Efficient Home Lighting
Design Document

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Project Description

Modern advances in LED technologies has led to large efficiency gains in the home lighting industry; however, the cost per LED is still much higher than alternatives. An LED bulb consists of a power supply and several LEDs. Each power supply consists of components like large electrolytic capacitors that can fail easily. The lifespan of LED bulbs can be increased by moving the power supply away from the bulb. The purpose of our project is to design a system including LED bulbs, switch-mode power supplies and a lighting control system that will improve upon these inefficiencies/costs. This project covers the whole spectrum of computer engineering/electrical engineering topics and skills.

System Level Design

System Requirements

The efficient home lighting project requires several components including software and hardware. One of the most important components of the project is designing a switching power supply that will efficiently convert an AC voltage into a regulated DC voltage. Another component is an embedded control system including a microcontroller and bluetooth module. The size of the power supply and embedded system are restricted by the size of a light switch box. Another important component of the project is the LED bulb that will consist of several LEDs, a mechanical enclosure, and a protection circuit. The last component of the project is a mobile application that can send commands to the embedded controller to control the lights from a person's phone.

Functional Decomposition

The functional decomposition of this project can be broken into two inputs. The first input is the user input and the second is the AC mains power. The AC mains is what will power the SMPS, microcontroller, bluetooth, and LED bulbs. It ill be at 120vrms AC. The user input will be from the iphone app, as well as the light switches on the wall. A functional decomposition is shown in **Figure A**.

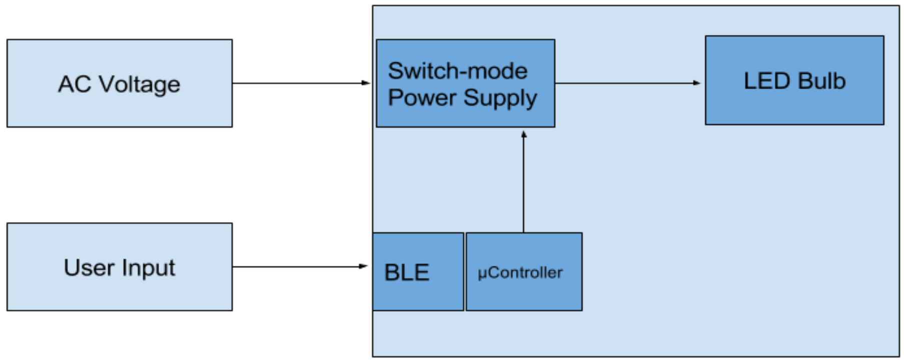

Figure A - Functional Decomposition

System Analysis

As a whole, the system will have a single power supply that will power multiple banks of LEDs. This allows the power supply to be optimized for efficiency without the normal constraints of placing the SMPS in a light bulb. The existing AC wires can then be rewired in the switch box to function as the DC lines for the bulbs. This idea will allow existing structures to rewire the lights without pulling new wire, which can be difficult and expensive. The only parts that will need replaced are the switch box and light bulb in order to update an existing house to our bulbs. An example diagram of our intended system is shown in **Figure B**.

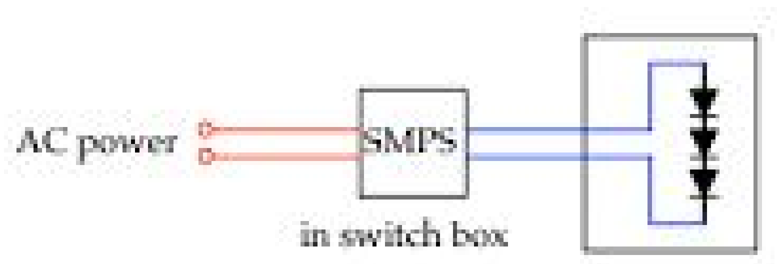

Figure B - System layout

Project Details

I/O Specification

The efficient home lighting system is fairly simple in terms of input and output specifications. The two main inputs into the system will be the 120V AC voltage from the home and the user input from the mobile application. The output from the system will be light from the leds. A user will be able to control lights with their smart device by using an intuitive user interface on a mobile application.

Interface Specifications

Each component in the system needs a well-defined interface in order for the system to remain modular. Modularity is necessary to allow an efficient design and revision process. Below is a short description of each component's interfaces. The modular specification is shown in the block diagram in **Figure C**.

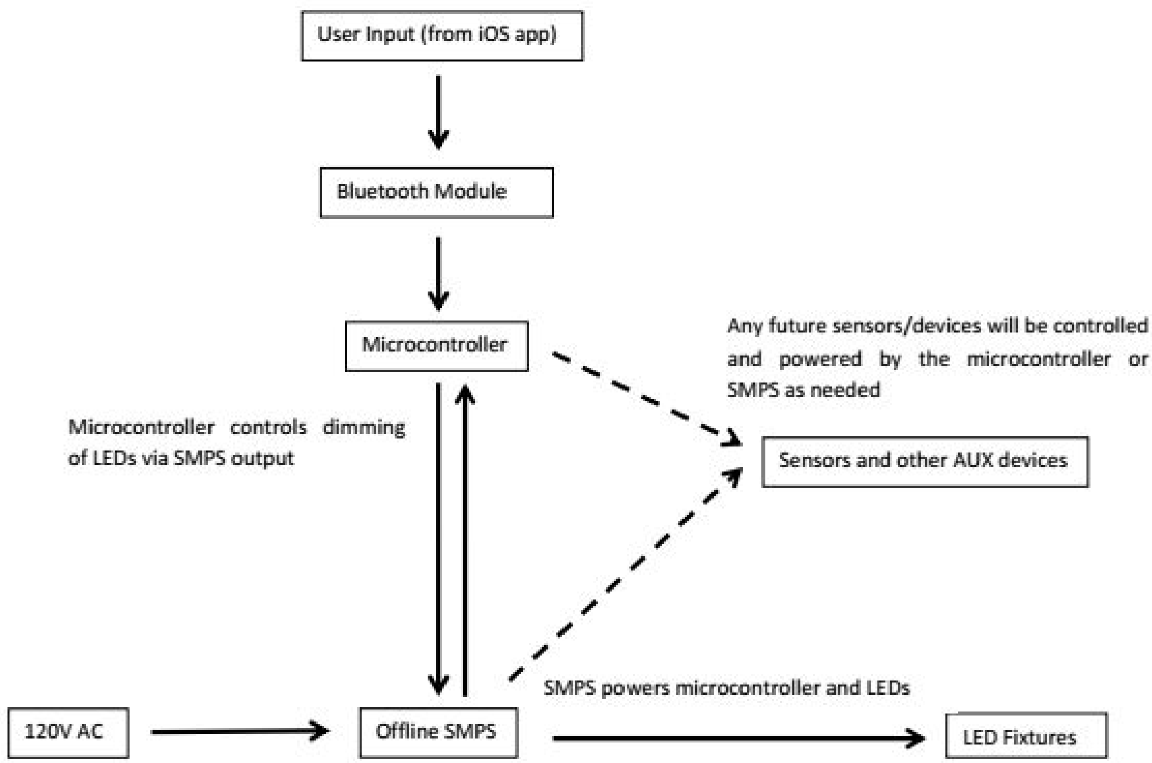

Figure C - System Block Diagram

Software/Embedded Specification

Embedded System

The embedded system will receive commands from iOS mobile applications over a bluetooth connection. These commands contain brightness and lighting bank information that will allow the microcontroller to control the lighting. Currently the commands consists of 5 characters with the first two characters designating the lighting bank and the ON/OFF state. The last three characters designate the PWM value. The microcontroller will have analog output pins connected to lighting banks. These pins will output a PWM wave to control the brightness of the lights.

The bluetooth/microcontroller embedded system is utilized using Atmel's ATMega328 microcontroller and a low energy bluetooth module, Nordic Semiconductor's nRF8001 The interaction between these devices is outlined in **Figure D**. Software is written in C/C++ using several open source libraries that were pre-existing. The embedded software is written for the Atmel AVR architecture and Nordic's bluetooth devices.

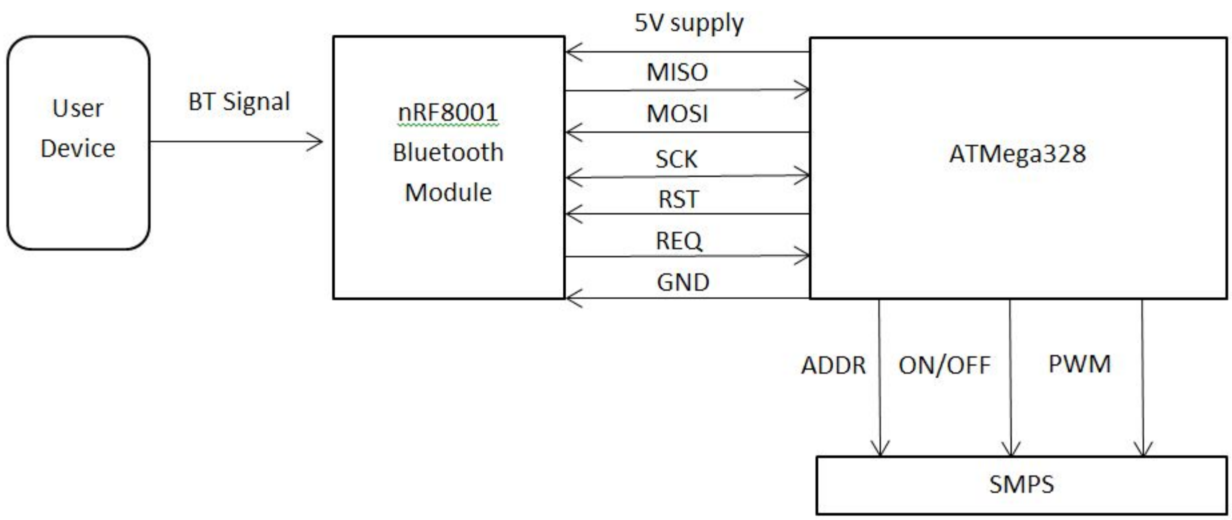

Figure D - Embedded System Overview

The bluetooth module will communicate with the user's mobile device using Bluetooth Smart v4.0 connectivity IC with integrated radio, link layer, and host stack supporting peripheral (slave) role operation. It will transmit data from the user to the microcontroller using serial USART communication. This device requires a 5V DC power supply in order to operate, and it uses on-chip linear regulators to drop the supply to 3.6V DC. The power will be supplied by the microcontroller. This device contains a 2.4GHz radio frequency oscillator with high co-existence performance, and it is compatible with the 16MHz crystal oscillator on chip. The ACI (application controller interface) is a 5-pin SPI slave-based communication, but the device will be configured as a USART serial communication device between the bluetooth module and the microcontroller.

The ATMega328 will be used to interface between the bluetooth module and the SMPS. The user will send 5 bytes to the bluetooth module, which will then be transmitted to the microcontroller via serial USART communication. The ATMega328 has been programmed such that these 5 bytes will dictate which strip of LEDs will be addressed, the ON/OFF state of the addressed LEDs, and the brightness relative to a number corresponding to a PWM output (0-255). The details of the encoded information transmitted in each byte is illustrated in **Figure E**.

Byte0	Byte1	Byte2	Byte3	Byte4
ADDR	ON/OFF	PWM[2]	PWM[1]	PWM[0]

Figure E - Encoded bytes for USART communication.

ADDR - address for the strip/bank of LEDs
ON/OFF - determines the state of the bank of LEDs
PWM[2:0] - pulse width modulate square wave, determines the brightness of the LEDs.

iOS Mobile Application

The iOS application will be written using Objective C. The application will use pre-existing Bluetooth services and software packages and will support iOS versions 8.0 and higher. A basic screen view of the intended application is shown in **Figure F**.

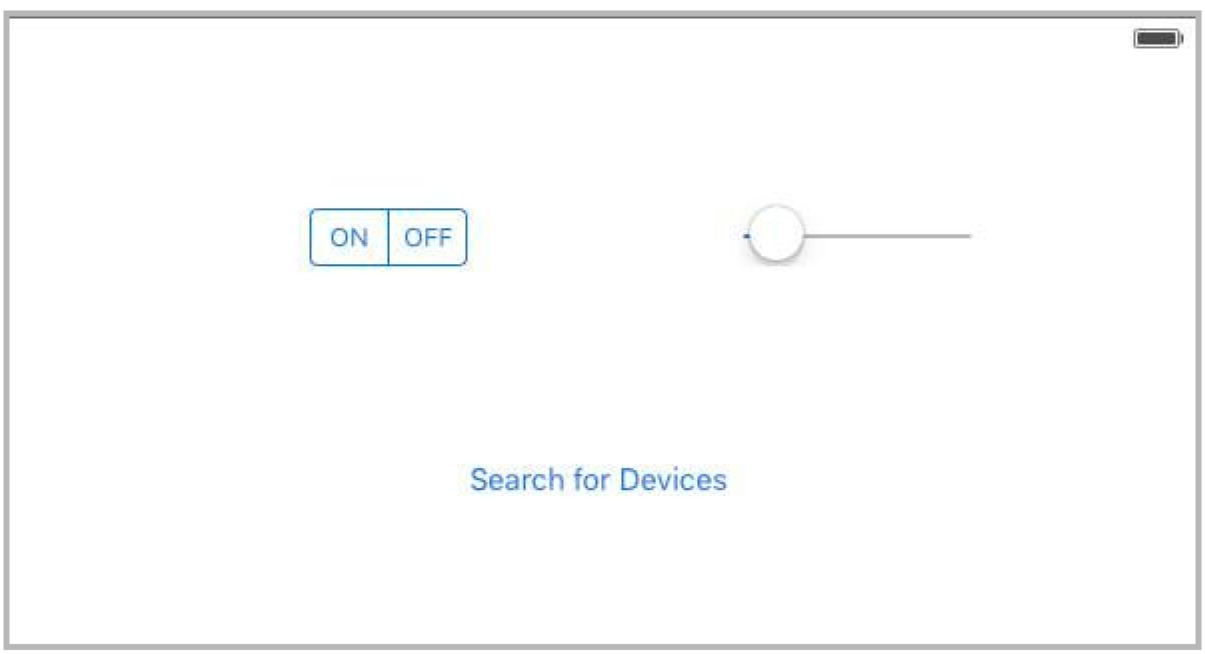

Figure F - iOS mobile application

The iPhone application uses the built-in Bluetooth to to connect to our microcontroller and send appropriate signals to the microcontroller, which will then be interpreted and propagated as signals to the LED bulbs. We are not using any additional frameworks aside from the built-in Bluetooth functionality. Only devices that are advertising the services we are specifically interested in will be paired with.

The general setup (**Figure G**) for the app is the following:

1- Scan for advertised services on other devices. All devices advertise and scan for services at the same time
2- Invite any peer that is discovered
3- Receive and accept a connection invitation
4- Notify the delegate when the connection status changes or data is received

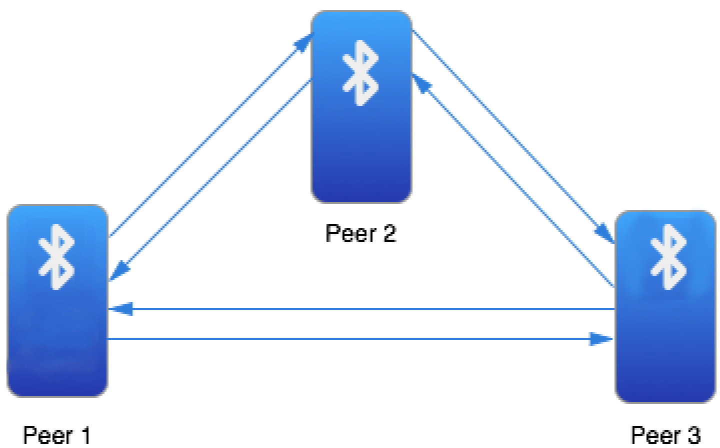

Figure G - Bluetooth peer communication.

Hardware Specification

Switch-Mode Power Supply

The switch-mode power supply will receive a $120V_{RMS}$ AC voltage from the residential lighting system. It will then output a DC voltage of 24V, which the NEC considers to be the maximum allowed "low voltage" with no enclosure in residential electrical systems.

The SMPS will be in the form of an isolated flyback (buck) converter. Isolation is a necessary safety feature due to high voltages that can be created during the switching process, and protects the user from being in direct contact with 120V AC. Two forms of isolation will be required: A flyback transformer will be necessary to isolate the high frequency-high voltage "input" to the buck converter, and a photodiode/IR LED to provide optical isolation in the feedback network that controls the duty cycle of the switching input. While the completed circuit has not been designed yet, a simple reference circuit using the LM 5021 controller can be seen in **Figure H.**

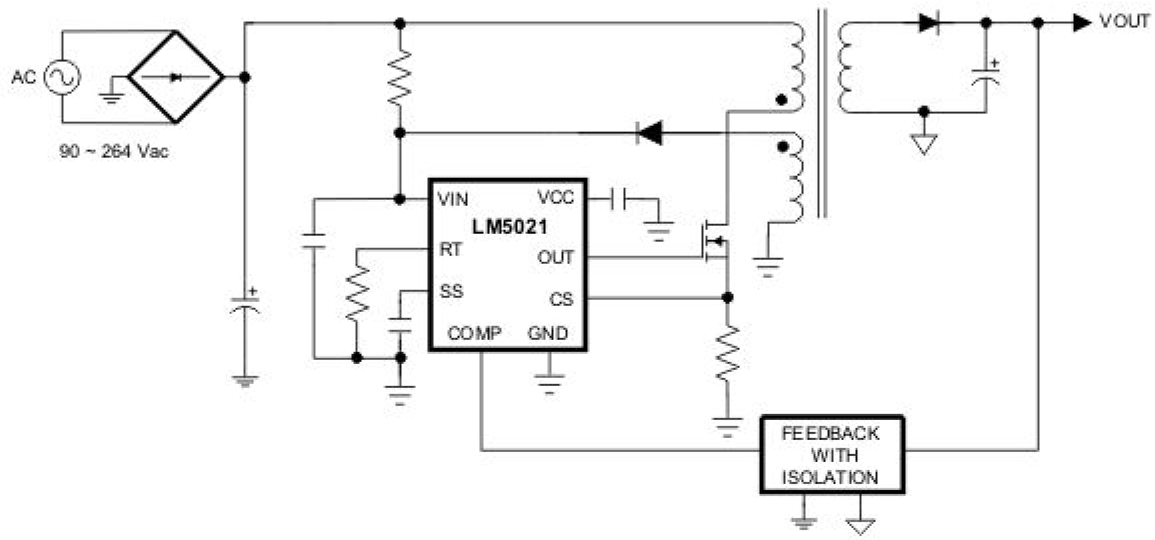

Figure H - Reference Circuit for Isolated Flyback Converter

Before tackling the complications an isolated converter, several iterations of a non-isolated DC-DC converter are being made for prototyping purposes. These converters are simpler to create, and will be provide the same basic functionality for the rest of the group to work with. Currently, the LT1076 is being used as the controller for switching and feedback. The current circuit is designed to have an input of 40V and output 24V with the ability to drive at least 1 Amp. **Figure I(1)** shows the current circuit and **Figure I(2)** shows the bill of materials used to create the circuit.

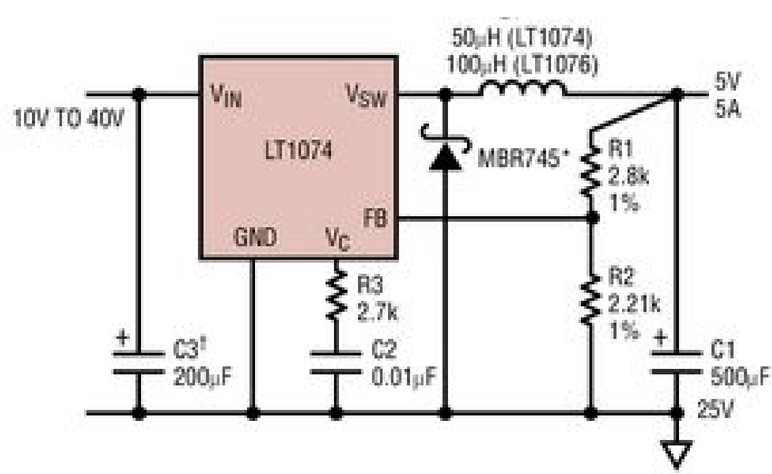

Figure I(1) - Circuit Used for DC-DC Converter using LT 1076

	A	B	C	D	E
1	LT1076	(Surface Mount)			
2	Identifier	Manufacturer	Value	Part Number	Cost
3	C1		500uF		
4	C2		0.01uF		
5	C3		200uF		
6	R1		2.2k		
7	R2		22.68k		
8	R3		2.7k		
9	L1	Eaton Bussman	100uH	513-1673-ND	3.87
10	D1			MBR745-E3/4Gi-ND	0.79
11	U1	LT		LT1076	6.78

Figure I(2) - BoM Used for DC-DC Converter using LT 1076

The only change from the reference design given by LT was the value of the feedback resistors R1 and R2, which provide feedback to the chip. This feedback is compared with a reference voltage to determine the output of the circuit (essentially an inverting amplifier with a 2.21 V offset).

LED Bulb

The LED bulb will have the standard socket that is used in every residential light bulb. This will then require a circuit protection element to protect against the accidental occurrence of putting the bulb in a AC socket. This protection device must protect against any sort of fire or destructive current through the device. The major specifications that we are wanting to meet with the LED bulb are outlined as followed.

CCT: <3000K
lm: >800lm
lm/w: >100lm/w

With the relocation of the SMPS from the typical LED bulb into the light switch, we are able to greatly reduce the complexity of the LED bulb. By reducing the amount of heat that the LEDs are exposed to, it also will increase their lifespan. The LED bulb that we will be designing then must meet certain specifications in order to work effectively for residential lighting. The major specifications that we are concerned with are: correlated color index, luminous output, lumens/watt, and cost per unit.

One of the most important attributes for residential lighting is the correlated color index (CCT). This index is based off of the color of light emitted from a blackbody lighting source at a given temperature, such as your typical incandescent bulb. The typical color for most incandescent residential lights is around 2700K. The color index for the respective temperatures is shown in **Figure J.** The range of commercially available white LEDs range over a vast range of the CCT. In order to get the closest to the incandescent LED, we are focusing on a CCT of less than 3000K.

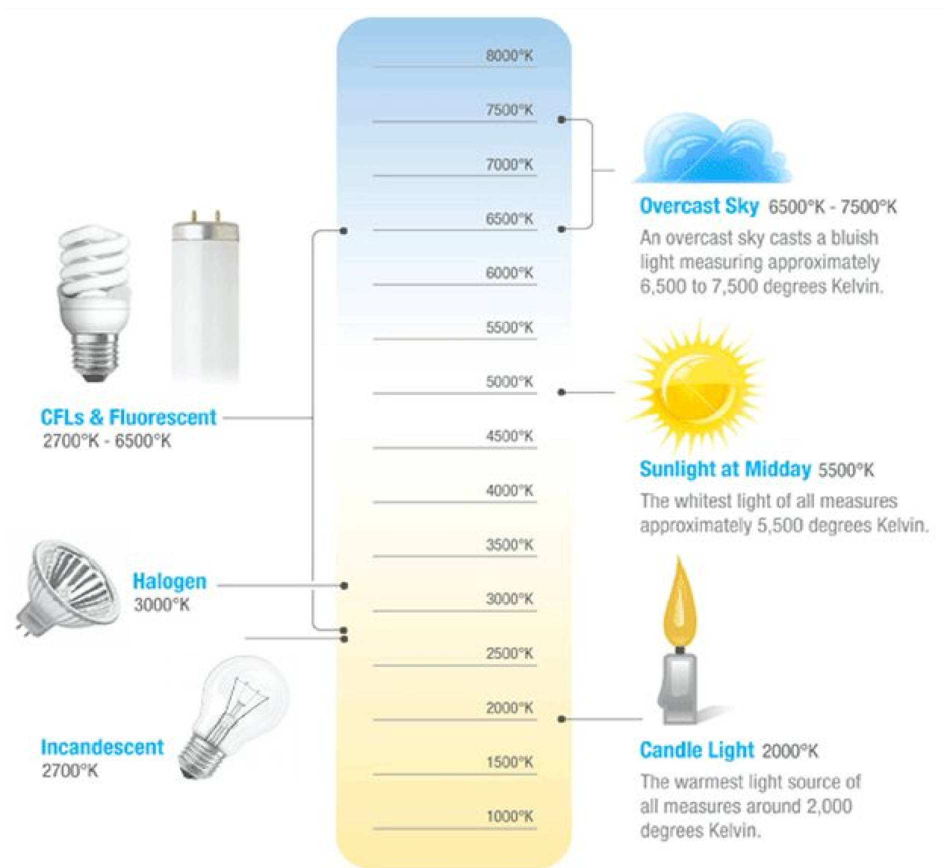

Figure J - Correlated Color Index with respect to standard lighting methods.
Source: http://www.feit.com/color-temperature

A typical 60w incandescent light bulb has a luminous flux of anywhere from 700 lm-900 lm. Knowing this, we are specifying that our bulb needs to produce at least 800lm. This will guarantee that our bulb can be utilized as a replacement for a standard 60w light bulb. The major reason for switching from incandescent lighting to LED is in the gain in efficiency. This is often measured in the amount of luminous flux generated (lumens) per the amount of power consumed (watts). There are two ways of looking at this efficiency definition or Luminous efficacy. The first is in regards to the LEDs themselves, and the other is in regards to the system as a whole. For the purpose of the LED bulb design, we put a specification that we wanted our bulbs to be at least 100 lm/w efficient in order to help increase the efficiency of the system.

By utilizing white LEDs with a high lumens output, we can also reduce our costs by reducing the number of LEDs needed to produce the 800lm. Using the criteria listed above along with the availability of various suppliers, we were able to assemble a list of LEDs that would work for our bulb design as shown in **Figure K.** The bulbs that are highlighted in blue in the figure have already been ordered and will undergo various testings to verify they will work for our application.

Part#		CCT (K)	lm/W	Flux (lm)	If (mA)	Vf (V)	CRI	Unit Price	Large Quantity Price	# Needed per 800lm	Bulb Cost (Unit Price)	Bulb Cost (Large Quantities)
XPGWHT-L1-0000-00CE7	Cree	3000	102	104	350	2.9	80	3.2	1.64	8	25.6	13.12
XMLAWT-00-0000-000LT20E7	Cree	3000	103	210	700	2.9	80	5.43	2.79	4	21.72	11.16
XPEHEW-H1-0000-00CE7	Cree	3000	99	104	350	3	80	4	2.05	8	32	16.4
XPGWHT-L1-R250-00DE8	Cree	2700	109	111	350	2.9	80	4.37	2.6	8	34.96	20.8
SPHWHTL3D305E6V0H3	Samsung	3000	121	125	350	2.95	80	2.2	0.69	7	15.4	4.83
TL1L3-LL1,L	Toshiba	2700	112	112	350	2.85	80	1.94	0.62	8	15.52	4.96
SPHWHTL3D305E6W0H3	Samsung	2700	121	125	350	2.95	80	1.96	0.61	7	13.72	4.27
LCW CR7P.EC-KULQ-5R8T-1	Osram	3000	113	117	350	2.95	80	2.26	0.95	7	15.82	6.65
SZ5-M1-WW-C8-V1/V2-GA	Seoul Semi	3050	120	124	350	2.95	80	2.21	0.65	7	15.47	4.55
LCW CQAR.CC-LUMQ-5R8T-1	Osram	3000	88	187	700	3.05	90	2.76	1.12	5	13.8	5.6

Figure K - LED Selection Table with purchased LEDs highlighted in blue.

The physical bulb will be greatly simplified by the elimination of the SMPS. However, a simple PCB design will still need to be developed in order to mount the LEDs in a suitable frame. A typical LED PCB layout for an off the shelf LED bulb is shown in **Figure L.**

Figure L - LED PCB Board.
Source: http://www.aliexpress.com/w/wholesale-pcb-board-led.html