LEaD Design:
Design Report

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Senior Capstone Design Project
UI CS - Wireless Tower of Lights
Sponsor - Dr. Robert Rinker

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Contents

1 Executive Summary

The University of Idaho has a Tower of Lights Show. The current "TowerLights" product involves LED-based light bars that are placed in front of front-facing widows of a large buildling (Theophilus Tower) and are then illuminated to play animations alongside/synchronously with music, the design is turning the project into a wireless system.
The goal is to enhance the current "TowerLights" product, To convert the system to a wireless operation. This requires the development of a wireless module that would be attached to each of the light bars. Thus this module has to sleep and wake up, as well as respond to wireless signals from a computer, these modules will need to be battery powered. Battery power must also be conserved by staying in the sleep state until needed. The purpose of this enhancement is to provide a certain level of portability. The features and solutions of the product are utilzing a 9V Li-Ion Battery with 600 mAh for power, also using the 802.15.4 (Zigbee) protocol with channels of 3 btyes. The product uses low power mode offered by the Atmega 328P microporcessor. Reviever modules on each lightbar (Zigbee) are featured as well. Finally, utilizing Zigbee protocol, to avoid Wifi interference. The product gives the user the ability to run a program that reads in .tan files and .wav files, have this program communicate with a XBee Wireless module on an Arduino that is attached to a computer via USB, then communicate wirelessly with the Arduino receivers. Each of these Arduino receivers are attached to an LED board, that will then communicate with each LED on that board through wired communication from the Arduino to the LEDs. The program that broadcasts the shows will be available for Linux based operating systems.
The merits of this system are in technical aspects the abiltiy to have a mobile light show system. This allows almost any building configuration to host a light show. Low-power mode allows easy setups for shows. In terms of business, the mobility allows other interested parties besides the University of Idaho to utilize this technology.
The test results conducted focus primarily on the bettery. Operation time is around two hours, and has been tested on mutliple accounts, on muitlple light bars. Other test reults include brightness of LEDs, and low-power mode, whose results came back to suggest use of 4 LEDs, and a low-power mode waking up every minute and a half.

2 Background

The University of Idaho has, for several years, done various projects involving the Tower of Lights Show and equipping the marching band with light-up glasses. The current "TowerLights" product involves LED-based light bars that are placed in front of front-facing widows of a large buildling (Theophilus Tower) and are then illuminated to play animations alongside/synchronously with music. The goal is to enhance the current "TowerLights" product. The current implementation of this product uses the ethernet wiring system in the building to control the LEDs. The goal of the project described is to convert this part of the system to a wireless operation. The motivation of this enhancement is to provide a certain level of portability, allowing more versatility in the system.
The oportunity associated witht this project is allowing other venues to use this system. The need comes from the desire of a simple to setup Light Show that doesn't provide difficulties to residents in the buildings. Some requests and interest in the system have developed recently, including using the system in downtown Coeur d'Alene. With another capstone team working on the gaphical interface of making the animations in the light show, the opportunity presented itself to make enhance this system.
The market for this type of product is fairly unknown, providing excellent business and educational oportuniites. Each light bar costs approximately thirty dollars, thus depeding on the size of the building, costs of the product will vary. This provides a very modular pricing point, favorable for many types of possible customers.

3 Problem Definition

3.1 Project Goal

The goal of the project is to the extend the versatility of the Tower Of Lights project, which at the moment, gives the user the ability to run a program which reads in a .tan file (animation files for the lights) and .wav files. Then this program communicates with a Arduino via Ethernet. Now, the Arduino communicates to each of the LEDs, and tells them which color and brightness to be, from the .tan file (thus it basically reads in animation info). The enhancement of the project involves providing cross-platform support, which means having to rework some of the TowerPlayer code so it doesn't use the Pulse library (which is Linux-specific). Also, the enhancement requires making the wired connection to the Arduinos on the LED bar to wireless, this is accomplished by having an Arduino Receiver on each LED Board that receives info sent out from the Arduino connected to the main computer running the program, that Arduino has a XBee Shield attached, which is a wireless module to transmit the info to each Arduino on a board. The Arduino now requires a portable power supply, which needs to be a 9V battery for each Arduino on an LED Board. The final enhancement is that since the LED Boards are running off battery, they require some kind of sleep mode, where they will still be able to receive info (so they can wake up).
The product will give the user the ability to run a program that reads in .tan files and .wav files, have this program communicate with a XBee Wireless module on an Arduino that is attached to a Computer via USB, then communicate wirelessly with each battery powered Arduino receiver, on each LED board, that will then communicate with each LED on that board through wired communication from the Arduino (same one that holds the receiver)to the LEDs. The program that runs through this procedure will be available for the OSX, Windows, and Linux based operating systems.

3.2 Deliverables

- **4 LightBar Prototypes** - 4 LEDs, LED Driver Circuit, 9V Battery, 1inX2in Board

- **Tower of Lights Code** - htx.c, towerarduino.ino, towerplayer.cpp, yswavfile.cpp, yswavile.h, uiGCx.ino, mrf24j.cpp, mrf24j.h

- **Documentation** - Design Report, Project Portfolio, Wikipage, Project Poster, Electronic Archive/File Management

3.3 Inventory Specifications and Contraints

The inventory specifications and contraints are shown in the figure below.

For Each LightBar

Component	Packag	Value	Unit Cos	Manuf	Manuf Part No	Distrib	Distrib Part No	Ref Nam	Qty
1N4148 Logic Diode	USER		$0.06	Parts Express	1N4148	Parts Express	1N4148	D2	1
2-pin to 9V Adapter	DIL	Battery	$1.19	Philmore	48-9000	intertex Electronics	PH-48-9000	J1	1
4-pin header	USER	LEDs		TE Connectivity	640456-4	Mouser Electronics	571-6404564	J3	1
6-pin header	USER	ISP	$0.60	Gravitech	6fx1L-254mm	Mouser Electronics	992-6FX1L-254MM	J5	1
atmega48-10p	DIL	ATMega	$1.87	Microchip	ATMEGA48V-10PU	Microchip Direct	ATMEGA48V-10PU	U3	1
BoardPadSmall	USER			Rx				J2	1
	USER			Tx				J4	1
CAP5mm (Cermaic Capacitor)	USER	1uf	$0.28	TDK	FA28C0G2A101JNU00	Mouser Electronics	810-FA28C0G2A10100	C3 C5	2
disccap	USER	.1uf	$0.30	KEMET	C320C104M5U5TA	Digi-Key	399-4266-ND	C1 C2 C4 C19	4
FET NChan - TN0604	USER	BLU	$0.98	Microchip	TN0604N3-G	Microchip Direct	TN0604N3-G	Q1	1
	USER	GRN						Q2	1
	USER	RED						Q3	1
LED-T1 (Through Hole Red Diffuse)	USER		$0.37	Broadcom Limited	HLMP-1301	Mouser Electronics	630-HLMP-1301	D1	1
LM78L05	USER	5v	$0.67	Texas Instruments	LM78L05ACZ/NOPB	Mouser Electronics	926-LM78L05ACZ/NOPB	U2	1
MCP1700 3.3V 250mA	DSC	3.3v	$0.45	Microchip	MCP1700-3302E/TO	Mouser Electronics	579-MCP1700-3302E/TO	U4	1
MRF24J40MA	DIL		$9.12	Microchip	MRF24J40MA-I/RM	Microchip Direct	MRF24J40MA-I/RM	U1	1
R0.25W (Carbon Film Resistor)	R035	390K	$0.05	Multicomp	MCF 0.25W 390K	Newark	38K0372	R1	1
R0.125W (Carbon Film Resistor)	R035	10K	$0.10	RadioShack	2710006	RadioShack	2710006	R3 R4 R5 R8	4
R1W (Metal Film Resistors)	USER	15 ohms	$0.70	Vishay	CPF115R000FKB14	Mouser Electronics	71-CPF1-15R0FT1	R2 R7	2
R1W (Metal Film Resistors)	USER	22 ohms	$0.36	Vishay	MBE04140C2209FC100	Mouser Electronics	594-MBE04140C2209FC1	R6	1
Rotary Dip (Coded Rotary Switch)	DIL	7.4mm	$2.17	CTS	220AMC04R	Mouser Electronics	774-220AMC04R	SW2	1
Switch - mini slide PCB	USER		$0.58	E-Switch	EG1201A	Mouser Electronics	612-EG1201A	SW1	1
XTAL/Resonator (Ceramic)	DSC	16MHz	$0.95	adafruit	1873	adafruit	1873	XTAL1	1
9V Li Ion Battery		600 mAh	$6.99	EBL	LN-8161	newegg	9SIABFB5250166		2
1 in. x 2 in. x 8 ft. Furring Strip Board			$1.05	Home Depo	100009348	Home Depo	100009348		1
Total			**$28.84**						**34**

Figure 1: Inventory Specifications and Contraints

4 Project Plan

4.1 Team Roles and Responsibilities

- **Budget Director:** Adrian Beehner
- **Client Liaison:** Kevin Dorscher
- **Designer:** Paul Martin
- **Documenter:** Andrew Butler

Roles Were Selected/Assigned By: Team consensus, with evaluating the strengths and weaknesses of teammates and accordingly assigning roles based on these. Discussion/volunteering for responsibilities will be the primary method, if this proves inefficient, a variation of team voting will be required. Some roles will not be individual responsibilities however, but instead a collaborative effort that requires the professional coordination and responsibility of the entire team.

Responsibilities: budget, primary contact client, organize team meetings, team documentation, scheduling, project management, onlien repository management, communication management, desigining, prototyping, testing, researching, diagrammming, analyzing, modeling, and manufacturing/assembly.

4.2 Schedule

The actual shchedule and the intended schedule differed greatly from one another. This is seen in the Gantt Chart figure shown in the Appendices. When examining the task of "Planning/Adjustments", it is clear that we did not reach our one month goal, as it led into October. While it was assummed this task would be simple, it provided a challenge to understand and coordiate the scope of the project. Hardware decisions became problematic, as it was only halfway finished by the end of October as seen in the Gannt chart, this wasn't entirely resolved until the beginning of december. The most problematic task that did not acoomplish its inteneded schedule is "Hardware Implementation", as for the month of Novemeber, only about 35 percent of it was accomplished. Partially due to the fact that other tasks were brought into the following months. The "Prototype and Unit Testing" task had the same issue. Evalutation didn't take much time, as the core design of the product was favorable, only lasting into the next month to finalize items. The "Produce Final Hardware" task went smoothly after the issues of prototyping and hardware implementation was accomplihsed, with the intented time being met. The "Hardware Scale and Software" task unexpectdly took more time, purely due the software being more elaborate and complex than orignally anticipated. "Testing" task for the product was fiarly simple, so intended and actual time had no differences. Finally the "Ship/Maufacture" task went smoothly, purely since the the client had fairly small needs/requirements for the process.

5 Concepts Considered

5.1 Battery Design

The list below discusses the attributes for the battery specification, including the requirements, battery chemistry, voltage/capacity, and options/alternatives. Figures "9V Battery Design Specification" and "18650 Lithium Ion Battery Design Specification" corresponding to this information are found in Appendix B.

Requirements

- Battery required to power the LightBar for TowerOfLights
- 3 LEDS on LightBar requires 800 mA
- Voltage must be within the range of 8.6 9.3 V (Charge)
- 10.5 V to run 3 LEDs in a series
- 7V for 2 LEDs in a series
- Microprocessor based wireless Module distributes the power supply to LEDs on each board

Chemistry

- **Lithium Ion:** rechargeable battery type, due to high energy density, tiny memory effect, and low self-discharged, lithium ions move from negative electrode during discharge, and back when charging
- **Alkaline:** Popular primary battery (non-rechargeable), dependent on reaction between zinc and manganese dioxide

Voltage/Capacity

- Each LED requires around 3.5 V and each color takes 270 mA
- A 9 V battery could support two LEDs in a series, 9V batteries support a wide range of mAh, generally from 400-700 mAh
- A 18650 Battery, which has 3.7 V, can be placed in a 18650 holder for 3 batteries, providing 11.1 V, enough to power 3 LEDs in a series (current LightBar setup), with 18650 supporting a range of 1600-3600 mAh

Options/Alternatives

- **18650 Battery:** large capacity (mAh), allowing LEDs to run longer and can be configured to run LEDs in a series, if making battery pack from these, but requires long charging
- **9V Battery:** Provides smaller capacity, but faster recharge rate. Can only run 2 LEDs for a single 9 V

Diagrams

5.2 Arduino / Receiver Design

Arduino / Receiver Design Specifications - Refer to figure in Appendix B - "Arduino / Receiver Design Specification"

Multiple Arduino Atmega 328P boards fitted with a shield and attached receiver chip

Programming of the individual Arduino Atmega 328P boards using the Arduino IDE (C++)

Receiver chip will delegate the sleep or wake-up modes for each individual light bar

Receiver will also handle input from the transmitting X-Bee, and output data to the LED driver circuit

Creation of the LED Driver circuit which will modify voltage as requested by each set of LEDs to provide a constant current power flow

After modifying voltage accordingly, the LED driver circuit will output the data stream from the receiver to the network that each Arduino Atmega 328P is connected to

5.3 LED Design

LED specifications and 2 potential solutions detailed below, these describe the requirements and proposed solutions/ideas.

Specifications

- 3 LEDs of each color (red, green, blue) per room
- Uses constant current (270-300 mA)
- Red LEDs drop 2.5V per diode
- Blue and green LEDs drop 3.5V per diode
- Colors are displayed with pulse-frequency modulation, as each diode can only be fully on or fully off at any moment

Circuit Options

- **Series** - Refer to figure in Appendix B - "Circuit diagram with LEDs in series"
- **Parallel** - Refe to figure in Appendix B - "Circuit diagram with LEDs in parallel"

5.4 Wireless Design

Frequency Requirements

- The wireless protocol needs to have an effective range of potentially up to 100 meters. Additionally, the frequency must be one that will work even in crowded venues, with lots of different cellphones, and Wi-Fi signals present.

Speed Requirements

- The wireless protocol needs to have the ability to send enough data fast enough to keep up with the Tower Lights show. Depending on the total number of light-bars, this number can change. The speed requirement will also depend on how many possible colors we implement and how many frames per second we will display.

Packet Requirements

- The information packets sent over the wireless protocol must contain all the information needed to set the individual light bars to the appropriate color. There can be only one packet that will be sent to all the light bars, and each light bar will be encoded with which part of the packet to read.

Potential Solution - Refer to Appendices for figure coressponding to "Zigbee Wireless Protocol" caption

5.5 LightBar Design

Wooden Structure The figure in the Appendices with the caption "Model of LightBar" coresponds tot he design of the Lightbar. The Lightbar is essentially a 1inX2in board the houses a battery, and the LEDs in either series/parallel, the LED Driver Circuit. This concept originates from the orignal TowerOfLights porject, which also utilized this design, mainly for its cost effectivness and easy mobility and structual integrity. Cheap, easy to obtain are the main draws of the item. The look of the LightBar itself however is not professional, to a large extent, although client never seeked a revisioned look on the LightBar.

3D Printered Structure Conceptually, that same figure mentiond above, althouh representing the wooden LightBar model, there was decision process as whether or not a 3D printed structure would be plausible, or at least to some extent holders for various components. This would allow cost effective designs, however its greatest hiderence is time and location, as the only readily avilable 3D Printer neeed for such as task was located at Unievrsity of Idaho's CDA CS location. The time of each lightbar print would also take upwards of 24 hours, based on this figure above. The 3D printer would provide a more professional look to the item.

6 Concept Selection

The method to decide which concepts to use in the product were done through the use of decision matrices. These matrices helped outlined the specific pros and cons of each design, while providing a thoughtful score. The following sections outline the selections chosen, via reference to the decision matrices.

6.1 9V Battery vs 18650 Battery

Conclusion

The final decision was to utlilze a 9V Battery. The decision matrix of this reasoning is shown in the figure below.

		ALTERNATIVES			
Decision Model		9V		18650	
Criterion	Weight	Rating	Score	Rating	Score
Ease of Implementation	5	4	20	3	15
Maintainability	5	3	15	4	20
Scalability	5	2	10	4	20
Voltage	3	4	12	2	6
mAh	4	2	8	4	16
Affordability	2	3	6	2	4
Obtainability	4	4	16	2	8
Extensibility	4	2	8	3	12
Sucessfulness	2	3	6	2	4
Durability	5	3	15	2	10
Quanitity	4	4	16	1	4
Total	43	34	132	29	119

How to rate an option?

Rating	Description
0	No fit
1	Low fit
2	Fit
3	Good fit
4	Excellent fit

Figure 2: 9V vs 18650 Battery

6.2 Series vs Parallel Circuit

The final decision was to utilize a parallel circuit. The decision matrix of this reasoning is shown in the figure below.

		ALTERNATIVES			
Decision Model		Series		Parallel	
Criterion	Weight	Rating	Score	Rating	Score
Ease of Implementation	5	2	10	4	20
Maintainability	5	3	15	3	15
Scalability	5	2	10	4	20
LEDs	3	3	9	4	12
Voltage	4	4	16	2	8
Affordability	2	4	8	2	4
Duration	4	2	8	3	12
Extensibility	4	3	12	3	12
Sucessfulness	2	3	6	4	8
Durability	5	2	10	4	20
Quanitity	4	3	12	2	8
Total	43	31	116	35	139

How to rate an option?

Rating	Description
0	No fit
1	Low fit
2	Fit
3	Good fit
4	Excellent fit

Figure 3: Series vs Parallel Circuit

6.3 WoodenLightBar vs 3D Print

The final decision was to utilize the wooden 1inx2in board for the LightBar. The decision matrix of this reasoning is shown in the figure below.

Decision Model		ALTERNATIVES			
		Wood Board		3D Print	
Criterion	Weight	Rating	Score	Rating	Score
Ease of Implementation	5	4	20	2	10
Maintainability	5	4	20	2	10
Scalability	5	4	20	1	5
Durability	3	4	12	1	3
Quality	4	3	12	2	8
Professional Look	2	1	2	4	8
Obtainability	4	4	16	1	4
Time	4	3	12	1	4
Sucessfulness	2	3	6	2	4
Accesability	5	3	15	1	5
Quanitity	4	4	16	2	8
Total	43	37	151	19	69

How to rate an option?

Rating	Description
0	No fit
1	Low fit
2	Fit
3	Good fit
4	Excellent fit

Figure 4: Wooden LightBar vs 3D Printed LightBar

6.4 Other Final Selections Process

The other choices, such as the 805.15.4 protocol, were galringly obvious choices or requested concepts from the sponder. These additional concepts neiher presented nor warrented further dicsussions/ diagrams/ decision matrices, or morphological charts on the matter.

7 System Architecture

7.1 Proof of Design

A discussion of the various components is shown below, providing evidence of components working together.

LightBar

- LightBar designed similar to original ”Tower of Lights” one
- 1 in x 2 in
- Size supports common sizes that are used for PCBs and LEDs

LED Driver Circuit

- Similar to ”Goofy Glasses” Circuit
- Schematic will be very similar, besides the fact that higher voltage and some other additional items will be added

Towerplayer Program

- Modified from various files from original ”Tower Player” programs:
  * towerarduino.ino
  * towerplayer.cpp
  * yswavfile.cpp
  * yswavfile.h

LED

- LEDs already function on ”Goofy Glasses”
- Similar design, with battery and circuit providing the power and data to correctly display specific color for LED
- Layout of LEDs will actually follow similar design as the original ”Tower of Lights” LightBar.

Battery

- 9V Lithium Ion Battery already working on Goofy Glasses
- Currently provides 30 minutes of run time
- Current Battery choices are between 9V Lithium Ion and 18650 (which would last longer)

A diagram that correlates to the information that is provided above discussing the proof of design id shown below. Images are provided in the diagram to help provide a visual for certain aspects.

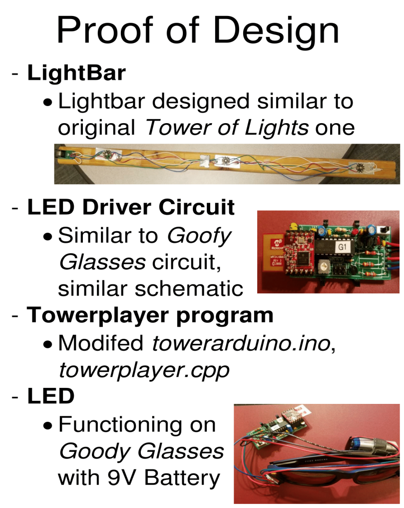


Figure 5: Proof of Design

7.2 Current Product

The current product flow in regards to the final product is shown below in Figure below. The current setup does not have any battery setup, and requires a wired connection. Changing this is the core of this project, which will improve the versatility of the TowerOfLights product.

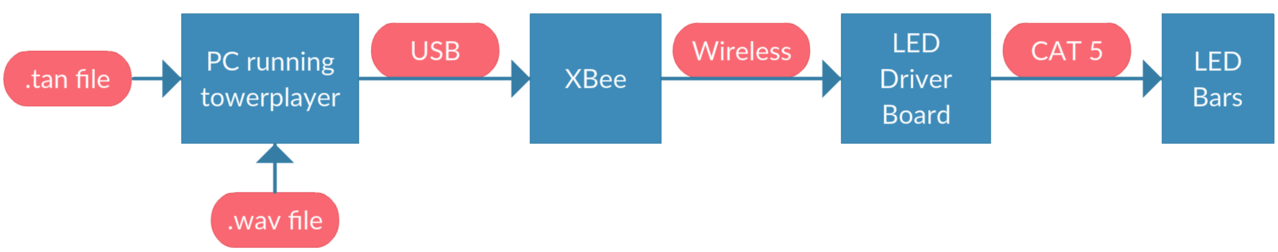


Figure 6: Current Product Flow

7.3 Desired Product

The desired product flow is shown in the figure below. The main focus is on the battery that should power each Arduino reciever, as well as the SPI protocol from XBee to the Receiver.

This is to make the process wireless instead of wired, which is the main goal of this endeavor, helping to justify the system architecture of the product.

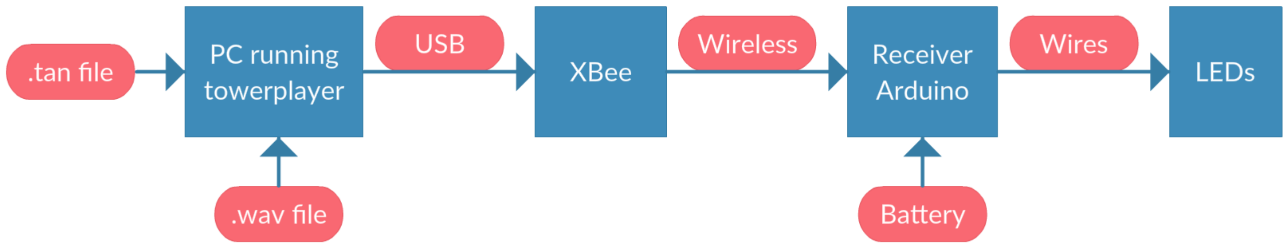


Figure 7: Desired Product Flow

7.4 PC Running TowerPlayer

The diagram for a flow chart depicting the sequence of actions for running the TowerPlayer program on a computer is shown in the figure below. This diagram helps with understanding the underlying software that needs to be setup and used before the hardware can successfully work together. It also demonstrates and justifies the system architecture of the project.

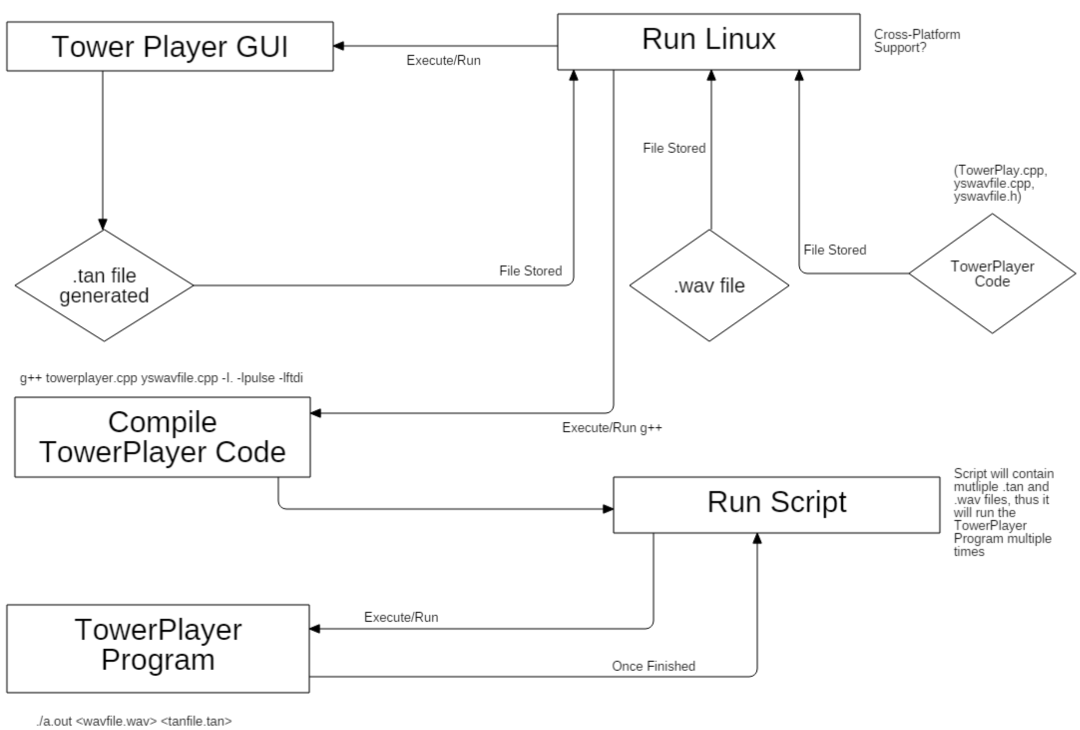


Figure 8: Flow Chart Diagram for PC Running TowerPlayer

8 Design Evaluation

Please refer to the Appendex "DFMEA Worksheet" for additional/corresponding information below.

8.1 DMFEA vs Project Specifications

Wireless LightBar System: The Wireless LightBar system's met the project specifications required by the client, with a risk priority of 1. The focus of the entire system was to make sure the user was able to utilize the system correctly. There were mainly only two way that the Light Bar could fail at this point, either the computer itself was not set up correctly, or the LightBar itself had failed to be assembled correctly. Every other issue with fail into the failures of the other major of components listed in the DMFEA. The dsign risks itself for the LightBar are mainly the components being fairly loose, but eve thought testing, the issue never arose. The best remedial action was thus to just make clear directions for user.

LightBar: The actual LightBar is the key of the product, and met the project's specifications, while being fairly low risk priority on the DFMEA. The reason was mainly due to very little requirement from the project specification, thus the LightBar could have precuations made to reduce risk. The only symptom of failure of the LightBar is that it fails to operate, thus no lights/effects come from the bar itself. There were two issues from this either computer error, or wireless protocol error, or user error. The team only ran into the user error one, by putting dead batteries into the lightbar. Thus the risk prioirty for this component was only 1. The remedial action was then to simply warn users of wireless protocol and computer errors.

TowerPlayerProgram: The TowerPlayerProgram is another key aspect to the product, the main specifications of the program were to meet the low-power mode settings and also split the 32 channels into 64. This was succeeded without making the failure/risk increase on the DFMEA. This is due the fact the only failure that can occur is that the program, which is loaded onto the LightBar cannot send data (thus the Lightbar shows nothing). The two reasons for this is computer user error (not running program correctly), or wireless protocol error, both which the team tested and never occured. Thus due to the low frequency of it happening, and its low severity, the risk prioity is 1, the lowest risk. The remedial action is to inform the user of requried libaries/software needed to use program.

TowerArduinoProgram: The TowerArduinoProgram is another key piece of software, function like the previous item. The same exact risks and issues that plague the TowerPlayer. There is on difference, mainly in that instead of the failure likely coming from comotuer user error, it comes from manufacturing error of incorreclt using Adruino IDE, and thus the program is not flashed onto the AtMega328P. However the issues both are similar, and software posses low risks, and thus risk priority is 1 again. The remedial action is to inform the user of requried libaries/software needed to use program.

LED Driver Circuit: The LED Driver circuit is one of the core aspects of the product, essentially communicating to LEDs to produce the lightshow. Thus this circuit has a much higher risk than the other components. The project specifications also constrained and hampered this issue further, as it was required that each LightBar have its own microcontroller, which means that every LightBar is at high risk for this component. The failure of the LED Driver Circuit can only amount from the crcuit becoming damaged/soldered incorrectly. Both of these failures have almost never occured in testing, however, these circuits, if damaged or not manufactured correctly can be harmful. The harmfulness of these circuits is why it gets a severity of risk at 4, the highest, as there is a very high likelyhood that if a circuit malfunction it could cause harm, or create a fire hazard. Thus the risk priority of the LED Driver circuit is a 4. The only remiedal action is a hazard and danger warning on product.

Other Components: All other components are purchased and manufactured elsewhere and are extremely simple, thus the only possible failure that can occur is component failure. These components almost all follow the project speficificaitons laid out, such as power on/off state, a microporcoessor, receiver chip, and so on. These requirements factored into a higher risk for the lightBar, as having more need created higher risks in many areas. Some component failures provide less risk than others. The main risk contenders are the logic dinodes, 4-pin headers, capacitors, transistors, resistors, and 9V lithium Ion battery. Since these products are past team's control, can at most add "warning" label to product, mentioning each piece's risk.

8.2 Testing Procedures

The testing procedures utilized in the project were fairly simple but provided stable data to understand the sucess of the components.

LED Driver Circuit: To test the circuit, a mutilmeter was to used to make sure the grounds are all 1 continuous circuit, and then test the power output to make sure the voltage level is correct with the schematic.
Another test was turning on the power switch and looking for the red Diode to turn on, signfiying correct power.
To test everything on circuit, the circuit was attatched to LightBar, LEDs, and flashed the towerarduino.ino program, and then send a demo code from ccomputer with receiver.

9V Battery: Battery was tested by simply running the LightBar wiht a dmeo continuously, and timing the operation time and recharge time. Over 20 tests had been conducted on a 9V 600 mAh Lithium Ion Battery that had been rechared.

TowerArduinoProgram: Program was tested by running out debugging information within the code itself, to see that correct information was being directly sent to receivers.

Transceivers and Receivers: Only plausbile test was to run LightBar with dummy demo program.

8.3 Testing Results

Testing results were postive, and little to no surprises occured, the results were shown on multiple lightbars, each manufactured by different individual, and each on either different (same model, but not exact same battery) or recharged batteries.

LED Driver Circuit: Circuit always functioned correctly, with no issues, besides user error. Test thorughly (around 20 times).

9V Battery: Battery's operational time was 2 hours, exceeding client's need of 45 minutes. Testing done thoroughly (20 times).

TowerArduinoProgram: Program achieved desired results were executed, tested thorughly (20 time), no issues.

Transceivers and Receivers: Both always operated correctly with no issues, tested throughly (20 times).

9 Future Work

9.1 Recommendations for Adoption/Implemtation

The sponsor only requested around 4 prototypes of the LightBar, for effective and practical use, a multiude of LightBars will be requried. Additionally, the previous capstone project working on the graphical interface that produces tan files should be bundled with this product if applicable, as it would provide the user with the full versaility of a light show. The sponsor should examine the idea of sotring program data for light show into the microporocessor itself, still via the receiver chip. This may produce less latency, however it is noted at the same time team did not occur any major latency issues that would present an issue to current design. For actual setup of the system, 2-3 days in advance would be recommened, the day of the show shouldn't need to worry, since the LightBars will stay in low power mode. It may be worth the sponsor's time to enhance the convience of this system by looking into solar power, or another enegery option, however the difficulty and time involved may be sluggish and problematic. It is recommended that the sponsor follows up with any additional questions for team, if said question did not have an answer in the documenation, via the contact info listed on the cover page.

9.2 Missing Features

Missing features that did not make their way into the current design are prevelant, yet understand in the scope of the product. The only core feature that did not make it in that was desiried was cross-platform support (requested by client). At the moment, the program still only operates with Linux Operating Systems, and Mac OSX and Windows OS are not supported. Team ran into library issues and time contraints and made the decision of what feature could be omitted without sacrificing the core premise of the product. Other features missing would not be classified as missing, so much as "desired", as all other core features made their way into the design.

9.2.1 Estimated Scope of Next Steps

The scope of the next steps is manufacuturing and assembly large scale, which depends on a variety of factors. The circuits themselves are not too complicated to produce and volunteers could easily help design a large magniutde and them and LightBars. The duration of this next steps primarily focueses on the labor willing to produce the LightBars, and the knowledge base. Essentially manufacturing and distrbuting this system to willing parties is the next step, with enought time, manpower, or both getting the system to willing consumers should be reasonable. Cost is difficult to estimate, for example, Theophilus Tower Dormitory having 40 windows on one side, 40 LightBars time 30 dollars for each would estimate 1,200 dollars just for parts. Likely costs would range 1,000 3,000 dollars for a building. Labor costs (volunteer, professional, amateur) for producing LightBars is unknown however.

A Calculations and Drawings

A.1 Drawing of Original Schedule

Drawings produce during Team Meeting of orignal schedule

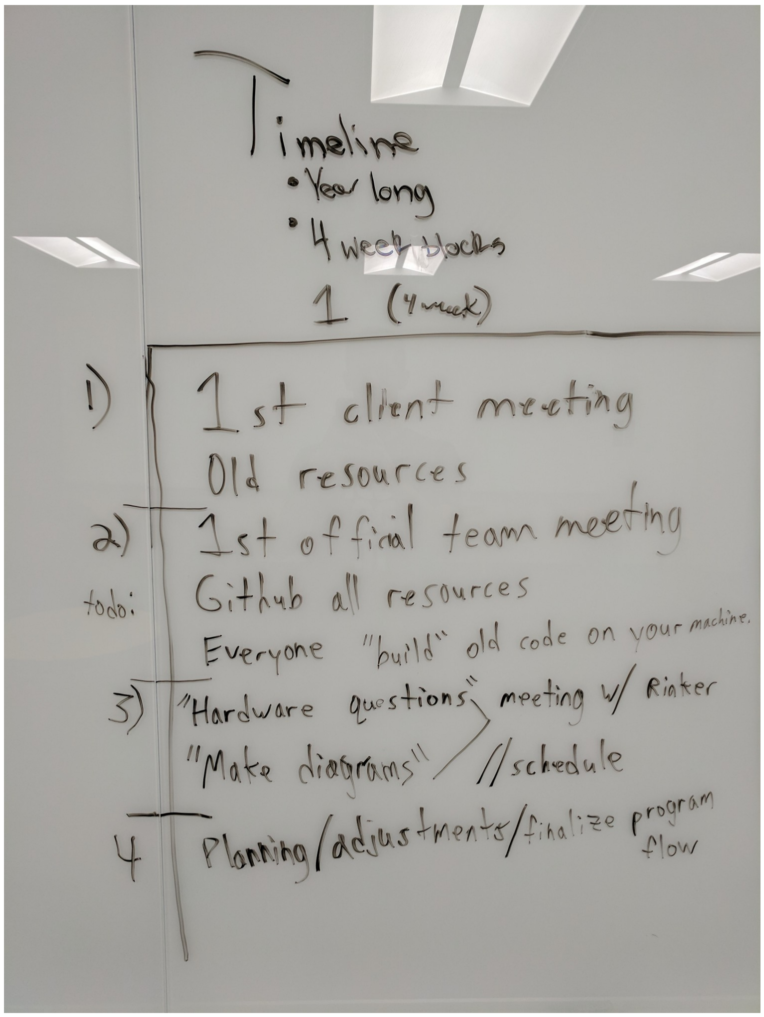


Figure 9: 9/14 Meeting Project Schedule

A.2 LightBar 3D Model

3D CAD Model of LightBar

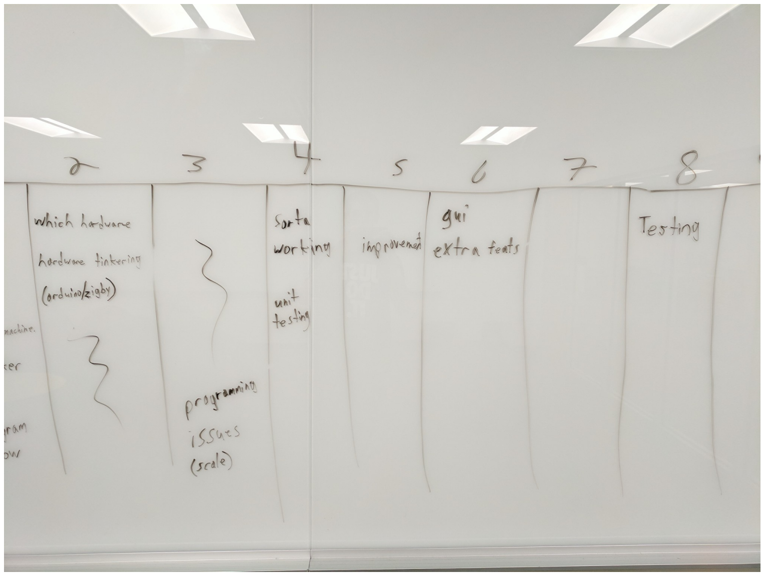


Figure 10: 9/14 Meeting Project Schedule

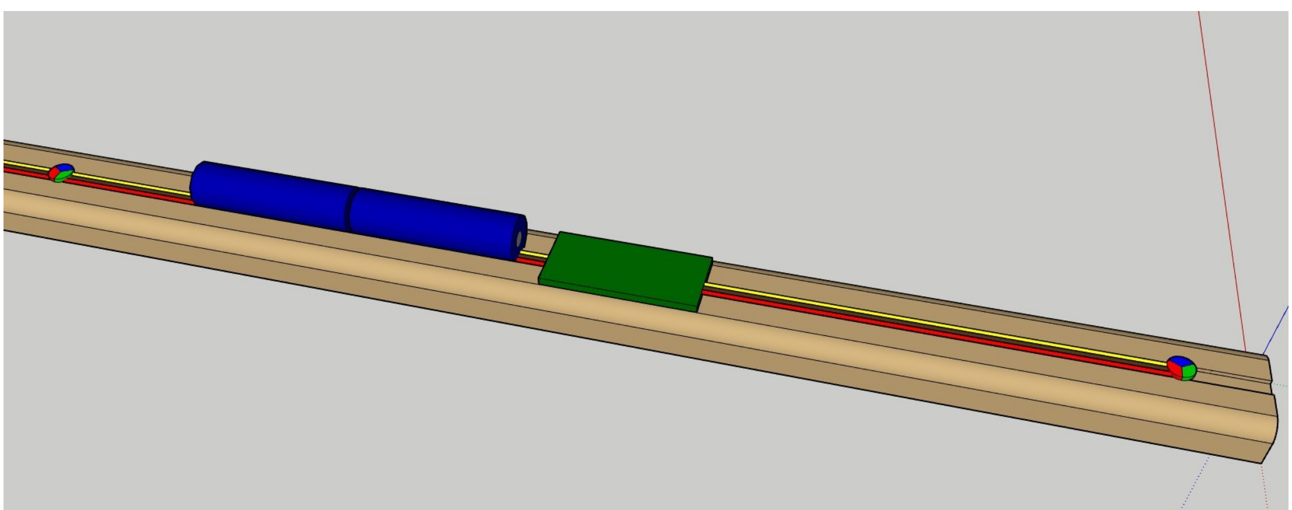


Figure 11: 3D Model of Final Product

B Tables and Figures

B.1 Arduino / Receiver Design Specification

The general diagram of the Arduino and reciever working together

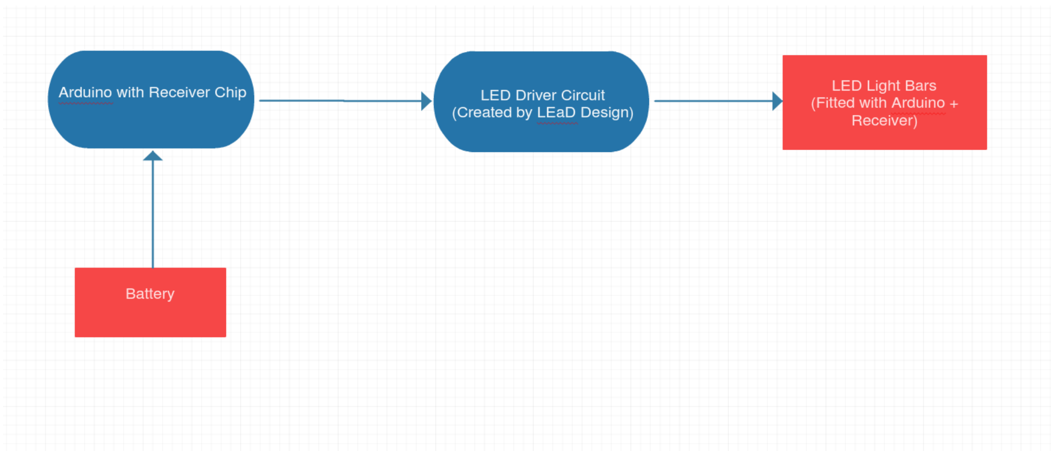
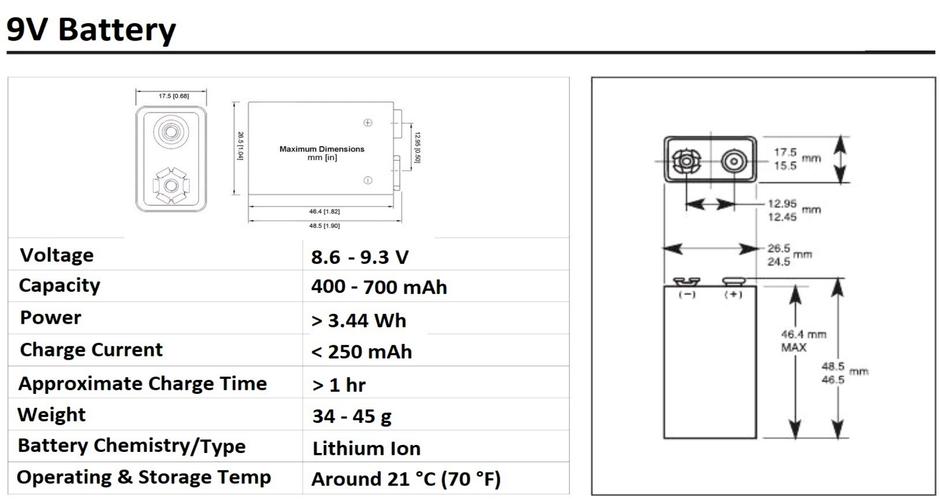


Figure 12: Arduino / Receiver Design Specification

B.2 Battery Design Specification

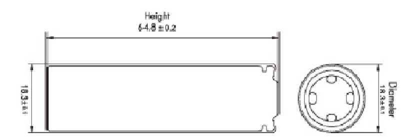
The diagrams containing the 9V Battery and 18650 Battery specifications.



Voltage	8.6 - 9.3 V
Capacity	400 - 700 mAh
Power	> 3.44 Wh
Charge Current	< 250 mAh
Approximate Charge Time	> 1 hr
Weight	34 - 45 g
Battery Chemistry/Type	Lithium Ion
Operating & Storage Temp	Around 21 °C (70 °F)

Figure 13: 9V Battery Design Specification

18650 Battery



Voltage	3.7 V
Capacity	1600 - 3600 mAh
Power	> 5.92 Wh
Charge Current	< 500 mAh
Approximate Charge Time	> 4 hr
Weight	45 - 48.5 g
Battery Chemistry/Type	Lithium Ion
Operating & Storage Temp	Around 21 °C (70 °F)

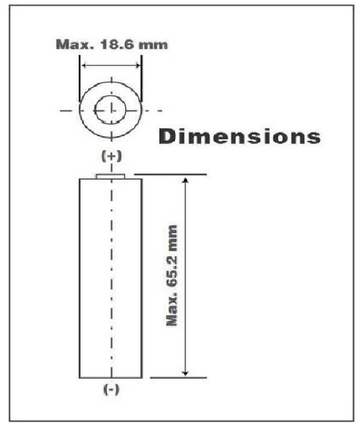


Figure 14: 18650 Lithium Ion Battery Design Specification

B.3 LED Design Specification

LED specifications and 2 potential solutions detailed below.

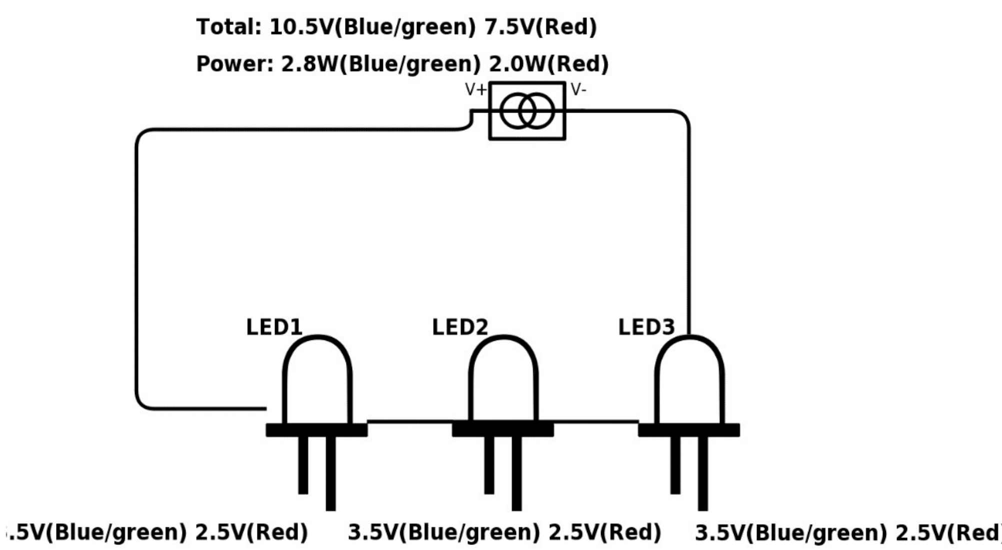


Figure 15: Circuit diagram with LEDs in series

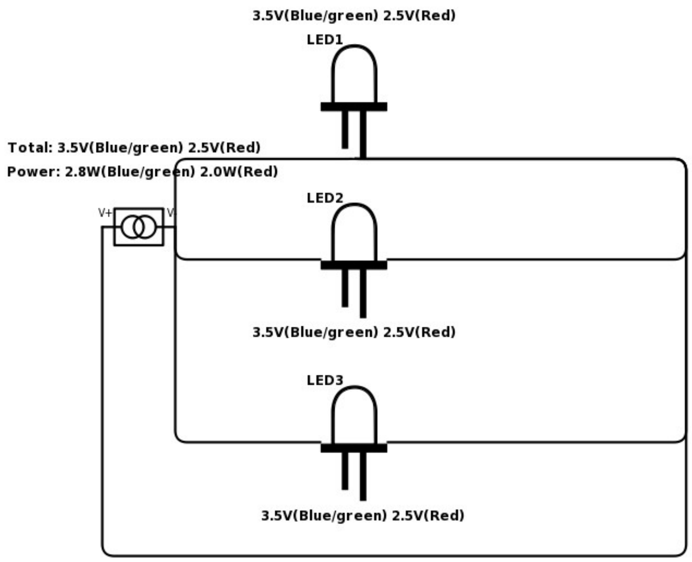


Figure 16: Circuit diagram with LEDs in parallel

B.4 LED Specification Adjustments

The General Specifications have been adjusted to more accurately reflect the design choices and concept.

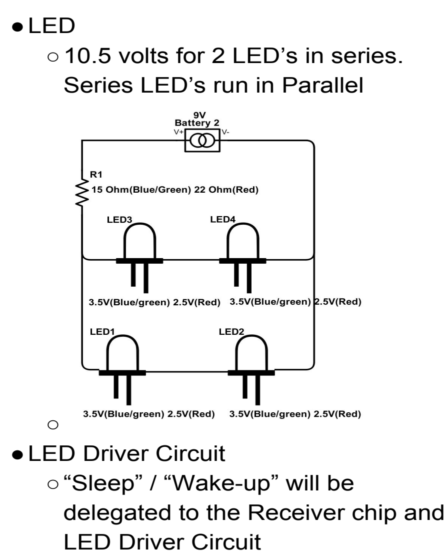


Figure 17: General Specification Adjustments

B.5 Wireless Design Specification

Specification of the wireless protocols at place, including the used 802.15.4 protocol

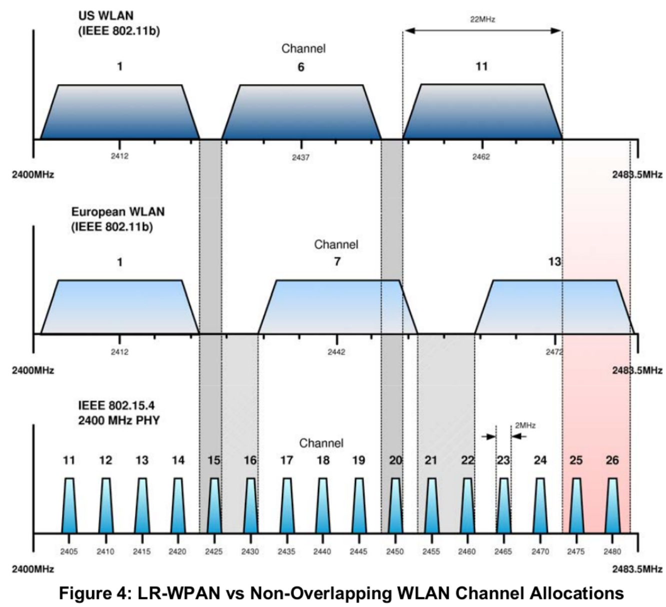


Figure 18: **Zigbee Wireless Protocol** Uses Channels Above Wi-Fi

B.6 Gantt Chart

The Gantt Chart representing our intended and actual shedule is shown in the figure below

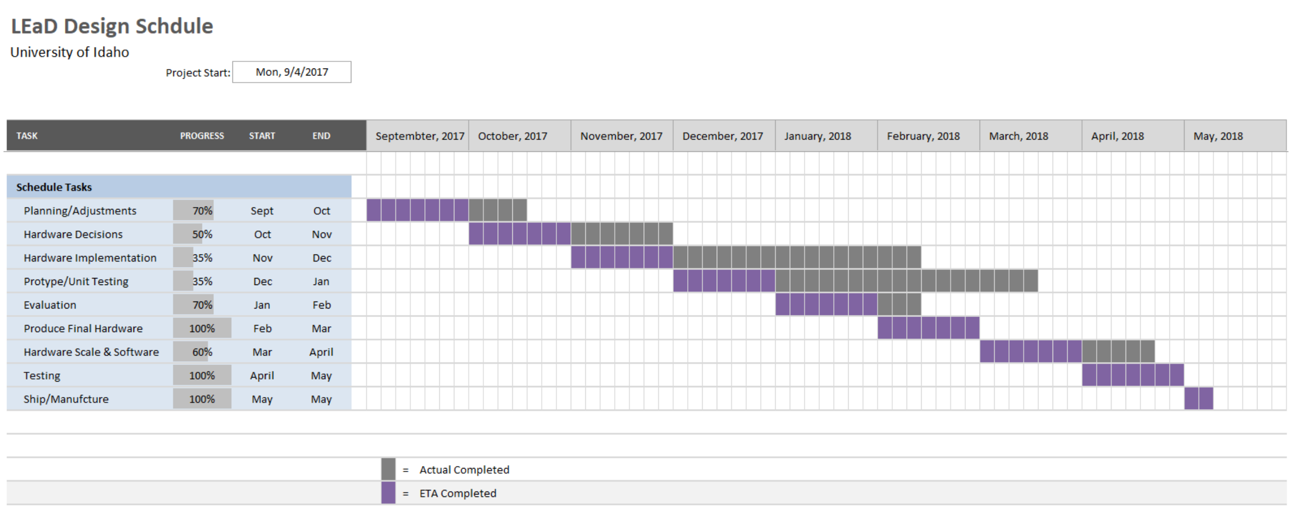


Figure 19: Hardware List

B.7 Bill of Materials

The bill of materials (BOM) is shown below.

For Each LightBar

Component	Package	Value	Unit Cost	Manuf
1N4148 Logic Diode	USER		$0.06	Parts Express
2-pin to 9V Adapter	DIL	Battery	$1.19	Philmore
4-pin header	USER	LEDs		TE Connectivity
6-pin header	USER	ISP	$0.60	Gravitech
atmega48-10p	DIL	ATMega	$1.87	Microchip
BoardPadSmall	USER			Rx
	USER			Tx
CAP5mm (Cermaic Capacitor)	USER	1uf	$0.28	TDK
disccap	USER	.1uf	$0.30	KEMET
FET NChan - TN0604	USER	BLU	$0.98	Microchip
	USER	GRN		
	USER	RED		
LED-T1 (Through Hole Red Diffuse)	USER		$0.37	Broadcom Limited
LM78L05	USER	5v	$0.67	Texas Instruments
MCP1700 3.3V 250mA	DSC	3.3v	$0.45	Microchip
MRF24J40MA	DIL		$9.12	Microchip
R0.25W (Carbon Film Resistor)	R035	390K	$0.05	Multicomp
R0.125W (Carbon Film Resistor)	R035	10K	$0.10	RadioShack
R1W (Metal Film Resistors)	USER	15 ohms	$0.70	Vishay
R1W (Metal Film Resistors)	USER	22 ohms	$0.36	Vishay
Rotary Dip (Coded Rotary Switch)	DIL	7.4mm	$2.17	CTS
Switch - mini slide PCB	USER		$0.58	E-Switch
XTAL/Resonator (Ceramic)	DSC	16MHz	$0.95	adafruit
9V Li Ion Battery		600 mAh	$6.99	EBL
1 in. x 2 in. x 8 ft. Furring Strip Board			$1.05	Home Depo
Total			**$28.84**	

For Xbee Shield Communicating With All LightBars

Component	Package	Value	Unit Cost	Manuf
Atmega 328P Chip			$0.00	Microchip
Xbee Shield		2.4Ghz	$0.00	SparkFun
Xbee Transmitter Chip		250k bps	$0.00	Digi International
Total			**$0.00**	

Figure 20: Bill of Matierals

For Each LightBar

Manuf Part No	Distrib	Distrib Part No	Ref Name	Qty
1N4148	Parts Express	1N4148	D2	1
48-9000	intertex Electronics	PH-48-9000	J1	1
640456-4	Mouser Electronics	571-6404564	J3	1
6fx1L-254mm	Mouser Electronics	992-6FX1L-254MM	J5	1
ATMEGA48V-10PU	Microchip Direct	ATMEGA48V-10PU	U3	1
			J2	1
			J4	1
FA28C0G2A101JNU00	Mouser Electronics	810-FA28C0G2A10100	C3 C5	2
C320C104M5U5TA	Digi-Key	399-4266-ND	C1 C2 C4 C19	4
TN0604N3-G	Microchip Direct	TN0604N3-G	Q1	1
			Q2	1
			Q3	1
HLMP-1301	Mouser Electronics	630-HLMP-1301	D1	1
LM78L05ACZ/NOPB	Mouser Electronics	926-LM78L05ACZ/NOPB	U2	1
MCP1700-3302E/TO	Mouser Electronics	579-MCP1700-3302E/TO	U4	1
MRF24J40MA-I/RM	Microchip Direct	MRF24J40MA-I/RM	U1	1
MCF 0.25W 390K	Newark	38K0372	R1	1
2710006	RadioShack	2710006	R3 R4 R5 R8	4
CPF115R000FKB14	Mouser Electronics	71-CPF1-15R0FT1	R2 R7	2
MBE04140C2209FC100	Mouser Electronics	594-MBE04140C2209FC1	R6	1
220AMC04R	Mouser Electronics	774-220AMC04R	SW2	1
EG1201A	Mouser Electronics	612-EG1201A	SW1	1
1873	adafruit	1873	XTAL1	1
LN-8161	newegg	9SIABFB5250166		2
100009348	Home Depo	100009348		1
				34

For Xbee Shield Communicating With All LightBars

Manuf Part No	Distrib	Distrib Part No	Ref Name	Qty
ATMEGA328P-AU	Microchip Direct	ATMEGA328P-AU		1
WRL-12847	Mouser Electronics	474-WRL-12847		1
XB24-API-001	Mouser Electronics	888-XB24-API-001		1
				2

Figure 21: Bill of Matierals

B.8 Prototype Progress

We have completed our first Wireless Lightbar prototype, utilizing 4 LEDs. The prototype can be viewed below:

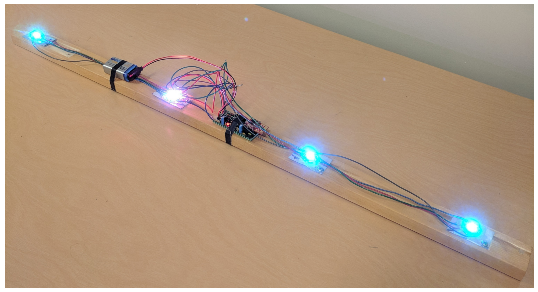


Figure 22: Prototype One

B.9 Hardware List/Cost of Materials

The figure below is the current Hardware list.

Hardware List

Hardware	Quantity	Cost of Unit	Description
Atmega 328P Chip	1	\$2.00 ~ \$6.00	Low-powered CMOS 8-bit microcontroller based on the AVR® enhanced RISC architecture.
MRF Receiver Chip	1 (For Every LED Driver Circuit)	~\$9.00 (1-25 Units Ordered) ~\$7.00 (26-99) ~\$6.00 (100+)	Certified 2.4 GHz IEEE 802.15.4 radio transceiver module. It has an integrated PCB antenna, matching circuitry, and supports the ZigBee, MiW and MiWi P2P protocols. The MRF module connects to hundreds of PIC microcontrollers via a 4-wire SPI interface
XBee Shield	1	\$0.00 (Provided by Dr. Rinker)	The Xbee shield translates data between your computer and the XBee. There's also a reset button, and a voltage regulator to supply the XBee with plenty of power. Works with XBee modules.
XBee Transmitter Chip	1	\$0.00 (Provided by Dr. Rinker)	2.4GHz XBee module, takes the 802.15.4 stack (the basis for Zigbee) and wrap it into a simple to use serial command set. These modules allow very reliable and simple communication between microcontrollers, computers, systems, and so on.
9V Lithium Ion Battery	1 (For every LightBar Board)	\$7.00 ~ \$12.00	9V Battery has a rectangular prism shape with rounded edges and a polarized snap connector at the top
18650 Lithium Ion Battery	3 (for every LightBar Board)	\$2.00 ~ \$5.00	The 18650 (18mm by 65mm) battery is a size classification of lithium-ion batteries, complete voltage range for most 18650s is between 2.5 volts and 4.2 volts.
Common Anode RGB LED	3 (For every LightBar Board)	~\$2.00	Units generally have four pins: one for each color (dinode) and a common anode. Use this one LED for three status indicators or pulse width modulate all three and get mixed colors
Arduino Wires	?	~\$2.00	TBA
LightBar Board	?	\$1.00 ~ \$10.00 (Quality of board)	The Board that will hold the components of the Light Bar. 1 in x 2in. size.
LED Driver Circuit (From Circuit Board Sheet)	1 (For every LightBar Board)	? (the Company 4PCB charges \$33.00 to make 60 in ² board that can hold as many circuits as the size allows, thus cost of unit depends on size of circuits, which is TBD)	Circuit that will modify the voltage as needed by each set of LEDs to provide constant current power flow and also output the data stream from the receiver to the network that each of the Arduinos are connected

Figure 23: Hardware List

C Computer Programs

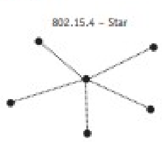
NA-Too Long!

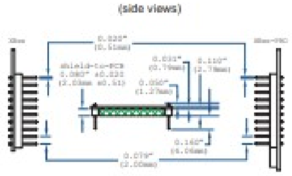
D Vendor Data Sheets

D.1 Xbee Transmitter Data Sheet

Platform	XBee® 802.15.4 (Series 1)	XBee-PRO® 802.15.4 (Series 1)	XBee-PRO® XSC
Performance			
RF Data Rate	250 kbps	250 kbps	10 kbps / 9.6 kbps
Indor/Urban Range	100 ft (30 m)	300 ft (100 m)	Up to 1200 ft (370 m)
Outdoor/RF Line-of-Sight Range	300 ft (100 m)	1 mi (1.6 km)	Up to 6 mi (9.6 km)
Transmit Power	1 mW (+0 dBm)	60 mW (+18 dBm)*	100 mW (+20 dBm)
Receiver Sensitivity (1% PER)	-92 dBm	-100 dBm	-106 dBm
Features			
Serial Data Interface	3.3V CMOS UART	3.3V CMOS UART	3.3V CMOS UART (5V Tolerant)
Configuration Method	API or AT Commands, local or over-the-air	API or AT Commands, local or over-the-air	AT Commands
Frequency Band	2.4 GHz	2.4 GHz	902 MHz to 928 MHz
Interference Immunity	DSSS (Direct Sequence Spread Spectrum)	DSSS (Direct Sequence Spread Spectrum)	FHSS (Frequency Hopping Spread Spectrum)
Serial Data Rate	1200 bps - 250 kbps	1200 bps - 250 kbps	1200 bps - 57.6 kbps
ADC Inputs	(6) 10-bit ADC inputs	(6) 10-bit ADC inputs	None
Digital I/O	8	8	None
Antenna Options	Chip, Wire Whip, U.FL, & RPSMA	Chip, Wire Whip, U.FL, & RPSMA	Wire Whip, U.FL, RPSMA
Networking & Security			
Encryption	128-bit AES	128-bit AES	No
Reliable Packet Delivery	Retries/Acknowledgments	Retries/Acknowledgments	Retries/Acknowledgements
IDs and Channels	PAN ID, 64-bit IEEE MAC, 16 Channels	PAN ID, 64-bit IEEE MAC, 12 Channels	PAN ID, 32-bit Address, 7 Channels
Power Requirements			
Supply Voltage	2.8 - 3.4VDC	2.8 - 3.4VDC	3.0 - 3.6VDC
Transmit Current	45 mA @ 3.3VDC	215 mA @ 3.3VDC	265 mA typical
Receive Current	50 mA @ 3.3VDC	55 mA @ 3.3VDC	65 mA typical
Power-Down Current	<10 uA @ 25° C	<10 uA @ 25° C	45 uA pin Sleep
Regulatory Approvals			
FCC (USA)	OUR-XBEE	OUR-XBEEPRO	MCQ-XBEEXSC
IC (Canada)	4214A-XBEE	4214A-XBEEPRO	1846A-XBEEXSC
ETSI (Europe)	Yes	Yes* Max TX 10 mW	No
C-TICK Australia	Yes	Yes	No
Telec (Japan)	Yes	Yes*	No

* XBee-PRO 802.15.4 TX Power restricted to 10 mW in Europe and Japan.





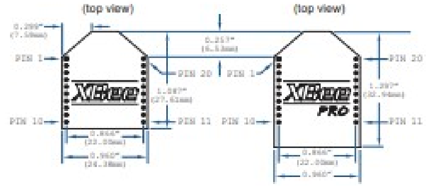


Figure 24: Xbee Transmitter Data Sheet

D.2 Atmega 328P Data Sheet

Configuration Summary

Features	ATmega328/P
Pin Count	28/32
Flash (Bytes)	32K
SRAM (Bytes)	2K
EEPROM (Bytes)	1K
Interrupt Vector Size (instruction word/vector)	1/1/2
General Purpose I/O Lines	23
SPI	2
TWI (I^2C)	1
USART	1
ADC	10-bit 15kSPS
ADC Channels	8
8-bit Timer/Counters	2
16-bit Timer/Counters	1

and support a real Read-While-Write Self-Programming mechanism. There is a separate Boot Loader Section, and the SPM instruction can only execute from there. In , there is no Read-While-Write support and no separate Boot Loader Section. The SPM instruction can execute from the entire Flash.

Figure 25: Atmega 328P Data Sheet Pg.1

Pin-out

Figure 5-1. 28-pin PDIP

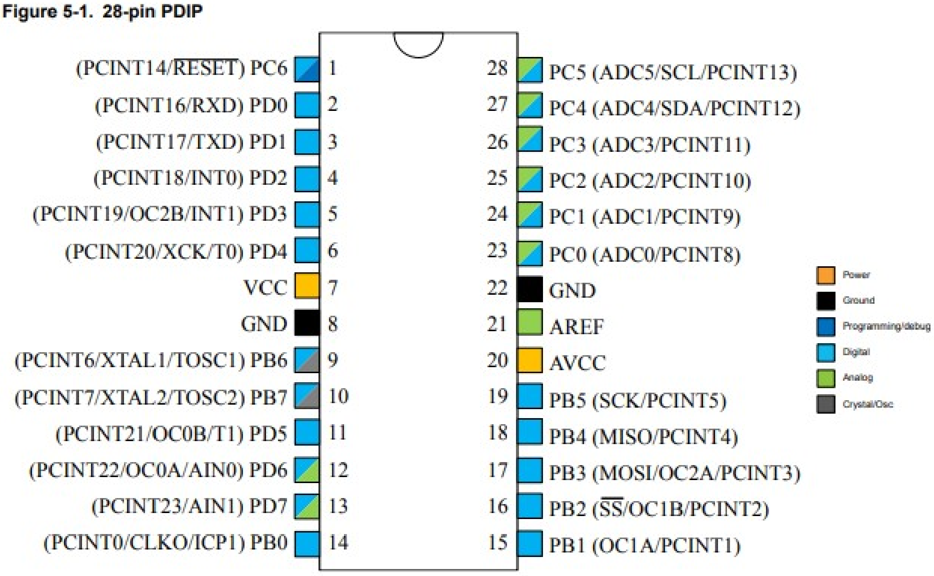


Figure 26: Atmega 328P Data Sheet Pg.2

D.3 Xbee Shield Data Sheet

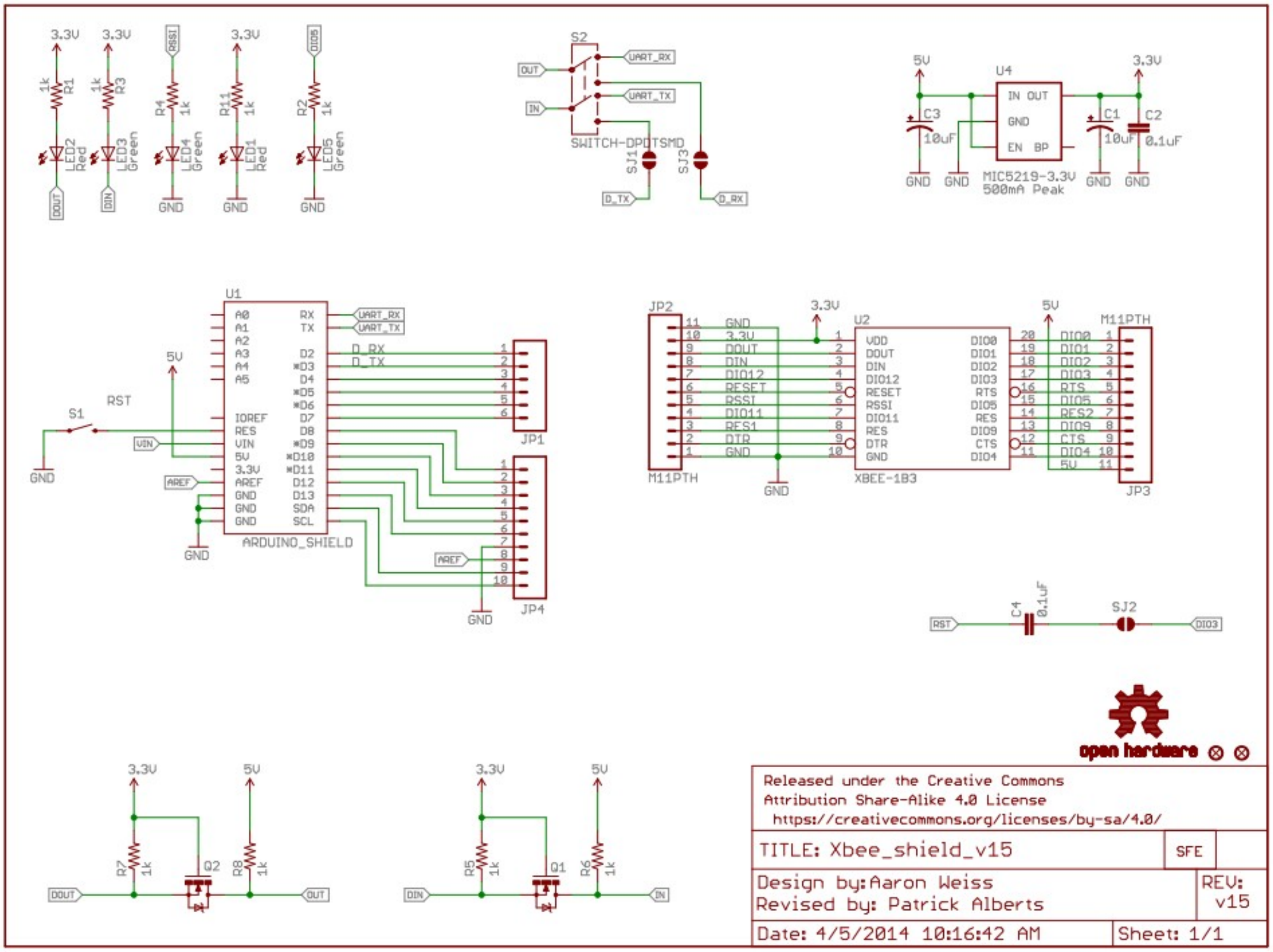
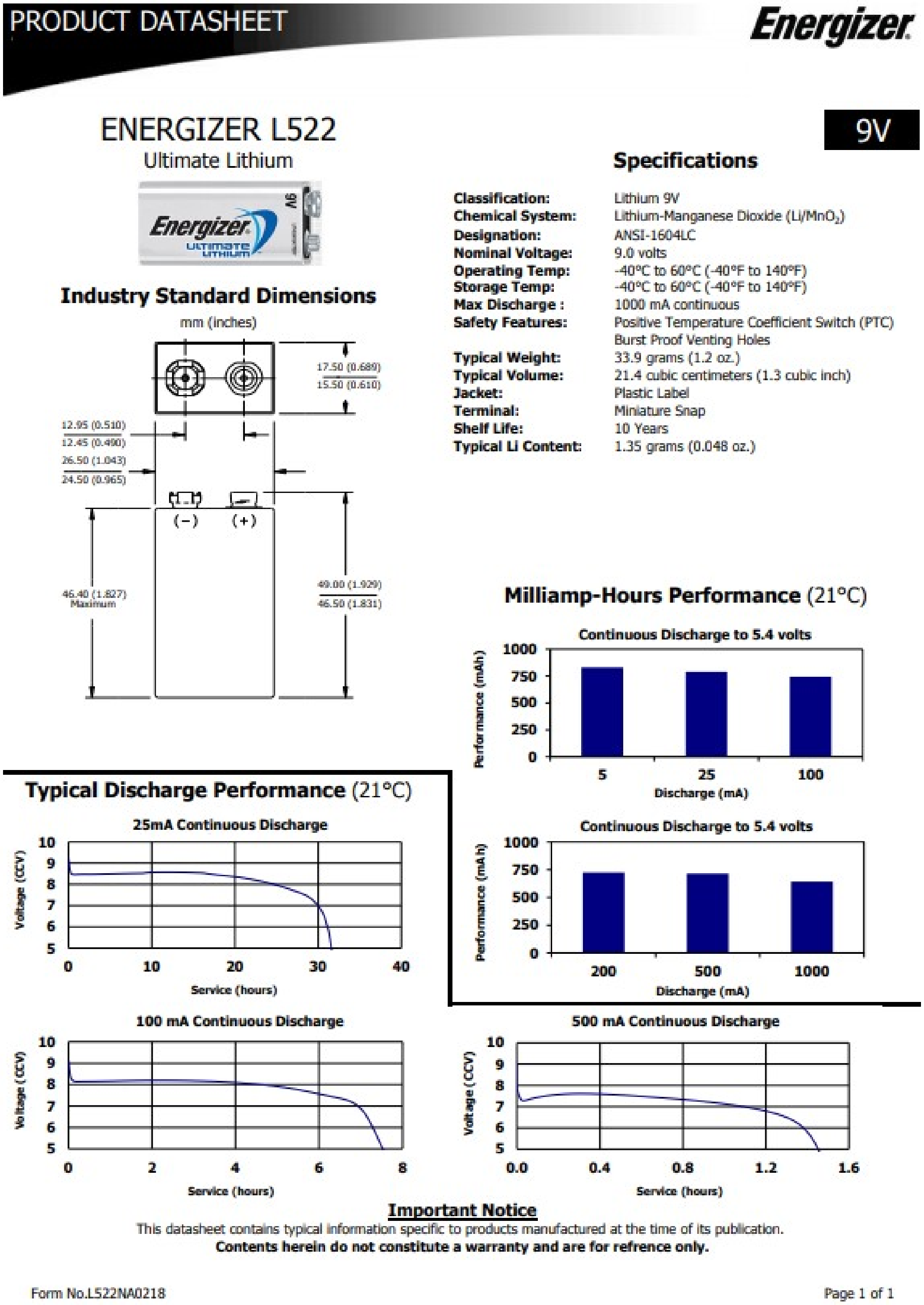


Figure 27: Xbee Shield Data Sheet

D.4 9V Battery Data Sheet



PRODUCT DATASHEET

Energizer

ENERGIZER L522

Ultimate Lithium

9V

Industry Standard Dimensions

mm (inches)

17.50 (0.689)
15.50 (0.610)
12.95 (0.510)
12.45 (0.490)
26.50 (1.043)
24.50 (0.965)
(−) (+)
46.40 (1.827) Maximum
49.00 (1.929)
46.50 (1.831)

Specifications

Classification:	Lithium 9V
Chemical System:	Lithium-Manganese Dioxide (Li/MnO_2)
Designation:	ANSI-1604LC
Nominal Voltage:	9.0 volts
Operating Temp:	-40°C to 60°C (-40°F to 140°F)
Storage Temp:	-40°C to 60°C (-40°F to 140°F)
Max Discharge :	1000 mA continuous
Safety Features:	Positive Temperature Coefficient Switch (PTC) Burst Proof Venting Holes
Typical Weight:	33.9 grams (1.2 oz.)
Typical Volume:	21.4 cubic centimeters (1.3 cubic inch)
Jacket:	Plastic Label
Terminal:	Miniature Snap
Shelf Life:	10 Years
Typical Li Content:	1.35 grams (0.048 oz.)

Milliamp-Hours Performance (21°C)

Typical Discharge Performance (21°C)

Important Notice

This datasheet contains typical information specific to products manufactured at the time of its publication.
Contents herein do not constitute a warranty and are for refrence only.

Form No.L522NA0218

Page 1 of 1

Figure 28: 9V Battery Data Sheet

E Shedule

E.1 Timeline - Diagram

This is the most recent timeline for the Wireless Tower of Lights project

September	Planning/Adjustments/Finalize Program Flow
October	Hardware Decision/Hardware Tinkering (Arduino/Xbee)
November	Hardware Implementation and Initial Prototyping
December	Prototype Product/Unit Testing
January	Product Improvement, Evaluation, and Final Product Hardware Decisions
February	Implementing and Producing Final Hardware
March	Hardware Scale Testing, Software Improvements
April	Testing
May	Ship/Manufacture (Deliver product)

E.2 Schedule - Orignally Planned

This is the original schedule, as planned by the LEaD Design Team

E.3 Schedule - Executed

This is the executed schedule, as accomplished by the LEaD Design Team

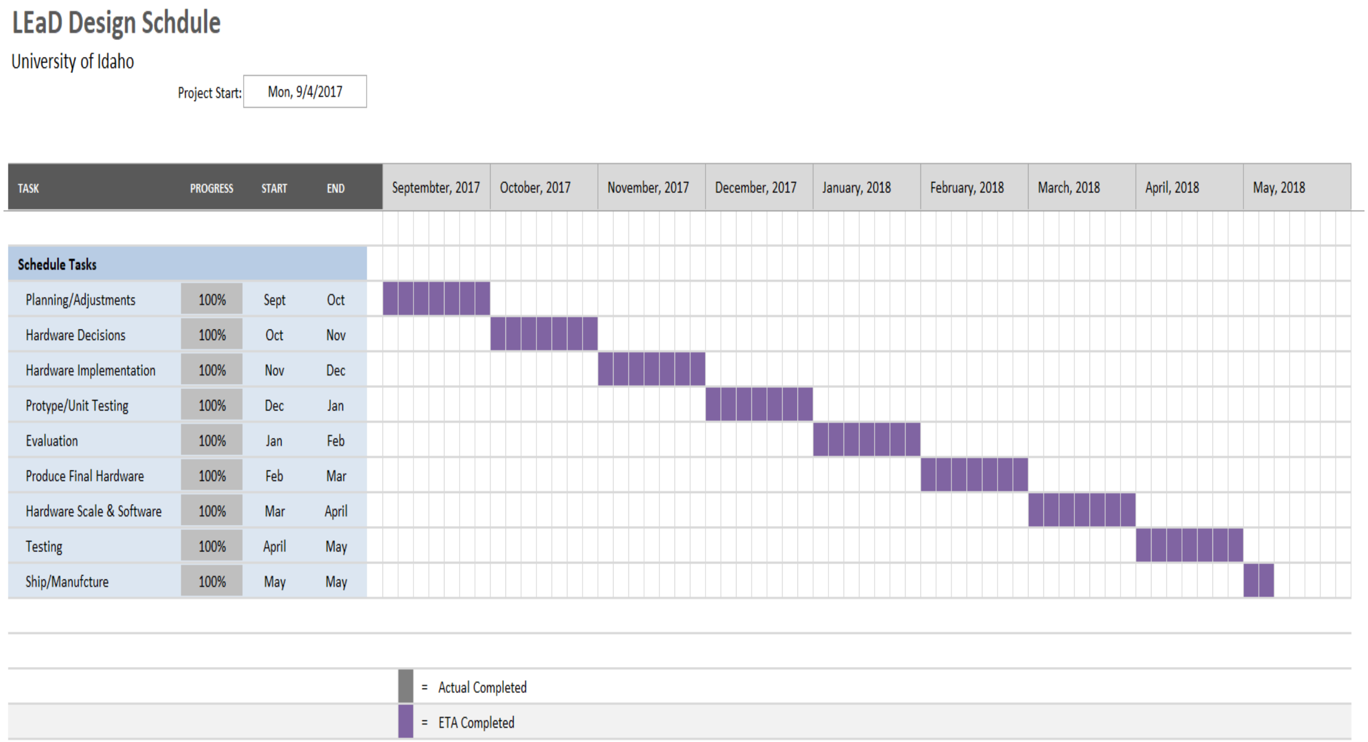


Figure 29: Schedule - Orignally Planned

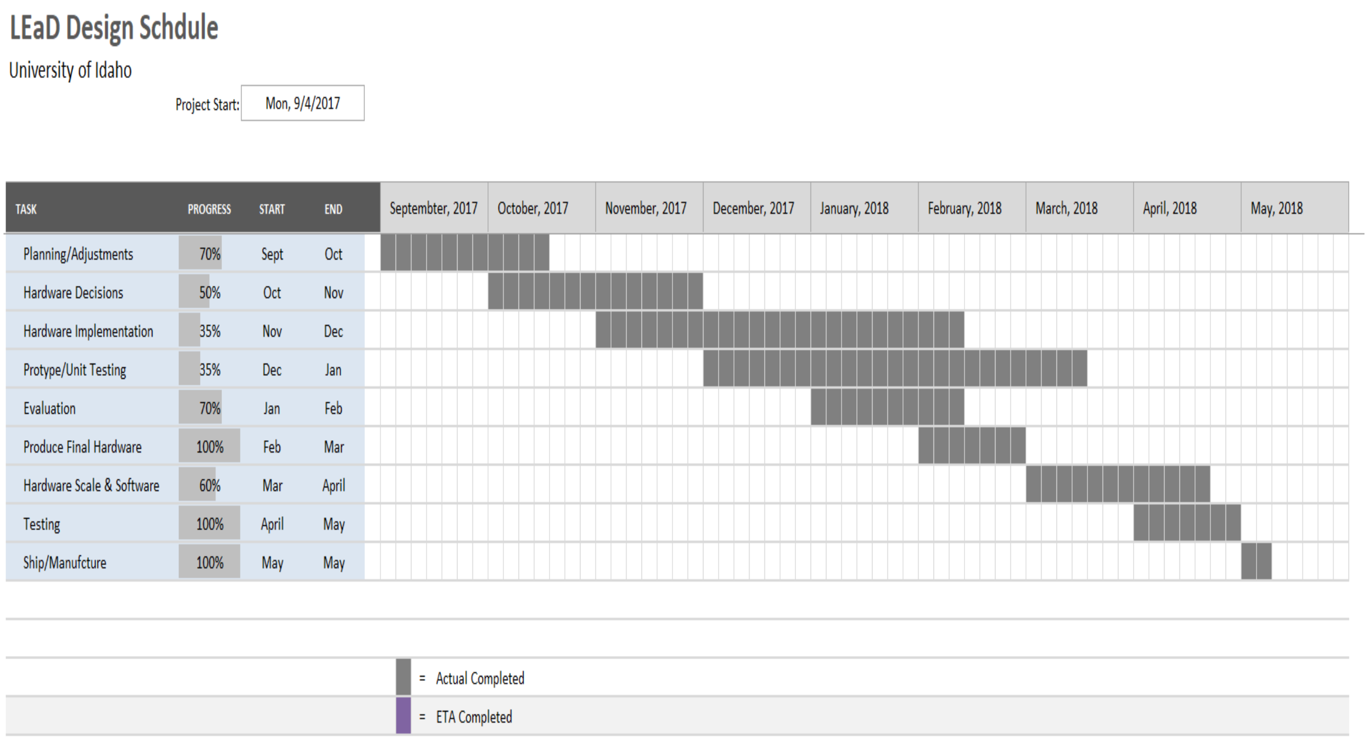


Figure 30: Schedule - Executed

F DFMEA Worksheet

The DFMEA is shown on the following page.

Description of component, subsystem, or function	Symptom (what?)	Effect (so what)	Failure mode (why?)	Probability of failure	Severity of effect	Risk priority	Remedial action
Wireless LightBar System	System Fails to Operate	User cannot use the desired system	1) User's Computer is not set up correctly 2) User failed to set up parts as directed	1	1	1	Make simple and clear directions for user
LightBar	LightBar fails tot Operate	User sees no effect from lightbar during operation	1) Wireless Protocol Error 2) Computer Error	2	1	1	Warn Users of Wireless Protol and Computer Errors
TowerPlayer Program	Audio/Frames for Display is Unsynced	User experience is frusterating/ruined and fails to meet design intent	1) User's Computer permissions/libaries not correct 2) Missing permissions/libraries 3) Wireless Protocol Error	2	1	1	Inform user of required libraries/software, warn of Wireless Protocol Errors
TowerArduino Program	Arduino does nothing	Cannot send or receive data (LightBar will show nothing)	1) Incorrect use of "Arduino" Software 2) Wireless Protocol Error	1	1	1	Inform user of required libraries/software, warn of Wireless Protocol Errors
LED Driver Circuit	Data is sent, but LightBar displays nothing	No feedback/display for User	1) Circuit became damaged	1	4	4	Warn User to handle LightBar carefully or create more protective case for circuit
Logic Diode	Temperature Increase	Major Damage to LED Driver Circuit Will Eventually Occur	1) Component Failure	1	4	4	Add "Warning" to Product

Figure 31: DFMEA

2-Pin to 9V Adapter	No Power Supply	The LightBar Will not Operate	1) Component Failure	1	2	2	Add "Warning" to Product
4-Pin Header	No Connection to LEDs	LEDs will not operate, thus no display	1) Component Failure	1	3	3	Add "Warning" to Product
6-Pin Header	NA	NA	NA	NA	NA	NA	NA
Atmeaga48-10p	Circuit Cannot Evaluate Data Received	Rest of circtuit useless, depends on microcontroleler for control	1) Component Failure	1	2	2	Add "Warning" to Product
BoardPadSmall	NA	NA	NA	NA	NA	NA	NA
CAP5mm (Ceramic Capacitor)	Short Circuit or High (Voltage) Leakage for Circuit	Prolonged use will bring about permanent damage (or system may fail to start entriely)	1) Component Failure	1	3	3	Add "Warning" to Product
Disscacap	Short Circuit or High (Voltage) Leakage for Circuit	Prolonged use will bring about permanent damage (or system may failt to start entriely)	1) Component Failure	1	3	3	Add "Warning" to Product

Figure 32: DFMEA

FET Nchan - TN0604	Thermal Runnaway, Short Circuit, Excessive Gate Leakage	Prolonged use will result in perminant damage and failure of system, short term, reduce reliability of system	1) Component Failure	1	3	3	Add "Warning" to Product
LED-T1 (Through Hold Red Diffuse)	No Red LED shining when Circuit is on	User doesn't know if circuit is on or off (dangerous) (on/off switch doesn't say "on" or "off")	1) Component Failure	1	4	4	Add "Warning" to Product. Add label for "On" and "Off" to switch
LM78L05	Short Circuit, or Open Circuit Burnout	Prolonged may bring about permanent damage (or system may fail to start entriely)	1) Component Failure	1	3	3	Add "Warning" to Product
MCP1700 3.3V 250 mA	Fluctuating Voltage (usually too high), or high temperature near microcontroller	Prolonged use will bring about permanent damage. Short term system will be unstable (LEDs flicker/unbirght)	1) Component Failure	1	3	3	Add "Warning" to Product
MRF24J40MA	No data received (from Xbee Transmitter)	Nothing will happen, circuit will act as though the towerplayer is not running	1) Component Failure 2) Wireless Protocol Error	1	2	2	Add "Warning" to Product & Discuss Wireless Protocols Errors
R0.25W (Carbon Film Ressitor)	Open Circuit Faults	Prolonged may bring about permanent damage (or system may fail to start entriely)	1) Component Failure	1	3	3	Add "Warning" to Product
R1W (Metal Film Resistors - 15 ohm)	Fail-Open Fault	Prolonged may bring about permanent damage (or system may fail to start entriely)	1) Component Failure	1	3	3	Add "Warning" to Product

Figure 33: DFMEA

R1W (Metal Film Resistors - 22 ohm)	Fail-Open Fault	Prolonged may bring about permanent damage (or system may fail to start entriely)	1) Component Failure	1	3	3	Add "Warning" to Product
Rotary Dip (Coded Rotary Switch)	NA	NA	NA	NA	NA	NA	NA
Switch - Mini Slide PCB	Circuit cannot connect/disconn ect	User cannot turn the circuit on/off (dangerous)	1) Component Failure	1	4	4	Add "Warning" to Product
XTAL/Resona tor (Ceramic)	Timing of circuity is incorrect, LightBars are not displaying , high failure rate	Whole System appears to be unreliable, may be harmful to overall functionality	1) Component Failure	1	2	2	Add "Warning" to Product
9V Li Ion Battery	LED Circuit Fails to turn on, or doesn't respond	LightBar won't display anything, no feedback to running towerplayer	1) Component Failure	1	1	1	Add "Warning" to Product. Remind user what battery type is required
1 in. x 2 in. x 8 in. Furring Strip Board	LightBar Doesn't stay in desired location or Components are loose on it	Odd-looking displays or components becomign damaged over time	1) Component Failure 2) Misuse of Component	1	1	3	Add "Warning" to Product. Adivse user to handle LightBar carefully
Atmega 328P Chip	Cannot run towerplayer.cpp and send data	LED circuit relies on this data, thus circuit/LightBar will do nothing	1) Component Failure 2) Computer Software Failure	1	2	2	Add "Warning" to Product. Inform user to check their "Arduino" software was installed correclty on computer

Figure 34: DFMEA

Xbee Shield	Cannot tansmit data from towerplayer.cpp	LED circuit relies on this data, thus circuit/LightBar will do nothing	1) Component Failure	1	2	2	Add "Warning" to Product
Xbee Transmitter Chip	Cannot tansmit data from towerplayer.cpp	LED circuit relies on this data, thus circuit/LightBar will do nothing	1) Component Failure 2) Wireless Protocol Error 3) Permission Errors	1	2	2	Add "Warning" to Product. Provide User with Instruction on how to set correct permission for use of product
towerarduino .ino	LED Circuits are unresponsive and do nothing during execution of towerplayer.cpp	LightBar does nothing during execution of towerplayer.cpp, so nothing happens in eyes of the user	1) Wireless Protocol Error 2) Atmega error	1	2	2	Inform user of required libraries/software, warn of Wireless Protocol Errors
towerplayer.c pp	User's computer gives error when trying to run towerplayer or data is not sent	Towerplayer and LightBars both do nothing, system completely fails	1) User's Computer permissions/libaries not correct 2) Missing permissions/libraries 3) Wireless Protocol Error	1	2	2	Inform user of required libraries/software, warn of Wireless Protocol Errors
yswavfile.cpp (& .h)	During execution of product, audio either doesn't sync or doesn't play at all	Ruins user experience of product and fails to meet design intent	1) User's Computer permissions/libaries not correct 2) Missing permissions/libraries 3) Wireless Protocol Error	1`	2	2	Inform user of required libraries/software, warn of Wireless Protocol Errors

		Very Probable	**Probable**	**Occasional**	**Remote**	**Improbable**
		5	**4**	**3**	**2**	**1**
Catastrophic	**4**	20	16	12	8	4
Critical	**3**	15	12	9	6	3
Marginal	**2**	10	8	6	4	2
Negligible	**1**	5	4	3	2	1

Severity of Effect

Catastrophic The failure causes substantial damage to the product itself or related items (including people), requiring repair.

Critical The failure causes significant damage to the product itself or related items, requiring repair.

Marginal The failure causes some damage to the product itself or related items, potentially requiring repair.

Figure 35: DFMEA

Negligible	The failure causes no significant damage.

<u>Probability of Failure</u>

Very	Every time
Probable	Most times
Occasional	Observed multiple times during the project.
Remote	Might be possible during the project.
Improbable	Maybe observed once during the project or predicted to happen after hand off.

Figure 36: DFMEA

G Overview of Folder/File Organization

NA