LUNALIGHT PROJECT

Solar-Rechargeable LED Lantern and Cell Phone Charger

by

Sean C. Dawson
Michael E. Deagen
Francisco N. Dye
Brian S. Mircheff
Ryan O. Ramelb

College of Engineering

California Polytechnic State University

San Luis Obispo

March 12, 2012

Statement of Disclaimer

Since this project is a result of a class assignment, it has been graded and accepted as fulfillment of the course requirement. Acceptance does not imply technical accuracy or reliability. Any use of information in this report is done at risk of the user. These risks may include catastrophic failure of the device or infringement of patent or copyright laws. California Polytechnic State University at San Luis Obispo and its staff cannot be held liable for any use or misuse of the project.

TABLE OF CONTENTS

List of Tables

List of Figures

List of Nomenclature

ABS Acrylonitrile butadiene styrene, a common thermoplastic that is used in the uPrint 3-D printer

Ammeter A device used to measure electrical current flowing through a wire

BOM Bill of materials, a tabulated list of the components of a system

Breadboard A construction base for prototyping electronic circuits without the need for solder

CAD Computer-aided design, using a computer program to construct a virtual 3-D model of a part

Diffuser An object that spreads out or attenuates the otherwise harsh glare from LEDs

Flux A substance that cleans the surface of a metal (in this case, solder) prior to joining of the metal

Heat sink A passive component that cools a device by dissipating heat into the surrounding air

IC Integrated circuit, a semiconductor device that incorporates many electrical components in one chip

Illuminance A measure of the light hitting a flat surface, often measured in lux (lumens/m^2)

LED Light-emitting diode, a device that converts electrical power into visible light using semiconductors

Light attenuation The gradual loss in intensity of light as it passes through a medium

Lumen A measure of the total amount of visible light emitted by a source

NiMH Nickel Metal-Hydride, a rechargeable battery technology common in low-cost solar lanterns

PCB Printed circuit board, a customized layout for electrical components that are later soldered

Reflow soldering A soldering technique where a populated PCB is sent through a conveyor oven

RPT Rapid prototyping, a small-quantity method of manufacturing small parts quickly with a 3-D printer

SMD Surface mount device, an electronic component mounted directly on the surface of a PCB

Solder A metal alloy with a relatively low melting temperature, used for joining electrical components

Executive Summary

Today, 1.6 billion people in the world do not have access to grid electricity. Villagers living off the grid in developing nations resort to kerosene lanterns to light their homes. The fumes from burning kerosene are toxic and lead to respiratory illnesses over time. Our sponsor, OneMillionLights, plans to help people to escape poverty by providing them with a clean source of light at night. Children that must work in the fields during the day can use a solar-rechargeable lantern at night to read or study, and street vendors can use the lanterns at night to improve their businesses.

The objective of this project is simple: design a portable lantern that recharges using solar power, can light up a small room, and has cell phone charging capability. Engineering a solar-rechargeable lantern involves the integration of several technologies, making the project well-suited as an interdisciplinary senior project. The LunaLight was designed by five engineers, with additional input from a graphic communications student and a finance student (Figure 1).

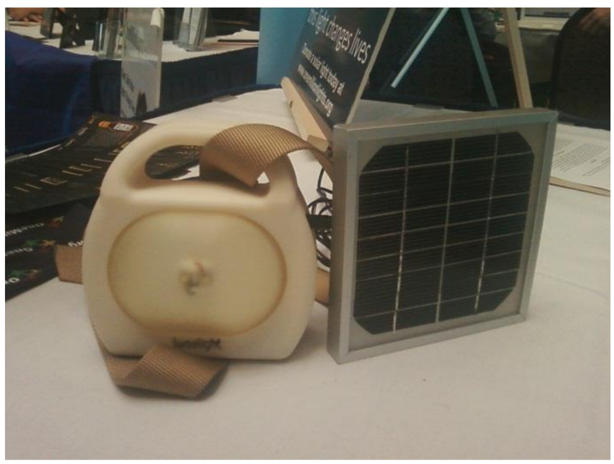


Fig. 1 LunaLight prototype at the S.T.E.P.S. Rotary conference on Jan. 28, 2012.

The LunaLight was designed to provide 6 hours of light on a full charge, and charge in 10 hours of direct sunlight using the external 2.5-W solar panel. The light has a USB port on the side and comes with a universal USB adapter to charge nearly every type of cell phone on the market. The dual LEDs provide twice the illuminance of a similar product already on the market. A slot in the bottom of the lantern allows the user to attach their LunaLight to the provided strap and hang the lantern from the ceiling or wear it as a hands-free light source.

This report outlines the senior project that began in September 2011 and will continue until June 2012. Using the many resources available at Cal Poly and a continuing collaboration with OneMillionLights, the LunaLight team will explore the potential commercialization of this product and establish the LunaLight project as a continuing project at Cal Poly.

Chapter 1: Introduction

This section provides a background on the sponsor, OneMillionLights, and the purpose of the project. Additionally, the problem statement is defined and the development of the project objectives and specifications is discussed. A section on project management details the involvement of those who worked on the team.

Sponsor Background and Needs

OneMillionLights is a non-profit organization that was created to distribute clean and healthy lighting as a replacement for harmful kerosene lamps. They aspire to provide light for studying, extending the workday, limiting carbon emissions and increasing income savings. Currently, they rely on donations from outside sources that allow them to purchase existing solar powered lights from other companies. Ideally, OneMillionLights would like to be able to supply a light of their own to distribute to developing communities. This would lower their operating costs and has the potential to help local economies by creating jobs if the light can be assembled locally.

Formal Problem Definition

OneMillionLights needs a solar powered light that is aesthetically pleasing and unique from the competing market with superior lighting capabilities.

Objective/Specification Development

The light must meet the following basic performance goals:

- Provide a comfortable reading light for 6 hours
- Fully charge in a day of direct sunlight
- Battery lifetime of approximately 1000 cycles, with replaceable batteries
- Capable of charging a cell phone

These performance goals were translate into a list of functional requirements (Table I).

Table I The functional requirements organized based on the primary components of the lantern.

Component	Functional Requirements
Solar Panel	**Power.** Fully charges battery in less than 10 hours of sunlight. **Size.** Similar dimensions to light for efficient packaging in box.
Printed Circuit Board	**LED driver.** Provides a constant current to the LEDs at the appropriate voltage (boost/buck LED driver). **Battery charger.** Protects batteries from deep discharge and overflow. Sleep mode to eliminate “vampire current” with an off-state battery discharge current of <15µA. Accommodates battery chemistry selected for the light. Capable of handling the solar panel selected for the light. Maximum power point tracking (MPPT).
Batteries	**Type.** Rechargeable NiMH, Li-Ion, or LiFePO4. **Capacity.** Can run the LEDs for 6 hours (this does not include cell phone

	charging). **Lifetime.** Last at least 1000 cycles (3-5 years of use). **Replacing.** Easily accessible in the housing with a simple connection to the PCB.
LED(s)	**Brightness.** Illuminance of 100 lux (for reading) from 2 ft away. **Spread.** Light emitted from a cone with an angle of >135°. **Heat sink.** Sufficient heat dissipation so that the LED mount is cool enough to be handled at thermal equilibrium. High-brightness LEDs are mounted on metal-core PCBs. **Color temperature.** Warm or neutral white (3000-4000K). **Efficiency.** At least 25% more efficient than the obsolete Philips Luxeon K2 LEDs that were donated to OML. **Lifetime.** Above 50% original light output after 10 yrs.
Optics	**Diffuser.** Softens light. Reduces glare and LED "hot spots." Less than 30% loss of illuminance from the diffuser. Sturdy as a structural component of the light. Made from off-the-shelf materials such as tubes or sheets. **Reflector.** Redirects photons that are otherwise unused.
Housing	**Impact resistance.** Withstands drop from 8 feet. **Stability.** Will not rock on uneven surface, doesn't tip. **Rain resistance.** Water does not enter housing in light rain scenario or moist environment. **Dust resistance.** Ports are covered to reduce potential damage from dust or small insects. **Aesthetics.** Looks good, no sharp corners, sleek form factor. **Portability.** Handle or strap for comfortable carrying. **Suspension.** Has hook/handle to hang from ceiling or belt. **Manufacturability.** Designed for machinability with simple tools or a CNC mill. **Simplicity.** Few moving parts. **Hardware.** Few, well-placed screws. **Switch.** ON/OFF switch. Cannot be accidentally turned on.
Cell Phone Adapter	**Compatibility.** Offers 3 most common cell phone interfaces. **Port.** 5V DC with a USB female port (compatible with most modern phones).
Misc.	**Shipping.** All components can be packaged in a box that is approx. 6"x6"x4". Shipping weight less than 2.5 pounds. **Assembly.** Option for simple on-site assembly. **Materials.** Green materials, with a focus on sustainability.

Project Management

Dr. Richard Savage has been the faculty advisor providing guidance, connections, and sources of funding to the project. Laura Chao, the Program Manager at One Million Lights, provided relevant data for the initial user needs assessment and gave feedback throughout the design process. The team of engineers was led by Michael Deagen, who has been involved since the development of the proof-of-concept prototypes in summer 2011.

Chapter 2: Background

This chapter provides a brief overview of similar products already in existence and discusses the current state of the art. Specific technical data relevant to the design process is described, as well as a basic system block diagram for a solar-rechargeable LED lantern and cell phone charger system.

Existing Products

The current market for solar powered lights consists of some products that are satisfactory products, as well as those that are sub-par. GTZ is a German organization that promotes international cooperation to create sustainable development throughout the world. This company created a document where they tested various standards to determine what current products on the market are and how they ranked amongst each other.

Below are some existing solar lights on the market and a few of their specifications[1].

- Aishwarya NEST-6543
    - Provides 360° of light
    - External solar panel
    - Resembles the current visual setup of kerosene lamps
    - Water resistant
    - Website: http://www.solarnest.net/lanterns.html
- Mighty Light
    - Multi-purpose light function
    - Incorporation of handle into the design
    - Multiple brightness settings
    - External solar panel
    - Website: http://www.cosmosignite.com/product-brief.htm
- D.Light S250
    - External solar panel
    - Multiple brightness settings
    - Mobile phone charger
    - Incorporation of handle into the design
    - Website: http://www.dlightdesign.com/products_D.LIGHT_S250_global.php
- The Solar Muscle
    - Integrated solar panel on the device
    - Weather and shock proof
    - Small and lightweight
    - Lasts for 8 hours on full charge, 15 if functioning at 50%
    - Website: http://flexiwaysolar.com/the-solution-our-solar-powered-led-light/

Current State of the Art

LEDs are semiconductors that emit light when electricity flows through the material. The most common color created is a red LED, but for the use of our project we will be using a high-brightness white LED. White LEDs are actually blue LEDs with a phosphor coating that scatters the light frequencies across the visible spectrum so that the LED appears white. White is a color that people in developed countries are used to seeing, and it provides a comfortable light that does not strain the eyes when reading or performing tasks. White LEDs come in different color varieties such as cool white, neutral white, or warm white. Warm white LEDs have a more aesthetically pleasing yellowish tint to the light, but are less efficient. Cool white LEDs are generally the most efficient in terms of lumens/W, but the bluish tint to the LED makes many people feel uncomfortable.

Rechargeable batteries allow people to repeatedly store energy without the waste typically associated with non-reusable alkaline batteries. The common rechargeable battery chemistries used today include NiMH, Li-ion, Li-$FePO_4$, and lead-acid. Coupled with solar power, rechargeable batteries give the user a sustainable off-grid energy collection and storage system. Solar panels are steadily becoming more efficient and less expensive, enabling their use in small solar lantern systems throughout the world. Solar

Specific Technical Data

In order to maintain good vision while reading, there are standards and requirements that companies must reach when making reading lights so that the user does not strain their eyes. The standard for reading such material is a minimum of 150 lux on the reading surface[2]; this amount of illuminance provides a comfortable reading atmosphere that does not strain the eyes. There are also requirements for the amount of lux needed for a normal living room area. For this type of area, it is required to have 300 lux of light emitted in order to view others and/or other objects in the vicinity[2]. These two situations are the applications that the LunaLight will most frequently be used in, so meeting these standards is incredibly important for the light to be successful in Kenya.

As stated previously in this report, the people of Kenya are using kerosene lamps and candles to illuminate their nightly activities. A kerosene lamp emits an average of 1 lux at a meter away[3], which is far below the requirement for reading and normal living room conditions. Kerosene lamps not only are hazardous to users by burns or respiratory problems, as well as being harmful to the users vision since they are constantly having to strain their eyes. The goal of the LunaLight is to put an end to all of these hazards and provide a comfortable reading or activity light that is safe and convenient for all of the consumers involved.

System Block Diagram

The core components of a solar-rechargeable LED lantern and cell phone charger include a solar panel to convert sunlight into electricity, rechargeable batteries to store the electricity, LEDs to provide light at a relatively low power, and a printed circuit board (PCB) to manage the electrical components. The system block diagram is shown in Figure 2.

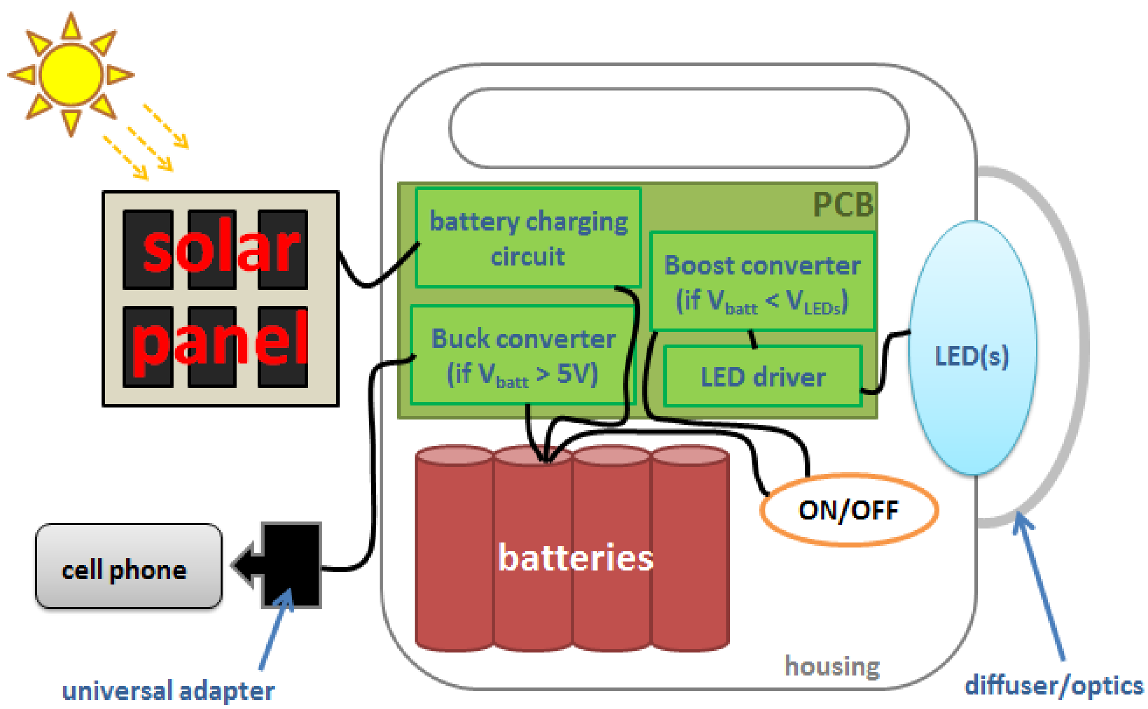


Fig. 2 The system block diagram shows the main components and their interrelationships in the design.

Chapter 3: Design Development

The design development includes a discussion of conceptual designs, selection of the concept, supporting preliminary analysis, and the results of proof-of-concept analysis.

Discussion of Conceptual Designs

The end of September 2011 marked the beginning of the next phase of the Sol Project. In the three months prior (Summer 2011), the project was in its beginning stages and two prototypes were developed. The first prototype was known as the "The Book" while the second was known as "The Lantern." The goal was to take what was learned in the development of these two primary prototypes, and build upon it to create an even better solar powered light. One of the main difficulties was the to satisfy all of the user needs, while also developing a light that was aesthetically pleasing to the eye. From September 2011 to December 2011, three more conceptual designs were generated; the extruded aluminum box design, the "Lunch Box" design, and the "Crescent" design.

The first conceptual design of the new school year was the "Hybrid" (Figure 3) It was decided when determining the functional requirements of the light that the intent was to maximize the amount of light emitted with the use of only two LEDs. As a result of these requirements, the two LEDs were mounted adjacent to one another on a 120° angle. A diffuser needed to be included in the design to prevent damage to the LEDs and allow a full 180° range of light. This design would maximize the amount of light, and it would potentially satisfy the durability and weight requirements. However, it would be bulky, "box-like", and therefore not aesthetically pleasing.

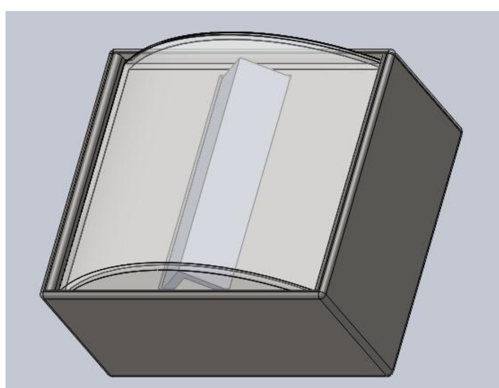


Fig. 3 CAD model of the "Hybrid" conceptual design.

The second conceptual design was known as the "Lunch Box" design (Figure 4). After the completion of our "Hybrid" conceptual design, it was brought to the attention of the team that plastic casting was a viable option on the Cal Poly campus. This allows for much more freedom in the design process due to the flexibility of using silicon molds. It was apparent that through plastic casting we could create our own solar light housing with rounded edges and more aesthetically pleasing features than the "Hybrid" design. The angled LED mount idea was kept from the original design, but a few modifications

were made: a handle on the top of the light, a smaller volume for the housing unit, filleted edges around the housing unit, and a dome shaped diffuser were incorporated. This new design enhanced the aesthetic appeal, made the light less bulky, kept the target of 180 degrees of useful light, and significantly decreased the overall weight of the solar powered light. Unfortunately, even though the aesthetics were improved, the design lacked originality and creativity. There was still more work to be done in order to come up with the perfect design that would meet all of the user and functional requirements while also making it a product that would catch people's attention.

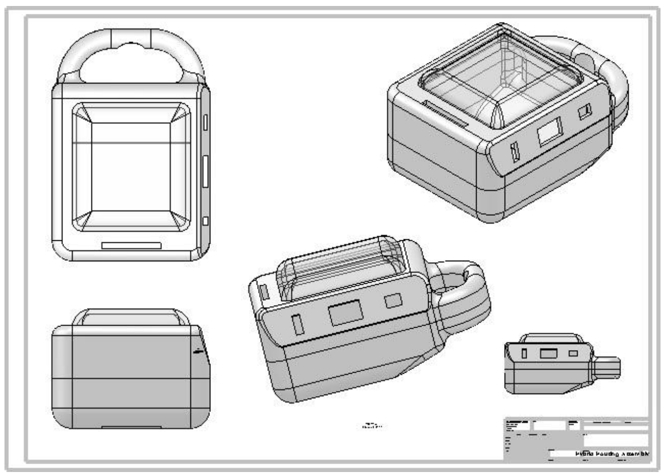


Fig. 4 The "Lunch Box" design is reminiscent of the "Hybrid" design but with improved aesthetic qualities.

The third and final conceptual design was at first known as the "Crescent" design (Figure 5). While working with the non-profit organization known as "One Million Lights," a name was brought up that everyone seemed to agree upon, "LunaLight." This opened up a new door in the design department, after deciding on this name, the design became influenced by the shape of the moon. Inspiration struck by having the handle on top of the light pushed back at an angle and to cut away some of the material in the middle of the housing to give the light a crescent moon shape. From the front view of the light, the housing was completely rounded out to give the appearance of a full moon. In addition to these major housing adjustments, the idea of incorporating a four-foot strap, complete with a buckle, was added to the design. The purpose was to give the consumer a "hands free" option (i.e. hang the light up or wear it around the waist or chest). This was incorporated into the design by creating a rectangular through-hole at the bottom of the housing fixture to allow the strap to slide through this hole, as well as the handle, and then be buckled for stability. This conceptual design gave the LunaLight the originality and creativity that was lacking in the earlier designs.

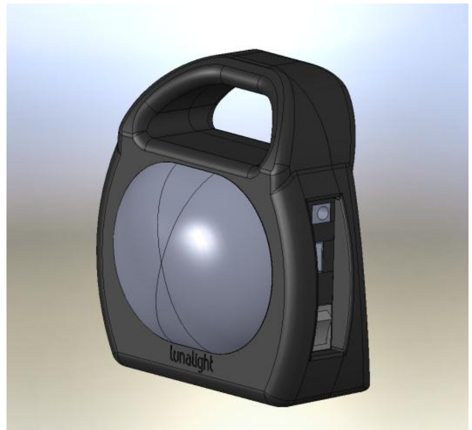


Fig. 5 CAD model of the "Crescent" design, later known simply as the LunaLight.

Concept Selection

The conceptual design process did not establish the three designs mentioned above simultaneously. We started with the "Hybrid" design, and modified as we learned more about what was possible for us to do. From the "Hybrid," the idea of having 180 degrees of light by mounting the two LEDs adjacent to each other at a 120 degree angle was kept and incorporated in the "Lunch Box" design. The "Lunch Box" design incorporates the handle at the top of the light, the strap that provides the option for hands-free use, and a rounded diffuser. The "Crescent" design, also known as the LunaLight, was a combination of what was learned through the previous conceptual designs and more. The main difference from the LunaLight design and the "Lunch Box" design was the shape of the housing. As alluded to in the previous paragraph, the LunaLight went away from the boxy design and went towards a crescent shape design from the side profile to give the light unique and original characteristics. It was taken into account that the light conforming to the chest is both helpful, and practical. This last version of the light met all of the functional and user requirements that were addressed in the preliminary objectives.

Proof of Concept Analysis

The printed circuit board (PCB) made during summer 2011 as a proof-of-concept for a solar lantern had several problems that needed to be addressed. The first issue with the board was its large 5" square footprint, which limited the ability to create a compact design. Secondly, the initial PCB was designed to accommodate two different prototype systems and therefore had some excess circuitry that could be eliminated. The battery charging circuit had to be replaced entirely due to the leakage of current from the batteries when in disuse. A leakage of roughly 5-15 mA would fully deplete the batteries in about two weeks of non-use. The revised PCB needed to eliminate this "vampire current," a small relative footprint in the design, and a strategic placement of the ports (USB and barrel) and connector terminals (battery and LEDs). The dimensions and tolerances of each of the components were taken into account to allow for easy manufacturability.

Chapter 4: Description of the Final Design

This section describes the design of the LunaLight, a cost breakdown for the prototype and mass manufacturing, a discussion of the component selection, schematics and wiring diagrams, and other considerations regarding safety and maintenance.

Overall Description/Layout

The final working design incorporated all of the features and considerations that were created throughout the development cycle. With the inspiration from the name "luna," the design was to resemble the phases of the moon. From the front it was made to slightly resemble a full moon while from the side to resemble a crescent moon (Figure 6).

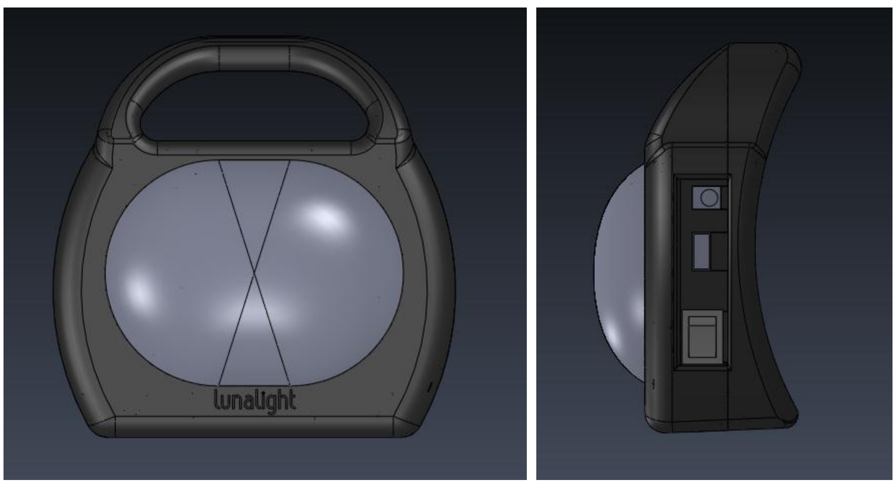


Fig. 6 Front and side views of the LunaLight design.

Detailed Design Description

The size remains within the original specified constraints to fit in a compact box determined by the size of the solar panel. The light consists of a total of seven (7) parts: Front and back portion of the housing, LED mount, Diffuser, assembled PCB, 2x2 battery pack (along with 4 AA batteries), and a rocker switch (Figure 7). Detailed drawings of each part can be found in Appendix B. The battery pack and rocker switch are off-the-shelf components, whereas the rest are designed and manufactured by us. As requested by the feedback from the users in Kenya, extra care has been taken into designing the housing with absolutely no sharp corners or edges. Additionally, no part of the housing will have exposed hardware as the screws will attach directly into the housing. The design has also minimized the amount of screws needed to eight (8): four for the printed circuit board and the remaining four to keep the housing together.

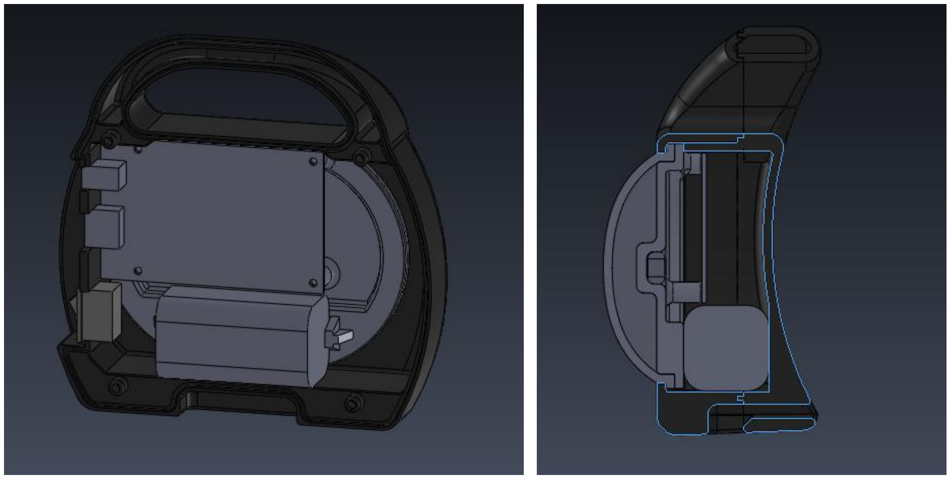


Fig. 7 Views of the internal components of the LunaLight.

The design utilizes the maximum available base (within the size constraints) for stability. To add additional weight to the lower end of the light, a portion of the bottom been filled in and the battery pack has been placed on the lower half of the light. The bottom is angled upwards to give the light a slight tilt upward when used on the floor without sacrificing stability. For operator ease-of-use a handle located on the top of the light has been integrated into the housing and designed with the desired form factor.

A unique design has been made to incorporate the use of the provided strap with the light. When fed through the opening for the handle and slot at the bottom of the light (with the strap crossing the back of the light), the strap is able to be used as a method to hang and angle the light. This assembly can also be used to strap the light across a person's body or waist, allowing for hands-free operation of the light. The curvature of the back of the light improves the ergonomics when the light is being worn across the chest with a strap.

On the issue of environmental factors, many aspects have been accounted for in the design of the light. The diffuser and buttons have been designed to have a tight fit on the housing. The two halves of the housing feature an offset, recessed seal typically used on electronic casings. The side button mount has been designed to recess into the housing as a way to avoid direct impact and elemental factors. This feature also helps to prevent accidental pressing of the switch when the light is placed into a bag or dropped, while remaining wide enough for a thumb to easily reach in to switch the power on and off.

For the assembly of the light, the printed circuit board is screwed onto the LED mount with four screws. The mount is then placed within the diffuser cavity and pushed out through the opening in the front housing, ensuring the two ports to fit snug into the side button mount. The on/off switch and battery pack are then attached to the PCB and placed into their corresponding locations on the present

assembly. The back housing is then put into place and secured with screws. The back housing features stops for both the battery pack and mount/diffuser ensure a sturdy assembly.

Cost Breakdown

For the initial 5-20 prototypes, the bill of materials (BOM) cost is approximately $84.00. This does not include shipping costs for the various components (see Appendix B for the detailed BOM). The mold cost for each plastic cast part was amortized over 50 mold uses (Appendix B). The cost breakdown shows that for these small quantities, the main cost contributor is the PCB and its components. The initial order of 20 boards led to a cost of $21.76 per board, but this price drops to $5.40 each when ordering 100 and $2.65 each when ordering 250. The other major contributors to the cost of the LunaLight are the solar panel and LEDs (Figure 8).

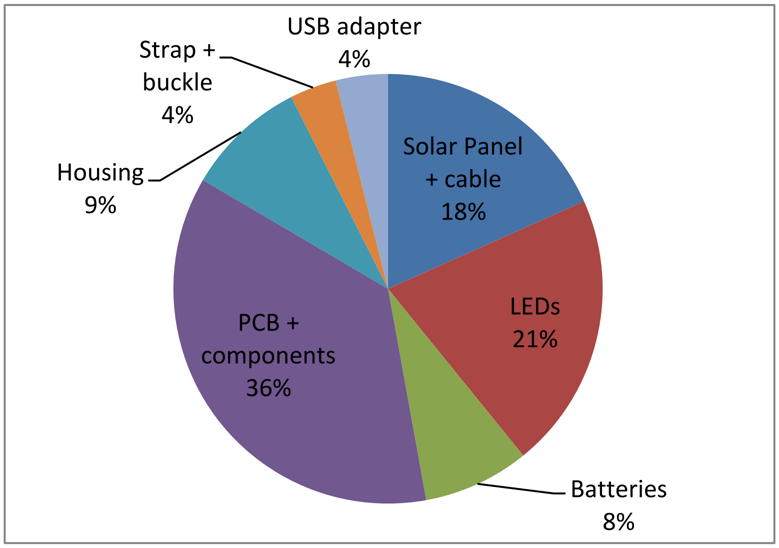


Fig. 8 Cost breakdown for the components of the LunaLight, assuming a quantity of 20.

Due to economies of scale, larger quantities will reduce the cost of each unit. Many suppliers offer significant price breaks for orders of 100, 500, or 1000+. Also, different manufacturing methods may be used to reduce the costs, such as injection molding for the plastic housing and primarily using surface-mount devices (SMD) on the PCB. Table II shows how the cost per unit drops assuming that the manufacturing methods stay the same and only takes into account the price breaks. Alternate manufacturing methods would reduce these costs further.

Table II The cost per unit drops about 40% solely from price breaks when increasing quantity from 20 to 1000.

	Cost (20)	Cost Est. (Qty. 100)	Cost Est. (1000)
Solar Panel + cable	$15.09	$11.00	$10.00
LEDs	$17.14	$16.24	$14.44
Batteries	$6.59	$5.61	$5.61
PCB + components	$29.88	$12.34	$8.50
Housing	$7.50	$7.00	$7.00
Strap + buckle	$2.90	$2.32	$1.88
USB adapter	$3.23	$3.00	$2.50
	$82.33	**$57.51**	**$49.93**

Material, Geometry, and Component Selection

Housing

After doing some preliminary research on the subject, we decided to choose plastics as our casting medium. It was determined that Smooth-On, a company that specializes in casting rubbers and plastics, was the best company to go through from their wide selection of products. Luckily, a Smooth-On representative was able to visit the Cal Poly campus allowing members of the LunaLight team to obtain valuable insight as to which types of plastics would be the most beneficial, as well as cost effective for our application. The representative pointed us in the direction of Smooth Cast 305 for the LunaLight housing, and a plastic called “Crystal Clear” for the diffuser. The Smooth Cast 305 is ideal for the housing since it is cost effective, durable, easy to use and machine-able if necessary. The “Crystal Clear” urethane plastic is optically clear with minimal shrinkage after curing. The end product will be a diffuser made from the “Crystal Clear” plastic with a frosted texture applied to further diffuse the light. The Smooth Cast 305 and Crystal Clear plastics will make up the entire exterior of the LunaLight.

LEDs

The goal was to pick an LED with high efficiency, which meant having a high light output coupled with a low current. It was determined relatively quickly that the Rebel LEDs made by Luxeon Star would be the best option. The next decision was what type of white LED to incorporate into the light. As a team, it was decided that we would test four different types of white Luxeon Rebel LEDs and test them to determine which was the most efficient. A pair of Warm White (3100K), ANSI White (2725K), ANSI White (3985K), and Neutral White (4100K) LEDs were all ordered from Luxeonstar.com and tested. We had a color range (i.e. Warm, ANSI, and Neutral White LEDs) to determine which ones would be the most visually appealing. We wanted to stray away from the Cool White LEDs since they tend to have a blue tint to them, which causes the viewer to feel cold. The kerosene lamp emits a warm white color, which we wanted to keep to retain some familiarity in light color that kerosene lamp users have become accustomed to.

Batteries

The next detail that we had to determine was the type of rechargeable battery that we were going to incorporate into the LunaLight. The four types of batteries that were researched were Lithium Ion, Nickel Metal Hydride (NiMH), Lithium polymer, and Lithium Iron Phosphate batteries. Some benefits of using the Lithium based batteries are their production of about 3.7 volts, which would only require two to power the light for our current design. However, this high voltage makes it difficult to charge the batteries in a timely manner with the current design constraints. Also, Lithium batteries do not have a standard size, making it difficult to easily find replacement batteries. Finally, the price of Lithium batteries is currently higher than NiMH batteries. The NiMH batteries however, come in the standard AA sizes and four of these batteries hold enough charge to power the LunaLight for the desired amount of time (6 hours). The voltage of four of these batteries combines to 5 volts, which is low enough to charge from the solar panel, yet high enough to power the LEDs with the correct circuitry. For these reasons, the NiMH batteries were chosen be incorporated in our final design.

Printed Circuit Board

The PCB contains two basic sub-circuits; one charges the batteries safely using solar panel, and the other drives the LEDs from the battery pack. The MC34063 is a DC-to-DC boost that was used in the summer 2011 prototypes. The LT3652 is a battery management chip that was designed for solar power applications and features maximum power point tracking (MPPT) capability as well as putting the battery in shutdown mode with the current is below 85 µA. Both integrated circuit (IC) chips, the MC34063 and LT3652, were externally programmed with resistors, capacitors, and inductors according to information provided within their respective datasheets.

A right angle USB port and PC-mount 2.5mm jack were selected for the purpose of mounting the ports directly to the PCB. The ports are precisely aligned so that they are flush with the housing when the PCB is secured within the lantern (Figure 9).

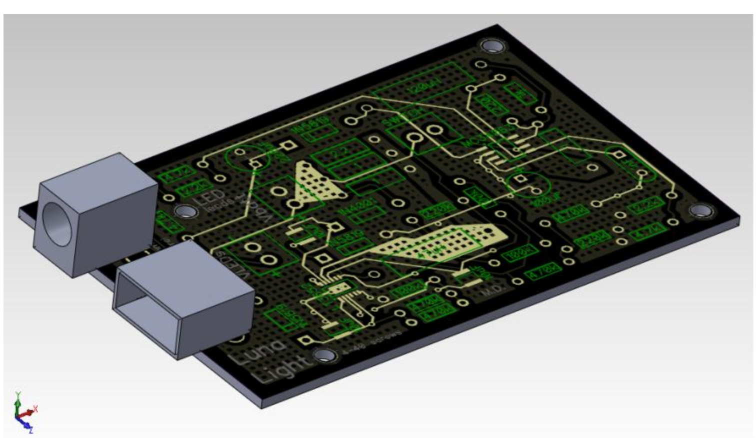



Fig. 9 The PCB layout was designed so that the barrel port and USB port would align in the housing.

Strap

The strap that comes with the LunaLight allows the user to hang the light from the ceiling or to wear the light and enjoy the ease of use with hands-free lighting. Straps with pre-attached side release buckles were purchased from StrapWorks.com. A 4-foot length of strap was chosen to allow the LunaLight to be worn across the chest of an average-sized adult (Figure 10).

Fig. 10 The LunaLight being worn hands-free with the strap.

The two strap materials sampled were flat nylon webbing and lightweight polypropylene. Flat nylon has better abrasion resistance, but is more expensive at $4.81 per strap. Lightweight polypropylene was chosen because it has better water and UV resistance, and only costs $2.90 per strap. StrapWorks offers a variety of strap colors at no additional cost, so we selected several different colors based on input from the team and OneMillionLights.

Flowcharts, Schematics, and Wiring Diagram

PCB Schematic

The PCB manages the electronic inputs and outputs in the system. Below is a basic system block diagram showing how the PCB interfaces with the solar panel, batteries, and LEDs (Figure 11). For a detailed schematic and bill of materials for the PCB, see Appendix B.

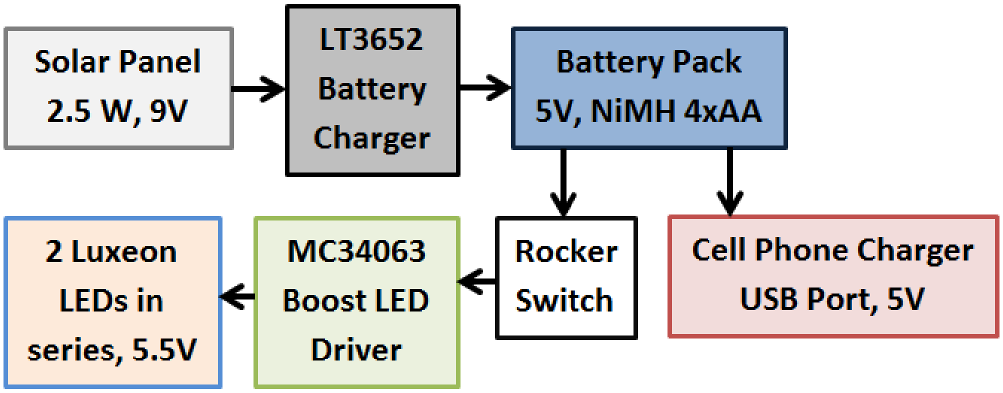


Fig. 11 A simplified schematic of the multiple functions of the PCB.

Wiring Diagram

The following wiring diagram shows how to connect the external components to the PCB (Figure 12). Note that black wires generally signify ground connections. The exception is the zip cord leading from the solar panel to the 2.5mm barrel plug, where the wire with the white stripe signifies ground. Care must be taken to ensure the solar panel, LEDs, and batteries are wired in the correct polarity.

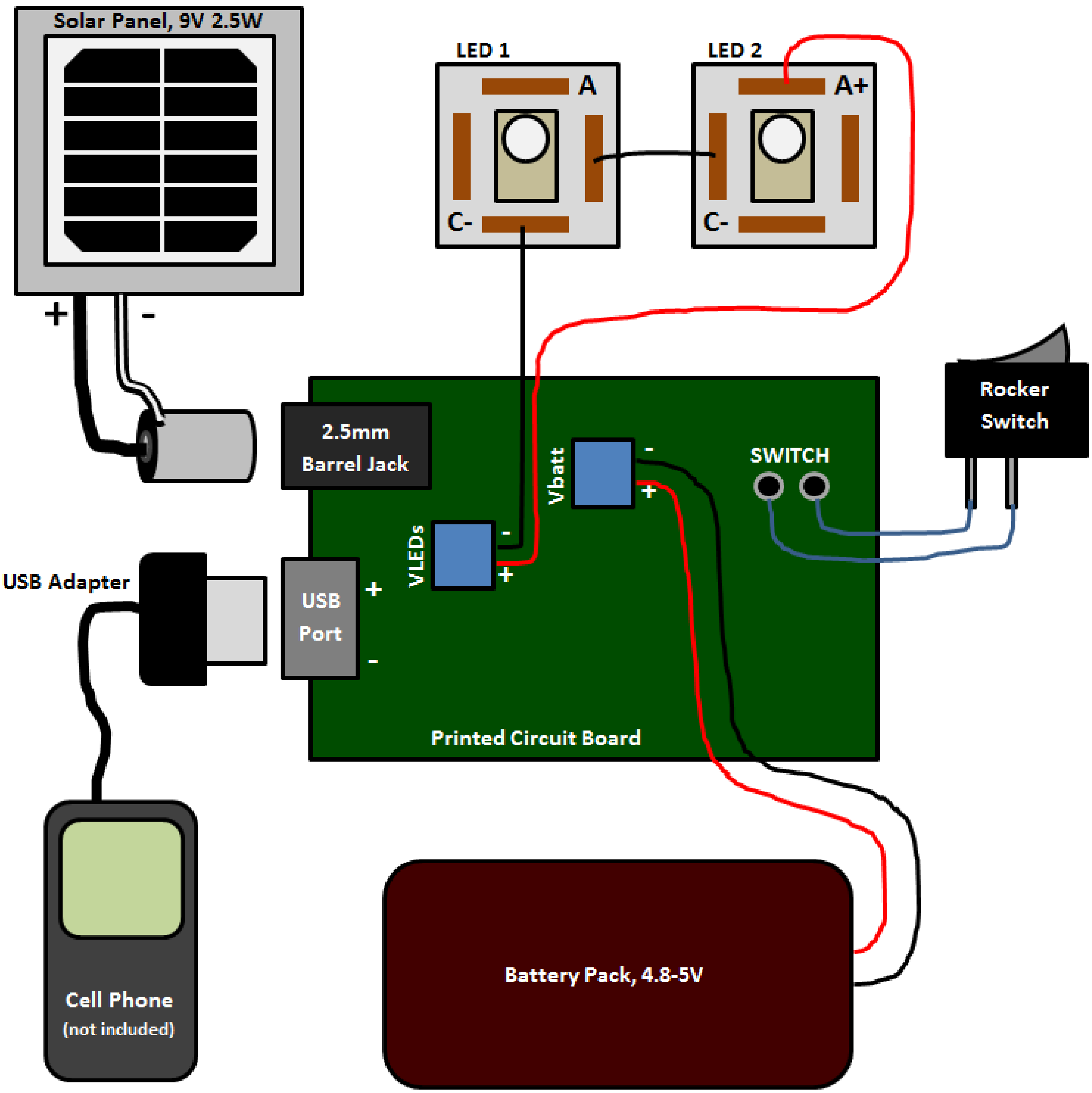


Fig. 12 Wire diagram showing how to properly connect external components to the PCB.

Safety Considerations

Do not remove the battery leads from the connector terminal block, this could cause battery shortage to occur. Do not submerge the lantern in water. Do not dispose of the lantern in a fire. Do not reverse the polarity of any of the leads. Only charge a single cell phone at a time, otherwise the lifecycle of the product will be significantly reduced. Turn the switch to the OFF position when the batteries are low. Securely mount the solar panel so that it may not fall on someone or become damaged. A damaged solar panel will compromise the ability to charge the batteries. Move the solar panel cable out of the way of human traffic to eliminate the hazard of tripping.

Maintenance and Repair Considerations

Charge the batteries by plugging in the solar panel and making sure the panel faces the sun directly. The batteries have an expected life of 1000-2000 cycles, and they can be replaced with any 4.8-5V NiMH battery pack (recommended capacity 1800-2600mAh). The thru-hole components are large enough to be replaced and soldered by hand if necessary. If either of the ICs are damaged, the circuit board must be replaced.

Chapter 5: Product Realization

This chapter outlines the manufacturing methods for production of the initial prototypes and how the prototypes may differ from the planned design. In addition, recommendations for future manufacturing of the design are provided along with cost estimations for future production.

Description of Manufacturing Processes Employed

PCB Assembly

The two ICs on the PCB are surface-mount devices (SMD) and should be soldered using the reflow soldering method. To assemble the prototype PCBs, the Heller 1500EXLMS reflow oven at Cal Poly was used. The "Marc_Thesis" file was used, with compartment temperatures of 140, 190, 280, and 170°F, and a conveyor speed of 21 cm/min.

First, apply solder paste to the SMD pads (Figure 13a) and send through the reflow oven (Figure 13b). Without having a proper stencil to apply solder paste, there will most likely be bridges between adjacent pads. Remove these bridges by contacting the pads with a soldering iron and allowing the solder to reflow (Figure 13c). Apply tacky flux to the pads (Figure 13d), carefully align the IC chips in the correct orientation (Figure 13e), and send through the reflow oven again (Figure 13f). Check the connections of the PCB with a continuity tester (Figure 13g). Note that there will be residue from the tacky flux (Figure 13h), and this can be cleaned with deionized water or isopropanol, or rubbing alcohol, and a toothbrush (Figure 13i).

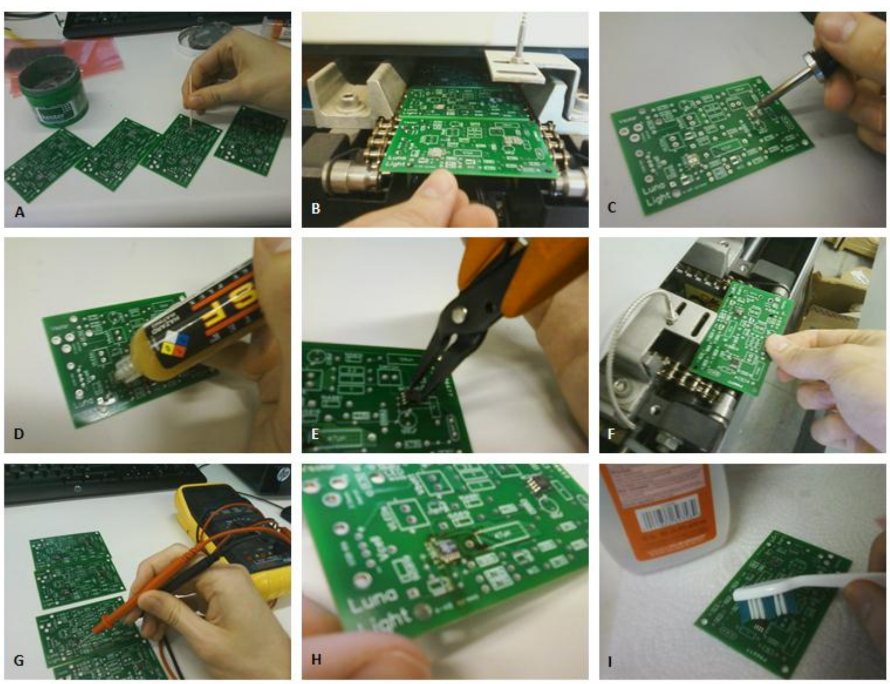


Fig. 13 Reflow soldering procedure for the two IC chips on the PCB.

The remaining components of the PCB must be soldered manually by placing the leads in each hole (note that the polarity is important for diodes and certain capacitors) and soldering the electrical connections from the back (Figure 14). A good solder joint forms a cone of solder between the pad and the component lead. After soldering the thru-hole components, clip the excess leads.

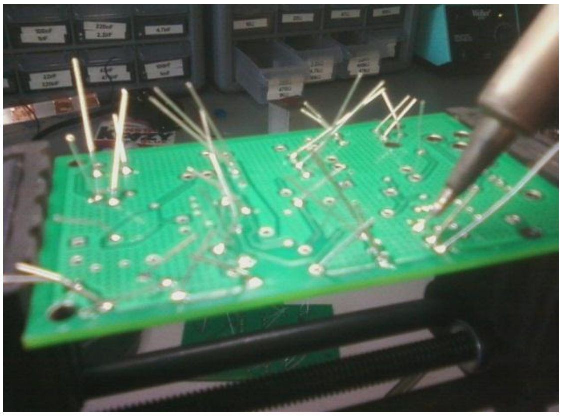


Fig. 14 Manual soldering of the PCB thru-hole components with a soldering iron.

Measure and cut wire to go from the switch to the PCB. About 3.75 inches per wire is sufficient. Solder the wire to the rocker switch leads, connect the wires to the PCB, and the PCB is fully assembled (Figure 15).

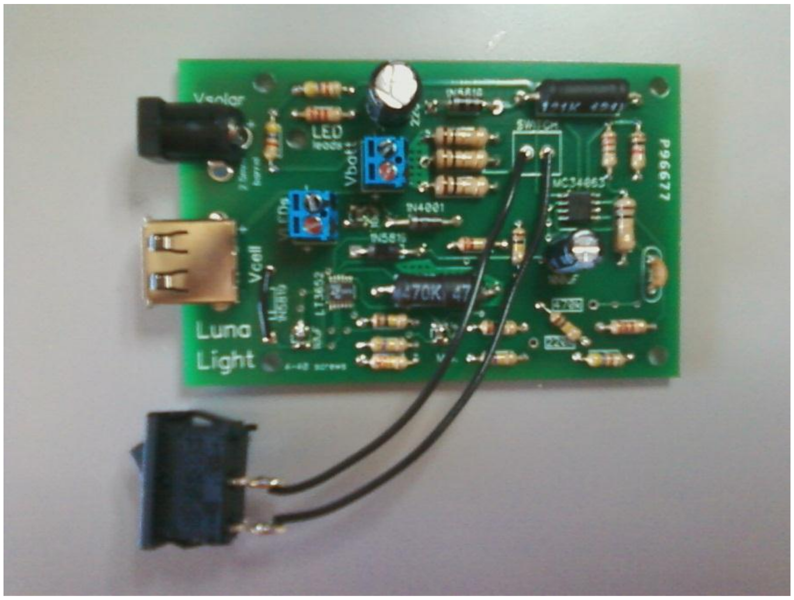


Fig. 15 Fully assembled PCB for the LunaLight, ready to be placed in the housing.

Cast Plastic Components for Housing

The SolidWorks components for the LunaLight housing were rapid prototyped (RPT) in ABS using a uPrint 3-D printer (Figure 16). The casting method was used to create the housing, diffuser and LED mount of the LunaLight project. A mold was created from each part using the Moldstar 30 Platinum silicone obtained from Smooth-On.

Fig. 16 LunaLight components made from rapid-prototyped ABS.

The outside face of each part was machined into a block of machinable wax (Figure 17). These machined parts had a better surface finish than the rapid prototyped parts, which gives a smooth surface texture to the final cast part.

Fig. 17 Front of the LunaLight machined out of wax.

The rapid prototyped and machined-wax parts are the basis for the mold. The frame of the mold was created using a granite slab and square wooden sections to create a boundary for the part (Figure 18a). Clay was placed on the inside and outside of the part as well as the wooden frame and granite piece to form a seal to prevent the liquid silicone from leaking outside of the mold. After the part was positioned correctly inside the frame, parts A and B of the silicone were carefully weighed and thoroughly mixed (Figure 18b). Liquid silicone was first poured over the machined-wax part then set aside to cure for twelve hours. Once cured, the mold was removed from the wax part, yielding the first

silicon mold. A rapid prototyped part was then placed into the silicone mold using clay to seal any gaps between the silicone and plastic part to prevent the parts from fusing together. Risers and a pour cup were added by attaching small glue stick rods to the surface of the part. The risers were placed in areas where air could potentially be trapped during casting. A release agent was sprayed on the surface of the silicone mold to prevent the two halves from bonding together. Silicone was then poured over the rapid prototyped part to create the second half of the mold (Figure 18c-d). This process was repeated for both the front and back of the housing. No machined-wax parts were used to mold for the diffuser or the LED mount, but a similar processing method was utilized. The diffuser was rapid prototyped using a different machine that has a smaller resolution, yielding a better surface finish.

Once the mold was created, the two halves were secured together with tape to prevent the mold from spliting apart and leaking during the casting process (Figure 18e-g). Parts A and B from Smooth-On 305 liquid urethane were mixed together and poured through a pour cup into the mold. The liquid plastic took seven minutes to gel, and a total of 30 minutes to fully cure (Figure 18h). After fully curing, these freshly casted parts were carefully removed from the mold. Seepage between the two halves of the mold created flashing along the parting line.(Figure 18i). A Dremel was used to smooth rough surfaces and remove the risers and pour cup. Holes were tapped into the posts of the housing to allow screws to secure the two halves together.

Fig. 18 Manufacturing process for the cast plastic components of the LunaLight.

The diffuser was molded the same way as the housing, pouring liquid silicone around the part until it cured, but the manufacturing process needed to be changed. Liquid urethane was placed in a vacuum chamber in order to draw the bubbles out of the liquid plastic, then it was poured into the mold. When the liquid urethane was removed from the vacuum, the remaining bubbles popped as it was poured into the mold. Once the part was finished curing in the mold, it was removed, and placed in an oven at low heat to finish the curing process. The surface was sand-blasted to improve the aesthetic and further diffuse the light.

How the Prototype May Differ from the Planned Design

There have been several changes since the creation of a prototype from the initial design. Initially, the diffuser was designed to be rounded out however, when the diffuser was printed there were flat spots, and the edges came together in points. Another issue was the size of the top handle. The initial design appeared proportional to the light, but in reality the handle was too small. Anyone using the handle could only fit three fingers through it at the most. It was awkward trying to hold the light with the handle comfortably due to this slight design flaw. The rounded design of the handle significantly reduced the space where one's hand would fit. The front slot seemed to work with the size of the strap used, but a problem arose when the light was placed on a flat surface.

The strap made the light off balance, causing problems when it needed to rest on a flat surface. The strap itself proved useful, but some problems with the size and color came up in the first trial run. Two sizes were tested, a three foot strap and a four foot strap. The three foot was too small, it could not fit comfortably around a person's shoulder. Whereas the four foot strap fit comfortable around the user. The decisions between what color buckle to use arose, white or black. It was decided that the white buckle looked cheaper and more fragile than the black did, so the black buckle was chosen in the final design.

The LED driver circuit was originally tested on a breadboard with the LEDs connected to an aluminum heat sink. The circuit was designed to run the LEDs at approximately 185 mA. Without a proper heat sink however, the LEDs run at a significantly higher current. With our current design having the LEDs attached to a urethane plastic mount, the equilibrium current is about 250 mA which may lead to a shorter life of the LEDs over time.

The battery charger circuit was designed off the datasheet assuming nominal voltage values from the batteries and solar panel. The actual battery charging performance was less than calculated, and some adjustments were made to the circuit. These adjustments included adjusting the maximum power point tracking of the solar panel, lowering the resistance of the current-determining sense resistor, removing the solar-protection Schottky diode (because the panel itself already came with a protection diode attached), and increasing the programmed float voltage. These adjustments increased the battery charging current from 90 mA to over 200 mA.

Battery placement in the first design was an issue due to the original orientation of the batteries. After the first design, it seemed best to buy batteries in a square block arrangement, where two batteries were placed side by side and a second row of batteries placed on top of that. This new arrangement saved room within the design, and aided in securing the batteries within the housing by being held snugly between the two sides of the housing.

The LED mount was held in place at the bottom with the battery pack, but the top had nothing securing it to the housing, so the next design had a flat post about 1.5" wide that held the LED mount in place. Posts were placed in four areas towards the corners of the light to secure the two halves of the housing from sliding. In the next design, these posts began to break off from the housing. This was largely caused by the layering method that resulted from the rapid prototype printing process. These layers created shear planes in the design, so they easily broke across these planes. The posts were redesigned to be thicker in diameter to prevent them from being broken off in the final design.

After the second iteration of the housing design, it was decided that a practice mold should be made in order to test the design's ability to be manufactured. This test run showed a few flaws in our molding process and housing design. First, the housing needed to incorporate a flat spot so a pour cup could fit within the design. The first run through showed that the pour cup created an undercut in the design. In addition, risers needed to be placed around the handle. The handle had some of the thinnest sections of the design, so any bubbles in the casting process would cause gaps and weak spots in the housing. The prototype also showed that the handle overall was too thin, and that the thin sections were cracking at low stresses. The handle was made thicker in some sections, and a ledge that was placed near the parting line was moved to the front half of the mold. This increased the amount of material on the front and helped diminish the thin sections in the handle.

Recommendations for Future Manufacturing of the Design

Future manufacturing and design of the LunaLight should be conducted on a large scale. This requires dies for injection molding, and buying materials in bulk. There is a high upfront cost to create the die out of tooling steel, but after the initial cost, the cost to produce a part dramatically reduces. The current method being used is appropriate for the time, money, and resources available. One benefit from injection molding is a quality uniform surface finish across the entire part. Each part takes a few minutes to make, and less machining time after the part is finished. This allows us to create more parts, in less time, for less money after paying the initial upfront cost.

Utilizing surface-mount devices (SMD) for the PCB would greatly improve the manufacturability of the lantern if the production quantity is scaled. Robotic pick-and-place machines can quickly populate a PCB designed with SMD. Automating this step of the production process is also important because it reduces the possibility of human error.

The components of the LunaLight would be manufactured in China, since this is the cheapest place to manufacture parts right now. Once produced, these individual parts would be sent in bulk to an

assembly center in local villages in Kenya. These assembly centers would hire local workers to take the parts sent from China and assemble them into a finished light. Lights would then be distributed to the final users from these centers. By going about this method, there are lower taxes on the materials coming into Kenya, since there is some assembly required. Assembly centers in Kenya will help the local economy by creating jobs in the area.

Cost Estimation for Future Production

Cal Poly has the equipment capability for large production quantities of PCBs, including a solder paste machine, pick-and-place machine for tape-and-reel SMD, and a reflow oven. The costs for future production include about $200 for a stainless steel stencil for the solder paste machine, along with solder paste and flux. The pick-and-place machine must be programmed, but once properly set up it can populate the PCBs quickly and without mistakes. The PCBs would then be sent through the reflow oven, whose conveyor can accept a new PCB every 15-20 seconds.

An alternative approach to mass-production would be to outsource the PCB production to an assembly house in China that would manufacture and assemble the boards for a fraction of the cost. A reputable manufacturer would need to be found to ensure product quality.

The current material costs total at about $84 for a LunaLight. These costs do not account for any labor or shipping costs. If the housing was formed by injection molding and the PCBs were ordered in larger quantities, then the material costs would drop significantly. Including shipping, the total cost of a LunaLight shipped to Africa is around $100.

The ideal way to manufacture the LunaLight would be to machine a die and injection mold the housing, diffuser and LED mount on a large scale. This would produce thousands of parts at the lowest price. The problem with this method is that it takes a lot of money to buy the machines and the dies.

Other parts such as the batteries, LEDs, solar panels, printed circuit boards and wiring for the all the connections will be purchased in large quantities. The prices for individual components are relatively double the price of each part if the parts are bought in quantities in the thousands.

To determine the costs of each part for injection molding, the SolidWorks files were sent to a company called Protomold, which provides quotes on injection molded parts depending on the size of a part and the amount of parts desired. The prices of these dyes are cheaper than other companies because these are created out aluminum, so the benefit is that this company can produce injection molded parts at a relatively cheap price. The tooling costs are cheaper for aluminum, but the downside to this is that each dye produces a couple thousand parts before it wears out. The price of each dye is between $3,200 and $5,500, depending on the part. The current method using silicone molds produce around a hundred parts at a cost of $7.50 for the material for one LunaLight. The estimated total price using parts produced by injection molding are $14.03 for all the parts total, counting the diffuser, LED mount and housing.

Chapter 6: Design Verification

This chapter outlines the testing procedures along with the results from each test. A specification verification checklist revisits the initial functional requirements and discusses which of these requirements have been met and which requirements were not met.

Test Descriptions

Solar Panel Testing Procedure

A method for testing the I-V behavior of the 2.5-W SinoSola solar panel with ¼-W resistors was developed to characterize the power output of the panel. The procedure is as follows:

1. Obtain resistors from 0.1 – 250 Ω rated for at least 2.5 W. This may involve connecting several resistors in parallel that are rated ¼-W apiece. (2.5 W/0.25 W = 10 resistors).
2. An example set of resistors could include 0.1, 1, 5, 10, 15, 20, 25, 30, 40, 50, 75, 100, 150, 200, and 250 Ω. The maximum power condition may occur when the resistor is 20-40 Ω, so using many resistors within this range should yield best results. Using an ohmmeter, measure the actual resistance of each resistor and place these values in the first column of a table.
3. Connect the +/- leads to an ammeter wired in series, point the solar panel so that it appears perpendicular to the sun, and fix the solar panel at the precise angle that provides the largest current. Record this current, which is the short circuit current (I_{SC}, in mA).
4. Next, wire a voltmeter in parallel to the +/- leads of the solar panel. Follow the same procedure as part three, and record this voltage as the open circuit voltage (V_{OC}, in V).
5. Using a light meter, measure the illumination upon the solar panel (in klx).
6. Starting with the smallest resistor, wire one of the resistors in series by connecting the ends of the resistor to the +/- leads of the solar panel (Figure 19). Using a voltmeter wired in parallel across the resistor, record the voltage across the resistor (in V).

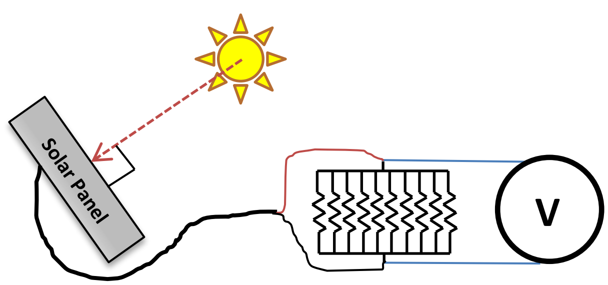


Fig. 19 Diagram of the solar panel testing set-up with ¼-W resistors wired in parallel.

7. Repeat Step 6 for each resistor, making sure that the solar panel remains pointed perpendicular to the sun. Taking measurements quickly ensures the most consistent sunlight.
8. Once all voltage measurements have been taken, calculate the current using Ohm's law (V=IR) and record these values in the table.
9. Calculate the Power, in W, using the formula P=IV and record these values in the table.

10. Plot the data in Excel, with voltage along the x-axis, current along the primary y-axis, and power along the secondary y-axis. See the example I-V curve below for a single cell (Figure 20).

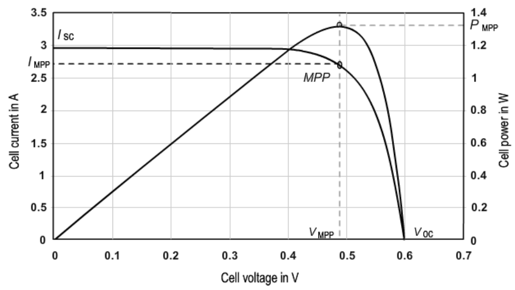


Fig. 20 Example I-V and power output behavior of a single solar cell.

11. The maximum power point (MPP) of the solar panel is the peak of the P-V curve. Record the maximum power (P_{MPP}), as well as the voltage (V_{MPP}) and current (I_{MPP}) at this point.
12. Compare the real V_{OC}, I_{SC}, P_{MPP}, V_{MPP}, and I_{MPP} to the specifications provided by the manufacturer.

Battery Duration Testing Procedure

The purpose of the battery duration tests was to compare the behavior of the different battery brands we ordered. The tests were performed by fully charging the batteries with a wall charger, placing the charged batteries in the LunaLight, turning the LEDs on, and recording data in intervals until the batteries ran out. The target light duration in the functional requirements was 6 hours.

In each test, measurements were recorded about every 15 minutes. A handheld ammeter was connected in series with the LEDs, and a handheld voltmeter was used to measure voltages across the batteries and the LEDs (Figure 21).

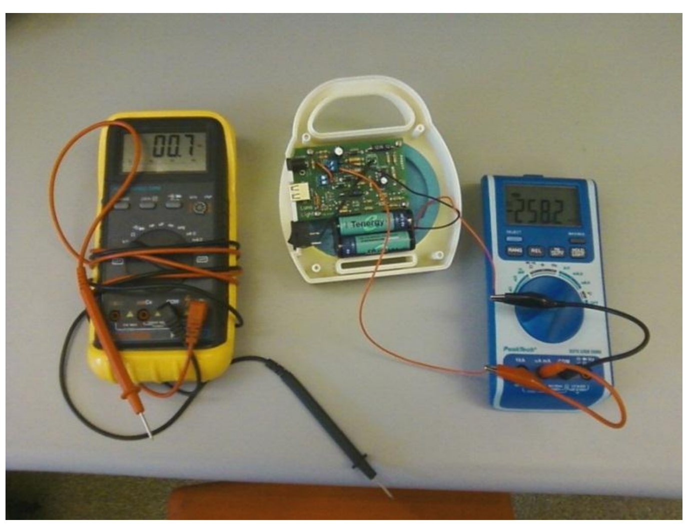


Fig. 21 Equipment used for the battery duration tests.

The LED current remained relatively constant throughout the test, and dropped about 50% within 15 minutes, indicating the end of the battery capacity. The LEDs were switched off once they had noticeably dimmed, and the battery voltage had dropped below 3 V.

Solar Battery Charging Tests

These tests were performed on sunny days with clear skies. The solar panel was mounted normal to the sun's rays, and the illuminance hitting the panel was measured with a light meter in klx. Direct sunlight on a cloudless day typically provides about 120 klx. A handheld multimeter was used to measure the open circuit voltage and short circuit current of the panel (Figure 22).

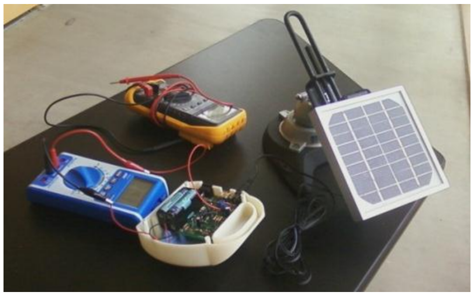


Fig. 22 Set-up for the solar battery charging tests.

The handheld ammeter was connected in series with the battery pack to measure the amount of current charging the batteries. Before the solar panel was plugged in, the amount of leakage current from the batteries was measured in µA. The solar panel was then plugged in, and the battery charge current was measured in mA.

Cell Phone Charging Tests

In the proof-of-concept design from summer 2011, it was found that cell phones will recharge when provided with a 5V DC output. To test the cell phone charging capability of the LunaLight, different cell phone types were plugged in using the universal USB adapter (Figure 23). The iPhone pulled about 273 mA from the batteries, and a Samsung phone pulled about 317 mA. The internal charging circuitry within the phone generally determines the charge current.

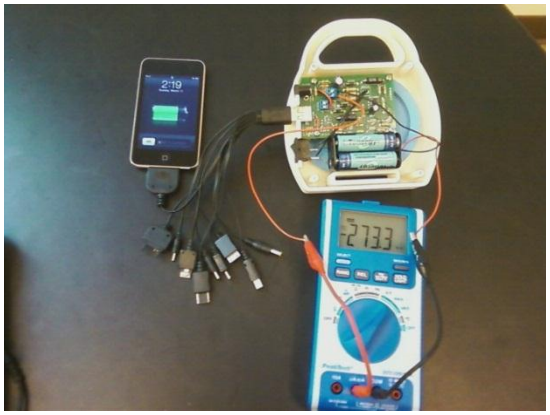


Fig. 23 Charging an Apple device with the LunaLight.

Light Attenuation Testing

In order to get an accurate idea of the amount of light loss from various angles of the light, a light attenuation test was created to obtain experimental data. It is important to observe the difference in the amount of light that is being emitted so that one can orient the light to obtain the best luminance.

1. Obtain a rotatable stand, light meter, ruler and the LED mount with attached LEDs.
2. Secure the LED housing on a rotatable stand.
3. Position the light meter so that it is 12 inches away from the mounted LED, and perpendicular to the mount (Figure 24).

Fig. 24 Set-up for light attenuation testing.

4. Limit the amount of ambient light by turning off the lights in a room and drawing the shades. Calibrate the light meter by zeroing it when the lights are off.
5. Turn on the LEDs and record the illuminance with and without the diffuser at the angles shown in Figure 25.

Fig. 25 Labeled diagram showing the angles at which the light measurements were taken from 12 inches away.

Light Distribution Testing

A method for determining the light distribution of the LunaLight with the diffuser on was developed. The purpose of this test was to view the range of luminance that the LunaLight emits on a plane located normal to the LEDs at a distance of two feet away. The procedure is as follows:

1. Fix the LunaLight, facing a whiteboard, at a distance of two feet away (Figure 26).

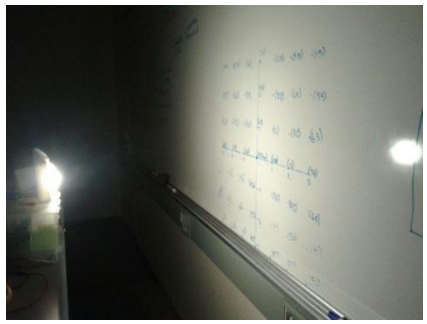


Fig. 26 The LunaLight positioned 2 feet from the whiteboard.

2. Draw a two-foot x-axis across the whiteboard followed by a two-foot y-axis, intersecting the x-axis at its midpoint. Make sure the (0,0) coordinate is located directly normal to the LEDs so that it will be the brightest point of illuminance when the light is turned on.
3. Draw points on the graph 4 inches apart, starting from the (0,0) coordinate, to fill the entire four quadrants. There will be a total of 49 points (Figure 27).
4. Turn on the LunaLight and measure the illuminance (in lux) at each point with a light meter.
5. Record data in excel and develop a 3D graph for ease of viewing the luminance at the various distances from the origin.

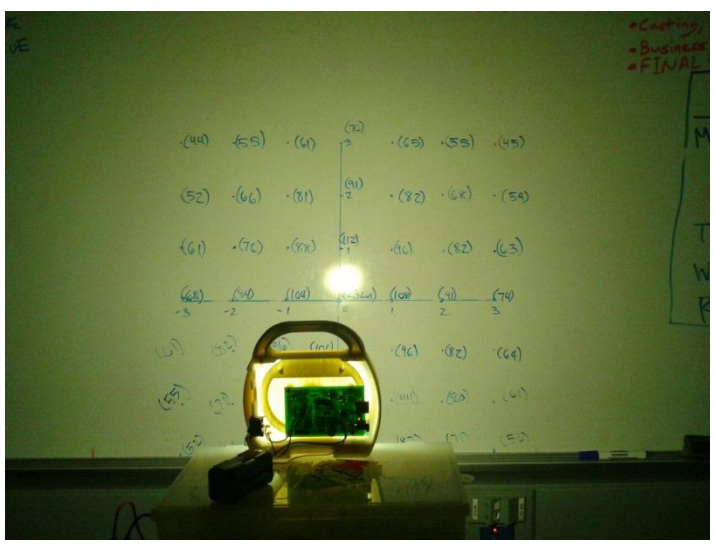


Fig. 27 The LunaLight illuminating the coordinate system on the whiteboard.

Detailed Results

Solar Panel I-V Characterization

The solar panel I-V behavior was plotted in Excel to find the maximum power point (Figure 28).

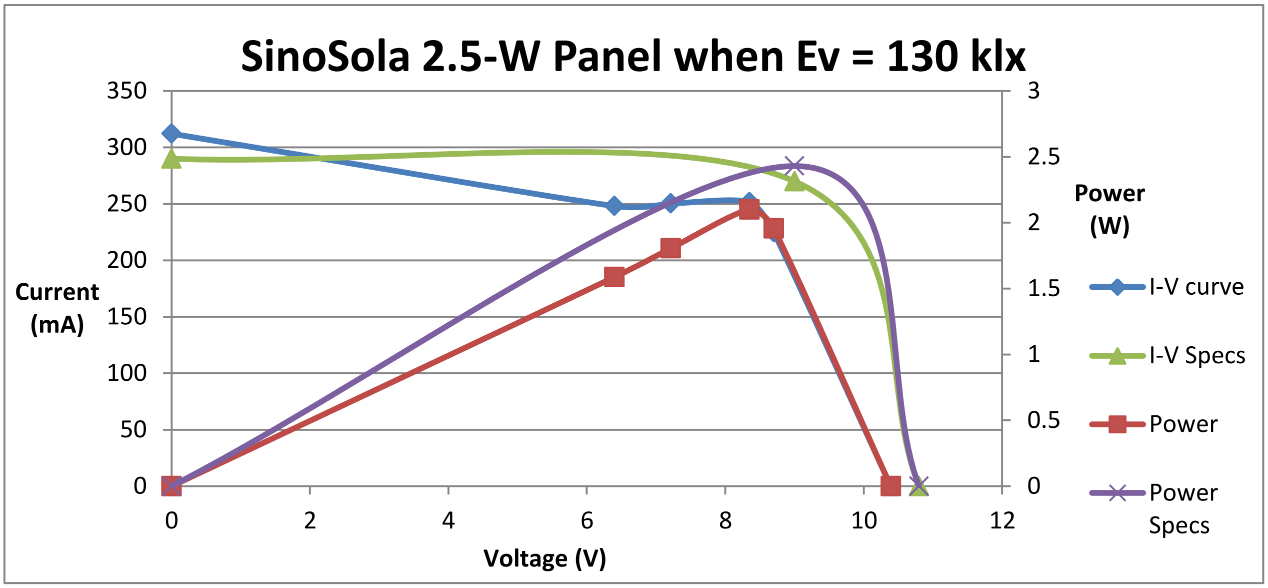


Fig. 28 The measured I-V and power curves compared to the manufacturer specs.

The manufacturer (SinoSola, in China) claims a maximum power point voltage of 9 V and maximum power of 2.5 W, with output tolerances of ±10%. The measured maximum power point voltage was 8.3V, which provided 2.1 W of power. The illuminance of the sunlight on the solar panel (measured in klx, or 10^3 lux) was 130 klx, a typical illuminance value for a sunny day with clear skies.

Battery Duration Results

The 4 types of NiMH batteries tested aided in the selection of the best battery for the LunaLight. Table III summarizes the results of the tests.

Table III The HiTECH 2100mAh and Tenergy 2000mAh outperformed the other two NiMH batteries.

Brand	Capacity (mAh)	Nom. Voltage (V)	Duration (hrs)	BOM Cost
ULTRALAST	1800	5	5.25	$16.59
HiTECH	2100	5	8.00	$9.39
Tenergy	2000	4.8	7.25	$7.99
Tenergy	2600	4.8	7.00	$6.78

An example of the battery and LED driver behavior over time is shown in Figure 29. In this test, the LEDs were kept on over 90 minutes after they began to dim. The boost circuitry provides a constant

voltage to the LEDs even as the battery voltage and current slowly decline. The sudden drop in LED current after 7.25 hours coincides with the point where the battery voltage begins to drop. Although the LED current approaches zero as the LEDs dim further, the battery voltage remains at about 2V. It is not recommended to maintain the batteries at this low of a voltage for long periods of time because they may fall into a state of "deep discharge" in which they cannot be recharged to their full capacity again.

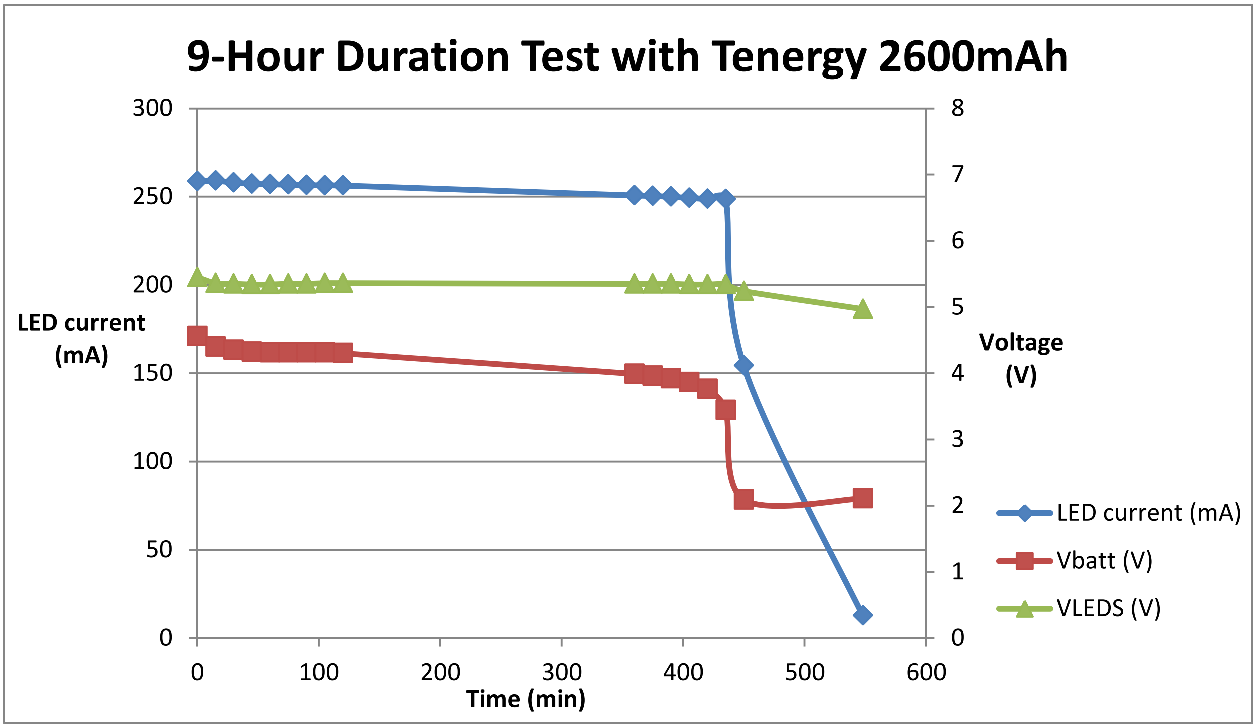


Fig. 29 The LED current, LED voltage, and battery voltage throughout a 9-hour test of Tenergy 2600mAh NiMH

Solar Battery Charging Results

Before performing the solar battery charge test, the leakage current from the batteries was measured to be 12 µA. This would theoretically take 19 years to drain a battery with a 2000mAh rating. Realistically, the NiMH batteries would self-discharge faster than this. Most NiMH batteries typically lose about half their charge when stored without use for a year.

The solar panel should be charging the batteries with at least 250 mA in full sunlight. However, the LT3652 circuit needed adjustments in order to provide sufficient current into the batteries. Initially, the circuit put 90 mA into the batteries in full sunlight, 36% of the theoretical maximum current. The maximum power point tracking (MPPT) resistor was changed from 235 kΩ to 194 kΩ, which increased the current to 125 mA, or 50% of the theoretical maximum.

It was then observed that the SinoSola panels come with a protection diode already installed into the back casing of the panel. By removing the extra protection diode on the PCB, where there was a

measured voltage drop of 0.296V, the current was increased to 190 mA, or 76% of the theoretical maximum.

The resistor programming the float voltage was changed from 620 kΩ (for a float voltage of 5.54V) to 570 kΩ (for a float voltage of 5.73V). This increased the current to 208 mA, or 83% of the theoretical maximum.

Increasing the programmed float voltage further may increase the battery charge current, but one must be cautious not to put too high of a voltage across the batteries. This could potentially damage the battery cells.

It was found that the battery charging current decreases as the battery node reaches the programmed float voltage. There is still some battery-solar panel interplay that must be fine-tuned in order for the batteries to be fully charged in a single day from the solar panel.

Assuming a 67% efficiency of converting input current to stored charge, putting 250 mA into the Tenergy 2000mAh batteries will charge them in 12 hours. Putting 208 mA into the batteries will take 14.4 hours to fully charge the batteries. Because of this, the user will get less than 7.25 hours of LED light on a full day's charge.

By comparing an ammeter connected in series with the solar panel (showing 184.6 mA) to an ammeter connected in series with the batteries (showing 171.4 mA), it was found that the LT3652 is about 93% efficient in converting current from the solar panel into current charging the batteries. To achieve the maximum power, the circuit needs to apply the correct load on the panel, at which it is only about 85-88% efficient.

Results from Light Attenuation Test

The results from the light attenuation test are shown in Table IV.

Table IV The areas of maximum light attenuation are the far left and right of the diffuser, where the diffuser wall is furthest from the LEDs.

Position	Illuminance (lux) from 12 inches away		% Lost from Attenuation
	Without Diffuser	With Diffuser	
1	46	44	4.3%
2	372	297	20.2%
3	428	401	6.3%
4	405	389	4.0%
5	69	66	4.3%
6	171	89	48.0%
7	257	232	9.7%
8	273	253	7.3%
9	150	104	30.7%

Results from Light Distribution Test

A 3-D surface chart was made in Excel to display the light distribution results (Figure 30). This graph shows the light distribution of the LunaLight at a distance of two-feet away from a flat surface. The brightest point of the light is located at the (0,0) coordinate and was measured to be 123 lux. The darkest points on the graph were located on the extreme corners of the graph. These measured values ranged from 44 to 56 lux.

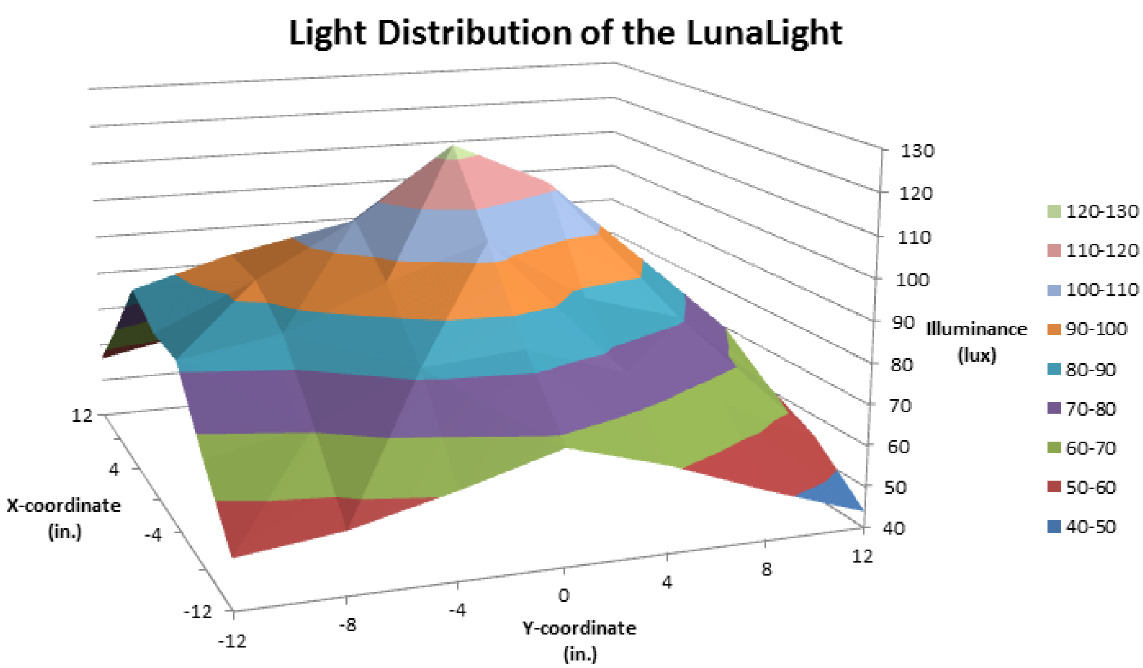


Fig. 30 A 3-dimensional surface chart showing the illuminance provided by the LunaLight from 2 feet away.

Specification Verification

The following checklist revisits the functional requirements and determines which specifications were met, not met, or exceeded (Table **V**).

Table V The functional requirements of the lantern compared to the actual performance.

Component	Specification	Met?
Battery	Power the LEDs for 6 hours on a full charge	Exceeded (7 hrs)
	Easily accessible in the housing, simple connection to the PCB	Met
LED	Illuminance of 100 lux from 2 ft. away	Met
	Light spread out in an angle >135°	Met
	Sufficient heat sink to prolong LED life	Not Met
	Warm or Neutral White color temperature	Met
PCB	LED driver provides constant current to LEDs	Met
	Deep discharge protection	Not Met
	"Vampire current" less than 15 μA	Met
	Charges batteries from solar panel in 10 hours or less	Not Met (15-20 hrs)
Optics	Diffuser softens the light and reduces LED glare	Met
	Reflector minimizes amount of "lost photons"	Not Met
Housing	Resistant to light rain	Met
	Withstands drop from 8 feet	Not Tested
	Ports are covered to reduce humidity/dust damage	Not Met
	Handle or strap for comfortable carrying	Met
	Sleek form factor, no sharp edges	Met
Cell Phone Charger	Accommodates 3 most common cell phone interfaces	Exceeded (10 total)
	5V DC output with a USB female port	Met
Solar Panel	Theoretically can charge the battery in less than 10 hours	Not Met (12 hrs)
	Similar dimensions to light for compact packaging in box	Met
Misc.	Packaged in a box with inner dimensions 6"x6"x4"	Met
	Simple design, could be assembled locally	Met

Chapter 7: Conclusions and Recommendations

This chapter concludes the report by summarizing some of our findings and providing recommendations for the continuation of the project. The project will be continued in spring 2012.

Manufacturability of Housing

For small production quantities, plastic casting is a good procedure for manufacturing the housing. Because the rapid-prototype machine has a resolution of 0.01”, the lines of material from the printer are noticeable. To obtain a good surface finish and parting line on the cast part, it is recommended to machine a wax mold frame for the part, as was done with the LunaLight front and back components of the housing.

Functionality of the PCB

The successes of the PCB are as follows:

- There were no mistakes made in the layout connections
- All the components were dimensioned and hole tolerances were met
- The LED driver puts a constant current into the LEDs throughout the battery life
- The battery charger circuit directs current into the LEDs
- The leakage current is only 12 µA

The deficiencies of the PCB are as follows:

- The LT3652 circuit does not put a full 250 mA into the batteries
- There is no deep discharge protection built into the circuitry; it is the responsibility of the user to turn off the lantern when the LEDs have dimmed
- The USB port is a simple DC connection to the 5V battery pack; there is no regulation of the cell phone charging current

PCB Revision Recommendations

Before the LunaLight is ever mass-produced, there are some design improvements that should be made to the PCB. These improvements will improve the product performance and enhance the user experience with the LunaLight lantern (Table VI).

Table VI Several future considerations for the PCB design, ranked by level of urgency.

Urgency	Improvement	Description
High	ESD Protection	Electro-static discharge can lead to the failure of IC chips and can be prevented by strategically placing capacitors between inputs and the ICs, allowing a static charge "lightning bolt" to travel to the ground node without harming important devices
	Undervoltage lockout	Prevent the batteries from entering deep discharge by switching off the circuit once the battery voltage falls below a certain amount
	USB current regulation	The circuit should follow the USB standard either for a 5V output with either a) 500 mA or b) 1000 mA of current
Medium	SMD components	Improves manufacturability and reduces human error when all the components are surface-mount; thru-hole components are better for hobbyists or those without much soldering experience
	Multiple brightness settings	High brightness, low brightness, and off; this can be accomplished with a push button and PWM driver or a slide switch with a few transistors designed into the boost circuitry
Low	Battery fuel gauge	LED indicator tells the user when the battery is charged; also, an indicator could show how well the battery is being charged by the solar panel at any given moment
	Mount LED onto PCB	Takes care of heat sink problem if thermal vias are designed into the PCB; improves manufacturability and assembly

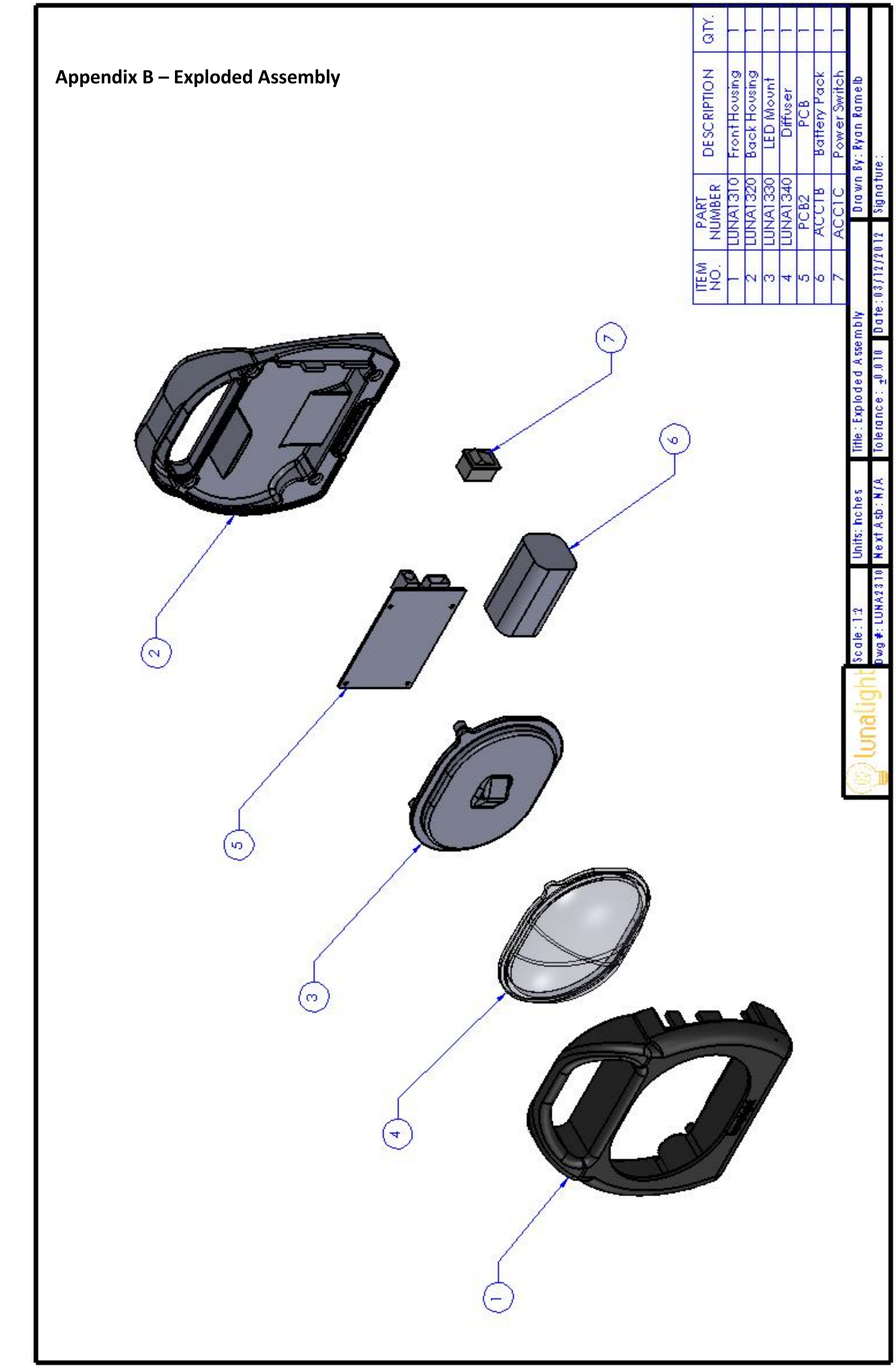
References

1) Grüner, Roman. "Solar Lantern Tests." Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ). May 2009.
2) Machala, Mike. *Kerosene Lamps vs. Solar Lanterns*. Stanford University, Fall 2011. Nov, 19, 2011. < http://large.stanford.edu/courses/2011/ph240/machala1/>

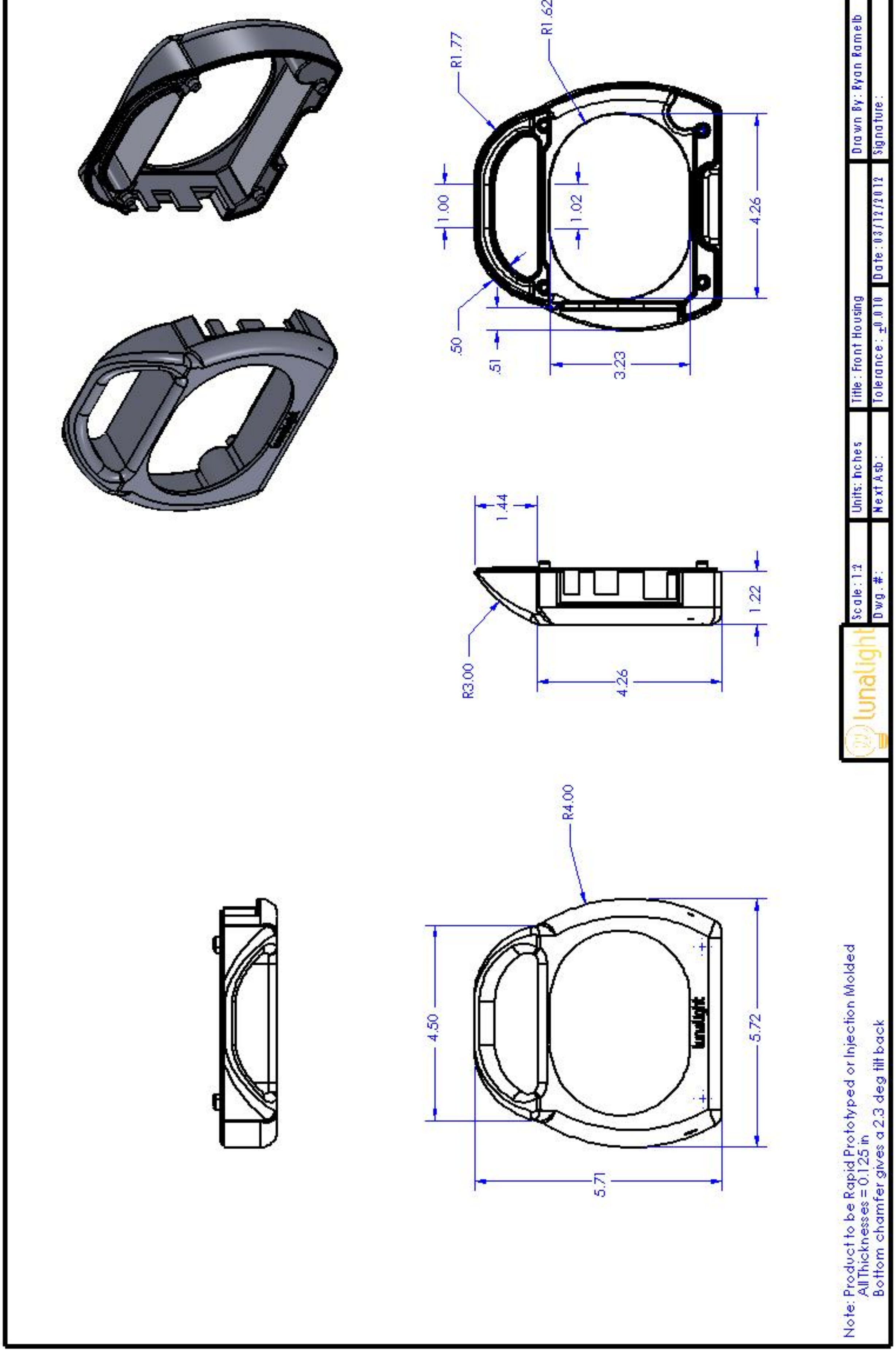
Appendix A – QFD Matrix

Attribute	Weight	Measurable Objective
Operation - **Duration of light** - **Cell phone charging** - **Solar recharging**	15%	6 hours of light from full battery charge Charges cell phone in 1-1.5 hours Recharges from solar panel in one day of sunlight (8-12 hours)
Quality of Light	5%	Neutral/Warm (Color temp: 3000-4500K) Diffuser to soften light and reduce glare
Durability - **Impact Resistance** - **Water Resistance**	10%	Withstands drop from 8ft Resistant to light rain Few (if any) moving parts
Ergonomics/Portability	10%	Handle for carrying the lantern Ability to hang lantern from a belt or strap
Shipping Ability - **Weight** - **Volume**	15%	Shipping weight <2.5 lbs (1.13 kg) Corrugated box 6"x6"x4" (75% volume of d.Light S250 box)
Safety	10%	No sharp corners Battery overcharge protection
Manufacturability	10%	Manufacturable in quantities of 25-50 Simple assembly Minimal number of screws
Aesthetics	10%	Sleek, unique design, rounded edges
Cost	10%	$50-60 BOM for quantities of 25-50
Schedule	5%	Quick mock-up prototypes by 1/28/12 Final design by 3/9/12

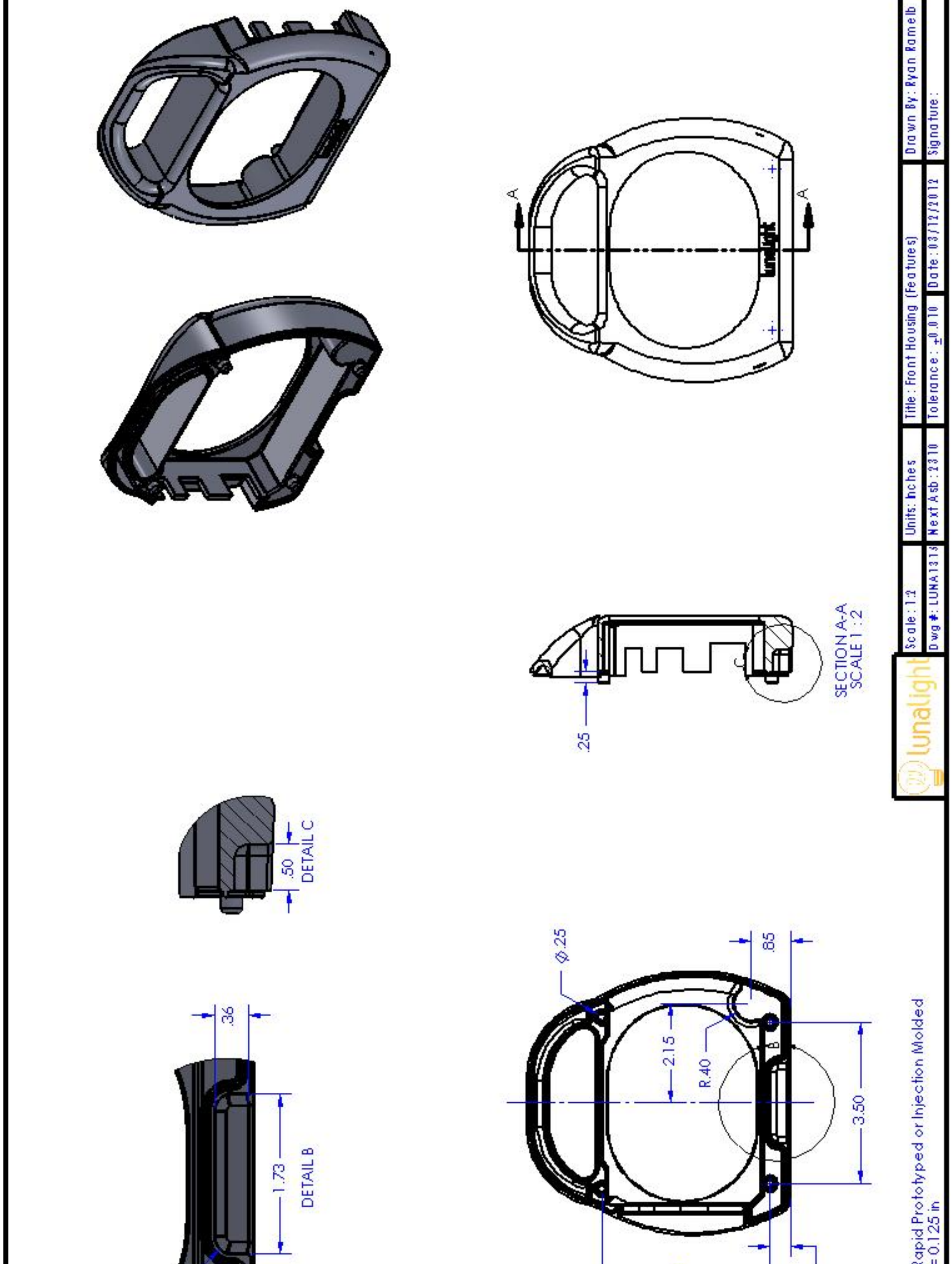
Appendix B – Exploded Assembly



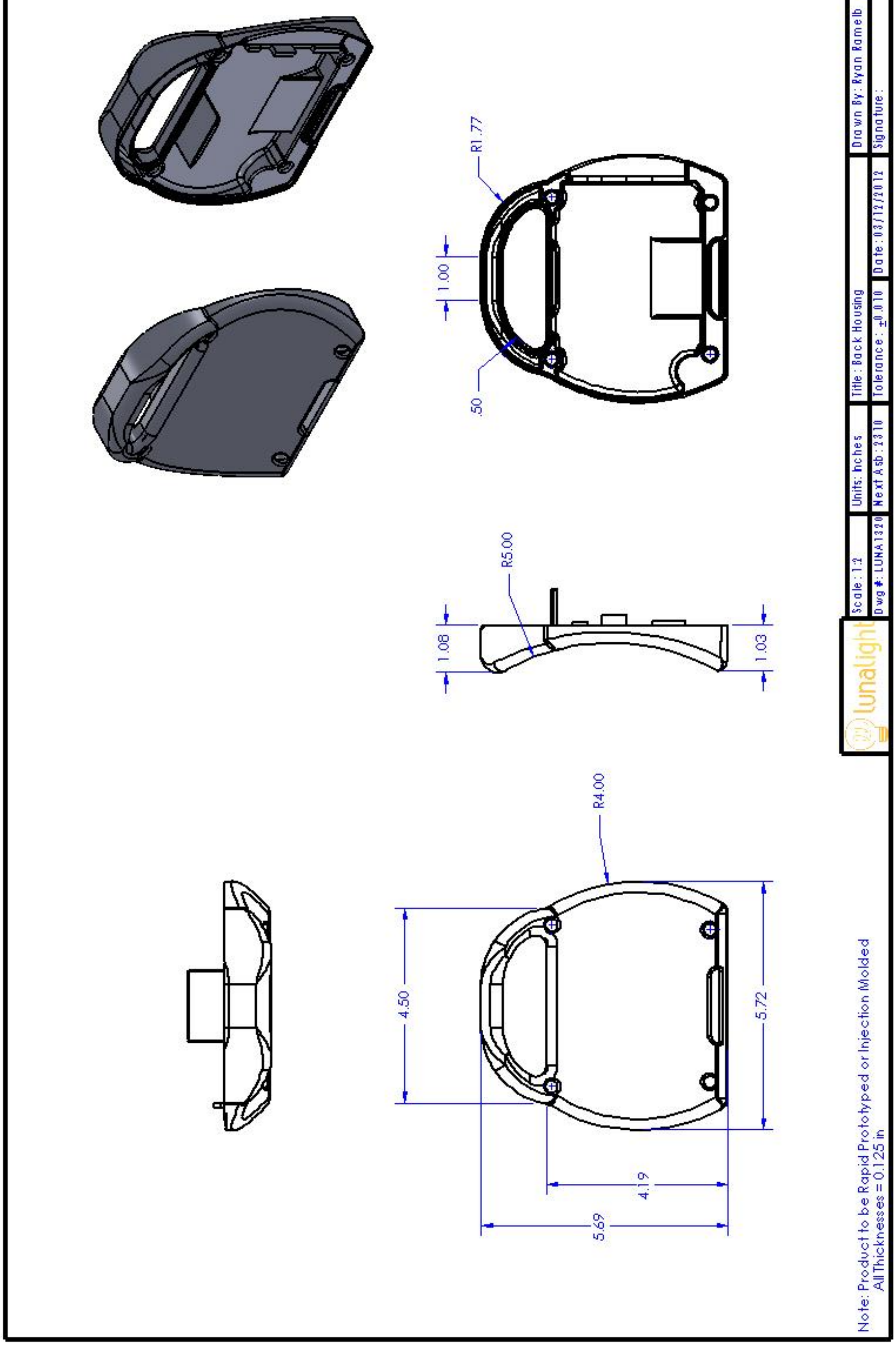
Appendix B – LunaLight Front



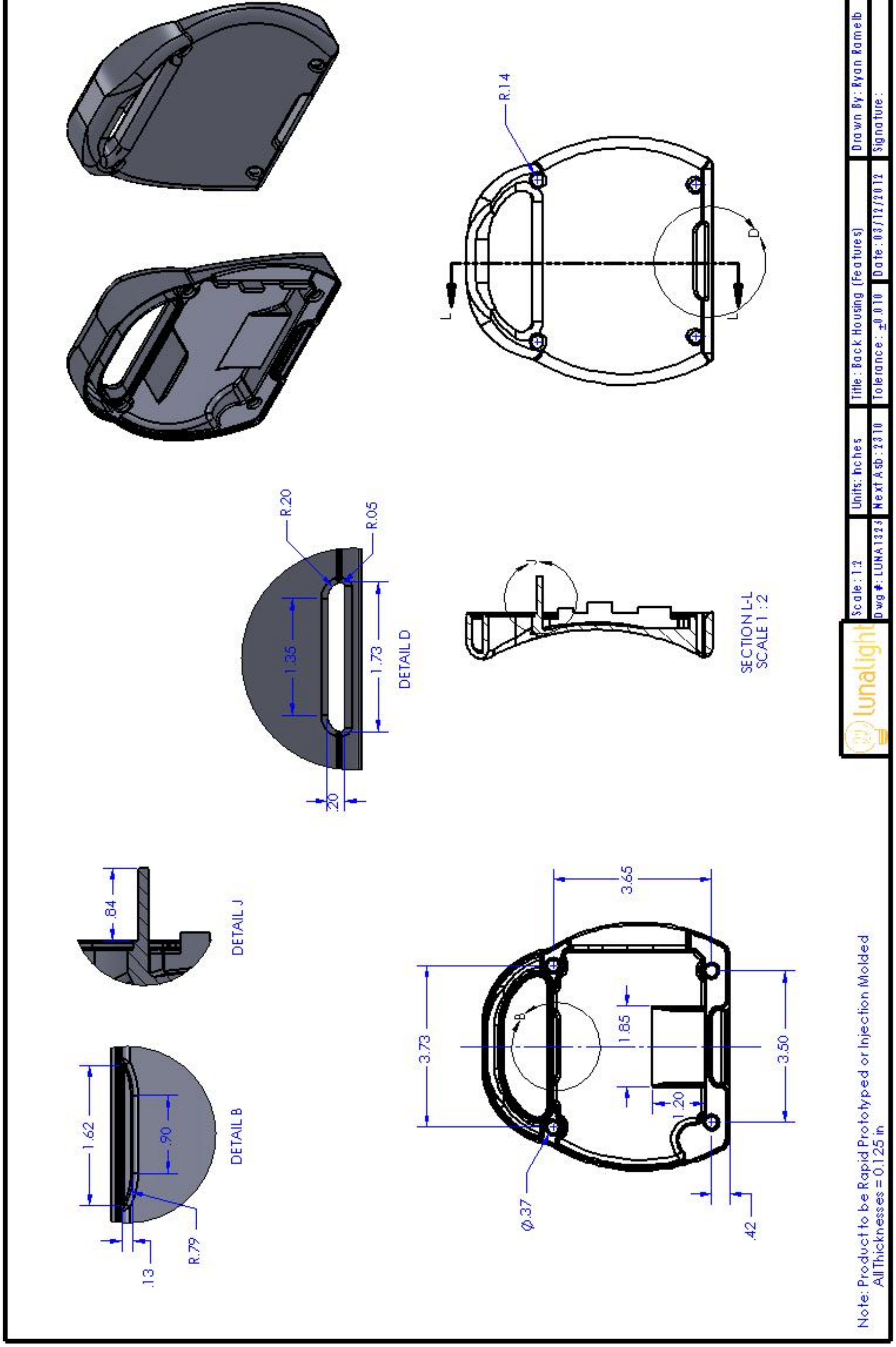
Appendix B – LunaLight Front, Detailed



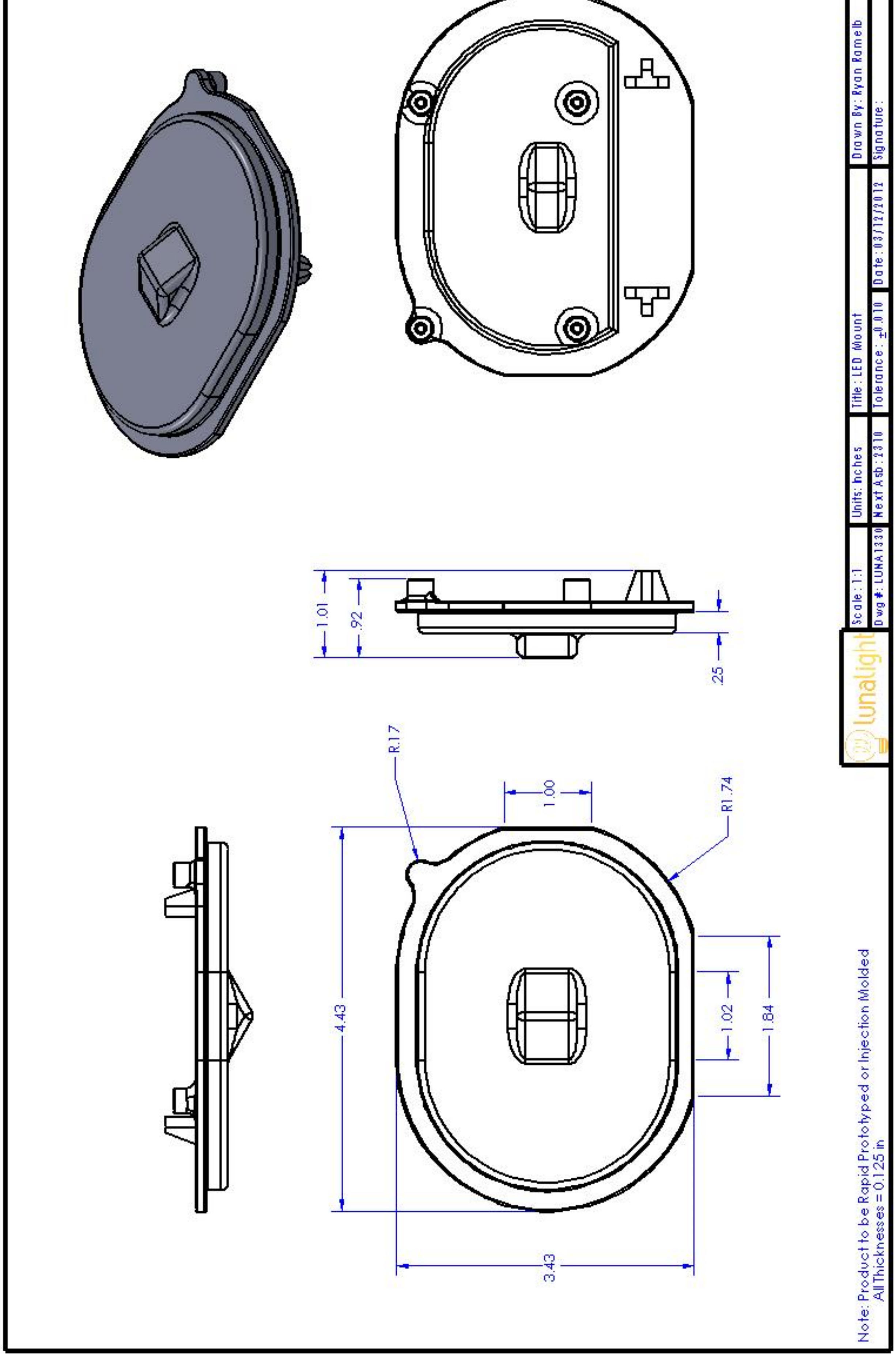
Appendix B – LunaLight Back



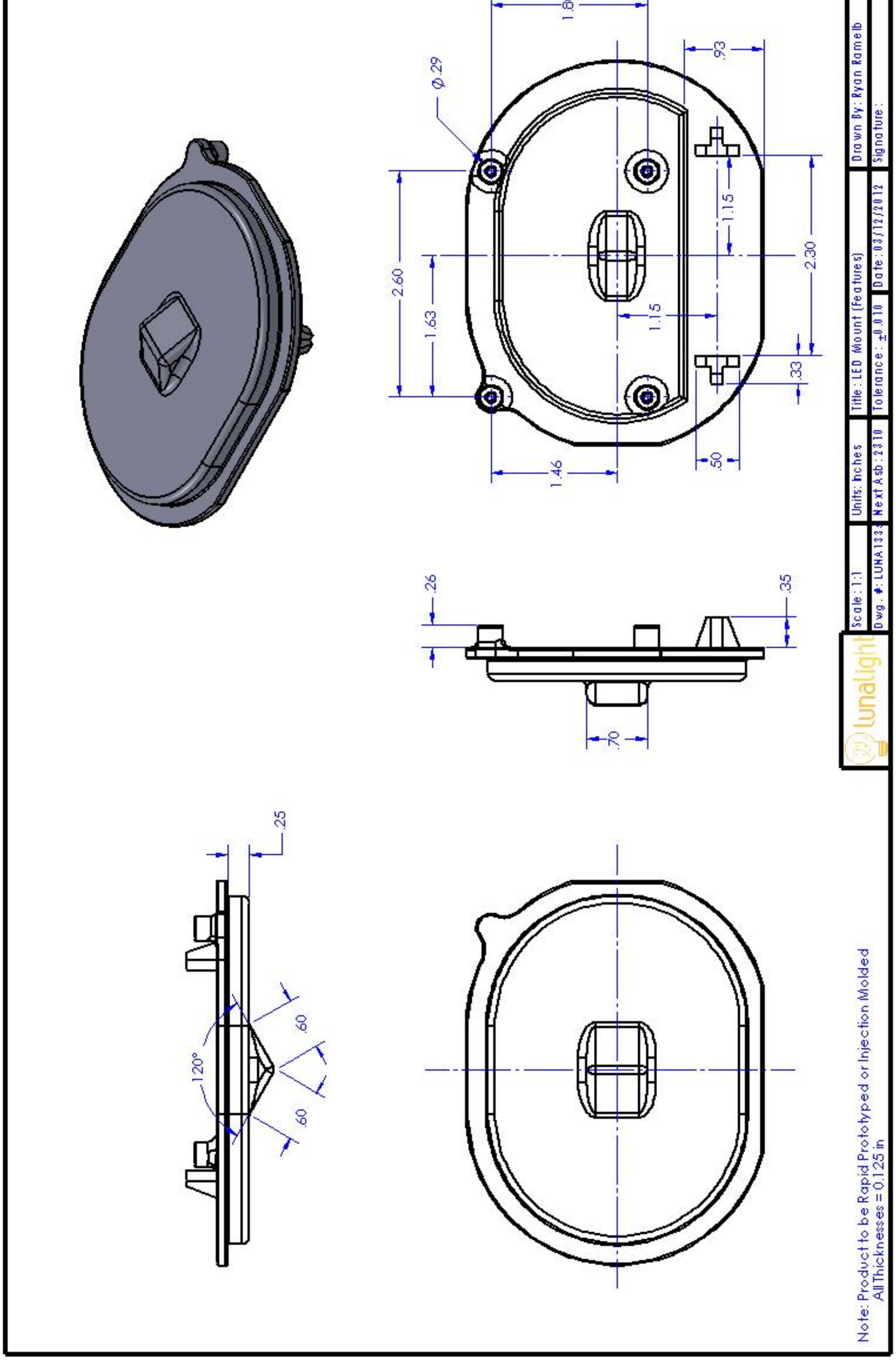
Appendix B – LunaLight Back, Detailed



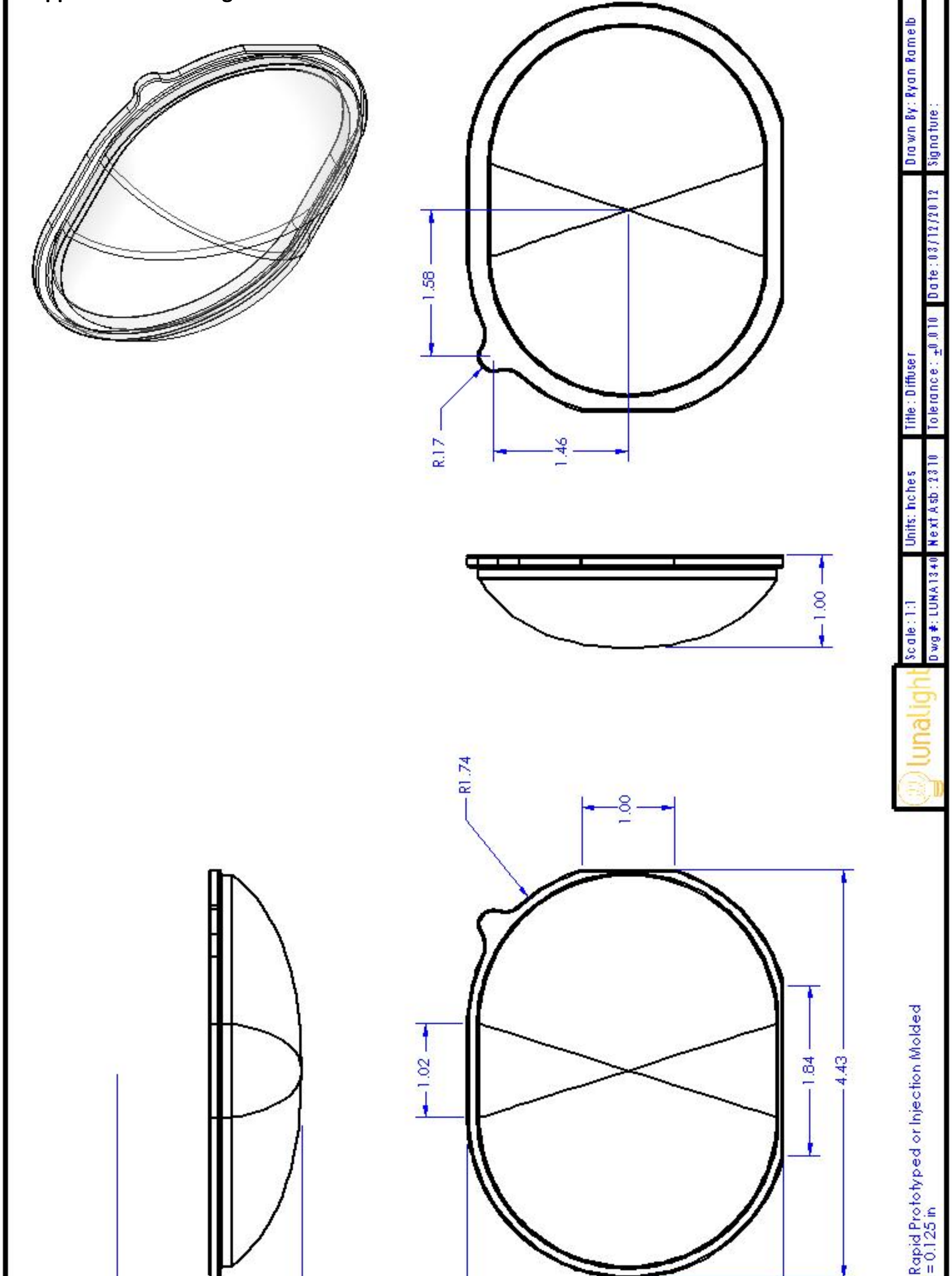
Appendix B – LunaLight LED Mount



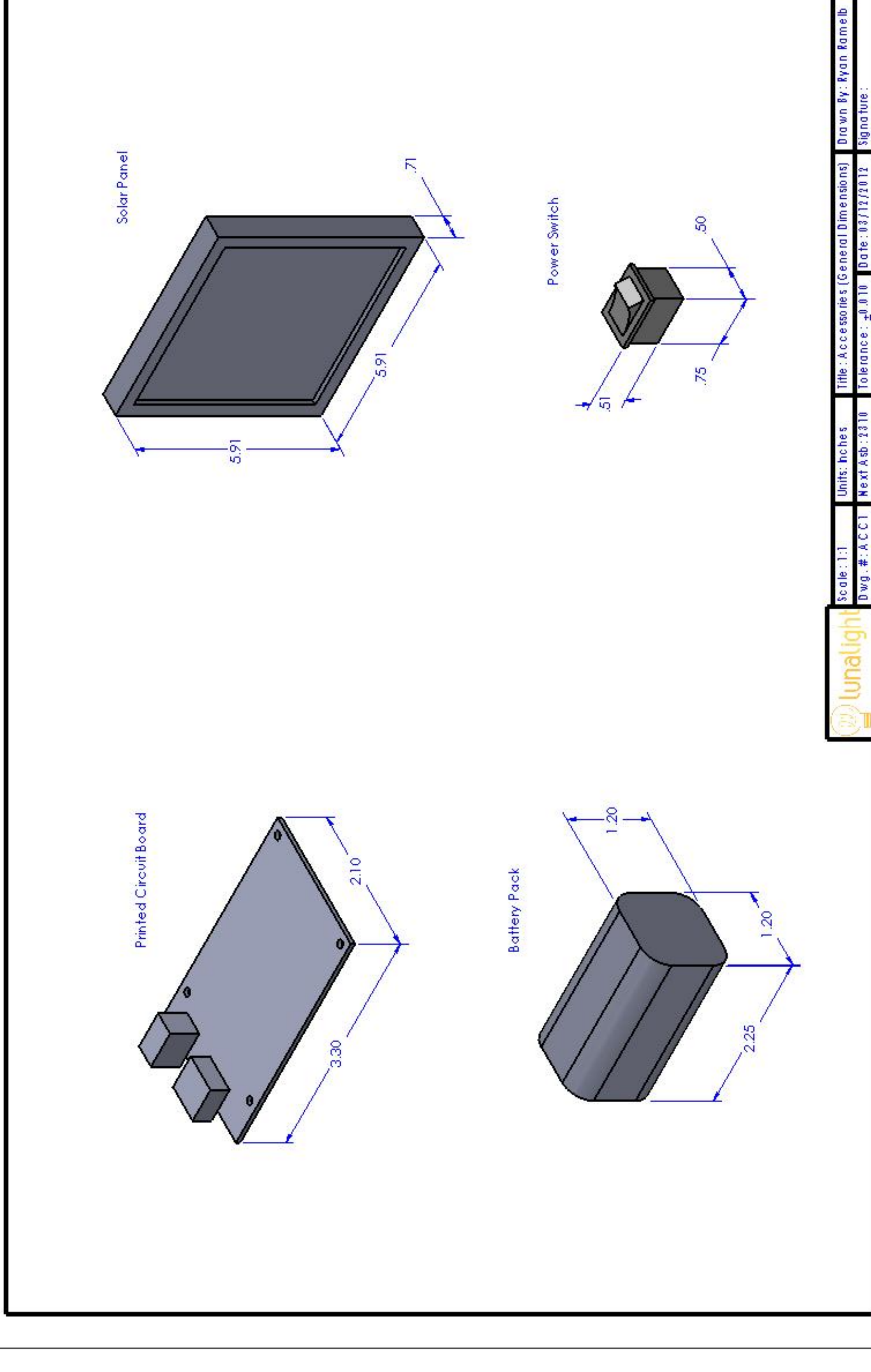
Appendix B – LunaLight LED Mount, Detailed



Appendix B – LunaLight Diffuser



Appendix B – LunaLight Accessories



Appendix B – BOM

Bill of Materials
Project: LunaLight
Date: Mar. 11, 2012

Item No.	Description	Part No. (manufacturer)	Drawing No.	Supplier	Qty. (per unit)	Wt. (ea., g)	Total wt. (g)	Cost (ea.)	Total Cost	Notes
1	2.5-W solar panel, 150x150x18mm	SA2.5-18 (SinoSola)	ACC1A	Energy Efficient Products, Inc.	1	361.2	361.2	$13.50	$13.50	cost lowered to ~$10 if purchased in larger quantities from manufacturer
2	Neutral White (4100K) Rebel LED, pre-mounted on Saber 10mm square base	LXML-PWN2 (Philips Lumileds)		Luxeon Star LEDs	2	0.3	0.6	$8.57	$17.14	LEDs are $5.82 each and Saber 10mm MCPCBs are $0.68 if ordered separately
3	NiMH battery, 2600mAh, "AA", 1000 recharge cycles	10308 (Tenergy)		All-Battery.com	4	26.1	104.4	$1.45	$5.80	$1.31 each in qty. 100+
4	4-AA battery holder, 2x2 square	BH-343-1A-R (Jameco ReliaPro)	ACC1B	Jameco Electronics	1	9.4	9.4	$0.79	$0.79	$0.65 in qty. 100+
5	1-1/2" Lightweight Propylene side release strap, 4'	SRBS112L (Strapworks.com)		Strapworks.com	1	49.9	49.9	$2.90	$2.90	25% off in qty. 51-150
6	10-in-1 Mobile Phone USB Adapter	B0049ME3BM (CellularFactory)		Amazon.com	1	38.9	38.9	$3.23	$3.23	ordered from Amazon
7	LED Mount, cast urethane plastic	LunaLight_Mount	LUNA1330	Smooth-On (plastic, silicone)	1	37.4	37.4	$1.00	$1.00	Mold cost amortized over 50 uses
8	LunaLight housing (front), cast urethane plastic	LunaLight_Front	LUNA1310	Smooth-On (plastic, silicone)	1	110.1	110.1	$2.50	$2.50	Mold cost amortized over 50 uses
9	LunaLight housing (back), cast urethane plastic	LunaLight_Back	LUNA1320	Smooth-On (plastic, silicone)	1	110.7	110.7	$2.50	$2.50	Mold cost amortized over 50 uses
10	Diffuser, transparent cast urethane plastic	LunaLight_Diffuser	LUNA1340	Smooth-On (plastic, silicone)	1	31.4	31.4	$1.50	$1.50	Mold cost amortized over 50 uses
11	Pan Head Phillips self-tapping 18-8 SS screw, #4 3/8"	92470A108		McMaster-Carr	4	0.4	1.6	$0.04	$0.16	sold in packs of 100
12	Pan Head Phillips self-tapping 18-8 SS screw, #6 1/2"	92470A148		McMaster-Carr	4	1.0	4	$0.04	$0.15	sold in packs of 100
13	Printed Circuit Board	P96677, order Qty. = 20	PCB2	Advanced Circuits	1	14.6	14.6	$21.76	$21.76	Qty. 100 = $5.40 ea., Qty. 250 = $2.65 ea.
14	Battery management IC, LT3652, MSOP-12	LT3652EMSE#PBF		Linear Technology	1	0.1	0.05	$4.36	$4.36	Qty. 100 = $3.70 ea.
15	DC-to-DC boost IC, MC34063, SOIC-8	316881 (supplier Jameco)		Jameco Electronics	1	0.1	0.05	$0.45	$0.45	Qty. 100 = $0.39 ea.
16	Schottky diode, 1N5819	743681 (supplier Jameco)		Jameco Electronics	3	0.1	0.3	$0.14	$0.42	
17	Diode, 1N4001	35975 (supplier Jameco)		Jameco Electronics	1	0.1	0.1	$0.05	$0.05	
18	Capacitor, ceramic, SMD 0805, 10 uF	1858797 (supplier Jameco)		Jameco Electronics	3	0.0	0	$0.12	$0.36	
19	Capacitor, ceramic disc, .001 uF	15192 (supplier Jameco)		Jameco Electronics	1	0.1	0.1	$0.04	$0.04	
20	Inductor (choke), 47 uH	642572 (supplier Jameco)		Jameco Electronics	1	1.5	1.5	$0.10	$0.10	
21	Inductor (choke), 120 uH	642610 (supplier Jameco)		Jameco Electronics	1	1.5	1.5	$0.10	$0.10	
22	Capacitor, electrolytic, radial, 220 uF	198872 (supplier Jameco)		Jameco Electronics	1	1.0	1	$0.08	$0.08	
23	Capacitor, electrolytic, radial, 100 uF	198970 (supplier Jameco)		Jameco Electronics	1	0.6	0.6	$0.08	$0.08	
24	Resistor, axial, 1.0 Ω, 1/2W, ±5%	659577 (supplier Jameco)		Jameco Electronics	4	0.3	1.2	$0.04	$0.16	
25	Resistor, axial, 220 Ω, 1/4W, ±5%	690700 (supplier Jameco)		Jameco Electronics	1	0.1	0.1	$0.03	$0.03	
26	Resistor, axial, 1 kΩ, 1/4W, ±5%	690865 (supplier Jameco)		Jameco Electronics	1	0.1	0.1	$0.03	$0.03	
27	Resistor, axial, 2.2 kΩ, 1/4W, ±5%	690945 (supplier Jameco)		Jameco Electronics	2	0.1	0.2	$0.03	$0.06	
28	Resistor, axial, 4.7 kΩ, 1/4W, ±5%	691024 (supplier Jameco)		Jameco Electronics	3	0.1	0.3	$0.03	$0.09	
29	Resistor, axial, 100 kΩ, 1/4W, ±5%	691340 (supplier Jameco)		Jameco Electronics	3	0.1	0.3	$0.03	$0.09	
30	Resistor, axial, 220 kΩ, 1/4W, ±5%	691420 (supplier Jameco)		Jameco Electronics	1	0.1	0.1	$0.03	$0.03	
31	Resistor, axial, 330 kΩ, 1/4W, ±5%	691462 (supplier Jameco)		Jameco Electronics	1	0.1	0.1	$0.03	$0.03	
32	Resistor, axial, 470 kΩ, 1/4W, ±5%	691500 (supplier Jameco)		Jameco Electronics	2	0.1	0.1	$0.03	$0.06	
33	Connector terminal block, 2-pos 3.5mm, straight thru	2094506 (supplier Jameco)		Jameco Electronics	2	0.9	1.8	$0.29	$0.58	Qty. 100 = $0.19 ea.
34	USB Female port, right angle thru-hole	2096181 (supplier Jameco)		Jameco Electronics	1	2.0	2	$0.39	$0.39	Qty. 100 = $0.29 ea.
35	2.5mm DC barrel jack, PC mount	101186 (supplier Jameco)		Jameco Electronics	1	1.4	1.4	$0.49	$0.49	Qty. 100 = $0.29 ea.
36	ON/OFF switch, black, rocker	316014 (supplier Jameco)	ACC1C	Jameco Electronics	1	3.2	3.2	$0.99	$0.99	Qty. 100 = $0.75 ea.
37	Wire, solid, 22 AWG, red, 0.5'	36856 (supplier Jameco)		Jameco Electronics	1	0.2	0.2	$0.04	$0.04	$7.95 for roll of 100', $5.95 ea. for Qty. 10+
38	Wire, solid, 22 AWG, black, 1.5'	36792 (supplier Jameco)		Jameco Electronics	1	0.6	0.6	$0.12	$0.12	$7.95 for roll of 100', $5.95 ea. for Qty. 10+
39	Zip wire to connect from solar panel, 10'	100280 (supplier Jameco)		Jameco Electronics	1	34.7	34.7	$0.80	$0.80	Qty. 10 (1000 ft) = $0.695 per 10'
40	2.5mm DC barrel connector	147336 (supplier Jameco)		Jameco Electronics	1	2.5	2.5	$0.79	$0.79	Qty. 100 = $0.59 ea.
41	6x6x4" corrugated box for shipping	BOX664 (Box Partner)		Amazon.com	1	74.5	74.5	$0.56	$0.56	these are standard corrugated boxes, not custom

Appendix B – Cost Calculations for Cast Parts

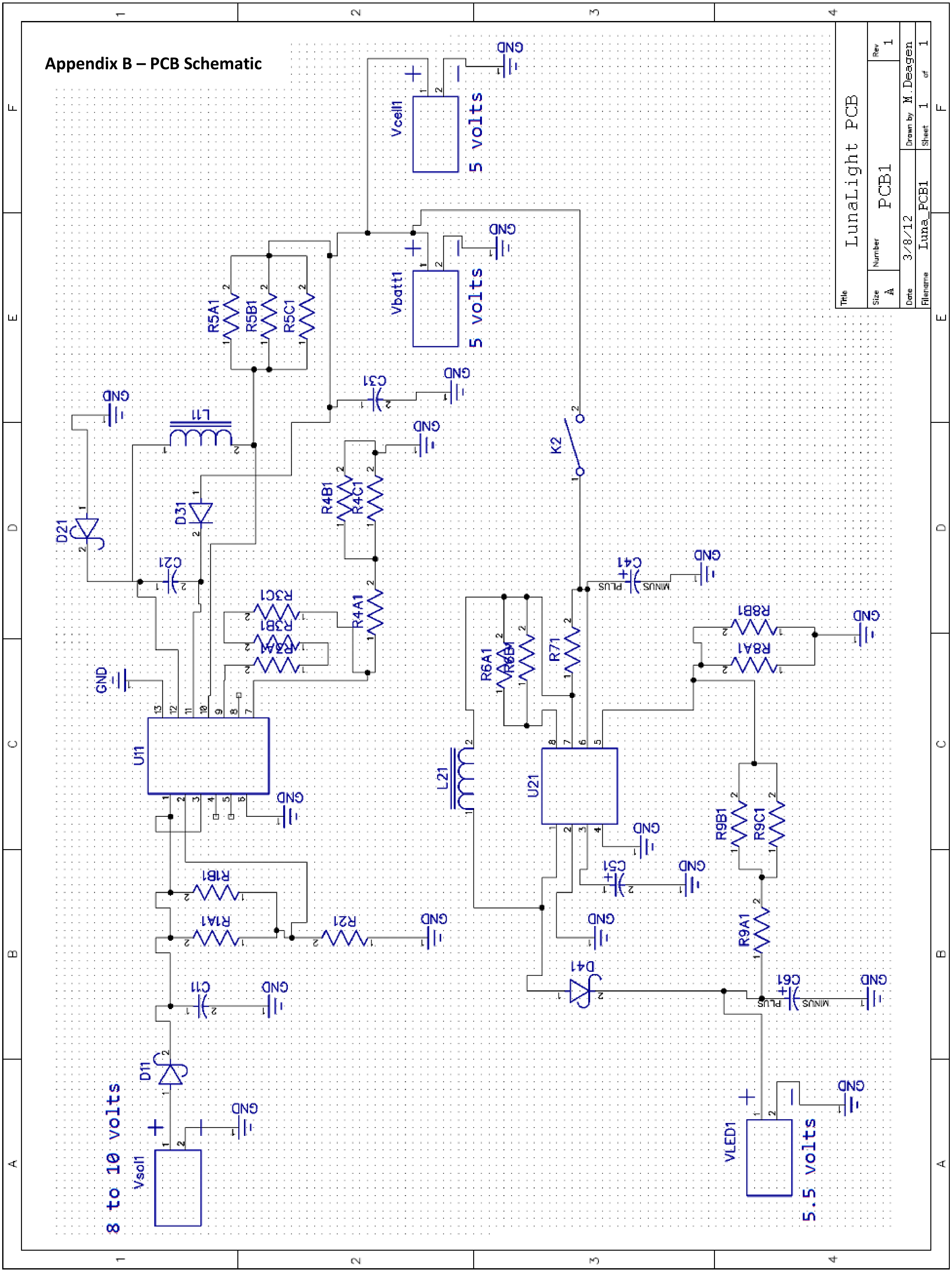
Cost Calculations of Cast Parts for LunaLight

1 lb ≈ 453.59 grams

Raw Material	Description	Supplier	Cost	Weight (lbs)	Cost in $/g
Crystal Clear 202	transparent urethane casting resin	Smooth-On	177.06	15.2	0.02568109
Smooth-Cast 305	bright white urethane casting resin	Smooth-On	85.85	15.4	0.01229012
Mold Star 30	silicone mold rubber	Smooth-On	172.94	17.6	0.02166304
SO-Strong 9-pack sampler	color tints for urethane plastic	Smooth-On	28.25	0.3	0.20760305

LunaLight Part	Material	Mold Weight (g)	Part Weight (g, after casting)	Color tint (g)	Mold Uses	Mold Cost	Plastic Cost	Total Cost
LunaLight_Front	Smooth-Cast 305	1790	150	1	50	0.7755367	1.84351793	$2.83
LunaLight_Back	Smooth-Cast 305	1500	150	1	50	0.6498911	1.84351793	$2.70
LunaLight_Mount	Smooth-Cast 305	900	53	0	50	0.3899346	0.65137634	$1.04
LunaLight_Diffuser	Crystal Clear 202	900	44	0	50	0.3899346	1.12996782	$1.52

Appendix B – PCB Schematic



Appendix B – PCB Bill of Materials

Bill of Materials
Project: LunaLight PCB
Date: Feb. 24, 2012

Item	Qty.	Ref. des.	Description	Value/Part #	Package	Manufacturer	Manufacturer Part #	Vendor	Vendor Part #
1	1	N/A	Printed Circuit Board	P96677	3.3x2.1in. FR4	Advanced Circuits	PCB_Luna		
2	1	U11	Battery management IC	LT3652	MSOP-12	Linear Technology	LT3652EMSE#PBF		
3	1	U21	DC-to-DC boost IC	MC34063A	SOIC-8	Fairchild Semiconductor	MC34063AD	Jameco	316881
4	3	D11, D21, D41	Schottky diode	1N5819	axial	On Semiconductor	1N5819G	Jameco	743681
5	1	D31	Diode	1N4001	axial	On Semiconductor	1N4001	Jameco	35975
6	3	C11, C21, C31	Capacitor, ceramic	10 uF 16 V	SMD 0805	Murata Electronics	GRM21BF51C106ZE15L	Jameco	1858797
7	1	C51	Capacitor, ceramic	.001 uF 50V	ceramic disc	Jameco ValuePro	DC.001-VP-R	Jameco	15192
8	1	L11	Inductor (choke)	47 uH	axial	Jameco ValuePro	5800-470	Jameco	642572
9	1	L21	Inductor (choke)	120 uH	axial	Jameco ValuePro	5800-121	Jameco	642610
10	1	C61	Capacitor, electrolytic	220 uF	radial	Jameco ValuePro	EC22016H611-R	Jameco	198872
11	1	C41	Capacitor, electrolytic	100 uF	radial	Jameco ValuePro	EC10035H611-R	Jameco	198970
12	3	R71, R5A1, R5B1	Resistor	1.0 Ω, 1/2W, ±5%	axial	Jameco ValuePro	CF1/2W1R0JRC	Jameco	659577
13	1	R5C1	Resistor	2.2 Ω, 1/2W, ±5%	axial	Jameco ValuePro	CF1/2W2R2JRC	Jameco	659657
14	1	R6A1	Resistor	220 Ω, 1/4W, ±5%	axial	Jameco ValuePro	CF1/4W221JRC	Jameco	690700
15	1	R6B1	Resistor	1 kΩ, 1/4W, ±5%	axial	Jameco ValuePro	CF1/4W102JRC	Jameco	690865
16	2	R8A1, R9B1	Resistor	2.2 kΩ, 1/4W, ±5%	axial	Jameco ValuePro	CF1/4W222JRC	Jameco	690945
17	3	R8B1, R9A1, R9C1	Resistor	4.7 kΩ, 1/4W, ±5%	axial	Jameco ValuePro	CF1/4W472JRC	Jameco	691024
18	3	R21, R3B1, R3C1	Resistor	100 kΩ, 1/4W, ±5%	axial	Jameco ValuePro	CF1/4W104JRC	Jameco	691340
19	2	R3A1, R6A1	Resistor	220 kΩ, 1/4W, ±5%	axial	Jameco ValuePro	CF1/4W224JRC	Jameco	691420
20	4	R1A1, R1B1, R4A1, R4C1	Resistor	470 kΩ, 1/4W, ±5%	axial	Jameco ValuePro	CF1/4W474JRC	Jameco	691500
21	3	VLED1, Vbatt1, K2	Connector terminal block	2 position 3.5mm	straight thru-hole	On-Shore Technology	OSTTE020161	Jameco	2094506
22	1	Vcell1	USB Female port	4 position	right angle thru-hole	Adam Tech	USB-A-S-RA	Jameco	2096181
23	1	Vsol1	2.5mm DC barrel jack	2.5 mm barrel port	PC mount	Jameco ValuePro	GCD014A	Jameco	101186
24	1	N/A	ON/OFF switch	Rocker, black	Rocker	Jameco ValuePro	R13-66A-B-02-R	Jameco	316014
25	1	N/A	AA battery holder	4-AA	square	Jameco ReliaPro	BH-343-1A-R	Jameco	216179
26	4	N/A	NiMH battery	2600mAh	"AA"	Tenergy		All-Battery	10308
27	1	N/A	2.5-W solar panel	9V, 2.5W	150x150x18mm frame	SinoSola	SA2.5-18	Energy Efficient Products	EEP-SP-2.5
28	2	N/A	Pre-mounted neutral white LED	4100K	10mm square base	Philips Lumileds	LXML-PWN1-0120	Luxeon Star LEDs	LXML-PWN1-0120

Appendix C – List of Vendors, Contact Information and Pricing

1. **Energy Efficient Products, Inc.**
   Website: http://www.eepsales.com/
   Contact: 1-877-788-4337 (Viktor Klyachko)
   Pricing: 2.5-W Solar Panel normally $14.99 + shipping, price break of $13.50 + shipping for qty. 9
2. **Luxeon Star LEDs**
   Website: http://www.luxeonstar.com/
   Contact: service@luxeonstar.com
   Pricing: ~$9 for a pre-mounted LED
   5% discount for 10-49, 10% for 50-499, 15% for 500-999, 20% for 1000+
3. **Advanced Circuits**
   Website: http://www.4pcb.com/
   Contact: ashley@4pcb.com (Ashley Trahan)
   Pricing: Orders below 500 will cost about $500-700 total
   Price per PCB drops greatly with increasing quantity ($21.76 for 20, $2.65 for 250)
4. **Smooth-On**
   Website: http://www.smooth-on.com/
   Contact: bwheeler@reynoldsam.com (Brooke Wheeler)
   Pricing: $85/gal. of Mold Star and Smooth-Cast resin, $175/gal. of Crystal Clear
   Offers 10% educational discount with copy of student ID
5. **StrapWorks**
   Website: http://www.strapworks.com/
   Contact: 1-541-741-0658
   Pricing: $3 per side release strap
   10% off (25-50), 20% off (51-150), 25% off (151-350), 30% off (351-500), 35% off (501+)
6. **All-Battery**
   Website: http://www.all-battery.com/
   Contact: 1-510-979-9969
   Pricing: $3 per NiMH AA battery, but many are advertised as 50-60% off
7. **Jameco Electronics**
   Website: http://www.jameco.com/
   Contact: 1-800-831-4242
   Pricing: Offers some price breaks, but is generally high-priced and meant for small quantities
8. **McMaster-Carr**
   Website: http://www.mcmaster.com/
   Contact: 1-630-600-3600
   Pricing: Generally high-priced, but can ship quickly and is good for small quantities

Appendix D – Vendor Supplied Data Sheets

1. **Mold Star 30**
   Platinum Silicone Rubber
   Vendor: Smooth-On
   Datasheet: http://www.smooth-on.com/tb/files/MOLD_STAR_15_16_30_TB.pdf
2. **Smooth-Cast 305**
   Bright White, Ultra Low Viscosity Liquid Urethane Plastic
   Vendor: Smooth-On
   Datasheet: http://www.smooth-on.com/tb/files/Smooth-Cast_300q,_300,_305___310.pdf
3. **Crystal Clear 202**
   Clear Urethane Casting Resin
   Vendor: Smooth-On
   Datasheet: http://www.smooth-on.com/tb/files/CRYSTAL_CLEAR_200_TB.pdf
4. **SO-Strong Colorants**
   Color Tints for Urethane Rubbers, Plastics, & Foams
   Vendor: Smooth-On
   Datasheet: http://www.smooth-on.com/tb/files/So-Strong_Tints.pdf
5. **LT3652**
   Power Tracking 2A Battery Charger for Solar Power
   Vendor: Linear Technology
   Datasheet: http://cds.linear.com/docs/Datasheet/3652fc.pdf
6. **MC34063**
   1.5 A, Step-Up/Down/Inverting Switching Regulators
   Vendor: Jameco Electronics
   Datasheet: http://www.onsemi.com/pub_link/Collateral/MC34063A-D.PDF
7. **USB-A-S-RA**
   Right angle PC-mount USB Type A Female Port
   Vendor: Jameco Electronics
   Datasheet:
   http://download.siliconexpert.com/pdfs/2009/3/18/8/15/39/adam_/manual/catpg127-134.pdf

Appendix E – Work Breakdown Structure

Duration (man-hours) is a rough estimate of the time spent for each task. The following task list may be incomplete.

TOTAL (est.): 718 man-hours

No.	Task Name (bold = milestone)	Dependency	Resource(s)	Duration (man-hrs)	Start Date	Finish Date
1	Formation of Team		Dr. Savage, Mike	3	9/19/11	9/26/11
2	Team Contract	FS 1	Mike	2	9/26/11	10/3/11
3	Background Research on User & Needs	FS 2	Everyone	12	10/3/11	10/7/11
4	Project Requirements Document	FS 2	Everyone	10	10/7/11	10/10/11
5	Defining the Functional Requirements	FS 3	Everyone	6	10/7/11	10/11/11
6	Brainstorm Conceptual Designs	FS 5	Everyone	6	10/11/11	10/15/11
7	CAD Model of “Hybrid”	FS 6	Ryan	5	10/15/11	10/16/11
8	Selection of LEDs to Test	FS 3	Sean, Mike	2	10/6/11	10/13/11
9	Determine Performance Goals of PCB	FS 3	Mike	4	10/6/11	10/13/11
10	Comparison of Battery Technologies & Cost	FS 5	Brian	2	10/6/11	10/13/11
11	Light Diffusion Research	FS 5	Francisco	3	10/11/11	10/16/11
12	**Conceptual Design Review**	FS 6	Everyone	1	10/17/11	10/17/11
13	Designing the Housing	FS 7	Ryan	8	10/18/11	10/25/11
14	Selection of Diffuser Material	FS 7	Francisco	3	10/18/11	10/24/11
15	Finalize Battery Selection	FS 10	Brian	5	10/18/11	10/23/11
16	Testing of Luxeon Rebel LEDs	FS 8	Sean, Francisco	12	10/25/11	11/8/11
17	Meeting with Kendra Kimlinger	FS 1	Mike, Sarah, Joyce	1	10/28/11	10/28/11
18	Selection of Battery Management IC	FS 9	Mike	8	10/20/11	10/27/11
19	Research into Off-the-Shelf Enclosures	FS 12	Ryan	5	10/26/11	11/4/11
20	**Group Meeting with Laura Chao**	FS 11	Everyone	3	11/1/11	11/1/11
21	LED Driver Design & Testing	FS 9	Mike	6	11/7/11	11/10/11
22	**Meeting with Martin Koch about Casting**	FS 11	Everyone	2	11/7/11	11/7/11
23	Brainstorming of Name for Light	FS 12	Everyone, OML	8	11/1/11	11/20/11
24	Battery Charger Circuit	FS 18	Mike	12	11/11/11	11/12/11

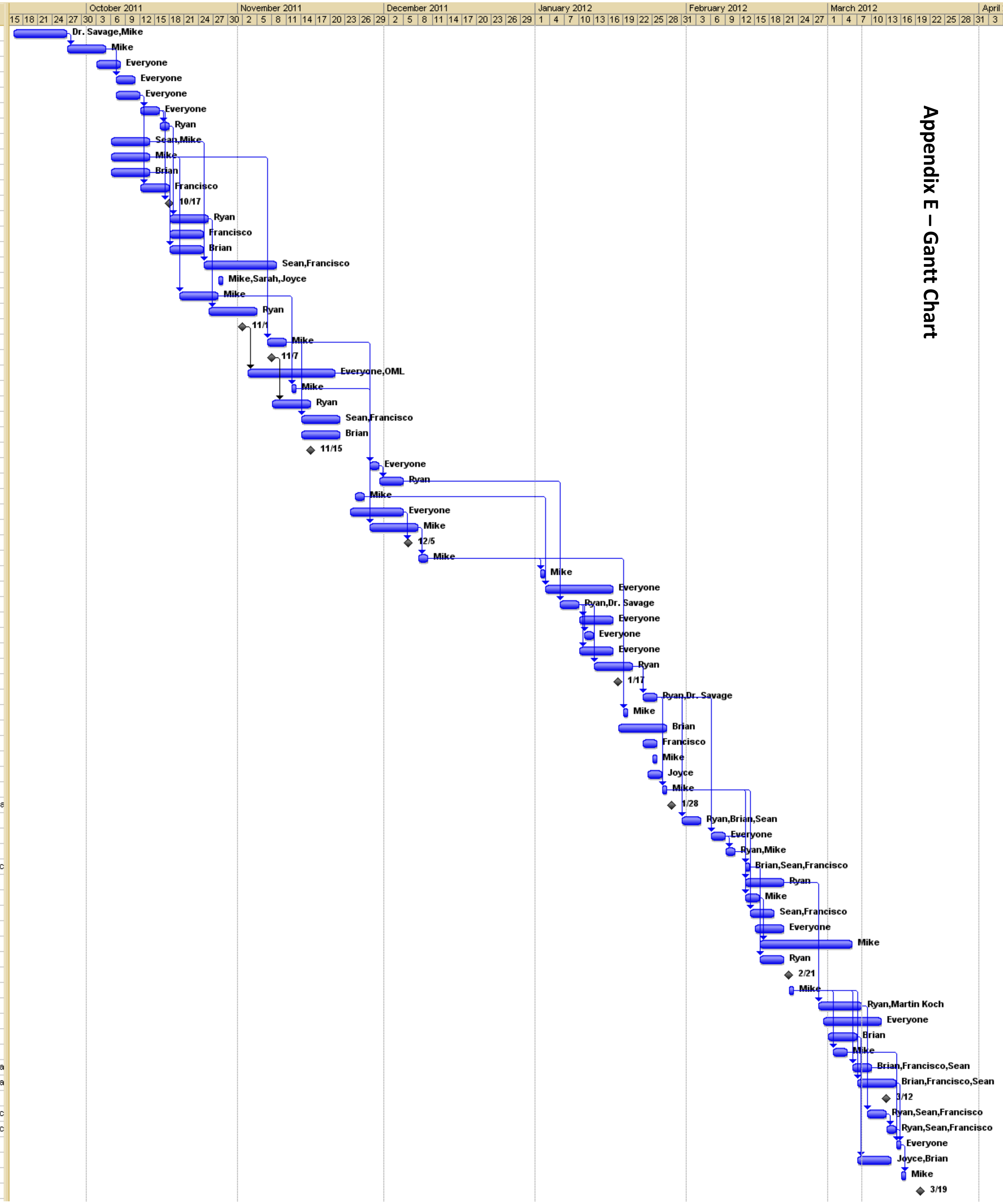
	Design					
25	Redesign of Housing for Plastic Casting	FS 22	Ryan	10	11/7/11	11/14/11
26	Initial Duration Tests of LEDs, Batteries	FS 21	Sean, Francisco	10	11/14/11	11/21/11
27	Assemble Initial Bill of Materials	FS 25	Brian	6	11/14/11	11/21/11
28	**Conference Call with Barrett Raftery**	FS 20	Everyone	1	11/15/11	11/15/11
29	Conceptual Design of LunaLight	FS 23	Everyone	6	11/28/11	11/29/11
30	Detailed CAD of LunaLight	FS 29	Ryan	25	11/29/11	12/4/11
31	CPConnect Proposal	FS 12	Mike	10	11/25/11	11/26/11
32	Writing Conceptual Design Report	FS 29	Everyone	25	11/24/11	12/4/11
33	Design and Layout of PCB	FS 24	Mike	25	11/28/11	12/7/11
34	**Submit Conceptual Design Report**	FS 32	Everyone	1	12/5/11	12/5/11
35	Ordering PCBs through Advanced Circuits	FS 33	Mike	2	12/7/11	12/8/11
36	Assembly of First PCB	FS 35	Mike	2	1/2/12	1/2/12
37	Set-up of New CPConnect Lab	FS 31	Everyone	15	1/3/12	1/16/12
38	Rapid-Prototyping of LunaLight Housing	FS 30	Ryan, Dr. Savage	6	1/6/12	1/9/12
39	Suggest Improvements for Housing	FS 38	Everyone	10	1/9/12	1/13/12
40	Learn Moldmaking from Martin Koch	FS 38	Everyone	10	1/11/12	1/12/12
41	Selection of Straps for Housing	FS 29	Everyone	8	1/9/12	1/13/12
42	Improve Housing Design	FS 39	Ryan	20	1/13/12	1/20/12
43	**Design Review**	FS 42	Everyone	1	1/17/12	1/17/12
44	Rapid-Prototype Updated Housing	FS 42	Ryan, Dr. Savage	6	1/23/12	1/25/12
45	Reflow Soldering of ICs on PCBs	FS 35	Mike	4	1/19/12	1/19/12
46	Preparation for Rotary Conference	FS 43	Brian	6	1/18/12	1/27/12
47	LunaLight Project on Yolasite	FS 44	Francisco	4	1/23/12	1/25/12
48	Information for Flyers & Poster	FS 43	Mike	4	1/25/12	1/25/12
49	Poster and Flyer Design	FS 48	Joyce	10	1/24/12	1/26/12
50	Assembly of Initial Prototypes	FS 44	Mike	4	1/27/12	1/27/12
51	**Rotary S.T.E.P.S.**	FS 50	Mike, Ryan, Brian,	8	1/28/12	1/28/12

	Conference at UCSB		Sean, Sarah, Joyce, Barrett			
52	Making Silicone Molds for Revised Parts	FS 44	Ryan, Sean, Brian	16	1/31/12	2/3/12
53	Practice Run of Mold for Front	FS 44	Everyone	10	2/6/12	2/8/12
54	Improve Moldmaking Technique	FS 53	Ryan, Mike	6	2/9/12	2/10/12
55	Casting Attempts of Practice Mold	FS 53	Brian, Sean, Francisco	3	2/13/12	2/13/12
56	Wax Mold-Frame Design	FS 54	Ryan	10	2/13/12	2/20/12
57	Solar Panel Characterization	FS 55	Mike	4	2/13/12	2/15/12
58	LED Illuminance Testing	FS 50	Sean, Francisco	6	2/14/12	2/18/12
59	Preparation for Final Design Review	FS 43	Everyone	30	2/15/12	2/20/12
60	Solar Charging, Battery Duration Test	FS 45	Mike	35	2/15/12	3/2/12
61	Adjust CAD Model for Manufacturability	FS 55	Ryan	20	2/16/12	2/20/12
62	**Final Design Review**	FS 59	Everyone	1	2/21/12	2/21/12
63	Order Last of the LunaLight Parts	FS 62	Mike	2	2/22/12	2/22/12
64	Manufacture of Wax Mold-Frame	FS 56	Ryan, Martin Koch	30	2/28/12	3/7/12
65	Final Design Report and Documentation	FS 62	Everyone	60	2/29/12	3/11/12
66	Box Manufacturing Considerations	FS 63	Brian	6	3/1/12	3/6/12
67	Assembly of 7 Panels and 8 PCBs	FS 63	Mike	12	3/2/12	3/4/12
68	Manufacture 7 LED Mounts	FS 52	Brian, Francisco, Sean	10	3/6/12	3/9/12
69	Manufacture 7 Diffusers, Vacuum Chamber	FS 52	Brian, Francisco, Sean	20	3/7/12	3/14/12
70	**Submit Final Design Report**	FS 65	Everyone	1	3/12/12	3/12/12
71	Make Molds for Front & Back of Housing	FS 64	Ryan, Sean, Francisco	12	3/9/12	3/12/12
72	Manufacture 7 Fronts & Backs of Housing	FS 64	Ryan, Sean, Francisco	10	3/13/12	3/14/12
73	Assemble 7 Prototype Lights	FS 72	Everyone	20	3/11/12	3/14/12
74	Design Box, Print, Laser-Cut	FS 66	Joyce, Brian	15	3/7/12	3/13/12
75	Package 7 LunaLight Lanterns	FS 73	Mike	2	3/14/12	3/15/12
76	**Present Prototypes to OneMillionLights**	FS 75	Mike	2	3/19/12	3/19/12

Appendix E – Gantt Chart

Gantt Chart

	Task Name	Duration	Start	Finish	Predecessors	Resource Names
1	Formation of Team	7 days	Fri 9/16/11	Mon 9/26/11		Dr. Savage,Mike
2	Team Contract	6 days	Tue 9/27/11	Tue 10/4/11	1	Mike
3	Background Research on User	5 days	Mon 10/3/11	Fri 10/7/11		Everyone
4	Project Requirements Document	2 days	Fri 10/7/11	Mon 10/10/11	2	Everyone
5	Defining Functional Requirements	3 days	Fri 10/7/11	Tue 10/11/11		Everyone
6	Brainstorm Conceptual Designs	4 days	Wed 10/12/11	Sat 10/15/11	5	Everyone
7	CAD Model of "Hybrid"	2 days	Sun 10/16/11	Mon 10/17/11	6	Ryan
8	Selection of LEDs to Test	6 days	Thu 10/6/11	Thu 10/13/11		Sean,Mike
9	Determine Performance Goals of PCB	6 days	Thu 10/6/11	Thu 10/13/11		Mike
10	Comparison of Battery Technologies & Cost	6 days	Thu 10/6/11	Thu 10/13/11		Brian
11	Light Diffusion Research	6 days	Wed 10/12/11	Mon 10/17/11	5	Francisco
12	**Conceptual Design Review**	1 day	Mon 10/17/11	Mon 10/17/11	6	Everyone
13	Designing the Housing	6 days	Tue 10/18/11	Tue 10/25/11	7	Ryan
14	Selection of Diffuser Material	5 days	Tue 10/18/11	Mon 10/24/11		Francisco
15	Finalize Battery Selection	5 days	Tue 10/18/11	Mon 10/24/11	10	Brian
16	Testing of Luxeon Rebel LEDs	11 days	Tue 10/25/11	Tue 11/8/11	8	Sean,Francisco
17	Meeting with Kendra Kimlinger	1 day	Fri 10/28/11	Fri 10/28/11		Mike,Sarah,Joyce
18	Selection of Battery Management IC	6 days	Thu 10/20/11	Thu 10/27/11	9	Mike
19	Research into Off-the-Shelf Enclosures	8 days	Wed 10/26/11	Fri 11/4/11	13	Ryan
20	**Group Meeting with Laura Chao**	1 day	Tue 11/1/11	Tue 11/1/11		Everyone
21	LED Driver Design & Testing	4 days	Mon 11/7/11	Thu 11/10/11	9	Mike
22	**Meeting with Martin Koch about Castin**	1 day	Mon 11/7/11	Mon 11/7/11		Everyone
23	Brainstorming of Name for Light	14 days	Thu 11/3/11	Sun 11/20/11	20	Everyone,OML
24	Battery Charger Circuit Design	1 day	Sat 11/12/11	Sat 11/12/11	18	Mike
25	Redesign of Housing for Plastic Casting	7 days	Tue 11/8/11	Tue 11/15/11	22	Ryan
26	Initial Duration Tests of LEDs, Batteries	7 days	Mon 11/14/11	Mon 11/21/11	21	Sean,Francisco
27	Assemble Initial Bill of Materials	7 days	Mon 11/14/11	Mon 11/21/11		Brian
28	**Conference Call with Barrett Raftery**	1 day	Tue 11/15/11	Tue 11/15/11		Everyone
29	Conceptual Design of LunaLight	2 days	Mon 11/28/11	Tue 11/29/11	23	Everyone
30	Detailed CAD of LunaLight	4 days	Wed 11/30/11	Sun 12/4/11	29	Ryan
31	CPConnect Proposal	1 day	Fri 11/25/11	Sat 11/26/11		Mike
32	Writing Conceptual Design Report	8 days	Thu 11/24/11	Sun 12/4/11		Everyone
33	Design and Layout of PCB	9 days	Mon 11/28/11	Wed 12/7/11	21,24	Mike
34	**Submit Conceptual Design Report**	1 day	Mon 12/5/11	Mon 12/5/11	32	Everyone
35	Ordering PCBs through Advanced Circuits	2 days	Thu 12/8/11	Fri 12/9/11	33	Mike
36	Assembly of First PCB	1 day	Mon 1/2/12	Mon 1/2/12	35	Mike
37	Set-up of New CPConnect Lab	10 days	Tue 1/3/12	Mon 1/16/12	31	Everyone
38	Rapid-Prototyping of LunaLight Housing	2 days	Fri 1/6/12	Mon 1/9/12	30	Ryan,Dr. Savage
39	Suggest Improvements for Housing	5 days	Tue 1/10/12	Mon 1/16/12	38	Everyone
40	Learn Moldmaking from Martin Koch	2 days	Wed 1/11/12	Thu 1/12/12	38	Everyone
41	Selection of Straps for Housing	5 days	Tue 1/10/12	Mon 1/16/12	38	Everyone
42	Improve Housing Design	6 days	Fri 1/13/12	Fri 1/20/12	38	Ryan
43	**Design Review**	1 day	Tue 1/17/12	Tue 1/17/12		Everyone
44	Rapid-Prototype Updated Housing	3 days	Mon 1/23/12	Wed 1/25/12	42	Ryan,Dr. Savage
45	Reflow Soldering of ICs on PCBs	1 day	Thu 1/19/12	Thu 1/19/12	35	Mike
46	Preparation for Rotary Conference	8 days	Wed 1/18/12	Fri 1/27/12		Brian
47	LunaLight Project on Yolasite	3 days	Mon 1/23/12	Wed 1/25/12		Francisco
48	Information for Flyers & Poster	1 day	Wed 1/25/12	Wed 1/25/12		Mike
49	Poster and Flyer Design	3 days	Tue 1/24/12	Thu 1/26/12		Joyce
50	Assembly of Initial Prototypes	1 day	Fri 1/27/12	Fri 1/27/12	44	Mike
51	**Rotary S.T.E.P.S. Conference at UCSB**	1 day	Sat 1/28/12	Sat 1/28/12		Mike,Ryan,Brian,Sea
52	Making Silicone Molds for Revised Parts	4 days	Tue 1/31/12	Fri 2/3/12	44	Ryan,Brian,Sean
53	Practice Run of Mold for Front	3 days	Mon 2/6/12	Wed 2/8/12	44	Everyone
54	Improve Moldmaking Technique	2 days	Thu 2/9/12	Fri 2/10/12	53	Ryan,Mike
55	Casting Attempts of Practice Mold	1 day	Mon 2/13/12	Mon 2/13/12	53	Brian,Sean,Francisc
56	Wax Mold-Frame Design	6 days	Mon 2/13/12	Mon 2/20/12	54	Ryan
57	Solar Panel Characterization	3 days	Mon 2/13/12	Wed 2/15/12	50	Mike
58	LED Illuminance Testing	4 days	Tue 2/14/12	Sat 2/18/12	50	Sean,Francisco
59	Preparation for Final Design Review	4 days	Wed 2/15/12	Mon 2/20/12		Everyone
60	Solar Charging, Battery Duration Test	13 days	Thu 2/16/12	Mon 3/5/12	57	Mike
61	Adjust CAD Model for Manufacturability	3 days	Thu 2/16/12	Mon 2/20/12	55	Ryan
62	**Final Design Review**	1 day	Tue 2/21/12	Tue 2/21/12		Everyone
63	Order Last of the LunaLight Parts	1 day	Wed 2/22/12	Wed 2/22/12		Mike
64	Manufacture of Wax Mold-Frame	7 days	Tue 2/28/12	Wed 3/7/12	56	Ryan,Martin Koch
65	Final Design Report and Documentation	8 days	Wed 2/29/12	Sun 3/11/12		Everyone
66	Box Manufacturing Considerations	4 days	Thu 3/1/12	Tue 3/6/12		Brian
67	Assembly of 7 Panels and 8 PCBs	1 day	Fri 3/2/12	Sun 3/4/12	63	Mike
68	Manufacture 7 LED Mounts	4 days	Tue 3/6/12	Fri 3/9/12	63	Brian,Francisco,Sea
69	Manufacture 7 Diffusers, Vacuum Chamber	6 days	Wed 3/7/12	Wed 3/14/12	63	Brian,Francisco,Sea
70	**Submit Final Design Report**	1 day	Mon 3/12/12	Mon 3/12/12		Everyone
71	Make Molds for Front & Back of Housing	2 days	Fri 3/9/12	Mon 3/12/12	64	Ryan,Sean,Francisc
72	Manufacture 7 Fronts & Backs of Housing	2 days	Tue 3/13/12	Wed 3/14/12	71	Ryan,Sean,Francisc
73	Assemble 7 Prototype Lights	1 day	Thu 3/15/12	Thu 3/15/12	67,68,69,72	Everyone
74	Design Box, Print, Laser-Cut	5 days	Wed 3/7/12	Tue 3/13/12	66	Joyce,Brian
75	Package 7 LunaLight Lanterns	1 day	Fri 3/16/12	Fri 3/16/12	73	Mike
76	**Present Prototypes to OneMillionLight**	1 day	Mon 3/19/12	Mon 3/19/12		Mike



Gantt Chart