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neoSpectra
Technologies Incorporated

March 5, 2007

Mr. Lakshman One
School of Engineering Science
Simon Fraser University
Burnaby, British Columbia
V5A 1S6

RE: ENSC 440 ChromaTap Design Specification

Dear Mr. One:

The attached document, *The ChromaTap Design Specification Build 1.0a*, outlines the design specification for the first battery-powered build for our ENSC 440 Project, the ChromaTap.

This design specification will outline the design decisions that we have made in developing this version of the ChromaTap product. As you know, the ChromaTap is a solution for hot water safety which will light the flow of water different intensities of red for hot, and blue for cold, giving the user a visual indicator of water temperature. The ChromaTap will be available in both faucet add-on and showerhead replacement versions, and this design specification discusses both versions.

NeoSpectra Technologies is made up of four savvy students. Scott Chen, Jacky Cheng, Derek Pang, and Jim Wang will be doing the product development as part of ENSC 440. William Ng, although not currently enrolled in ENSC 440, has been a cofounder of NeoSpectra, and he is valuable source for market and technical consultation.

If you have any questions or concerns, please feel free to contact me personally at 604-306-9511, or the group by e-mail at ensc440-neospectra-tech@sfu.ca.

Sincerely,

Derek Pang

Derek Pang
Project Lead
NeoSpectra Technologies Inc.

Enclosure: The ChromaTap Design Specification Build 1.0a

neoSpectra

Technologies Incorporated

THE CHROMATAP DESIGN SPECIFICATION

Build 1.0a

[The ChromaTap Design Specification Build 1.0a]

Project Team
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Submitted to
Mr. Lakshman One
Mr. Steven Whitemore
School of Engineering Science
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Issue Date
March 5, 2007

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GLOSSARY

BJT Bipolar Junction Transistor. A three-terminal (base, collector, emitter) device constructed of doped semiconductor material used in amplifying or switching applications.

LED Light Emitting Diode. A low power, high intensity light hailed primarily for its longevity and low cost, and also for the simplicity of its implementation in circuits.

mAh Milliampere-hour. A unit of electric charge. One milliampere-hour is equal to 3.6 coulombs, and is the amount of electric charge transferred by a steady current of one ampere for one hour.

NTC Negative Temperature Coefficient. A NTC thermistor has its resistance inversely proportional to the temperature it is subject to.

Op-Amp Operational amplifier. DC-coupled high-gain voltage amplifier with differential inputs and a single output.

REP Rated Electric Power.

SMD Surface Mount Device. A standard acronym for a surface mount package.

SMT Surface Mount Technology. A manufacturing technique in which components that are designed for mounting on the surface of a substrate or PC board are used.

Solidworks A powerful software package allowing users of CAD (Computer Aided Design) and other tools used to develop products.

Zero-Point From the ChromaTap functional specification, the zero-point of ChromaTap means both red and blue LEDs are OFF at the room temperature of 25°C.

Executive Summary

Household safety is a growing concern for parents with young children in their care. Thousands of children are injured in the home each year, and the most common injuries among children are burns and scalds. In particular, hot water is a common hazard because it is easily accessible by children, who can suffer serious scalds from as little as one second of contact.

The ChromaTap is an easy to use and affordable solution to the problem of hot water burns in the home. It will address this problem both at the sink and in the shower, by lighting the water stream different intensities of red for hot and blue for cold. This provides a reasonable visual indication of water temperature for the user without compromising the availability of hot water, or requiring costly installation like the other current solutions available.

The objective of our project is to evaluate different design solutions for the ChromaTap (both faucet and shower versions) for engineering merit and commercial potential, focusing on the categories of size, power, reliability, safety, cost, and ease of use. To do this, we will explore three alternate methods of powering the ChromaTap: battery, solar, and water power.

The project is divided into two major phases: Increment 1 and Increment 2. In Increment 1, three different prototypes of the NeoSpectra ChromaTap- powered by battery, solar panel, and water turbine – will be constructed and tested, and are scheduled to be completed as a "proof of concept" at the end of April 2007. The Increment 2 involves mechanical and miscellaneous feature improvements on the prototype, and revisions to the mechanical and electrical design with the ultimate goal of commercializing of the ChromaTap.

This design specification document details the design decisions that we have made thus far for the battery powered version of the Chromatap. The development for the water and power generation modules has not progressed to the point where a design specification is appropriate, and specifications for these modules will be submitted by April 2007 in our final Increment 1 design specification.

Section 1. Introduction

The NeoSpectra ChromaTap is an innovative faucet add-on which gives users a visual indicator of water temperature, thus reducing the incidence and probability of hot water related injuries, as well as providing novelty value. It achieves this goal by implementing an internal water temperature sensor and providing an instant visual feedback to the user by lighting the water up with continuous red-blue bi-color spectra, where red represents temperature higher than room temperature, and blue represents below room temperature. In addition, the intensity of the light is designed to reflect the magnitude of water temperature deviation from the room temperature. A shower version, which is a showerhead replacement providing similar temperature visual indication to the faucet version, is also planned.

While being a stylish household decoration, the ChromaTap is also an educational device for underage users, and a safe-guard device for seniors. It is a compact, and simple attachment, which works with all water taps, and is intended to be safe, affordable, and easy to use and install.

The project is divided into three increments, with increments 1 and 2 slated for completion as part of ENSC 440. Increment 1 will produce three different prototypes for the ChromaTap, powered by solar, water, and battery power. Increment 2 will improve upon the prototype deemed the best power solution for the ChromaTap. Increment 3 will add further improvements, resulting in the final production prototype.

1.1 Background

Traditionally, although having control over the water temperature, users often cannot tell the water temperature simply from the knob position, or by looking at the water stream. Moreover, the actual water temperature usually lags behind the user's chosen setting depending on what was last going through the pipes. The user is lacking a safer method of acquiring feedback about temperature information. However, the ChromaTap is going to solve all of these problems.

1.2 Scope

This document describes the design specifications for the battery powered variant (Build 1.0a) of the ChromaTap project. It covers the design of the battery power generation module, input conversion module, control and processing module, output conversion module, and casing and mechanical module. Detailed descriptions of these modules can be found in the System Overview section. The design of certain modules may need to be slightly modified for other power generation modules (solar or hydroelectric), and if applicable, this is mentioned in the section discussing that module. Potential specifications toward the production model may be discussed in this document. A general test plan is also outlined to verify the functionality of the prototype and ensure all final builds in Increment 1 satisfy all the applicable functional requirements specified in *The ChromaTap Functional Specification*.

1.3 Intended Audience

The primary intended audience for this document is the project managers, the development engineers, and the quality assurance personnel at NeoSpectra Technologies Inc. The design specifications outlined in this document demonstrate the solutions chosen by the NeoSpectra Engineering Team with the ultimate goal of satisfying the requirements set forth in the functional specification. In the long term, this document also acts as a reference document for the marketing staff.

Section 2. System Overview

The ChromaTap, the proposed solution to the hot water tap problem, is an easy-to-install faucet attachment that provides an instant visual indication of the water temperature by turning the water stream to blue or red at various intensities. The natural association between red and hot or between blue and cold offers a much quicker feedback that most people can easily comprehend, especially children. A showerhead replacement with temperature-sensitive lighting is also proposed to help protect children and elders in their showers.

ChromaTap shines over the current design solutions. It has the advantage of being affordable and easy to install, while providing a colorful and a continuous visual cue for water temperature. It also allows safe access to hot water when needed. ChromaTap aims to be safe, affordable, and easy to use. To achieve these goals, we will be choosing ChromaTap designs based on a balance of size, power, reliability, safety, cost, and ease of use. Figure 2.1 depicts a simple demonstration of the ChromaTap's operation.

Figure 2.1 : Conceptual Overview of the ChromaTap System

The ChromaTap is extremely easy to use: no direct user interface is required for normal operation. The user can easily install the ChromaTap faucet attachment (or a showerhead replacement) in less than a minute. After a successful installation, the device automatically turns on when the user switches on the water tap. Then, the visual indictor of the ChromaTap outputs an appropriate lighting effect: red for hot and blue for cold. The intensity of the lighting is continuously updated according to the temperature of the water. The operating temperature of the ChromaTap ranges from 0°C to 80°C. When the user switches off the tap, the device automatically turns off.

Figure 2.2 outlines the general system architecture of the ChromaTap for both lavatory faucet and showerhead variants.

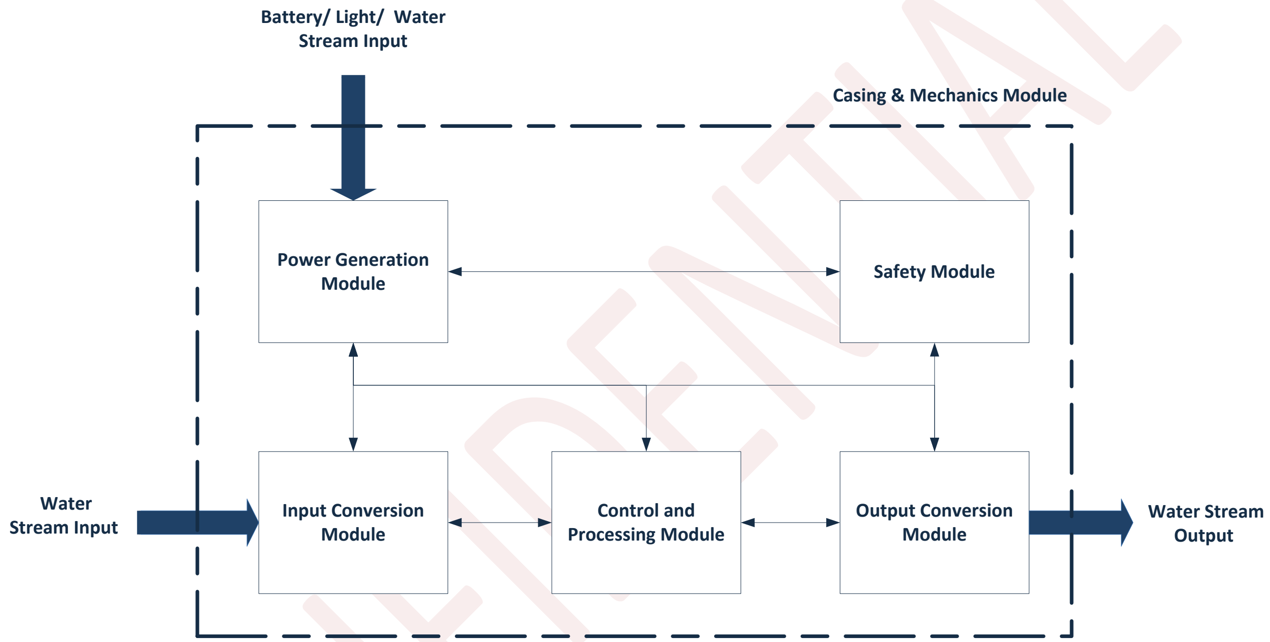

Figure 2.2 : ChromaTap System Architecture Overview

2.1 Power Generation Module

The power generation module is responsible for generating and managing a stable power source for the entire system. We currently have proposed three design alternatives for the power generation module: a battery-powered module, solar-power module, and hydroelectric module. However, alternative power generation solutions will be also evaluated. A final power generation method will be chosen appropriately by weighting its associated benefits, costs and design limitations. In this document, only battery-powered module's design is specified. Implementation details for other solutions will be added to an additional design specification document that will be completed before the end of the project.

2.2 Input Conversion Module

The input conversion module activates the entire ChromaTap system when the user turns on the faucet or the showerhead. The module then gathers the temperature information from the water stream and converts this information into an appropriate format for the Control and Processing Module to evaluate. Modification of the input conversion module may be necessary when connecting to different types of power generation modules.

2.3 Control and Processing Module

The control and processing module assesses the input temperature information and generates an appropriate output to the output conversion module. We may also implement a power management control system to conserve power.

2.4 Output Conversion Module

The output conversion module receives the output information from the control and processing module and converts this information into an appropriate visual indication for the user. The faucet and showerhead variants may have different output configurations and methods.

2.5 Safety Module

The safety module ensures the safety and reliability of the device both mechanically and electrically. The module may be closely integrated with other system components. We will design a robust and safe device that will satisfy various international safety standards and codes. We will also perform reliability testing to counter system failures such as water leaks, power shorts and surges, and corrosion.

2.6 Casing and Mechanical Module

We have designed two types of casing modules: one for the faucet add-on, and another for the showerhead. Different power modules may also require different casing designs. We will also perform detailed mechanical simulation and testing to ensure the usability and reliability of the device.

Section 3. Power Generation Module

The power generation module delivers and regulates all the electric power required by the ChromaTap system. The module should only supply the system power when a user turns on the faucet or shower and activates the system. It should also protect the system from any power supply irregularities, such as a power surge, and prevent any power leakage.

3.1 Module System Design Overview

For the battery-powered variant (Build 1.0a) of our ChromaTap project, the power generation module solely relies on a standardized lithium coin cell as its power source. A simple circuit shorting mechanism will facilitate the role of a system switch, and will activate the system when a constant stream of water flow is detected.

3.2 Power Source

The power generation requires two 3VDC CR2032 lithium coin cells with a nominal energy capacity of 225mAh. The two lithium cells will be connected as a dual power supply network with a positive and negative power rail of ±3V. The Panasonic manganese dioxide lithium CR2032 battery cell, as illustrated in Figure 3.1, is chosen for Build 1.0a's power source because it offers an optimal balance of size, reliability, cost and energy capacity compared to other battery choices, such as 1.5V Alkaline LR44s.

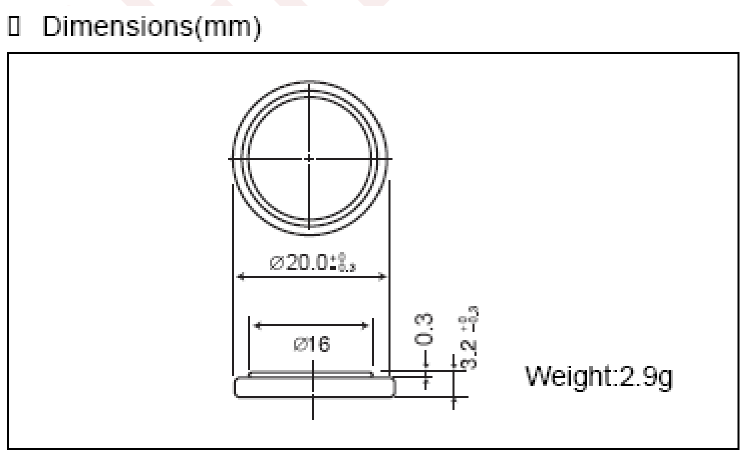

Figure 3.1 : Dimension of Panasonic Manganese Dioxide CR2032 Lithium Cell Battery (Panasonic, 2005)

Furthermore, the thin profile form factor also allows for a shorter height requirement for the mechanical casing, giving users a larger height clearance for washing their hands. Table 3.1 summarizes the specifications of the Panasonic CR2032.

Table 3.1 Panasonic CR2032 Lithium Battery Cell Specification (Panasonic, 2005)

Nominal voltage (V)	**3**
Nominal capacity (mAh)	**225**
Continuous standard load (mA)	**0.2**
Operating temperature (^oC)	**-30 to +60**
Unit Cost (@4,000 units)	**$0.14**

3.3 Power Activation Unit

The power activation unit is connected to the input activation mechanism as discussed in Section 7.2.7. When the input is activated by a flowing water stream, the power supply will be connected to the circuit components of the system. As illustrated in Figure 3.2, the power activation unit is a three terminal switch that connects the two battery sources to a common ground, creating a positive 3VDC and a negative 3VDC power supply. If the three-terminal power activation switch is not used, the power activation unit would require two separate switches on both power supplies, increasing the spatial requirements for the system.

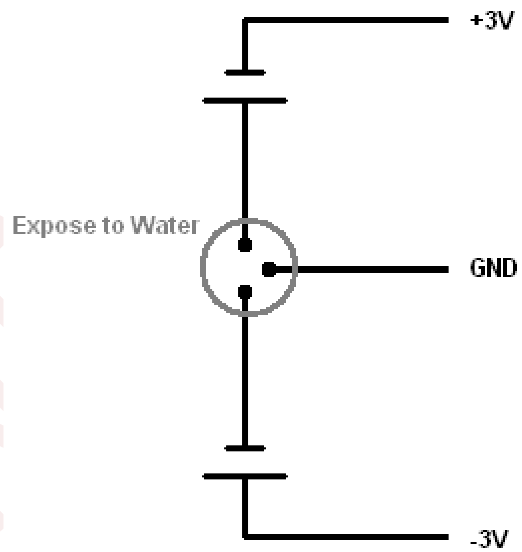

Figure 3.2 : Three Pad Power Activation Switch Configuration

3.4 Environmental Requirements

Due to rapid discharge issues with lithium battery, a generic current limiter circuit, as shown in APPENDIX A, is necessary to protect all electronics from potential power surges and prevent the battery and other components from overheating. For each power supply, a bipolar junction transistor (BJT) and a 10Ω sensing resistor will be configured to detect the amplitude of the input current, and redirect all the current to the common ground when the input current exceeds 65-85mA.

A 2N3604 NPN BJT is needed for the positive supply, and a 2N3606 PNP is required for the negative supply. These BJTs, as shown in Figure 3.3, are selected for Build 1.0a because they offer wide temperature operational range and are available from our past microelectronics courses. The 10 Ω sensing resistor will turn on the BJT transistor when the voltage across the resistor exceeds 0.65V or the input current is above 65mA. When the BJT transistor is turned on, most of the input current will be redirected to the common ground, minimizing the current outputted to the system. For the increment 3 commercial prototype, surface-mounted BJTs with and resistors shall be used. The selected BJTs should sustain a maximum collector current of 200mA or higher, which allows the current limiter to be functional at a current level of 100% over the current limit.

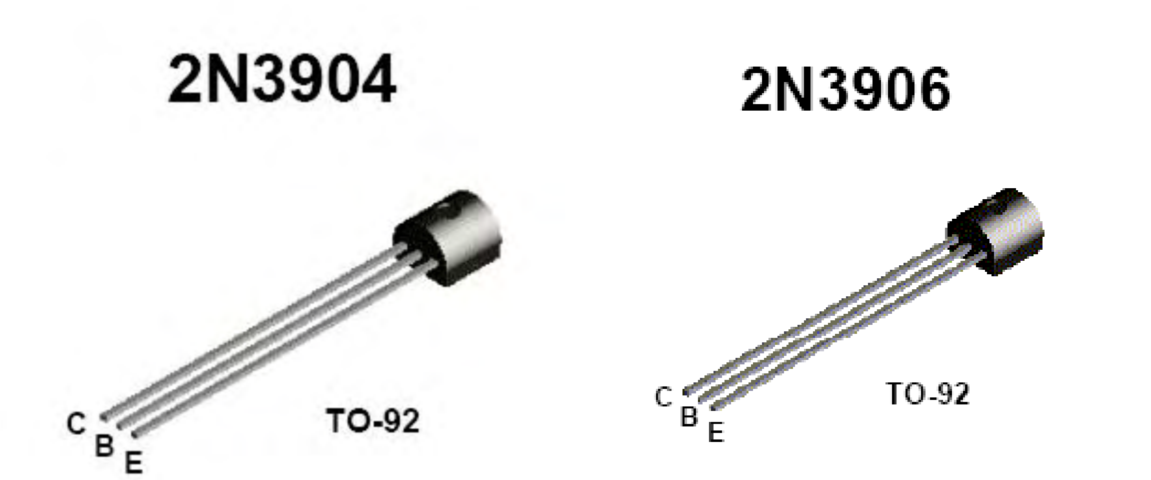

Figure 3.3 : 2N3904 NPN and 2N3906 PNP Bipolar Junction Transistor with operating temperature from -55 to 150ºC.
(National Semiconductor, 2001)

Although the electric circuits of the system should not consume more than 16mA as outlined in the functional specification, a lower circuit limit would require a higher resistance value for the sensing resistor. The higher resistance value will lower the supply voltage applied to the system, and induce higher voltage fluctuations when the current does not stay constant. As a result, a higher current limit is implemented in the power control unit, and is still sufficient in protecting the circuit.

3.5 Module Unit Cost

Table 3.2 lists all the components used in the power generation module and the total unit cost of the module.

Table 3.2 Power Generation Components Cost for Build 1.0a

Components	Quantity	Volume Unit Price (at 1,000 units and up)	Total Unit Cost
2N3904 NPN BJT	1	$0.027	$0.027
2N3906 PNP BJT	1	$0.027	$0.027
Panasonic CR2032 Lith. Coin Cell	2	$0.14	$0.28
Resistors (10Ω)	2	$0.009	$0.018
Total			**$0.352**

Note that this table does not include the cost of the three-terminal system switch.

3.6 Functional Specification List

The functional characteristics of the power generation module design are listed in Table 3.3.

Table 3.3: Functional Specification List for Design Alternative #2

Functional Characteristics	Expected Value	Required Value (from Functional Spec.)	Met?
Supply Voltage	3.00V±2%	3.00V±10%	Y
Power	0.8mW (Peak)	<1mW (Peak)	Y
Response Time	<1ms	<10ms	Y
Maximum Current Drain	< 65 to 80mA	>16mA	Y
Faucet ver. Battery Life	60 to 80 days	3 years (average)	N
Shower ver. Battery Life	30 to 45 days	3 years (average)	N

With an energy capacity of 440 mAh stored in the two lithium cells and an average operational current of 10mA in the system, our design only supports up to 80 days of normal operation before user is required to replace the batteries, or sustains up to 44 hours of continuous operation. As a result, this design alternative does not meet the power service time requirement. Alternative power generation designs from Build 1.0B (Solar) and Build 1.0C (Hydroelectric) should be evaluated and considered.

Section 4. Input Conversion Module

4.1. Design Choices Overview

The input conversion module in general consists of only two 0805 NTC SMD 10K thermistors and several regular 0805 SMD resistors designed to convert the external temperature readings into the corresponding voltage level. Through the control module, this voltage level will ultimately determine the pulsing duty-cycle sent to the output module, thereby effectively feeding the relative temperature readings back to the users in the form of colour and intensity. Figure 4.1 illustrates the implementation of the input conversion module that converts the temperature readings into scaled reference voltages.

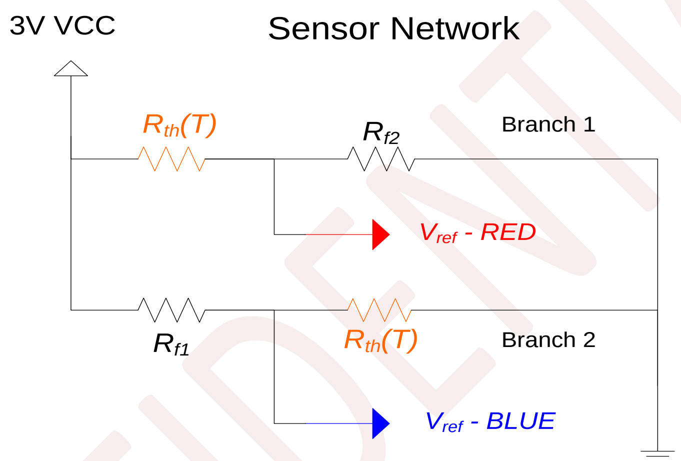

Figure 4.1 : Input Conversion Module

The fixed resistances are selected such that both branches of the module output the reference voltage of approximately 1.56V at the temperature of 25°C (room temperature). The output of branch 1 is directly proportional to the temperature while that of branch 2 is inversely proportional.

4.2. Temperature Measurement Unit

4.2.1. Part Selection

The 0805 NTC SMD 10KΩ Thermistor (P/N NCP21XV103p03RA) is used as the temperature sensor in our input conversion module. The typical reaction time of this series of thermistor is approximately 100ms, which is sufficient to meet the functional specification. Figure 4.2 shows the physical dimensions of a 0805 package.

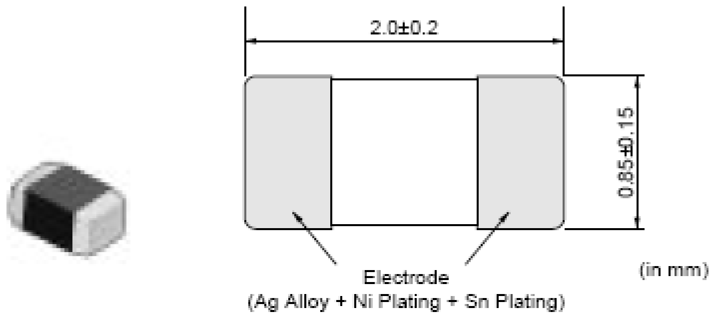

Figure 4.2 : The Physical Dimension of a 0805 Package

The rated electric power (REP) of this thermistor is 10mW, which is well below our application power of 50mW. The operating temperature range is -40°C - 120°C, which again is much wider than our application range of 0°C - 100°C. The B factor, which measures the accuracy of the thermistor, is 3900 3%; this will guarantee a temperature reading accuracy of 5%, as specified in the functional specifications.

It is worth noting that most surface mount thermistors are very much identical in thermal-resisting characteristics. As long as the response time remains within 100ms, any other replacement thermistors from different manufacturers will be acceptable.

4.2.2. Thermistor Characterization in Water

Before the design implementation, we have performed an experiment on characterizing the thermistor in water. As shown in Figure 4.3, the temperature-resistance response of the thermistor in water is an inverse exponential curve.

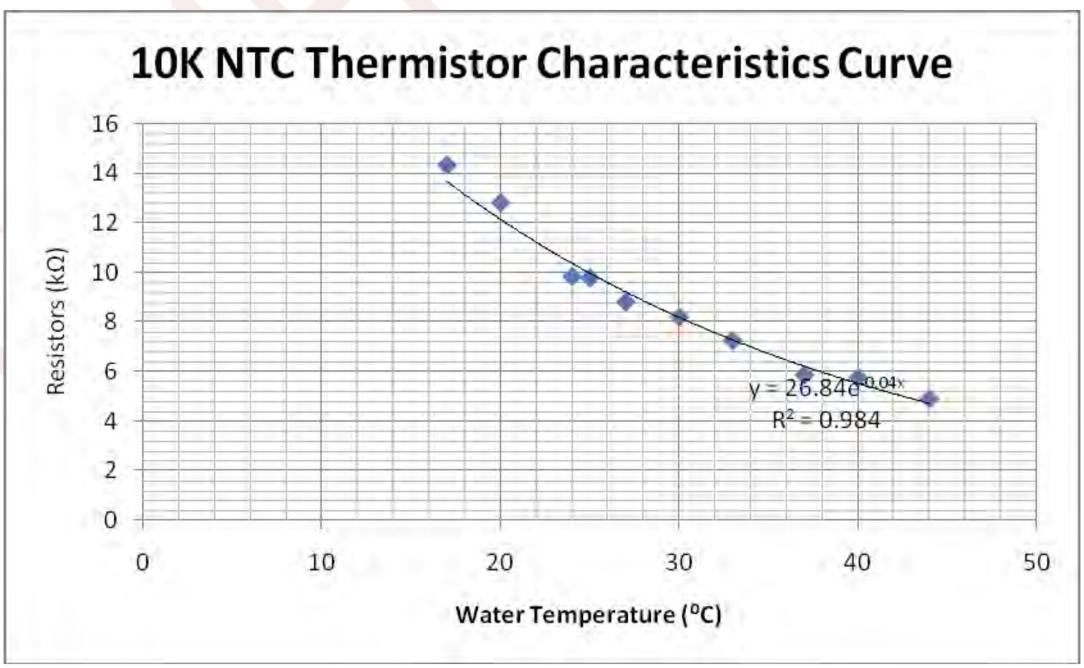

Figure 4.3: Experimentally Determined Temperature-Resistance Characteristic Curve

From this curve we have constructed a mathematical model for the thermistor, as shown in Eq.4.1, where $R_{th}(T)$ is the thermistor resistance at a given temperature T.

$$R_{th}(T) = 378.19T^{-1.1404} \qquad \textbf{(Eq. 4.1)}$$

We have then applied the model to the circuit presented in Figure 4.1, and performed several simulations in Maple to determine the appropriate implementation of the entire input module. In detail, the proper resistor values (R_{f1} and R_{f2}) are accurately determined by substituting T = 25°C into Eq.4.1, then substituting the value of $R_{th}(T)$ back into Figure 4.1, and solving for the value of R_{f1} and R_{f2} when V_{ref}-*Blue* = V_{ref}-*Red* = 1.56V. Figure 4.4 shows the temperature-voltage response of the finalized input conversion module.

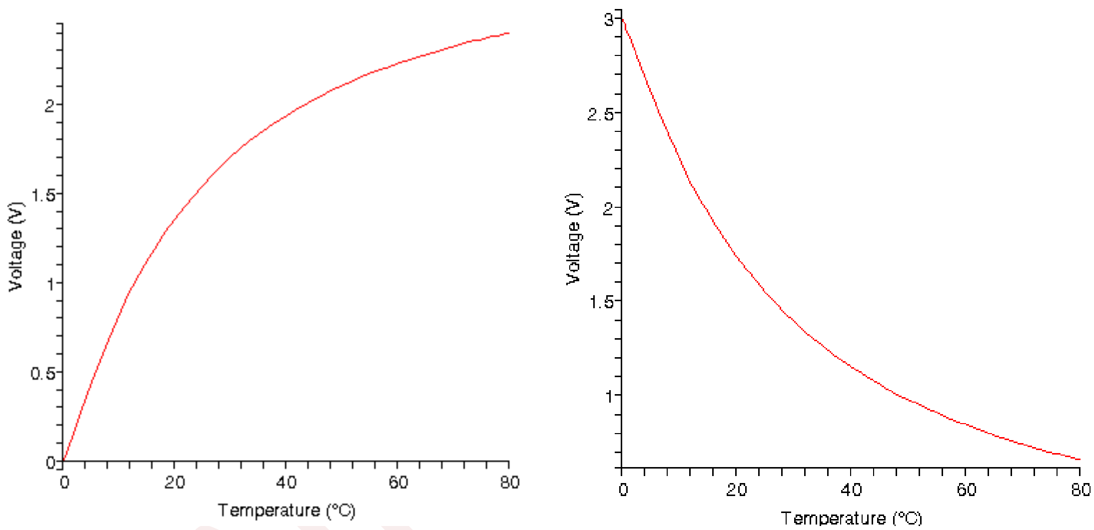

Figure 4.4 : Temperature-Voltage Response of the Input Conversion Module
(Branch 1: left, Branch 2: right)

4.3. Cost Analysis

The 0805 package thermistor is generally very low cost. The retail price for the thermistor is $0.228 CAD/unit, and can be purchased in large quantity at a price of $0.02 CAD/unit. The regulator 0805 package resistors are also very low in price. When purchased in large quantity, the price of a single resistor is as low as $0.005 CAD. In general, the expected cost of the entire input module is around $0.03, which is well below the expected prototype cost.

4.4. Functional Specification List

The final implementation of the input conversion module has the following functional characteristics listed in Table 4.1.

Table 4.1: Functional Specification List for Input Conversion Module

Functional Characteristics	Expected Value	Required Value (from Func. Spec.)	Met?
Size	5mm x 5mm x 1mm	15mm x 15mm x 15mm	Y
Power	0.273mW (Peak, 100°C)	<10mW (Peak)	Y
Update Frequency	Virtually Instantaneous	<60Hz	Y
Accuracy	± 3%	± 5%	Y
Operating Voltage	3V	3V	Y
Voltage Fluctuation	± 15mV (± 0.5%)	± 10%	Y
Response Time	~100ms	~10ms	N
	The response time of 100ms is a conventional low-price thermistor characteristic. To meet the specified 10ms response time, a more expensive thermistor must be used. Considering the cost-benefit factors, we decided to settle with the 100ms response time in order to meet the cost constraint.		
Response Linearity	Inverse Exponential	Linear	N
	The natural response characteristic of a thermistor is inverse exponential (can be modeled with cubic polynomial). Solutions such as linearization circuits can on one hand incur more cost, and other the other hand significantly increase the module size. The visual effect observed by the user after linearization, however, is insignificant. Thus, we decided to not linearize the response.		

Section 5. Control and Processing Module

5.1 Design Choices Overview

The control and processing module (control module) is designed to process the information from the input module and output the voltage pulses to the output module. In our initial design stage, we have considered three alternative control module designs, each of which will be subject to design specification analysis in the following subsections.

Our three control module design candidates utilize two distinct conceptual streams: duty-cycle variation control, and output current variation control. All three alternative designs will operate at 3V VCC, and should have a response time within 1ms. Also, as long as the functionality remains the same, surface-mount components are more preferred in order to limit the module size.

5.2 Design Alternative #1 – Voltage Comparator Design Overview

The first alternative design for the control module is the duty-cycle variation control. The module generates a +1.56V-offset triangular wave (0.83V Peak-Peak) internally with a bi-stable multivibrator and an integrator, and feeds the wave to the positive terminal of the two comparators. The reference voltages fed from the input module are connected to the negative terminals of the comparators. When the reference voltage goes above 1.56V, the comparators will output pulse trains to the output module; the duty-cycle of the pulse train is proportional to the reference voltage level, as shown in Figure 5.1.

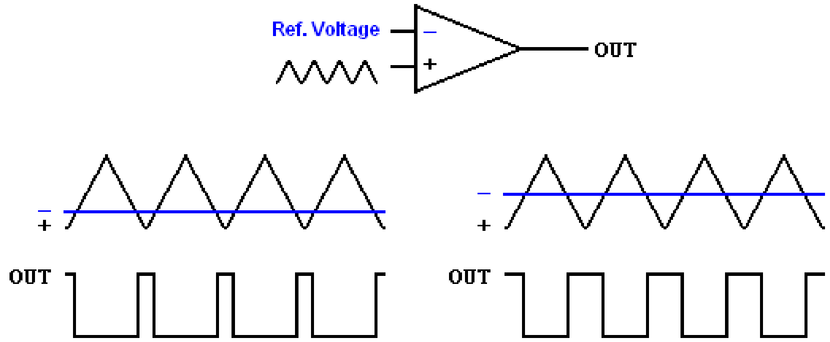

Figure 5.1 : Concept of Voltage-Comparing Duty-Cycle Variation

Design Advantage

This design, accompanied with the two-branched input conversion module, gives us an easy control over the zero-point adjustment. The design is also a one-chip solution, which effectively limits the module size. Finally, pulsing duty-cycle variation creates a more consistent luminosity variation than does output current variation.

5.2.1 System Components

The overall system implementation is shown in Figure 5.2.

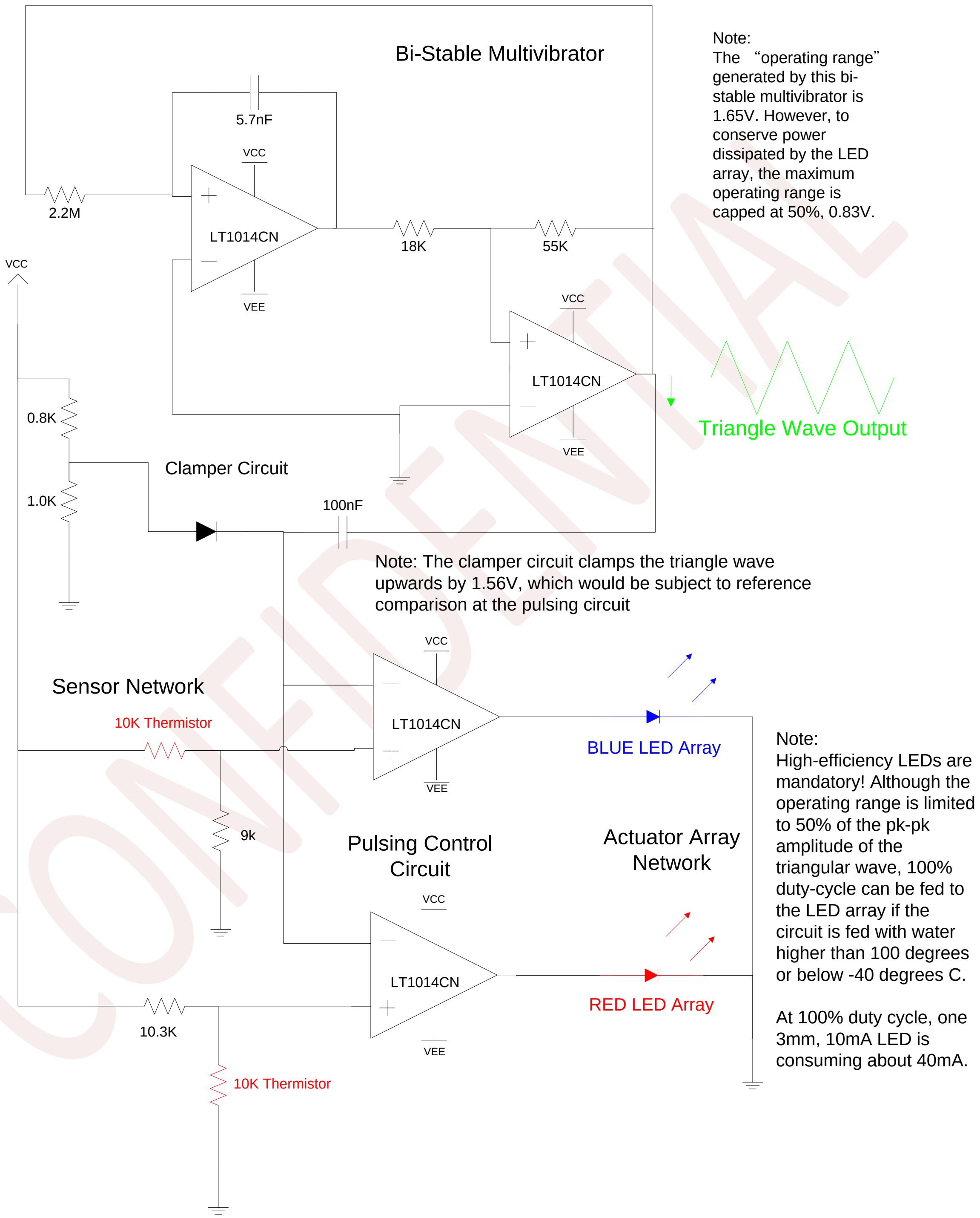

Figure 5.2 : Overall Implementation of Design Alternative

Table 5.1 summarizes the required components for the design.

Table 5.1: Required Physical Circuit Components

Circuit Element	Physical Component
4 Operational Amplifiers	SMD LT1014N Micropower Quad OpAmp
Diode	SMD 0.7V Signal Diode
Capacitor	SMD Ceramic Non-Polar Capacitor
Resistor	SMD 0805 Resistor

The operational amplifier chip serves two purposes: dual-channel comparators and triangular waveform generator. The 0.7V signal diode along with a capacitor creates a clamper circuit to clamp the triangular wave upward for 1.56V (set by the voltage divider).

In order to leave as much usable power as possible for the output module, the control module must consume less than 5mW of power. The LT1014N Micropower Quad OpAmp is the key for this design to meet the power consumption limit. This specific op amp IC is specially designed for battery-powered devices. Each op amp unit on-chip consumes 200uW at maximum. The design alternative #1 is using all four op amps, therefore it will consume 800uW at maximum. If we are to use a conventional op amp for this design, the power consumption of the module is expected to consume more than 50mW of power.

5.2.2 Cost Analysis

Design alternative #1 for the control module is very inexpensive. The cost of the LT1014N micropower Op Amp dominates the cost of the module. LT1014N IC alone costs $4.50 CAD/unit in retail price, but can go as low as $0.80 CAD/unit when purchased in quantity. Other components (ie. capacitors, resistors, and diodes) cost less than $0.01 CAD/unit when purchased in quantity. Thus, the overall cost of this alternative design is roughly $1.00 CAD, which meets the design specification.

5.2.3 Function Specification List

The functional characteristics of the design alternative #1 are listed in Table 5.2.

Table 5.2: Functional Specification List for Design Alternative #1

Functional Characteristics	Expected Value	Required Value (from Func. Spec.)	Met?
Size	10mm x 12mm x 6mm	10mm x 12mm x 10mm	Y
Power	800uW (Peak, 25°C)	<5mW (Peak)	Y
Response Time	0.2 us/V	<10ms	Y
Operating Voltage	3V	3V	Y
Voltage Fluctuation	± 0.55 uV (± ~0%)	± 10%	Y
Response Linearity	Linear	Linear	Y

5.3 Design Alternative #2 – Current Variation

5.3.1 Design Overview

The second design alternative is to generate the 60Hz, 50% duty-cycle pulse train either from the Op Amp or BJT bi-stable multivibrator, and use the thermistor as the dynamic current limiter to control the current running through the output module. The pulsing frequency of 60Hz is a conventional LED pulsing frequency. The conceptual model is presented in Figure 5.3.

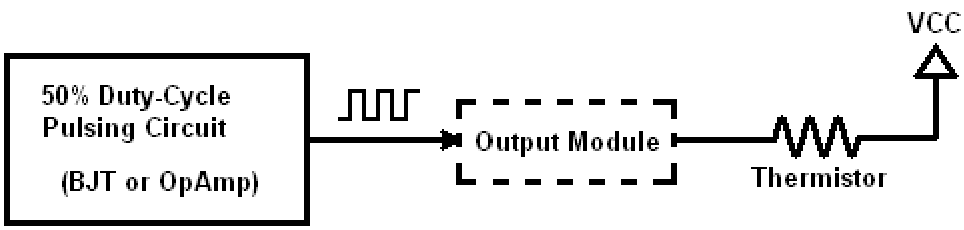

Figure 5.3 : Conceptual Model of the Design Alternative #2

In order to reduce the design size, we decided to use the BJT bi-stable multivibrator as the waveform generator, and feed the waveform to the output. The pulse generating circuit is shown in Figure 5.4.

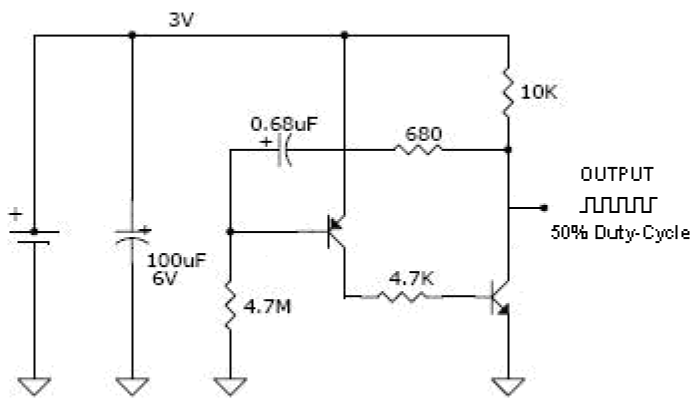

Figure 5.4 : BJT Bi-stable Multivibrator Implementation

Design Advantage

This design requires no IC, therefore conserves space. The power consumption of this design can be reduced significantly by replacing the BJTs with low-power FETs.

Why Not Used

Although the size and the power consumption of this design are largely reduced, other problems arise . First, the pulsing duty-cycle is fixed at 50%, which will cause the output module to consume unnecessary power. Ideally, in order to maintain a relatively efficient power consumption level, a duty-cycle of 10% to 20% is sufficient. Thus, as far as the power consumption is concerned, this design is less preferred.

Second, since the thermistors alone are functioning as the current limiter, controlling the zero-point becomes very problematic. A lot more mathematical simulations and calculations are required. Thus, in terms of design convenience, this design is less friendly.

Thirdly, the low-current LED (in the output module) usually has a sharp cutoff current boundary. Any current below this boundary will not light up the LED. Thus, with the current limiter design, the cutoff effect can cause discontinuities in the red-blue spectrum; this in general violates the fundamental requirements outlined in the functional specification.

5.3.2 System Components

The overall system implementation is shown in Figure 5.5, and the required components are listed in Table 5.3.

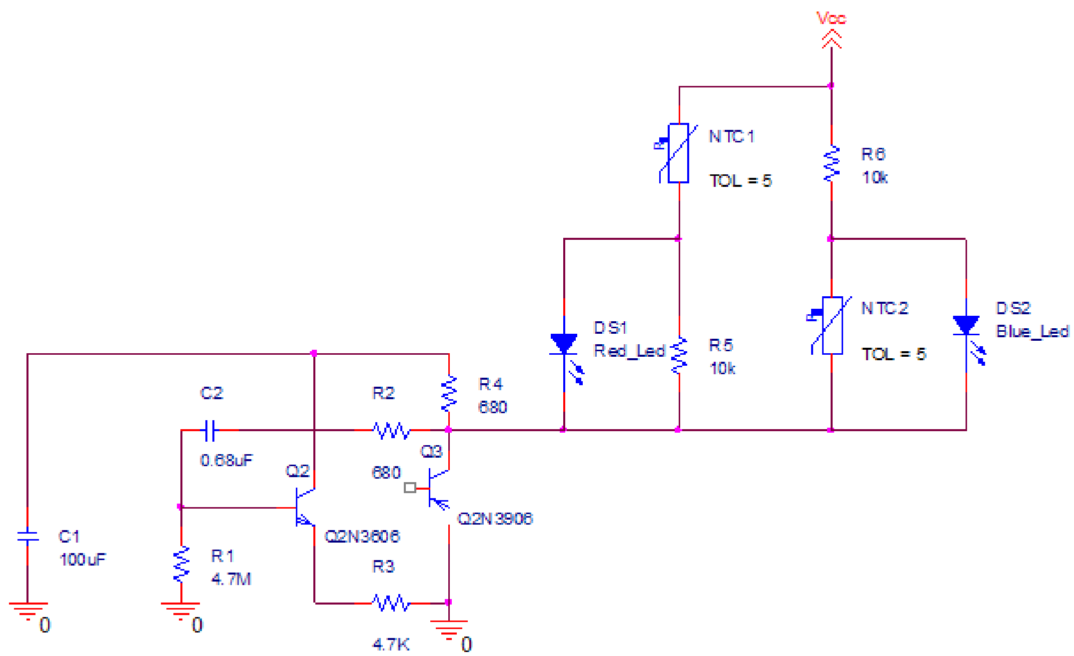

Figure 5.5 : Overall Implementation of Design Alternative

Table 5.3: Required Physical Circuit Components

Circuit Element	Physical Component
1 NPN Transistor	2N3904 NPN Transistor
1 PNP Transistor	2N3906 PNP Transistor
Polarized Capacitor	Polarized Ceramic Capacitor
Resistor	SMD 0805 Resistor

The two transistors, combined with the two resistors, serve as a two-stage voltage amplifier to achieve voltage vibration amplification. The RC feedback loop determines the oscillation frequency of the circuit, and the 100uF capacitor is the bypass capacitor.

5.3.3 Cost Analysis

The cost of the system is very low. Through-hole small-signal BJT transistors usually can be purchased at $0.01 CAD/unit when in large quantity. The polarized capacitors and the surface-mount resistors all have the same price range. Thus, the cost of the overall design is roughly around $0.20 CAD/unit.

5.3.4 Function Specification List

The functional characteristics of the design alternative #2 are listed in Table 5.4.

Table 5.4: Functional Specification List for Design Alternative #2

Functional Characteristics	Expected Value	Required Value (from Func. Spec.)	Met?
Size	10mm x 12mm x 3mm	10mm x 12mm x 10mm	Y
Power	1.7mW (Peak, 25°C)	<5mW (Peak)	Y
Response Time	Virtually Instantaneous	<10ms	Y
Operating Voltage	3V	3V	Y
Voltage Fluctuation	± 14mV (± 0.46%)	± 10%	Y
Response Linearity	Linear (Small Signal)	Linear	Y

5.4 Design Alternative #3 – Improved Current Variation

5.4.1 Cost Analysis

Inheriting the current varying concept from the design alternative #2, this design uses the thermistor as the current limiter to control the brightness of the LEDs in the output module. The pulsing circuit in design alternative #3, however, is constructed by two digital ICs to generate a 12.5% (one-eighth) duty-cycle pulse train, aiming to overcome the power consumption problem present in alternative #2.

The 12.5% duty-cycle pulse train generator circuit is shown in Figure 5.6. The third bit of the counter is one-eighth of the clock cycle, and is only set to HI when the oscillator has oscillated 8 times between 1 and 0. At the eighth time, the D flip-flip will see the logic HI at its D input, and will be set HI. The inverted output of the flip-flop therefore will become zero, which in turn asynchronously reset the counter. After reset, B3 will become zero immediately, and in the next clock cycle the D flip-flip will be set to logic LO again. As this one-eighth bi-stable vibration continues on, a 12.5% duty cycle pulse train will be effectively generated.

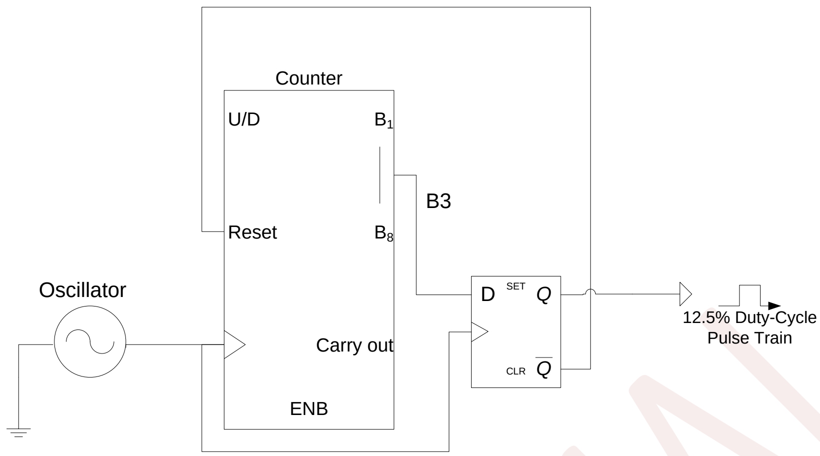

Figure 5.6 : 12.5% Duty-Cycle Pulse Train Generator

Design Advantage

The pulsing duty-cycle is optimized to reduce the power consumption at the output module. The pulse generation is done digitally, and changing the duty-cycle percentage is relatively easy.

Why Not Being Used?

Even though the pulse duty-cycle is much more optimized, the size of the module becomes unacceptably large in size. Furthermore, the power consumption of the control module skyrockets to hundreds of mW, which is way beyond the power consumption cap proposed in the functional specification.

5.4.2 System Components

The overall system implementation is shown in Figure 5.7.

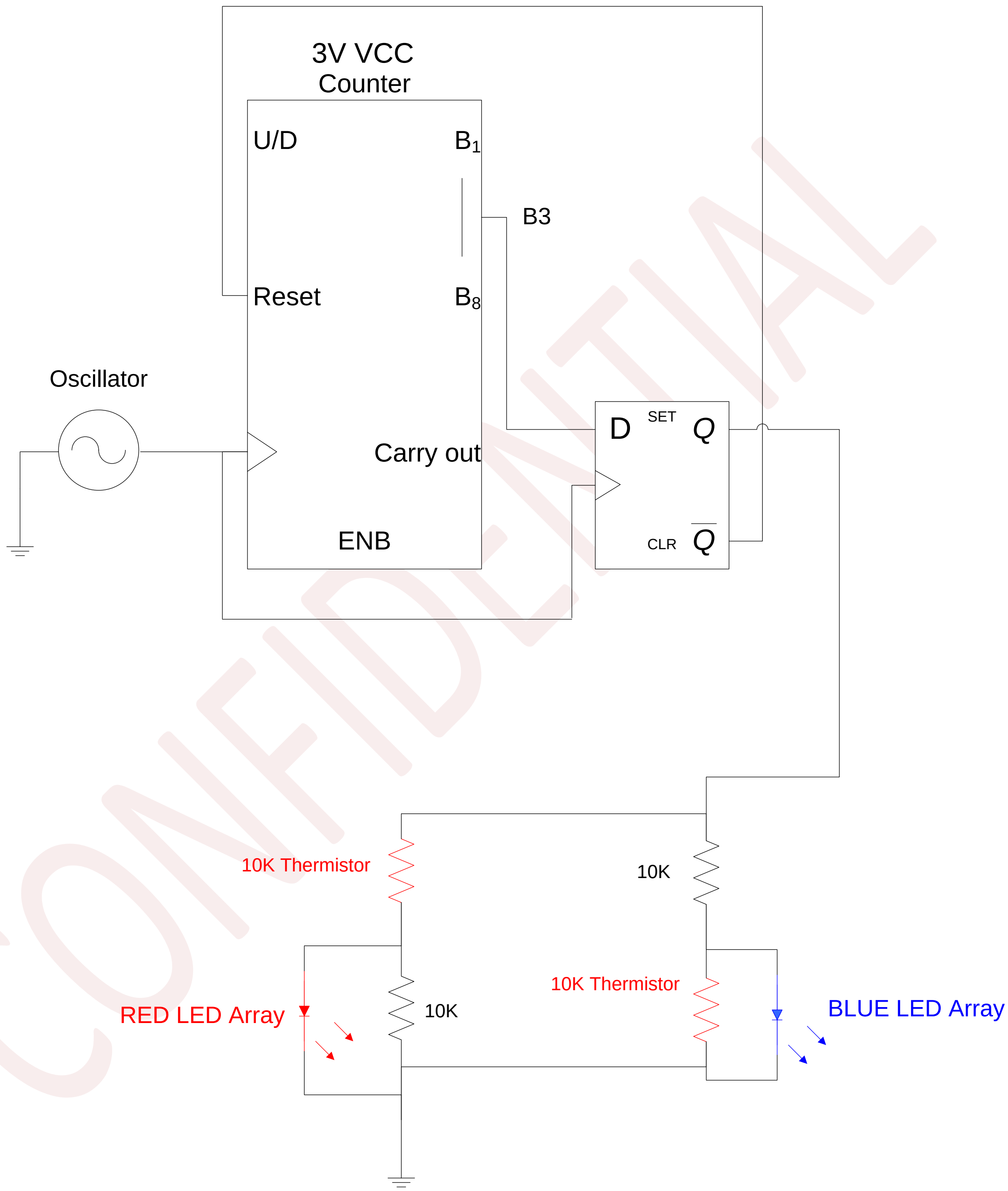

Figure 5.7 : Overall Implementation of Design Alternative

Table 5.5 summarizes the required components in the design.

Table 5.5: Required Physical Circuit Components

Circuit Element	Physical Component
1 16-bit Counter	SN74LV8154N 16-bit Counter IC
1 D Flip-Flop	74LVX374M Octal D Flip-flop IC
1 Oscillator	SMD Oscillator

5.4.3 Cost Analysis

The cost of the design alternative #3 is relatively high. The counter chip and the D flip-flop chip are available at $0.51 CAD/unit and $0.26 CAD/unit in large quantity. The surface-mount oscillator is usually carried at $0.30 CAD/unit when order in quantity. Thus, the total cost of the design is expected to be approximately $1.10 CAD, which is the highest among the three alternatives.

5.4.4 Functional Specification List

The functional characteristics of the design alternative #3 are listed in Table 5.6.

Table 5.6: Functional Specification List for Design Alternative #3

Functional Characteristics	Expected Value	Required Value (from Func. Spec.)	Met?
Size	12mm x 25mm x 5mm	10mm x 12mm x 10mm	N
Power	624mW (Peak, 25°C)	<5mW (Peak)	N
Response Time	< 20us (Datasheet)	<10ms	Y
Operating Voltage	3V	3V	Y
Voltage Fluctuation	± 30uV (± ~0%)	± 10%	Y
Response Linearity	Linear	Linear	Y

Section 6. Output Conversion Module

6.1 Design Choices Overview

The output conversion module is simply two LEDs, one blue and one red. Since LEDs are the most power-consuming components of the entire ChromaTap system, the LEDs selected for the final implementation must be highly power-efficient (20mW, ideally). If through-hole LEDs are used, the size of the LEDs should be at most 3mm in diameter; if surface-mount is possible for implementation, the 0805 package should be used.

6.2 Visual Indication Unit

In the final implementation, the output module will use two surface-mount LEDs in standard 0805 package. The dimensions of a 0805 package LED is shown in Figure 6.1. The luminosity of the output module should be at least 10 mcd, and the response time of the LEDs is to be near-instantaneous.

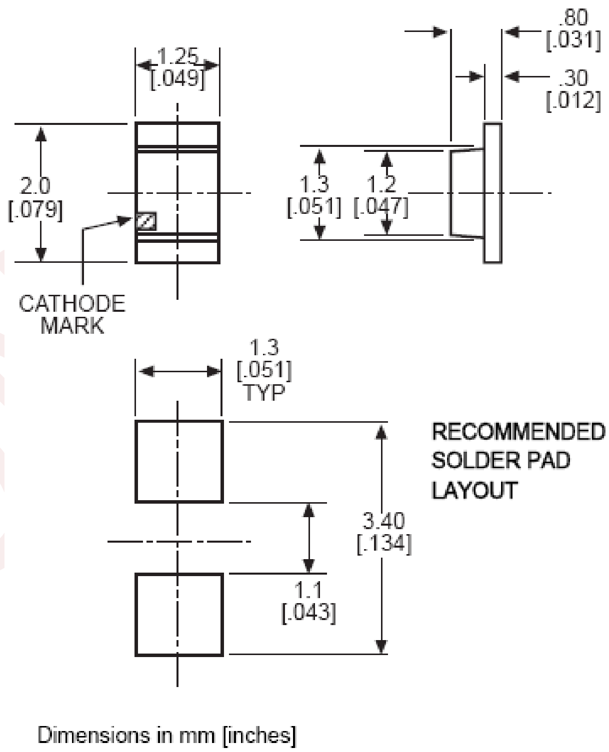

Figure 6.1 : 0805 Package LED Dimension

In combination with the input conversion module and the control and processing module, the output module should output a continuous blue-red spectrum with respect to the temperature band of 0°C ~ 100°C. The spectrum is illustrated in Figure 6.2.

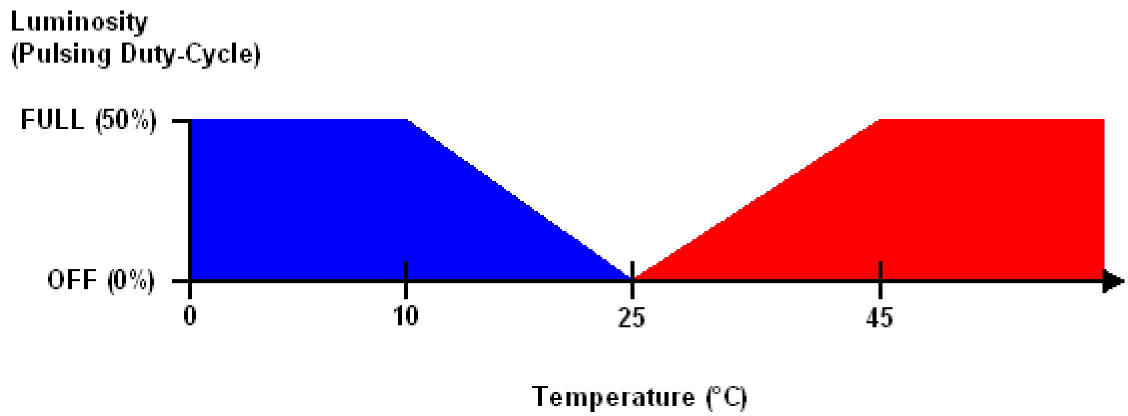

Figure 6.2 : The Temperature Dependant Blue-Red Spectrum

6.3 Cost Analysis

The cost of the output module is simply the cost of two LEDs. In general, the red surface-mount LEDs are very low in price, available usually in $0.10 CAD/unit when purchased in large quantity. The blue surface-mount LEDs are a bit more costly, usually carried at the price of $0.25 CAD/unit in large quantity. The overall cost of the output module is expected to be at maximum $0.40 CAD/unit.

6.4 Functional Specification List

The functional characteristics of the output module are listed in Table 6.1.

Table 6.1: Functional Specification List for the Output Module

Functional Characteristics	Expected Value	Required Value (from Func. Spec.)	Met?
Size	5mm x 2mm x 0.8mm	10mm x 10mm x 10mm	Y
Power	NOT YET DETERMINED	<20mW (Peak)	U
	The power rating of the LEDs is not yet determined at this stage of the project since the LED source is still ongoing.		
Response Time	Instantaneous	<100us	Y
Operating Voltage	3V	3V	Y
Voltage Fluctuation	NOT YET DETERMINED	± 10%	U
	The voltage fluctuation of the LEDs is not yet determined at this stage of the project since the LED sourcing is still ongoing.		

Section 7. Casing and Mechanical Module

7.1 Design Overview

The mechanical design of the ChromaTap is intended to meet or exceed the guidelines outlined in the functional specification while maintaining as small a physical footprint as possible. We have made use of the 3D design tool SolidWorks to create comprehensive models of each casing component for both the faucet and showerhead variants of the ChromaTap. Both variants of the Chromatap make use of proven techniques for water sealing used in typical faucet add-ons and showerhead replacements, design elements which are shared across many types of products and considered to be public domain knowledge. The detailed dimension of the casing components can be found in the Appendix.

7.2 Faucet Variant

A view of the current mechanical design (exploded view) is shown in the figure below. Components will be explained in the subsequent sections. Note that there is a spring module for the battery as well as an o-ring for water sealing.

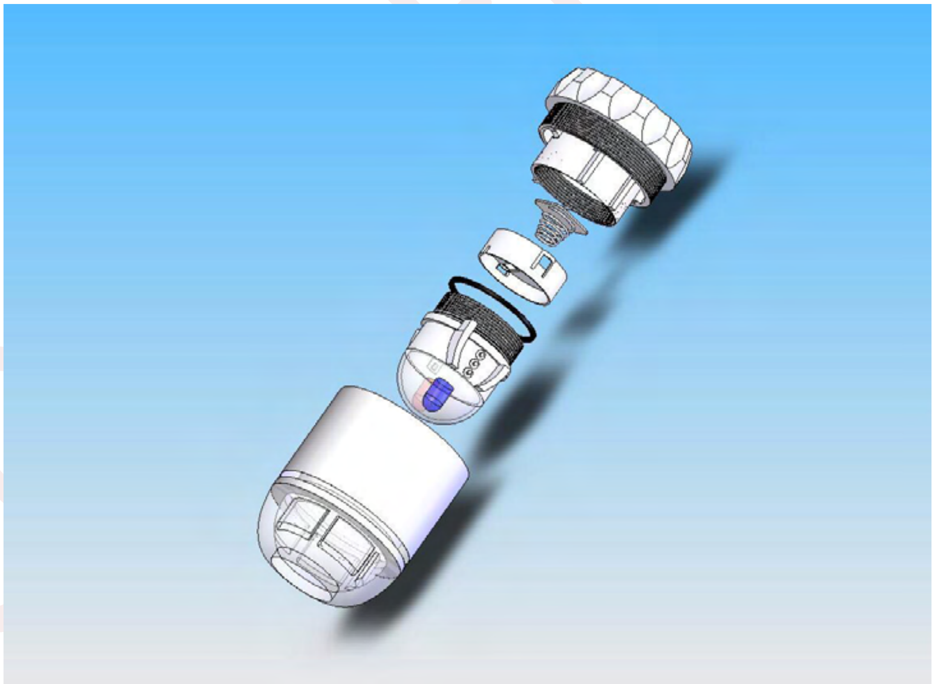

Figure 7.1 : Exploded View of Faucet ChromaTap

7.2.1 Choice of Materials

With the goal of meeting the requirements in the functional specification for shock resistance, operating temperature range, and cost, we have chosen to construct the final ChromaTap from polystyrene plastic. Common uses for polystyrene (other than the packing foam application) include plastic cutlery, and it is considered to be among the best materials for injection molding. Polystyrene will also meet the functional specification requirements for operating temperature and durability. Most importantly for our application, it is non-toxic, and relatively low cost compared to other more general purpose plastics, such as ABS or Polycarbonate. In fact, polycarbonate can cost up to 4 times as much as polystyrene.

Making the ChromaTap out of metal would be prohibitively costly since most metals are orders of magnitude more expensive than plastic, and also assembly processes may be more difficult than relatively simple plastic injection molding. Furthermore, making it out of metal provides no compelling benefits since the molded plastic would be durable enough to withstand daily use, and furthermore, would not need to be rust-proofed like a metal version.

7.2.2 Universal Faucet Adaptor

These components, pictured below, have one end that screws into the faucet and another that screws into the Chromatap. Thus, the two most common faucet sizes in North America can be accommodated in this way, with the user installing the appropriate adapter first onto the ChromaTap and then onto their faucet. Using threads ensures a waterproof and durable seal that will last a long time, while still being removable in case the user decides to change installation locations. Figures 7.2 and 7.3 show the universal adapter components.

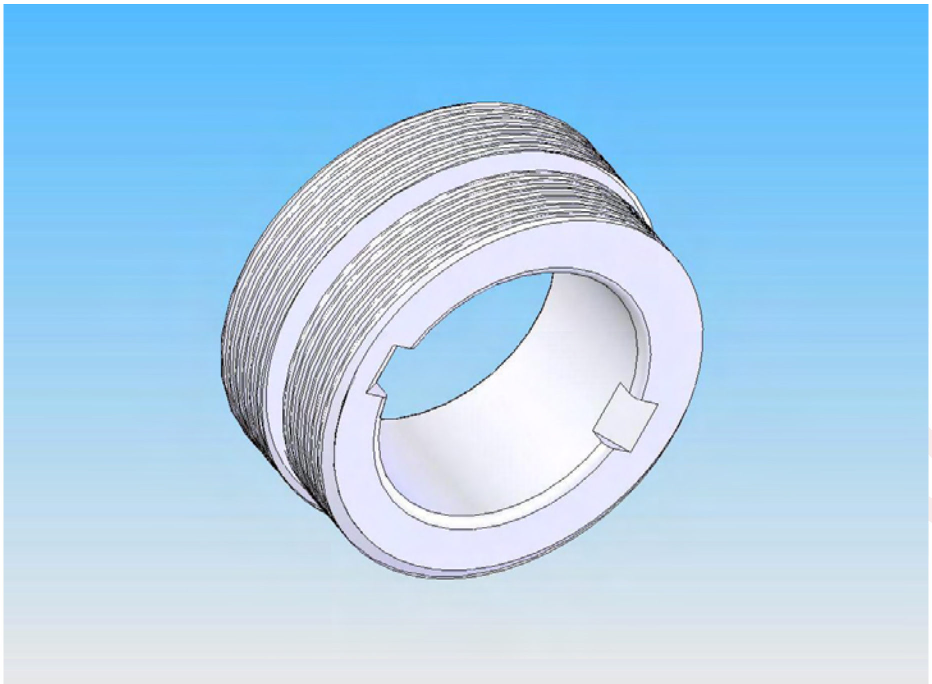

Figure 7.2 : Large faucet size adapter

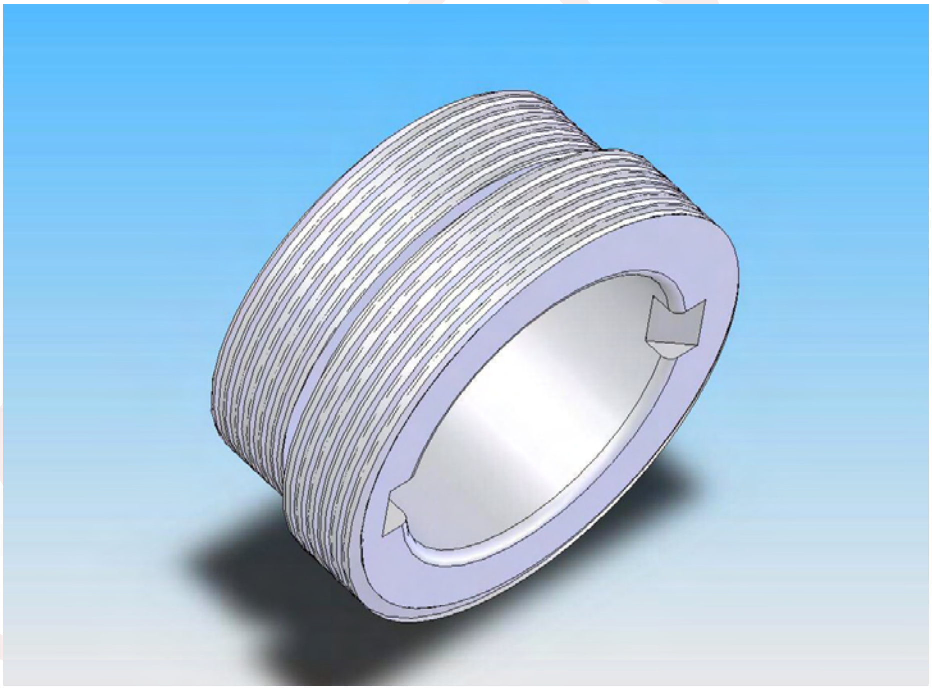

Figure 7.3 : Small faucet size adapter

7.2.3 Aerator

The aerator unit is a simple metal mesh which acts to insert air into the water flow. This reduces the amount of water that comes from the tap without affecting water pressure, thus conserving water. Aerators are standard for most faucet add-ons. Note that since the amount of water is reduced, an aerator may not be installed for the water powered version of the ChromaTap.

7.2.4 Body Compartment

The body compartment is designed to provide an outer covering for the ChromaTap and is removable for replacement of the battery. All circuit and output lighting components are ultimately enclosed in the upper body compartment. The upper body compartment also includes a stylish slit near the bottom to allow for some light from the LEDs to escape the casing, so the user can see the color both on the device itself, as well as in the water. The lower body compartment is made of transparent plastic and provides an output path for the water, and any excess light. Figures 7.4 and 7.5 show the body compartments.

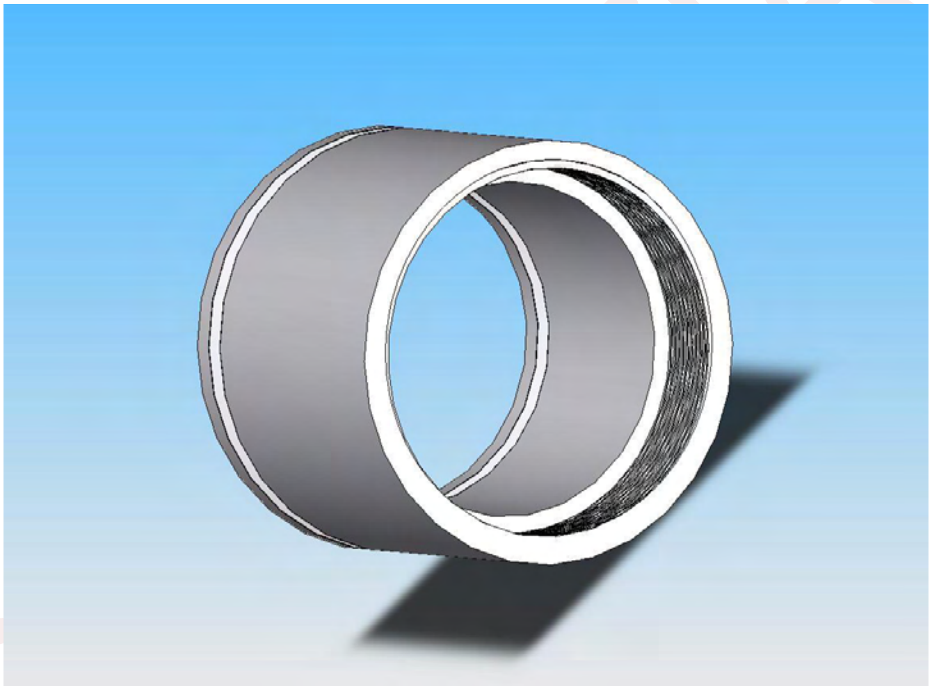

Figure 7.4 : Body Compartment (Upper)

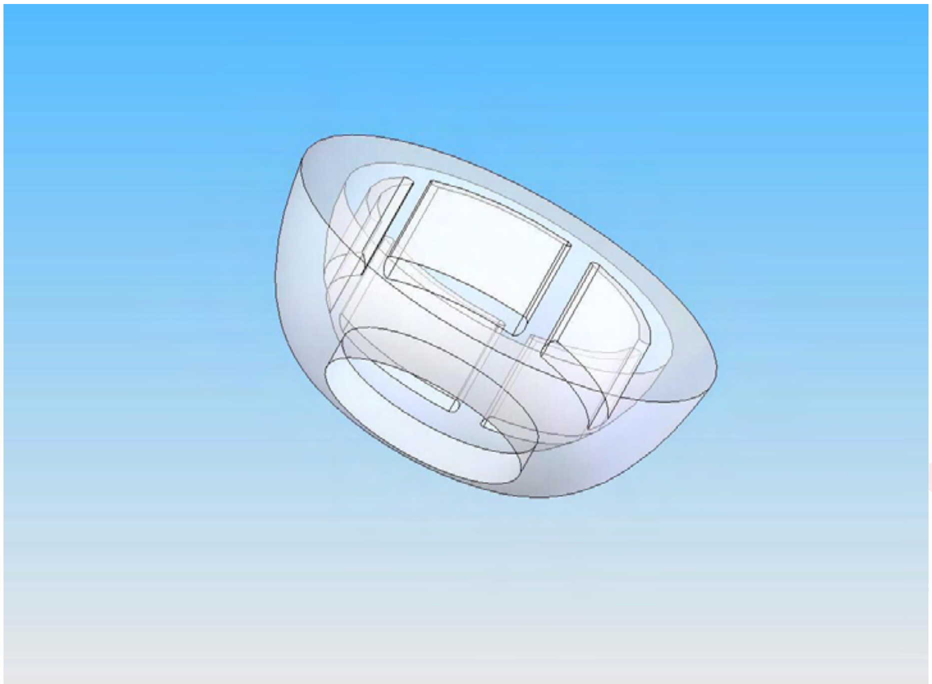

Figure 7.5 : Body Compartment (Lower)

7.2.5 Battery Compartment

The battery compartment stores the CR2032 batteries required to power the ChromaTap. One battery is inserted on each side.

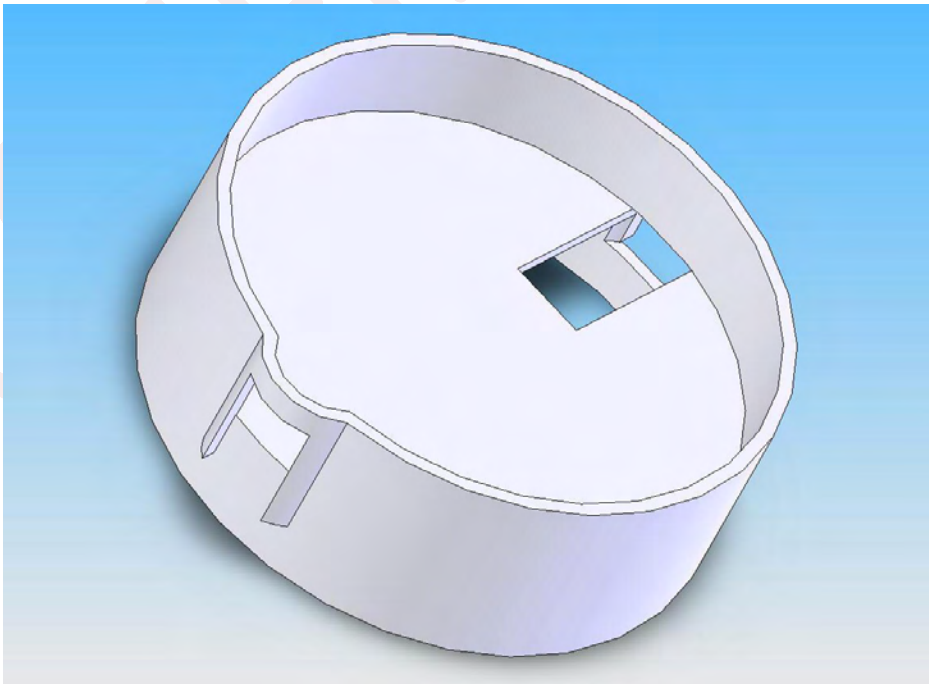

Figure 7.6 : Battery Compartment

7.2.6 Electronics Compartments

The electronics compartment of the ChromaTap provides a water-sealed compartment for the electronic components used, while allowing for openings for the input activation and thermistors, as well as the tips of the LEDs used for lighting. Figure 7.7 shows the compartment.

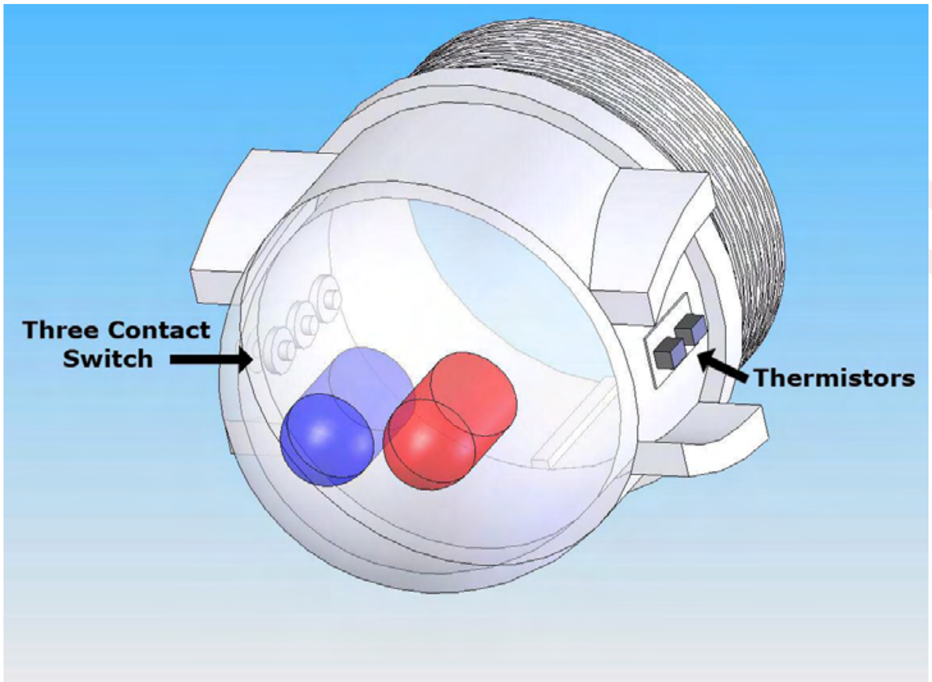

Figure 7.7 : Electronics Compartment

7.2.7 Input Activation Method

The ChromaTap mechanical casing makes use of three exposed contacts (which are part of the Input conversion modules) to turn the system on and off. As can be seen in Figure 7.7, there are two water channels which allows the input conversion module to access information, one on each side. One of these has the thermistors exposed for temperature sensing, and the other has the three exposed contacts used for input activation. These three exposed contacts will be shorted when there is water flowing through the ChromaTap, thus turning the ChromaTap on. When there is no water flowing, the contacts are open, and thus the ChromaTap is off. This is the most reliable method for input activation since it requires no moving parts and makes use of the water flow. The one disadvantage of the current solution is that the amount of water used to short the circuit is introduced as a resistance in the circuit path, but we anticipate that this resistance will be negligible, based on preliminary experimental results.

7.2.8 Expected Performance & Cost

Given our choice of materials and system design, we expect that the ChromaTap will meet the requirements in the functional specification. Prior to production, we will obtain detailed cost quotes for our given quantity and lean towards the use of recycled materials to save costs. As it stands, pricing for polystyrene is approximately 50 cents to 1 dollar US per pound of material used. Once our SolidWorks models are fully finished, we will be able to apply material properties to determine the exact weight of the ChromaTap as designed, and thus better able to quote the cost of the required material. Further, we will perform simulations in SolidWorks on the material to ensure that it meets the shock and durability requirements outlined in the functional specification – before a unit is ever produced.

7.3 Showerhead Replacement Variant

A view of the current mechanical design (exploded view) is shown in the figure below. Components will be explained in the subsequent sections.

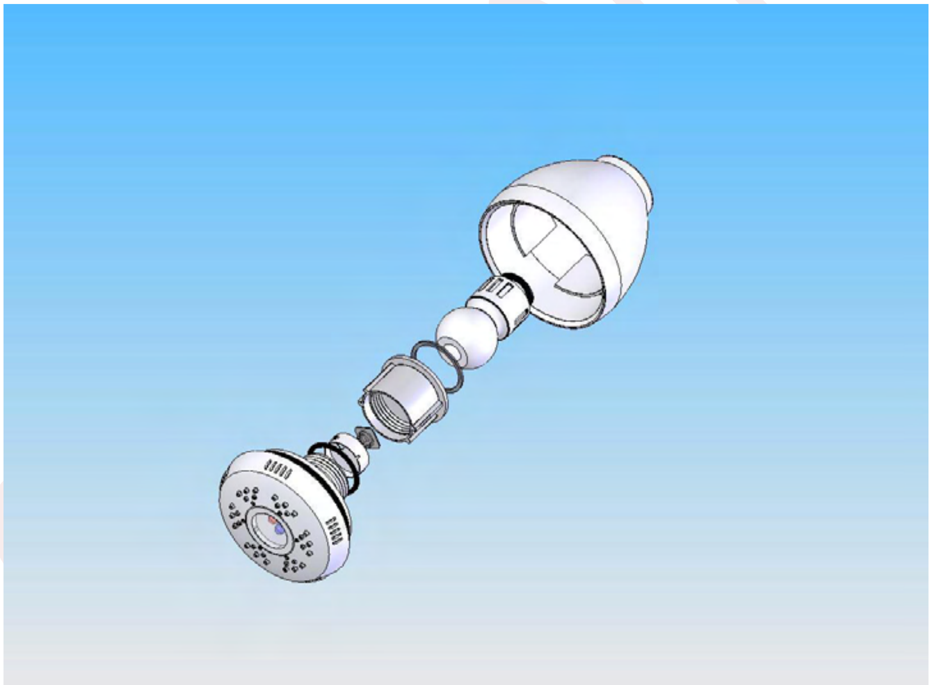

Figure 7.8 : Exploded View of Showerhead ChromaTap

7.3.1 Showerhead Design

The ChromaTap showerhead casing design is based on a conventional showerhead – for both familiarity to the user, and to avoid complexities with "re-inventing the wheel". Showerhead attachments are even more standardized than faucets, and one size is sufficient to fit most showerheads. Ideally, the showerhead will share material composition with the faucet version of the ChromaTap (see section 7.2.1), and will be made out of polystyrene.

7.3.2 Electronics Compartment

The ChromaTap showerhead electronics compartment is designed to seal water out while providing sealed interfaces for the input conversion module to interact with the water stream. This is designed similar to the faucet version. The compartment is shown in Figure 7.9 below.

Figure 7.9 : Electronics Compartment (back view)

7.3.3 Output Method

Like the faucet version, the showerhead variant of the ChromaTap uses two LEDs for output, and these LEDs are positioned in the center of the showerhead. It is depicted in Figure 7.10 below.

Figure 7.10 : Electronics Compartment, showing output method (front view)

7.3.4 Battery Compartment

The battery compartment is a shared part with the faucet ChromaTap, and uses CR2032s.

7.3.5 Ball Joint

The ball joint is used in conjunction with an insertion module to provide two channels of water flow for the electronics compartment. The use of an internal ball joint allows for rotation of the showerhead for the users convenience. These two components are shown in Figures 7.11 and 7.12 below.

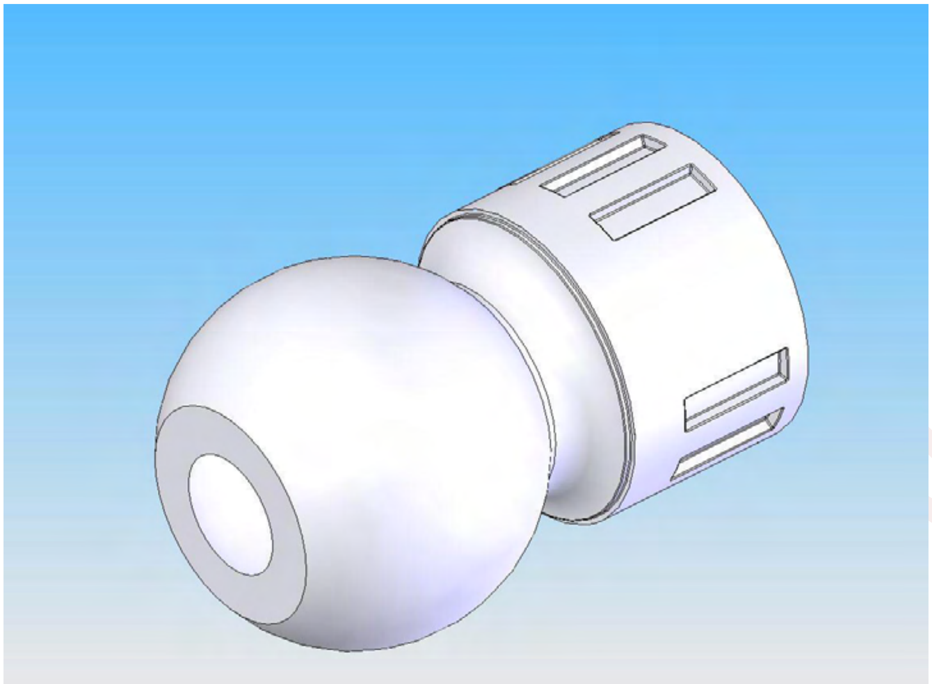

Figure 7.11 : Ball Joint

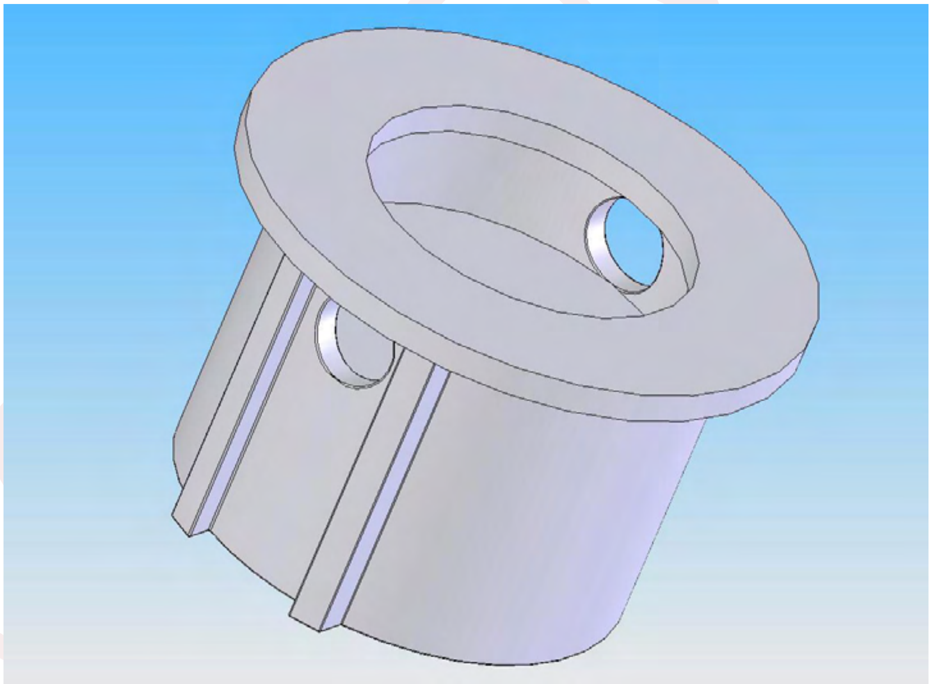

Figure 7.12 : Ball Joint Insertion component (threads on other end)

Section 8. System Design Constraints & Budget

8.1 Overall System Cost

Based on the design approach we have chosen for each module, we have estimated the total unit cost of the ChromaTap Build 1.0a to be $1.88. Table 8.1 outlines the component unit cost for each module. The detailed design and cost break down of each module will be discussed in the following sections.

Table 8.1: Unit Module Cost for ChromaTap Build 1.0a (Faucet Variant)

Module	Volume Unit Cost (at 1,000 units)
Power Generation Module	$0.352
Input Conversion Module	$0.030
Control & Processing Module (Design #1)	$1.000
Output Conversion Module	$0.400
Mechanical Casing	$0.100
Total	**$1.882**

Figure 8.1 shows a cost percentage breakdown of each module in terms of the total unit cost.

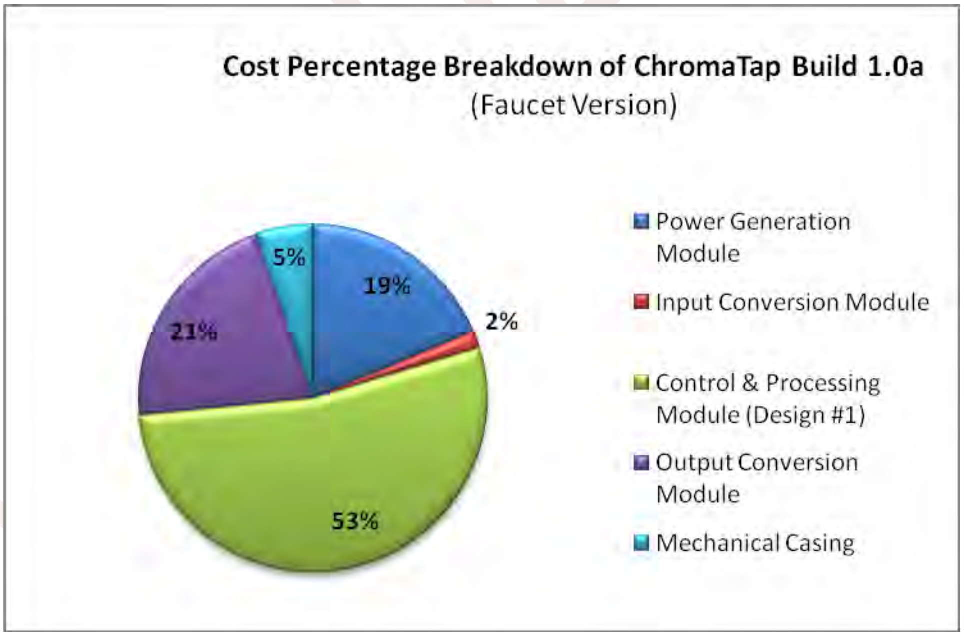

Figure 8.1 : Unit Module Cost Breakdown for ChromaTap Build 1.0a (Faucet Variant)

8.2 Energy Constraints

As indicated in Section 3, our battery-powered design only supports up to 44 hours of continuous operation. This battery life does not fulfill our functional requirements for the project. For future design consideration and improvement, Table 8.2 summarizes the power consumption for each of our module in the ChromaTap Build 1.0a.

Table 8.2: Energy Budget for ChromaTap Build 1.0a (Faucet Variant)

Module	Power Consumption (mW)
Power Generation Module	0.80
Input Conversion Module	0.27
Control & Processing Module (Design #1)	0.80
Output Conversion Module	30.00
Total	31.87

Figure 8.2 illustrates the consumption percentage breakdown of each module in terms of the total power consumption.

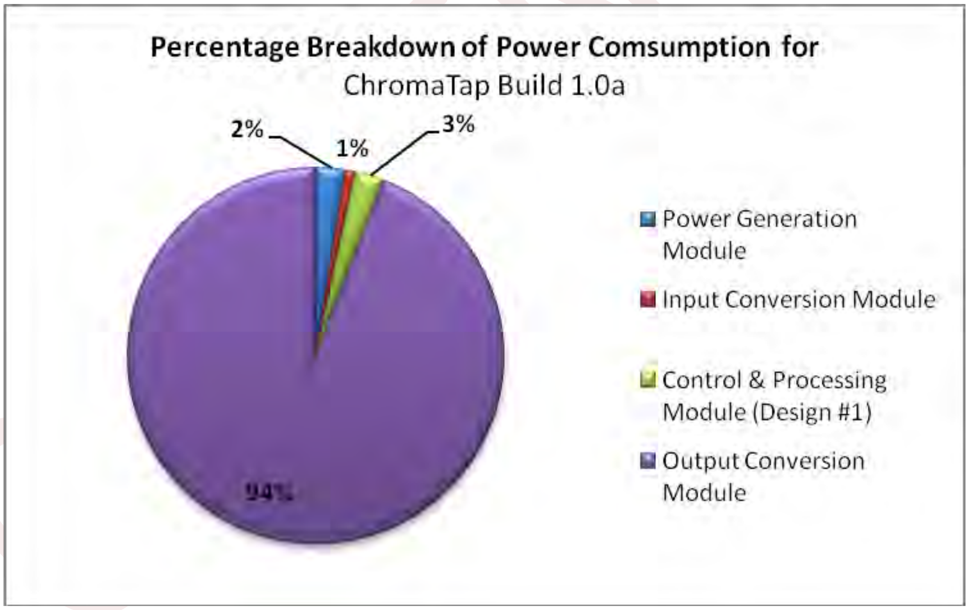

Figure 8.2 : Unit Module Cost Breakdown for ChromaTap Build 1.0a (Faucet Variant)

The total peak power consumption of Build 1.0a is totaled to be 31.87mW, which is 35% below our required consumption of 50mW. Nevertheless, the energy capacity stored inside the battery posed a tighter power consumption constraint in our circuit design. To meet our functional requirement, the energy capacity should be increased, and the power consumption should be lowered.

Section 9. System Test Plan

The System Test Plan outlined here is intended for testing the increment 1 prototypes of the ChromaTap. The intention of the tests proposed is to determine how well the prototypes meet the requirements outlined in the functional specification. For convenience, all the tests outlined in this section are summarized in the table below.

Table 9.1 Test Case Summary

Test Case #.	Test Case Title	Testing Category	Related Func. Requirements
T1	Basic Water Lighting Functionality Test	Overall System	R[1], R[3], R[7], R[8], R[12], R[17]-R[23]
T2	Intermediate Water Lighting Functionality Test	Overall System	R[9]-R[11], R[13]-R[15], R[16]
T3	Operating Temperature Test	Overall System	R[41]
T4	Input Conversion Module Basic Tests	Input Conversion Module	R[66], R[73]
T5	Input Conversion Module Technical Tests	Input Conversion Module	R[63], R[64], R[65], R[67], R[72]
T6	Output Conversion Module Technical Tests	Output Conversion Module	R[74], R[75], R[79], R[80]
T7	Control and Processing Module Technical Tests	Control and Processing Module	R[90], R[91], R[93], R[96]
T8	Power Generation Module Technical Tests	Power Generation Module	R[81]-R[84]
T9	Power Generation Module Longevity Test	Power Generation Module	R[85]
T10	Basic System Reliability Test	Reliability Testing	None

9.1 System Functionality Testing

Test Case #:	T1
Test Case Title:	Basic Water Lighting Functionality Test
Related Requirement(s):	**R[1], R[3], R[7], R[8], R[12], R[17]-R[23] (Increment 1 initial view – compare to requirements for increment 2)**
Description:	This test determines if the output of the ChromaTap is working properly. The test will involve verifying the color, intensity, and projection characteristics of the ChromaTap to ensure that these are in line with the requirements set forth in the functional specification.
Required Resources:	Water faucet, ChromaTap Prototype, angular measurement device
Expected Results:	We expect the ChromaTap will satisfy the basic requirements for changing color and intensity based on water temperature. More complex requirements will be examined in Test Case T2. Brightness characteristics in the functional spec will be met based on subjective evaluation in different lighting conditions, as well as referring to the datasheets of the parts used in order to determine the luminance and illuminance values. Finally, the ChromaTap should not turn on in the absence of water.

Test Case #:	T2
Test Case Title:	Intermediate Water Lighting Functionality Test
Related Requirement(s):	R[9]-R[11], R[13]-R[15], R[16]
Description:	This test determines if the ChromaTap accurately tracks changes in the water temperature by having the tester subjectively gauge the brightness responding near-linearly to changes in temperature. Also, a DMM or Oscilloscope will be used to acquire voltage points at a given temperature, providing a non-subjective way of evaluating the ChromaTap's performance.
Required Resources:	Water faucet, ChromaTap Prototype, Fast Response Thermometer, Oscilloscope, DMM.

Expected Results:	The ChromaTap should respond near-linearly to changes in temperature by adjusting the intensity of the lighting accordingly. At room temperature, no lighting should be activated, and above room temperature, the water stream will be lighted different intensities of red. Below room temperature, the water stream will be lighted different intensities of blue.

Test Case #:	T3
Test Case Title:	Operating Temperature Test
Related Requirement(s):	R[41]
Description:	This test determines that the ChromaTap will operate normally, given water temperatures ranging from 0°C to 80°C are run through the device. This can be tested in conjunction with T1 and T2.
Required Resources:	Water Faucet, boiling water, ChromaTap Prototype
Expected Results:	We expect that the prototype will not have a problem operating with extreme water temperatures.

9.1.1 Input Conversion Module

Test Case #:	T4
Test Case Title:	Input Conversion Module Basic Tests
Related Requirements:	R[66], R[73]
Description:	Tests Basic Functionality for the Input Conversion Module. T4 is actually done as a part of T1/T3.
Required Resources:	Water faucet, ChromaTap prototype
Expected Results:	We expect the Input Conversion Module to turn the circuit on when there is water, and off when there is not. We also anticipate it to work normally over the operating temperature range of 0°C to 80°C.

Test Case #:	T5
Test Case Title:	Input Conversion Module Technical Tests
Related Requirements:	R[63], R[64], R[65], R[67], R[72]
Description:	Tests technical features of the Input Conversion Module, such as power supply tolerances, power consumption, accuracy, and update frequency, to be in line with the functional specification requirements. An oscilloscope, DMM, and subsequent calculations are used to obtain figures for comparison.
Required Resources:	Water faucet, ChromaTap Prototype, Fast Response Thermometer, Oscilloscope, DMM.
Expected Results:	The Input Conversion Module should meet the requirements outlined in the functional specification for these technical requirements.

9.1.2 Output Conversion Module

Test Case #:	T6
Test Case Title:	Output Conversion Module Technical Tests
Related Requirements:	R[74], R[75], R[79], R[80]
Description:	These tests cover the technical characteristics of the Output Conversion Module such as power supply tolerances, power consumption, delay, conversion mapping, and update frequency. An oscilloscope, DMM, and subsequent calculations are used to obtain figures for comparison.
Required Resources:	Water faucet, ChromaTap Prototype, Fast Response Thermometer, Oscilloscope, DMM.
Expected Results:	The Output Conversion Module should meet the requirements outlined in the functional specification for these technical requirements.

9.1.3 Control and Processing Module

Test Case #:	T7
Test Case Title:	Control and Processing Module Technical Tests
Related Requirements:	R[90], R[91], R[93], R[96]
Description:	These tests cover the technical characteristics of the Control and Processing module such as power supply tolerances, power consumption, and delay. An oscilloscope, DMM, and subsequent calculations are used to obtain figures for comparison.
Required Resources:	Water faucet, ChromaTap Prototype, Oscilloscope, DMM.
Expected Results:	The Control and Processing Module should meet the requirements outlined in the functional specification for these technical requirements.

9.1.4 Power Generation Module

Test Case #:	T8
Test Case Title:	Power Generation Module Technical Tests
Related Requirements:	R[81]-R[84]
Description:	These tests cover the technical characteristics of the Power Generation module such as power supply tolerances, power consumption(regulation aspect), power supplied, and delay. An oscilloscope, DMM, and subsequent calculations are used to obtain figures for comparison.
Required Resources:	Water faucet, ChromaTap Prototype, Oscilloscope, DMM.
Expected Results:	The Power Generation Module should meet the requirements outlined in the functional specification for these technical requirements.

Test Case #:	T9
Test Case Title:	Power Generation Module Longevity Test
Related Requirements:	R[85]
Description:	This test examines the longevity of the power generation module. Specifically, the battery used must last 3 years. To test battery longevity, the ChromaTap prototype will be left running until the battery runs out, and then this figure will be divided by a typical usage metric to arrive at the figure for how long the battery change intervals will be.
Required Resources:	Calculator, ChromaTap prototype, Sample Users
Expected Results:	We expect the ChromaTap will meet or exceed this requirement.

9.2 System Performance Testing

System Performance testing is primarily intended to ensure that the ChromaTap meets the response time and lighting requirements set forth in the functional specification. For the purposes of this document, the relevant performance tests have been grouped into their respective modules, as this makes the most sense for Increment 1, where we do this testing module by module.

9.3 System Usability Testing

System Usability testing is not relevant for Increment 1, as none of these prototypes are designed for use by the end user.

9.4 System Safety Testing

System Safety Testing is also less relevant for Increment 1, since end users will not be interacting with the prototypes. Any relevant safety tests are grouped into their respective modules.

9.5 System Reliability Testing

Test Case #:	T10
Test Case Title:	Basic System Reliability Test
Related Requirements:	None
Description:	This test is on-going and will be partially done by running through test cases T1 to T9 and looking for erratic system behavior. More detailed reliability testing will be done in later increments.
Required Resources:	ChromaTap Prototype, water faucet.
Expected Results:	We expect no issues.

Section 10. Conclusion

This document has outlined the design specifications for build 1.0a of the ChromaTap, the battery powered implementation of the shower and faucet versions. We have done our best to meet the requirements outlined in *The ChromaTap Functional Specification*. To this end, our proposed design meets all critical functional specifications in the input conversion module, output conversion module, power generation module, control and processing module, and casing and mechanical design module.

The development of the next build 1.0x prototypes based on water and solar power generation is on-going, and the completion of the build 2.0 prototype based on the best power generation method is scheduled for completion by April 2007. We are committed to delivering a product which will be safe, affordable, and easy to use and install.

Section 11. References

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Digital Graphics

All digital graphics presented on the cover, table of content, and topic headers of this proposal are retrieved from the flickr[tm] photo sharing community (http://www.flckr.com) and other various sources .

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