Module in section 2.1.3

2.3 Communications Protocol

2.3.1 Communications Protocol Description

For our mesh network to operate in a consistent manner, we need to organize our data such that the MSP430 can determine proper functionality. The table below shows how the incoming bytes of information will be organized. Each byte has a start and stop bit. The start bit is a logical ‘0’ and the stop bit is a logical ‘1’.

For each operation mode, we will define the functionality behind the “Operation Mode Dependent Byte.” Section 2.3.2 explains these bytes for all the operation modes. The signal transmit success mode will tell the MSP430 to light up a transmit verification LED. This is done so that we know the intended recipient got the data properly. This is an FCC requirement.

Table 2-1Table 2-1: Operation Modes and their byte ID contains the bytes that we transmit per operation mode. Table 2-2 shows how each packet is organized. For the start byte, we look for four consecutive bytes of 0xA5. This was done because we were getting false positive start bytes from the circuit and ambient noise. This was causing an issue with communication reliability because the msp430 was always analyzing packets of data and when a module would transmit, the msp430 would not pick it up because it was not listening for information. The new start bytes got rid of these false positives.

Table 2-1: Operation Modes and their byte ID

Operation Mode	Byte to Transmit
Timing Functionality Mode	0x11
Test Synchronization Mode	0x22
Add Panel to Modular Strong Mode	0x33
Signal Transmit Success	0x44
Update System Time	0x55
Update Panel ID	0x66
End Timing Mode	0xFF

Table 2-2: Packet Organization

START	Intended Recipient ID	Sender ID	Operation Mode	Operation Mode Dependent Byte 1	Operation Mode Dependent Byte 2	STOP
0xA5 (four times)	0x??	0x??	0x??	0x??	0x??	x5A

2.3.2 Operation Mode Dependent Byte Descriptions

This section defines the operation dependent bytes if they have meaning for all of the operation modes.

2.3.2.1 Timing functionality mode

Operation Mode Dependent Byte 1:

This byte contains the timing distance that the user selected from the controller.

Operation Mode Dependent Byte 2:

This byte contains the set pace that the user selected from the controller.

2.3.2.2 Add panel to modular string mode

Operation Mode Dependent Byte 1:

This byte will update the panel's previous pointer.

Operation Mode Dependent Byte 2:

This byte will update the panel's next pointer.

2.3.2.3 Test synchronization mode

Operation Mode Dependent Byte 1:

This byte contains a running sum of the total number of panels in the system. This information is then relayed back to the controller.

2.3.2.4 Update System Time

Operation Mode Dependent Byte 1:

This byte contains the timing distance that the user selected from the controller.

Operation Mode Dependent Byte 2:

This byte contains the set pace that the user selected from the controller.

2.4 Controller Operation & Flow Chart

The Controller Unit acts as the user interface to the entire system. The Controller is a sequential machine that allows the user to enter various modes and adjust settings for the system. A full outline of the Controller software flow is shown in Figure 12-1 in *Appendix F*. This displays how the controller can transition from one state into the next. A pictorial view of the flow and operations in the controller is shown below. The actual device is shown in *Appendix G,* Figure 13-1.

The system starts with a welcome screen, Figure 13-2, followed by an immediate call to add panel mode, as shown in Figure 13-3. This allows the user to start building up the system immediately by turning on Display Units to connect back to the controller. When the first panel is added, the user is notified as shown in Figure 13-4.

After the first panel is added the user is taken to the main menu, Figure. Here the current selection is highlighted and the user can navigate using the touchpad using the center button as a select as shown in Figure. Here the user can enter any of the functional modes of the controller unit or toggle the backlight, Figure 13-7.

The first mode available in the Controller Unit is the Test/Sync mode, Figure 13-8. Here the unit sends out a signal to the first panel and waits to hear back, in the process counting the total number of panels, Figure 13-9. This mode is also entered when running the Swim Pacer mode in order for each panel to know the total number of units in the system. The Swim Pacer Mode then allows for the user to set the distance as well as adjust and commit the set pace for the system to follow, Figure 13-10. When the user selects end, it returns to the original main menu.

2.5 Panel Operation & Flow Chart

The Display Panels are the key to visualizing the pace underwater. These units communicate with each other and light up LEDs in order to visually show the pace to the swimmers. The software flow of these units involves the initial adding of the panel to the system. During this stage, the panel initially sends out a signal to indicate that it will join the system. Afterwards it waits for a return signal indicating it has been added and updates its internal position value. Then it waits for a signal to indicate what it should do. It either receives a test/sync signal in which it tests the connection between its neighboring panels or a swim pace signal in which it updates its timing information, lights up its LEDs, and pass on information to the next panel. This is outlined in *Appendix F* in Figure 12-2. The physical device is shown in *Appendix G* Figure 13-11.

3 Design Verification

3.1 Power Supply Module Verification

The verification procedure for the power supply module is shown in *Appendix D*, 10.1. The three components in the verification of the power supply are reverse voltage protection, 4.5V supply capability, and 3V supply capability.

In order to test reverse voltage protection, we connected the batteries which supply our circuit with energy backwards. At the same time, we connected a multi-meter in series with the batteries in order to read the current being supplied by the batteries. Figure 3-1 below shows the test setup.

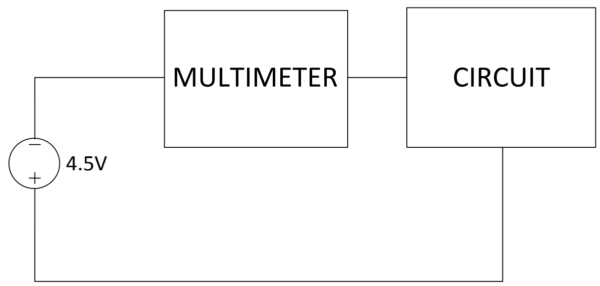


Figure 3-1: Reverse voltage protection test setup

To test the 4.5V and 3V supply capability of the power supply, we probed the outputs of the reverse voltage protection circuit and LDO during normal system operation. Our test results are shown in Table 3-1 below. Testing was done on both the controller and display modules to ensure both circuits are properly powered. The results show that all of our verification requirements have been met.

Table 3-1: Supply Module Test Results

Test	Display Module	Controller
Reverse leakage current (μA)	0.07	0.07
4.5 V rail (V)	4.495	4.499
3 V rail (V)	3	3

Aside from the functionality tests, we also considered battery lifetime to be an important metric of power supply performance. Battery lifetime was calculated separately for the display and controller modules. Battery lifetime for the controller was calculated using the following equation:

$$lifetime = \frac{Battery\ energy\ capacity}{\left(\frac{52\ weeks}{year}\right)\left(\frac{10\ hours}{week}\right)\left(\frac{3600\ seconds}{hour}\right)\left(\frac{4.5V * I_{load}}{week}\right)}$$

Equation 3

where I_{load} is the current drawn by the controller (20 mA) and the battery energy capacity is 113.4 kJ. The battery lifetime for the display module was calculated using the following equation:

$$lifetime = \frac{Battery\ energy\ capacity}{\left(\frac{52\ weeks}{year}\right)\left(\frac{10\ hours}{week}\right)\left(\frac{3600\ seconds}{hour}\right)\left(\frac{4.5V * I_{average}}{week}\right)}$$

Equation 4

In this case of the display module, the current drawn is not constant and therefore must be calculated as:

$$I_{average} = \frac{1}{25} * I_{LED} + \frac{24}{25} * I_{IDLE}$$

Equation 5

where I_{LED} is the current drawn by the display module when the LED's are being lit up (90 mA) and I_{IDLE} is the current drawn when the LED's are not being lit up (14 mA). The following results for battery lifetime were obtained:

Table 3-2: Battery Lifetimes

	Battery Lifetime (years)
Display Module	0.37
Controller Module	0.67

3.2 Communications Verification and Testing

One of the first tests that were performed was to send data across the Linx transceivers once they were wired up. I hooked up a pulse wave generator to one transceiver in transmit mode and then hooked up an oscilloscope to the input and output of the wireless system. I verified proper transmission by eyeballing the two channels of the oscilloscope.

The next task was to figure out how to transmit/receive using the Universal Asynchronous Receive Transmit (UART) technology on the MSP430. Utilizing code that Texas Instruments provides, I was able to transmit bytes of data through the TX pin of the msp430. I verified that the proper data was being output on this pin by hooking the oscilloscope up to it. I then verified that I could transmit this data properly over the Linx modules as in the first tests that I ran. Figure 3-2 reflects the circuit setup and shows the transmitted/received data on the oscilloscope.

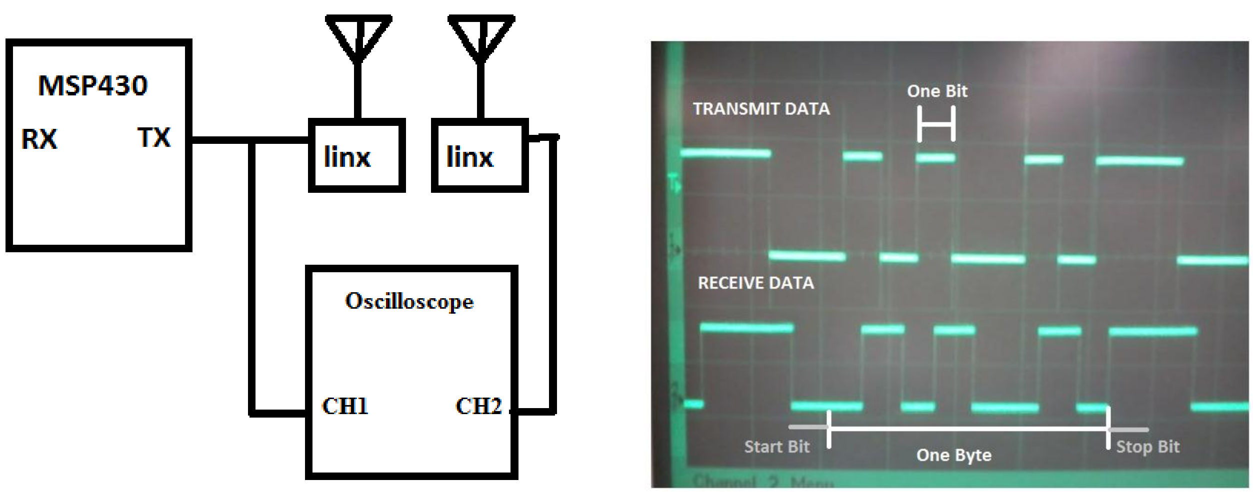


Figure 3-2: Figure on the left is the circuit setup for the figure on the right. In the figure on the right, the top waveform is a byte transmitted from one msp430 through the linx modules. The bottom waveform is the output on the other end of the linx modules.

The next item that was checked was that we were outputting data at the appropriate baud rate. We used the cursors on the oscilloscope to verify that each bit was 9600kHz. We then worked on the receive portion of the UART functionality. We initially hooked up two msp430s such that the TX of one went into the RX of another. We verified proper data reception by saving all incoming bytes of data and then viewed the registers in Code Composer Studio (CCS) to make sure that they reflected the data was being transmitted. Also, we used the oscilloscope to verify proper data transmission. Lastly, we hooked up the circuit like Figure 3-3 and verified proper data transmission across the Linx modules. Figure 3-3 also shows a successful packet transmission/reception and then rebroadcast.

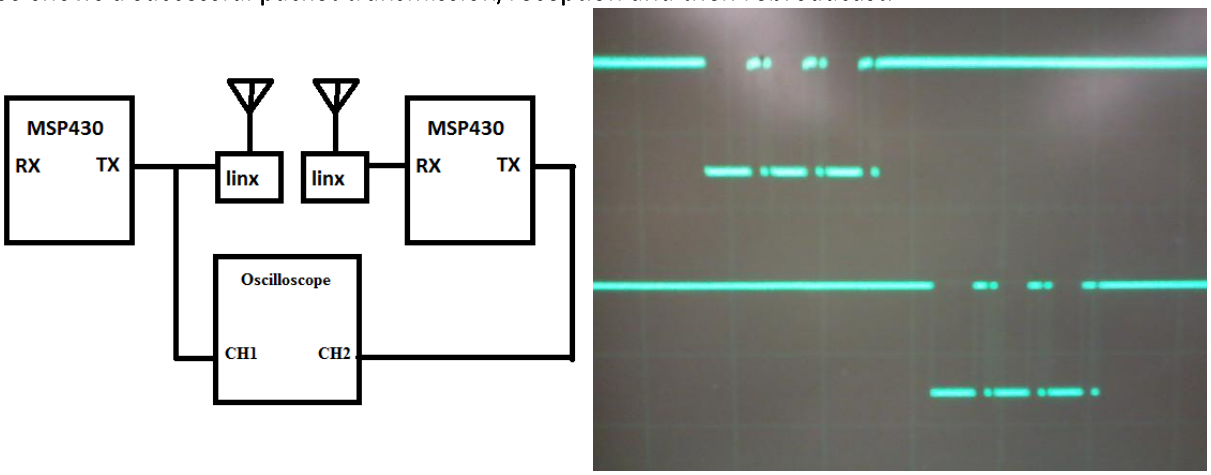


Figure 3-3: The figure on the left is the circuit setup for the figure on the right. In the figure on the right, the top waveform is 4 bytes of information transmitted from one msp430. The bottom waveform is the transmit line of another MSP430, where it echoes the received data. Data is transferred across linx modules.

3.3 LED Module Verification

The verification procedure for the LED module is shown in *Appendix D*, 10.1. Verification for the LED module consisting of testing whether our system was able to light the LED's and bias them at their optimal operating point, which is 25 mA. To complete testing, we set up a system to run timing mode and measured the voltage over lit LED's. We then used the voltage over the conducting LED's and the current-voltage characteristic graph provided by the manufacturer of the LED to determine the current at which the LED's were operating. We were able to successfully verify that the LED's were being driven at 25 mA.

4 Costs

4.1 Parts Costs

Table 4-1: Part Costs

Part (Part Number)	Manufacturer	Retail Cost ($)	Bulk Purchase Cost ($)	Actual Cost ($)
LEDs (WP7113ZGC)	Kingbright	0.42	60	25.20
MOSFET's (IRF7210PBF)	International Rectifier	0.78	19	14.82
BJT's (2N3904G)	On Semiconductor	0.06	10	0.60
PCB's		5.00	4	20.00
Resistors (RN60D6341FB14)	Vishay	0.31	20	6.20
Linear Regulator (TPS 79930)	TEXAS INSTURMENTS	1.10	4	4.40
Nokia 5110 LCD	Philips Semiconductor	5.90	1	5.90
Capacitive Touchpad (430BOOST-SENSE1)	TEXAS INSTURMENTS	10.00	1	10.00
MSP430 Launchpad (MSP-EXP430G2)	TEXAS INSTURMENTS	4.30	5	21.50
MSP430 (msp430g2553)	TEXAS INSTURMENTS	2.30	4	9.20
MSP430 (msp430g2452)	TEXAS INSTURMENTS	1.62	1	1.62
Linx Transceivers(TRM-315-LT)	Linx	15.00	4	60.00
Linx Antenna(ANT-315-CW-HD)	Linx	8.00	4	32.00
C Batteries	Duracel	1.25	12	15.00
Acrylic PVC Piping (10' x3/8")	ALSCO	8.20	2	16.40
Controller Housing	Glad	2.50	1	2.50
Panel Module Housing		7.50	3	22.50
Multiplexor (SN74LS157N)	TEXAS INSTURMENTS	0.66	1	0.66
Bidirectional Multiplexor (CD4053B)	TEXAS INSTURMENTS	0.26	4	1.04
Total				***269.54***

4.2 Labor

Table 4-2: Labor Costs

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***

4.3 Grand Total

Table 4-3: Grand Total

Section	Total
Labor	$39,375
Parts	*$269.54*
Total	***s$39,644.54***

5 Conclusion

5.1 Accomplishments

This project had many successes. The project rose above several challenges in the realms of hardware, software, and wireless. On the side of hardware, four completed and functional PCB's were fabricated and used in the final design. Also the use of low power devices allowed for a long expected battery life. With that the entire system successfully ran off of a battery supply. With respect to software, we were able to keep an accurate pace to within half a second. In addition we were able to provide real time updates, feedback, and a touch sensitive input. Wireless provided most of the challenges and some of the greatest success. The project was able to create an ad hoc network of panels as well as robustly communicated between the panels as well as to the controller. Overall the project was able to overcome a great number of challenges.

5.2 Ethical considerations

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. Also, 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.

5.3 Future work

While this project was a success there is room for improvement. There are several hardware changes as well as software improvements that can be made. On the side of hardware, improved PCB design including test points would help future development and testing. Also a separate MSP430 used exclusively for the communications protocols could improve wireless signals and increase functionality. On the software side, setting it up so that multiple systems could be used within close proximity, non-uniform panel distances or speeds, as well as new functions and debugging modes. This could expand the capabilities of the system to other applications that could use a pace setter such as running or cycling. In this regard there is potential to turn this good system into a greater one.

6 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

7 Appendix A: System Block Diagram and Dimensions

7.1 Block Diagram

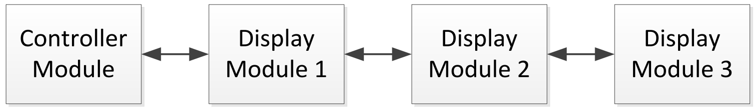


Figure 7-1: Top level block diagram

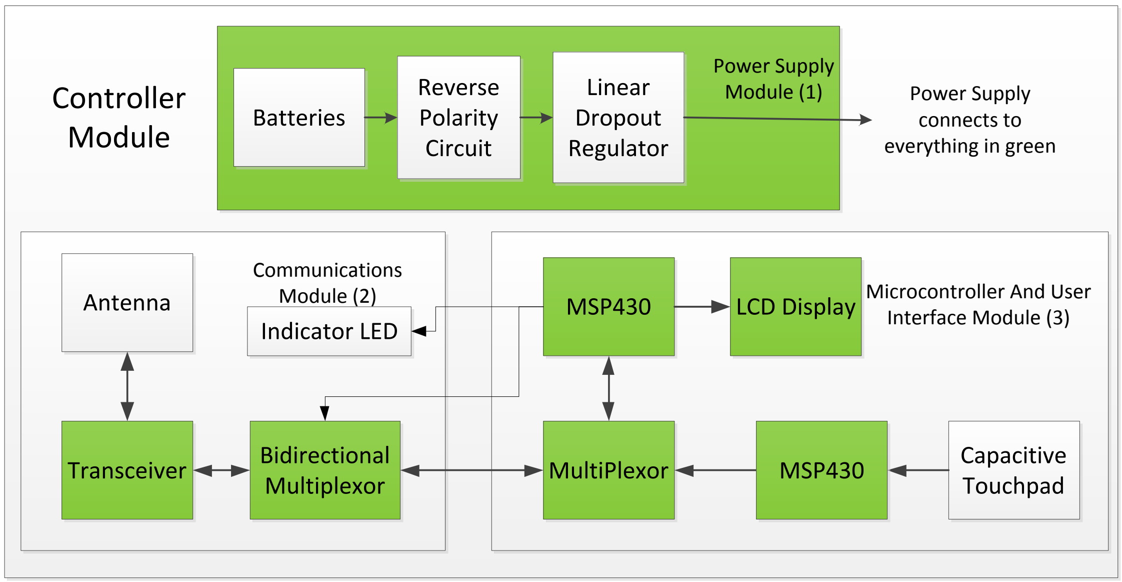


Figure 7-2: Controller module block diagram. (*) indicates the schematic number corresponding to the module.

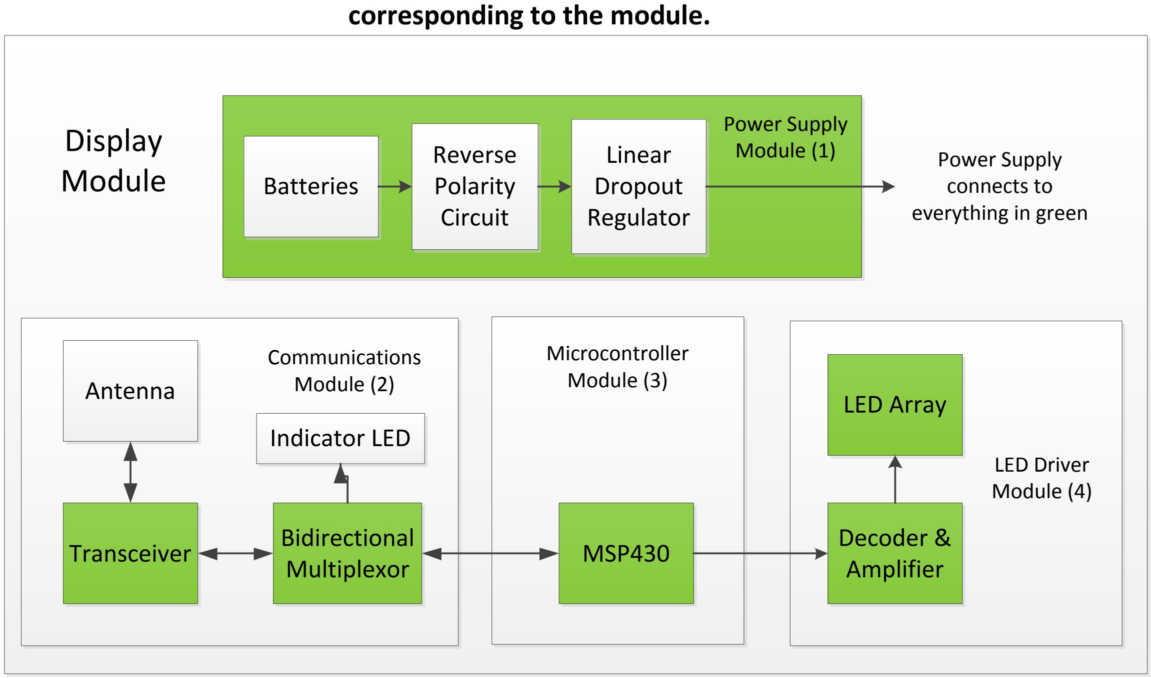


Figure 7-3: Display module block diagram. (*) indicates the schematic number corresponding to the module.

7.2 Dimensions

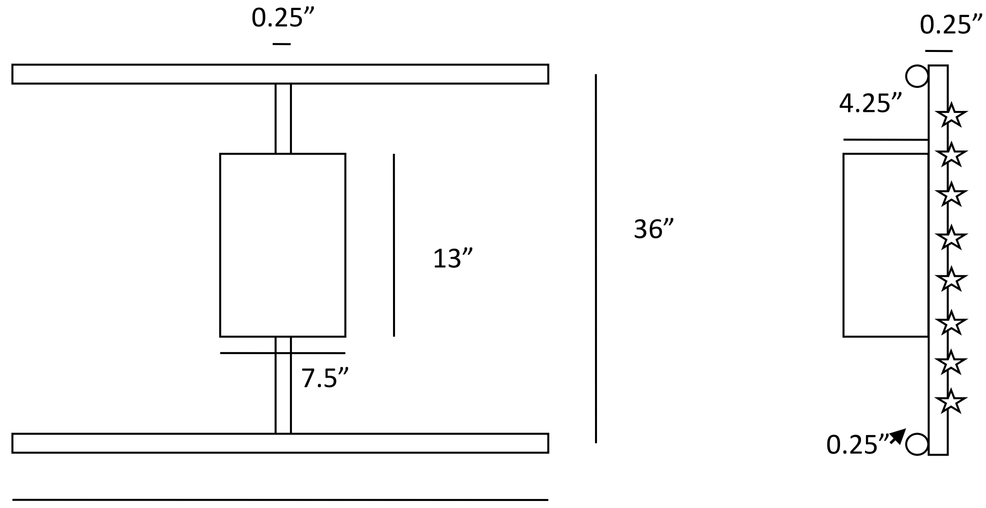


Figure 7-4: Underwater Module Dimensions

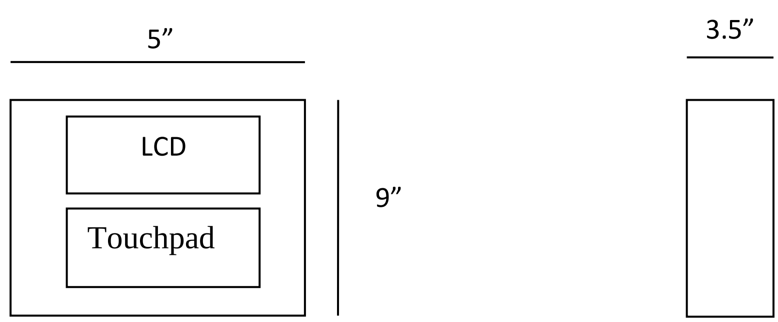


Figure 7-5: Controller Dimensions

8 Appendix B: System Schematics

8.1 Controller Module Schematics

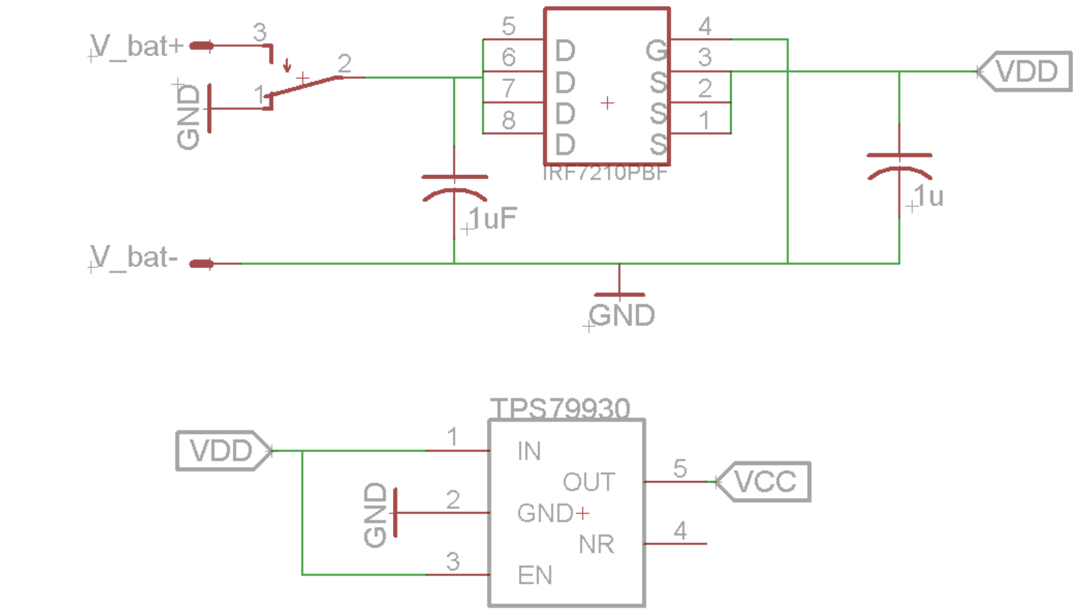


Figure 8-1: Schematic (1), Power supply module

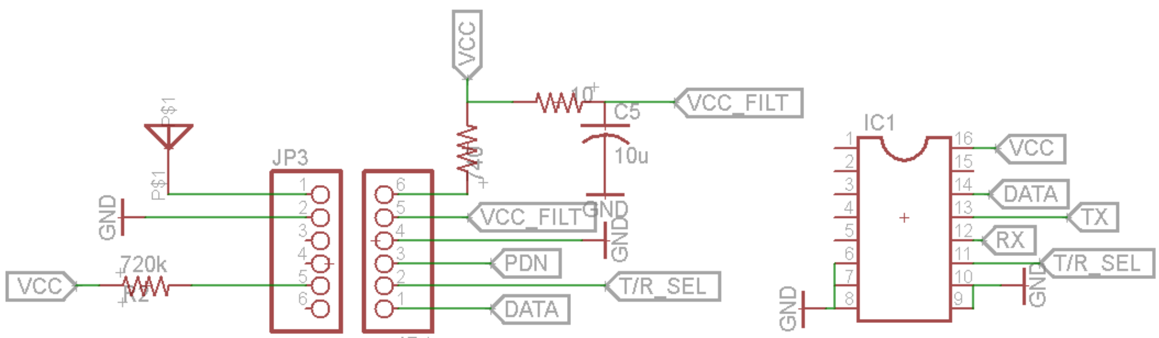


Figure 8-2: Schematic (2), Communications Module

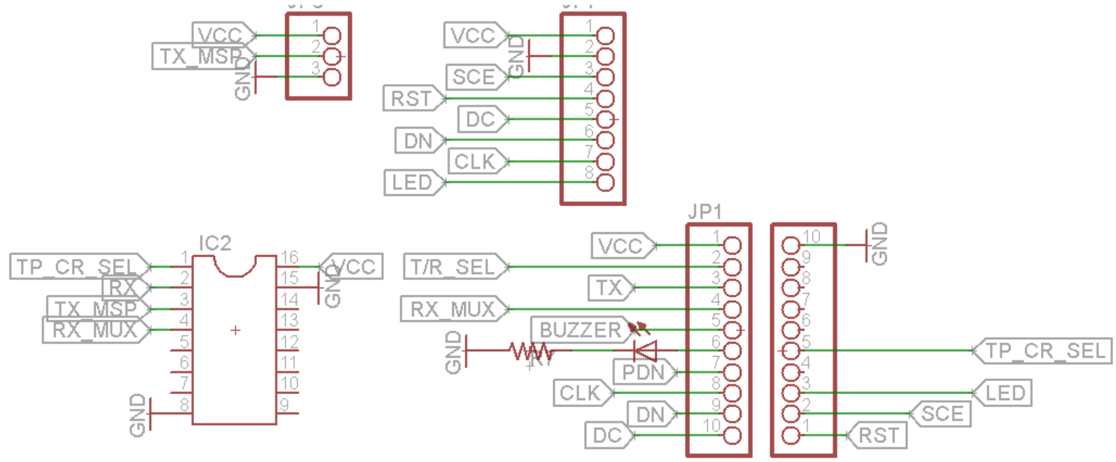


Figure 8-3: Schematic (3), Microcontoller and user interface module

8.2 Display Module Schematics

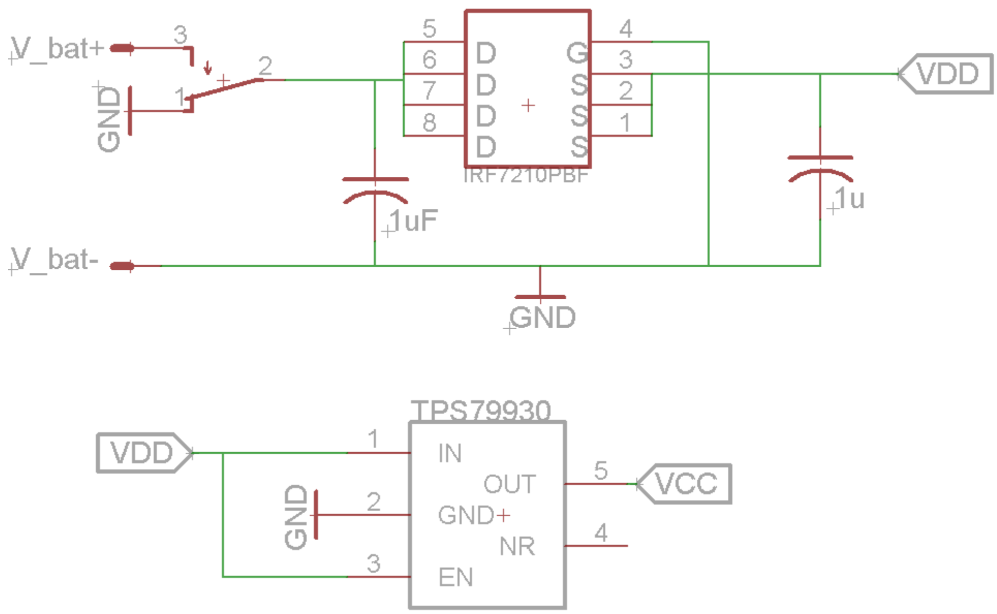


Figure 8-4: Schematic (1), Power supply module

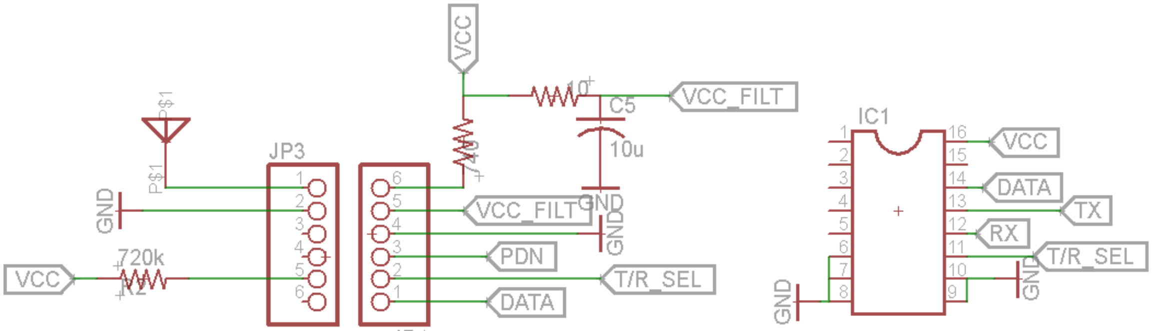


Figure 8-5: Schematic (2), Communications Module

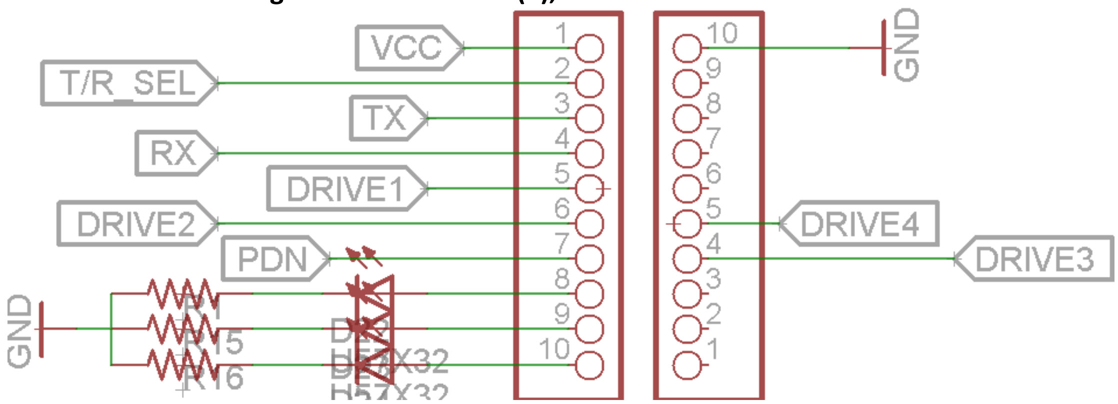


Figure 8-6: Schematic (3), Microcontroller Module

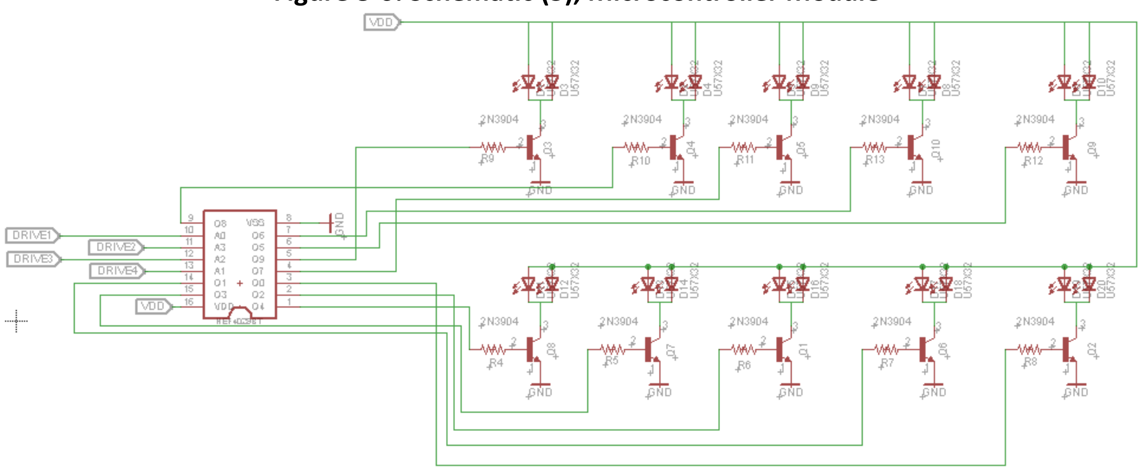


Figure 8-7: Schematic (4), LED Module

9 Appendix C: Simulations

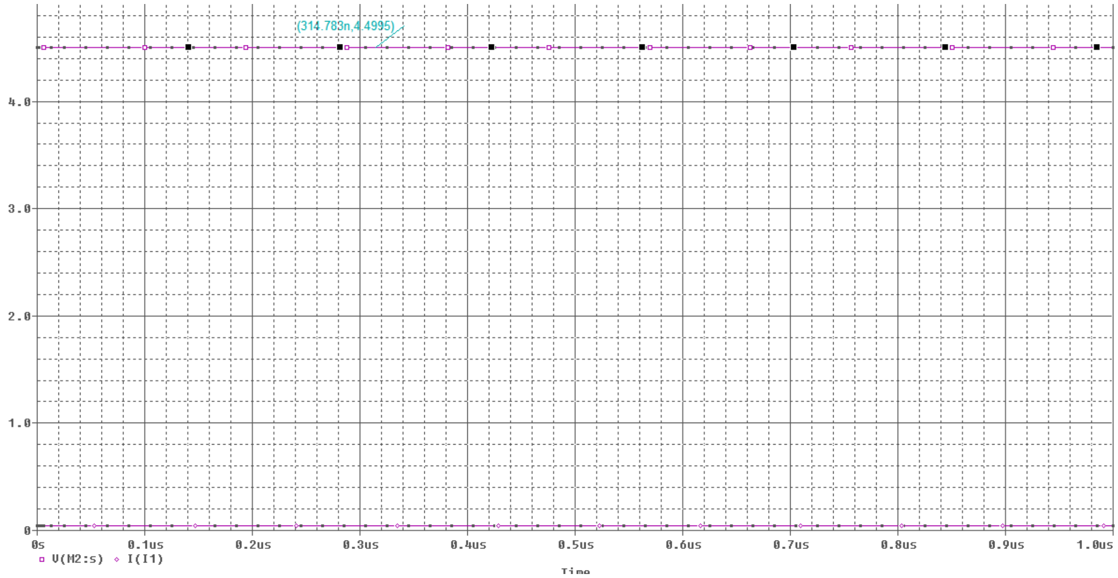


Figure 9-1: Output of MOSFET reverse voltage protection circuit with 4.5 V input

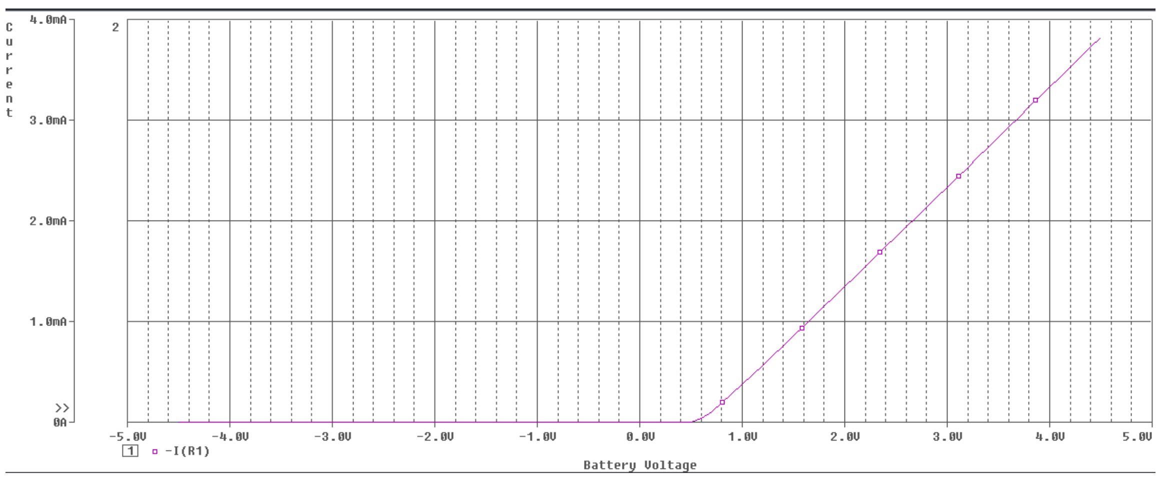


Figure 9-2: Current through MOSFET reverse voltage protection circuit as a function of input voltage

10 Appendix D: Requirement and Verification Table

Testing Procedures

10.1 Power Circuit

Requirement	Verification	Verification Status? (Y or N)
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.	Y
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.	Y
The power circuit provides a 3V DC voltage source a) Supply voltage is maintained at 3 V for output current in the range of 1-20 mA	a) 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	Y

	properly operating, the voltage should be 3.3 while the current varies from 1-20 mA.	

10.2 Wireless Communication

Requirement	Verification	Verification Status? (Y or N)
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	Y
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	Y

	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	Y
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	Y
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	Y

	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.	Y

10.3 Controller Module

Requirement	Verification	Verification Status? (Y or N)
MSP 430 & LCD Functionality	Only connect the LCD with the MSP 430, write characters and images to the screen. Use USB to power the	Y

	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.	Y
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.	Y

	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.	Y
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.	Y

10.4 Display Module

Requirement	Verification	Verification Status? (Y or N)
LED's light up a) LED's must light up when a 3 V control signal is sent. b) LED's should be operating at a 25 mA bias point, with a 5% tolerance.	a) First connect a power supply to the LED driving circuitry. The power supply should be connected from 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	Y

	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.	Y
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.	Y
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.	Y
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.	Y

10.5 System

Requirement	Verification	Verification Status? (Y or N)
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.	Y

	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.	Y
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.	Y
Waterproofing	Ensure that device housing is waterproof by submerging housing without circuits and checking for leaks.	Y

	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.	Y
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.	Y
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.	Y

	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.	

11 Appendix E: System Depiction

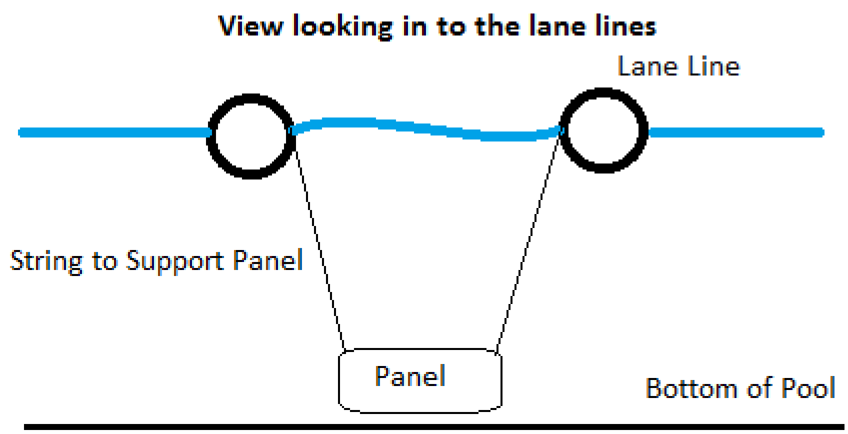


Figure 11-1: Underwater Depiction of Layout.

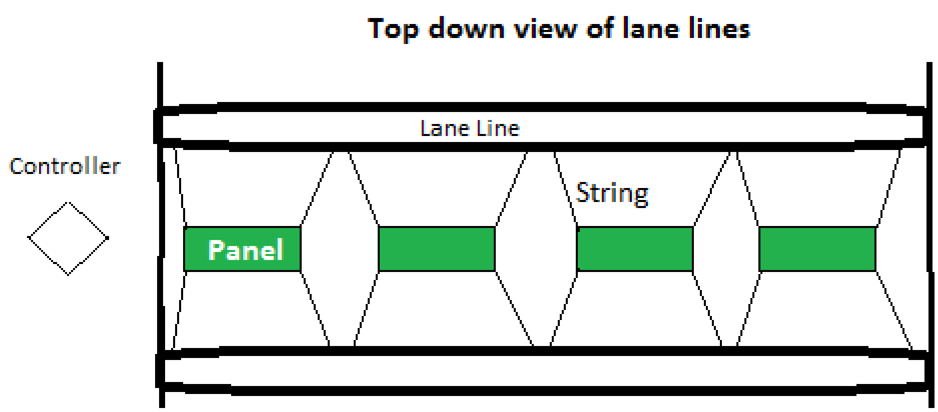


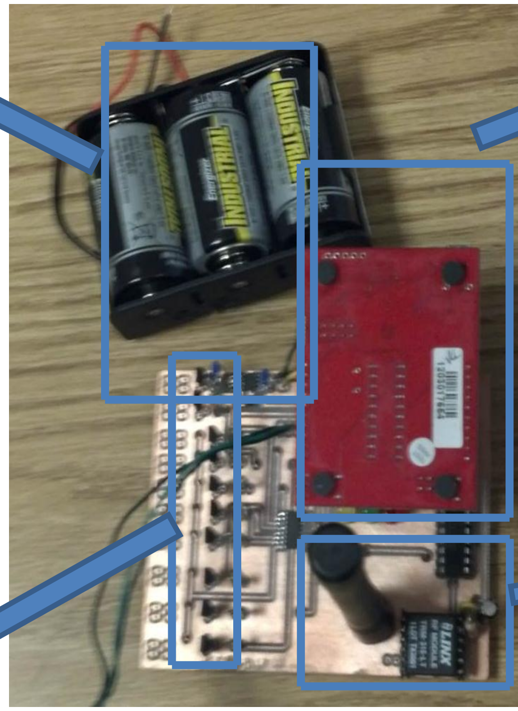
Figure 11-2: Top Down Depiction of Layout.

Power system

- Battery powered
- Reverse

Microcontroller

- Provides control signals for LED's
- Interfaces with communication



LED driver

- LED's biased at optimal operating point

Communication System

- Connects each display module to control unit

Figure 11-4: Display Module Circuit

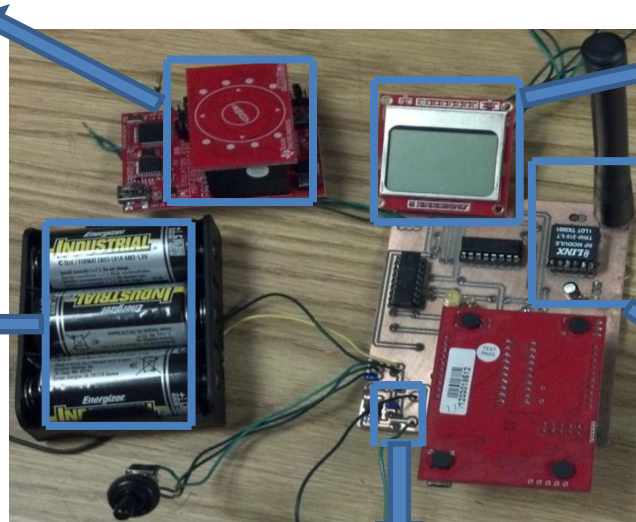
Touchpad

- Allows user to navigate system menu

LCD Screen

- Displays system menu
- Menu options:
  1. Synchronize
  2. Swim
  3. Backlight

Battery



Communication System

- Connects user interface to display system

Buzzer

Figure 11-3: Controller Module Circuit

12 Appendix F: System Flow Charts

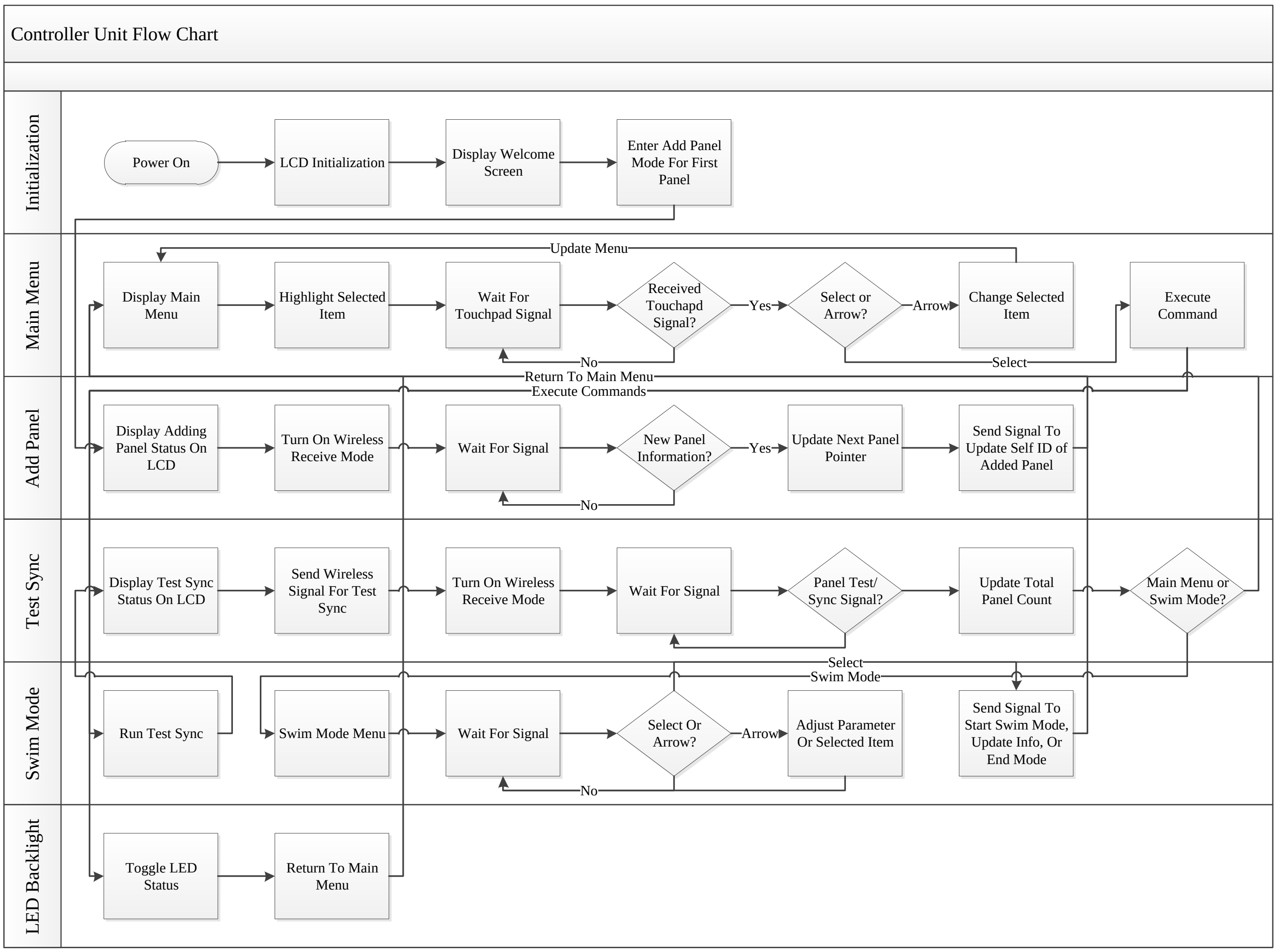


Figure 12-1: Controller Unit Software Flow Diagram.

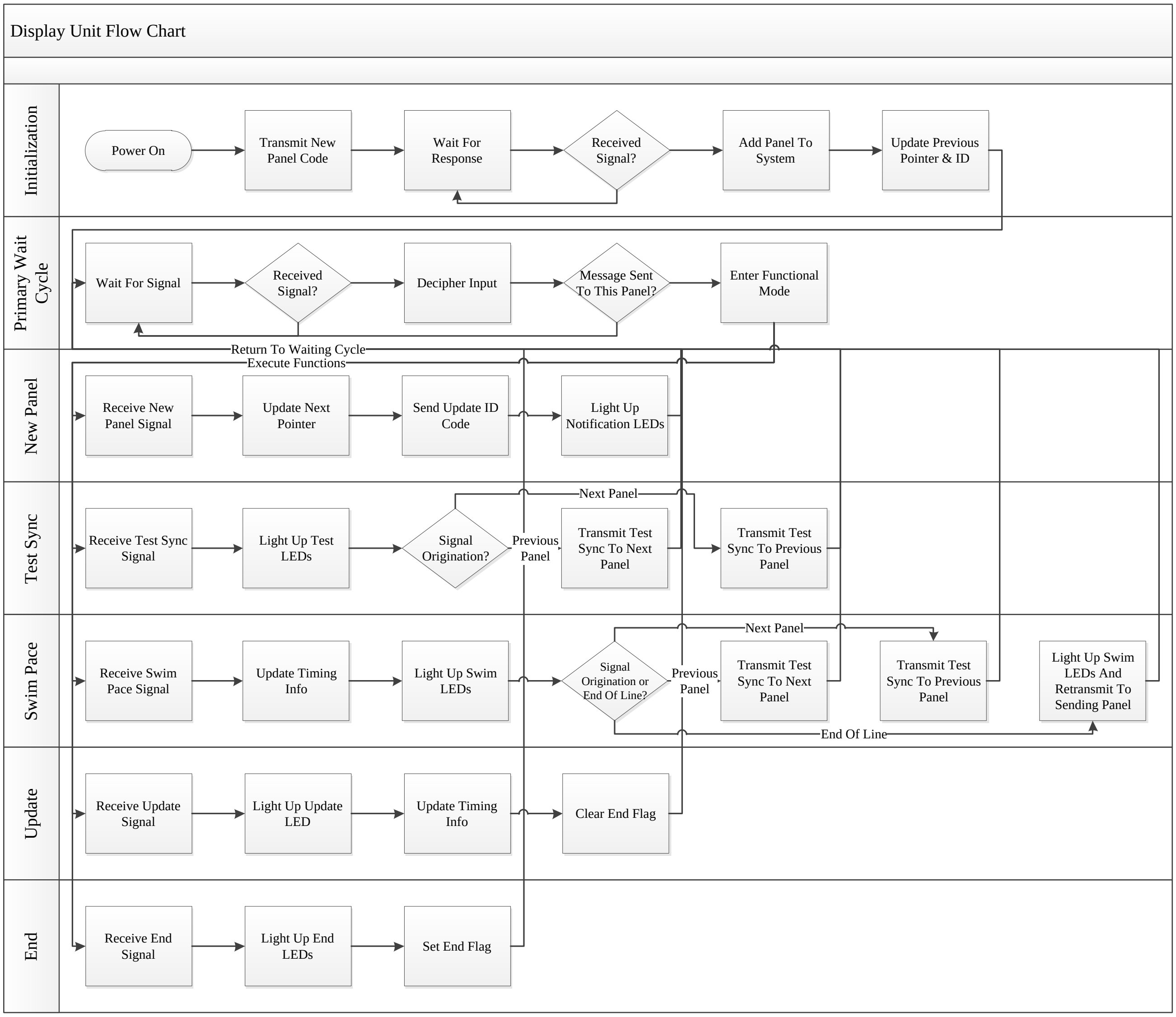


Figure 12-2: Display Unit Flow Chart.

13 Appendix G: Controller & Display Modules

Figure 13-1: Controller Unit.

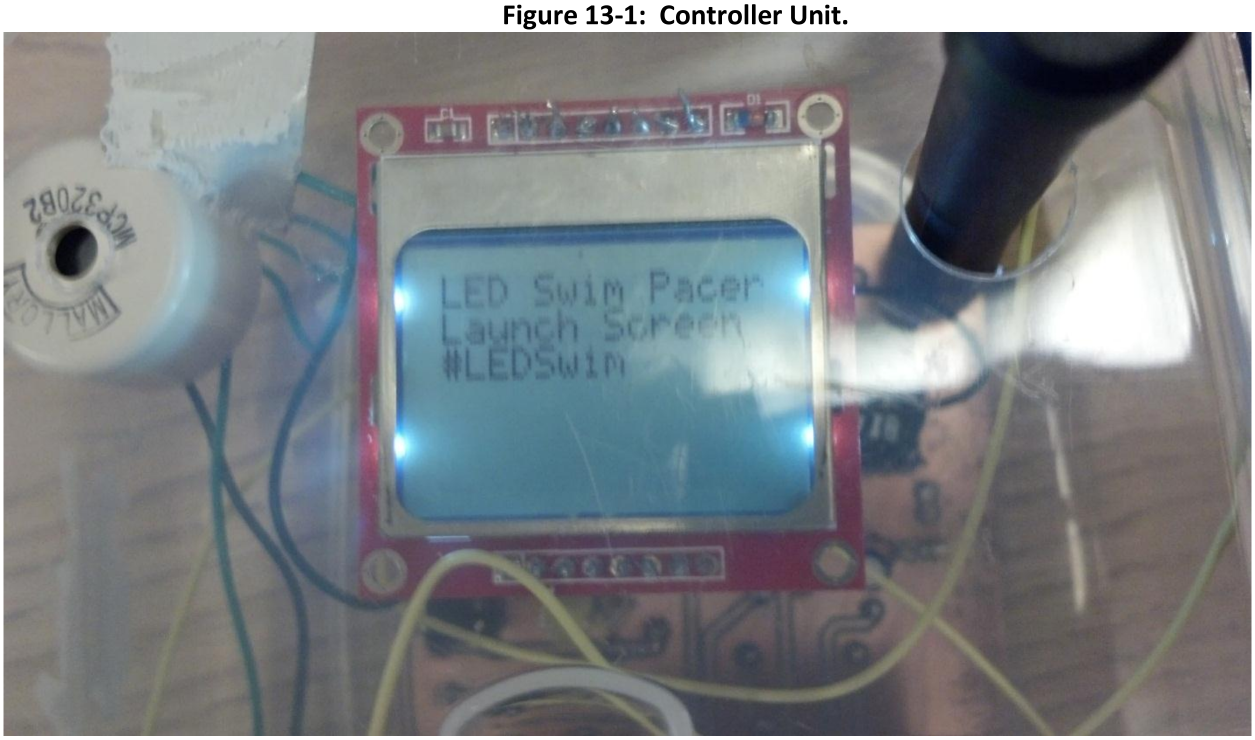


Figure 13-2: Welcome Screen.

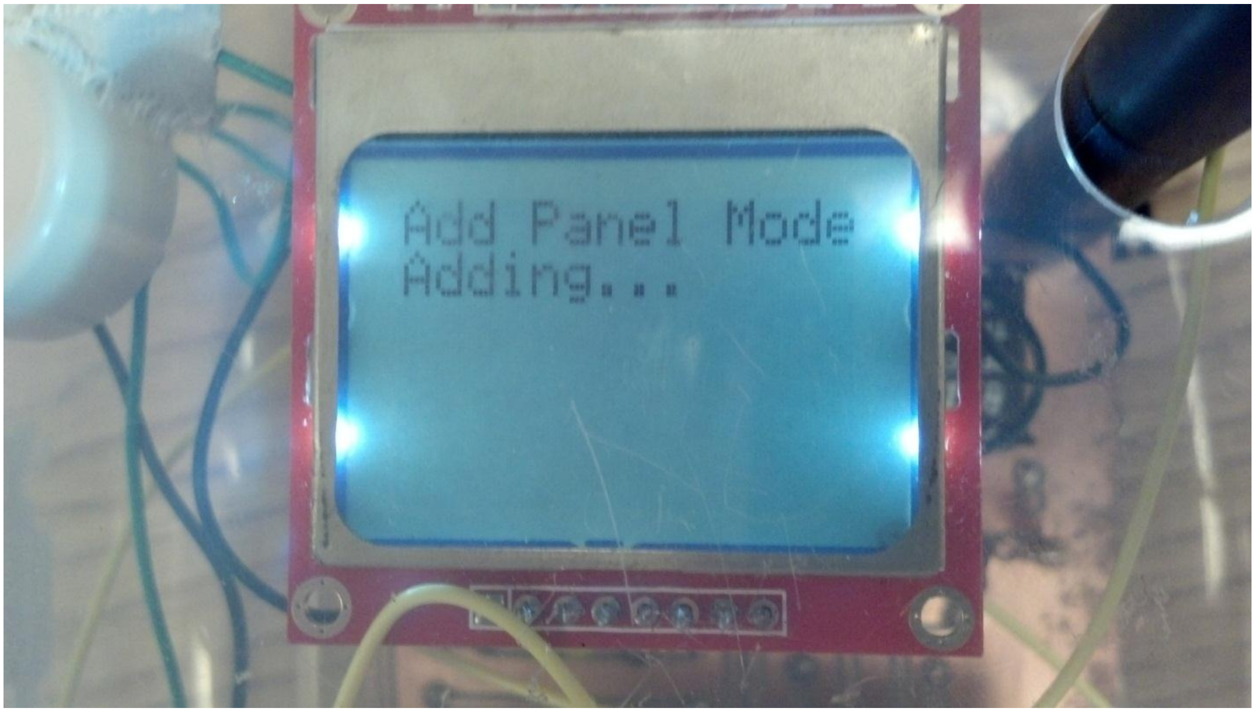


Figure 13-3: Add Panel Mode.

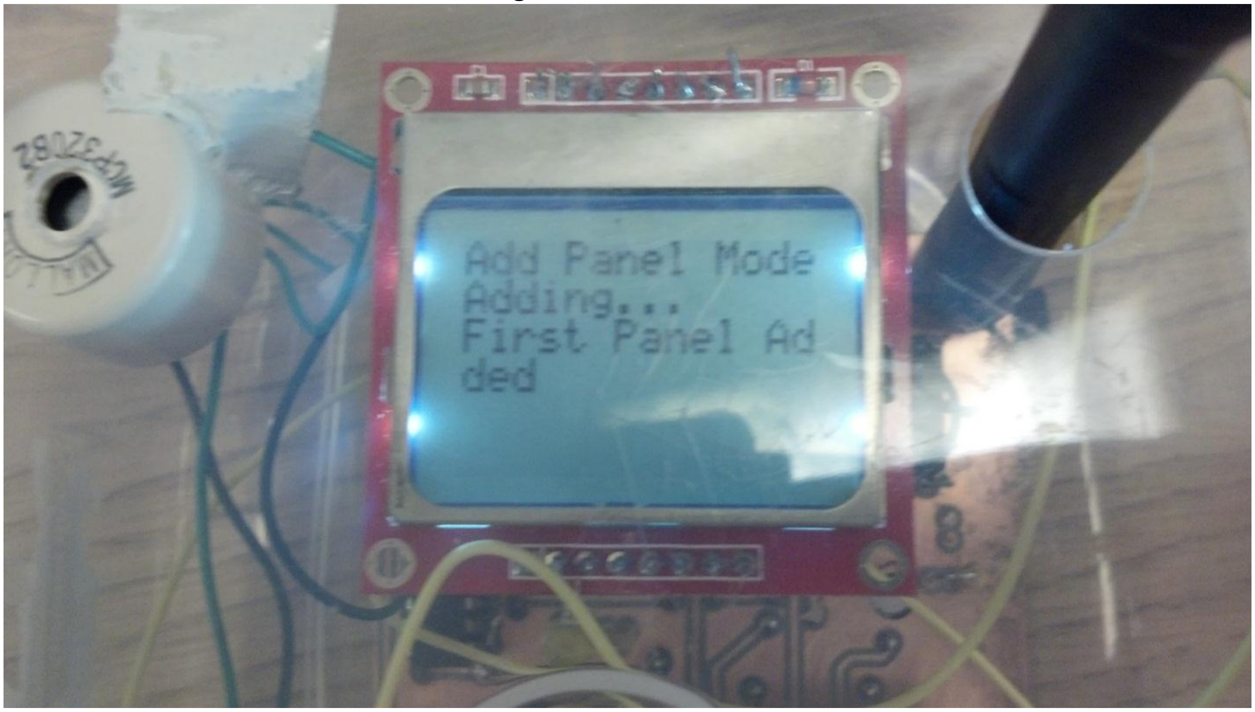


Figure 13-4: Panel Added Screen.

Figure 13-5: Main Menu

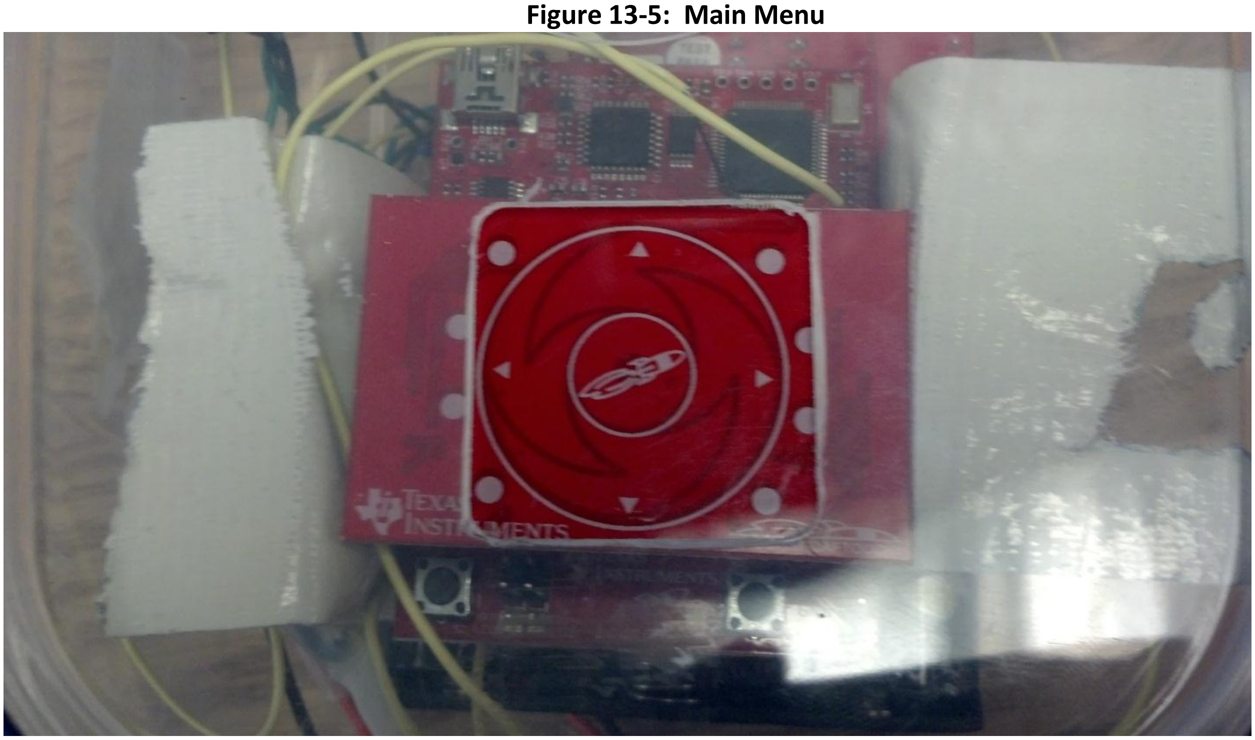


Figure 13-6: Touchpad.

Figure 13-7: LED Backlight.

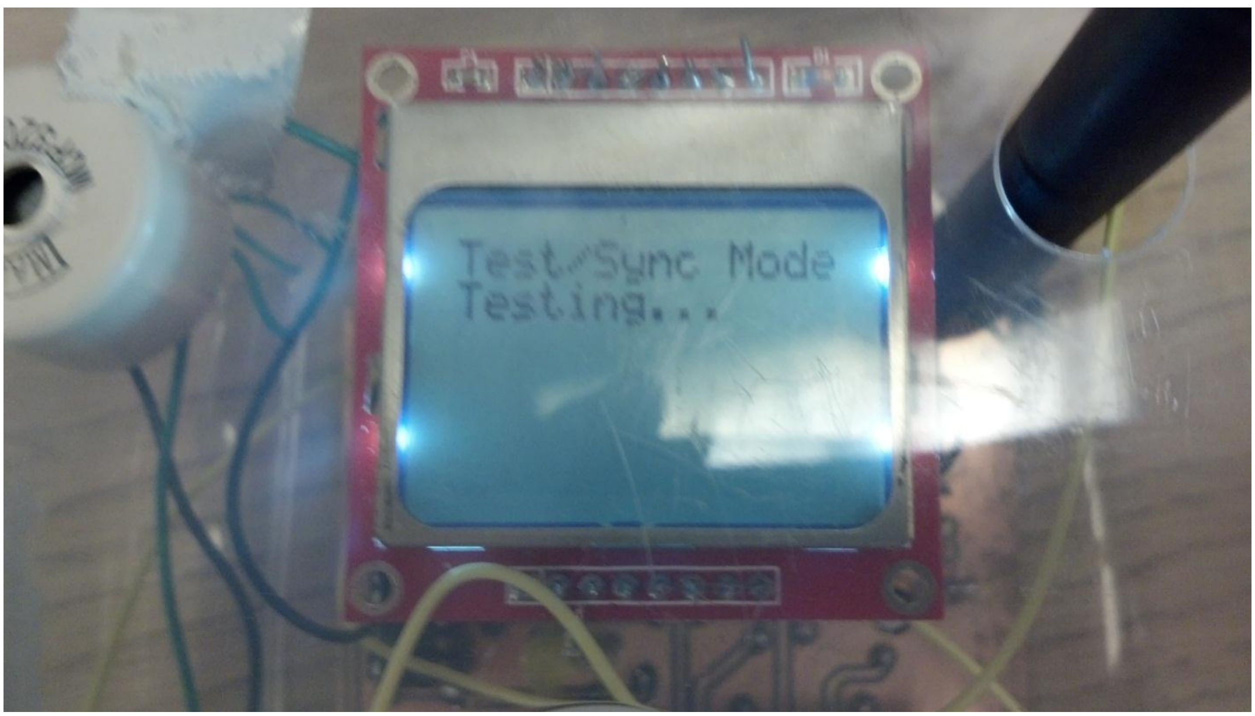


Figure 13-8: Test Sync Mode.

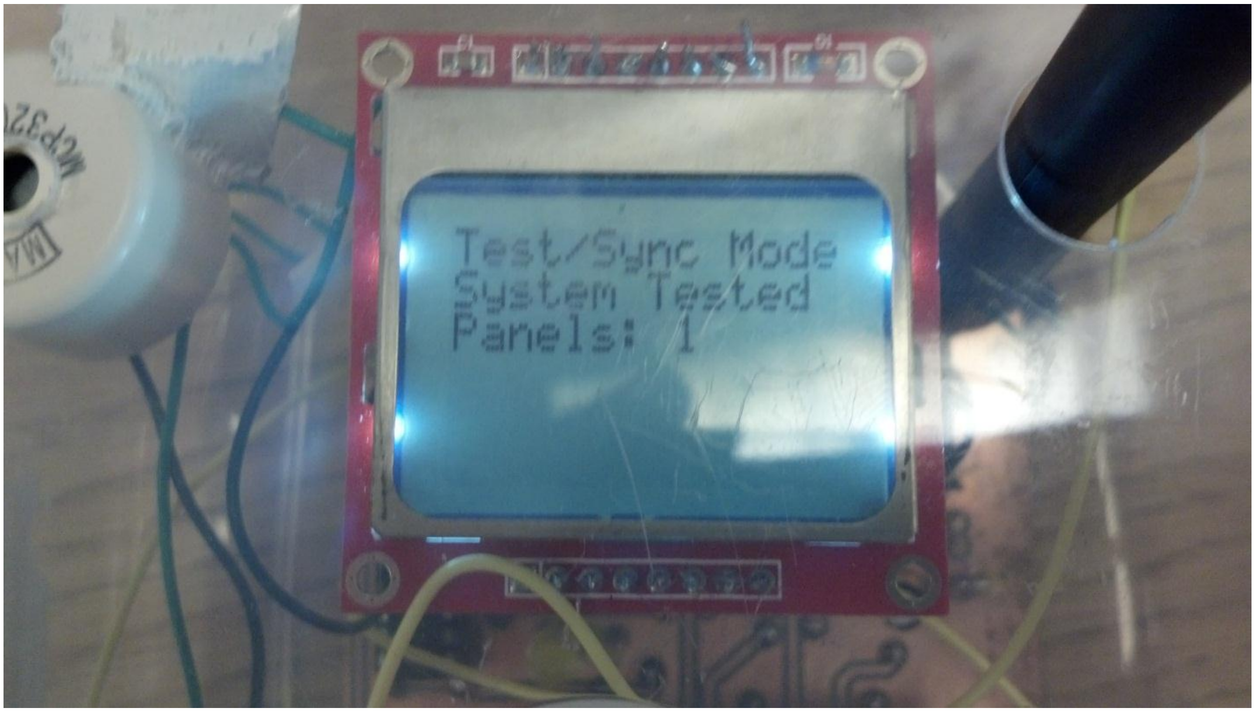


Figure 13-9: Test Sync Completed with Panel Count.

Figure 13-10: Swim Pace Screen.

Figure 13-11: One of the three Display Modules built.