Light of the World
High-Level Design

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EE 41430 – Senior Design
Dr. Schafer

Joe Altura
Brian Appleton
Sean Baur
James Yurkovich

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1 Introduction

The engineering world has taken a major turn toward designing energy efficient devices and technologies. This global "green" initiative has caused a great shift in engineering design wherein companies are sacrificing costs in order to make more environmental friendly decisions. The United States General Services Administration (GSA), as well as other government agencies, is working to reduce the environmental impact of the federal government.[1]

Due in part to large government tax incentives[2], many large companies are taking part in this green initiative. The automotive industry is shifting to hybrid and plug-in hybrid electric vehicles, while large commercial buildings are installing power management systems. One major way of reducing the energy consumption of buildings is to install more energy efficient lighting systems with control systems; many new buildings are being constructed with such lighting systems.

2 Problem Statement and Proposed Solution

Although many efficient lighting solutions exist, such as those offered by Lutron, these systems have their flaws. The primary issue with such systems is the monumental cost of converting massive buildings from incandescent lighting to more efficient systems, such as those that utilize compact fluorescent lamps (CFLs) or light emitting diodes (LEDs). This is because many of the high-end systems involve a control box wired into the wall. We will design and construct a prototype LED light that will be "plug and play" – able to be screwed into an existing socket without any additional installation.

A major part of our design is thus centered on the control for our bulbs. We will implement a user interface that will control individual bulbs from a mobile device (i.e. laptop or Android/iOS phone) without having to physically access a wall-mounted portal. With this control comes the idea of "smart lighting," systems that could be programmed to adjust for home automation, stage lighting control, or detailed response to motion sensors. Each of these applications has far reaching implications for reaching the goal of greener design systems. Additionally, the fact that incandescent light bulbs are being phased out provides greater opportunity for a system such as ours to have an impact on the market.

[1] FY 2011-2016 Strategic Sustainability Performance Plan, http://www.gsa.gov/graphics/staffoffices/SSPP_11022011.pdf
[2] Energy Policy Act of 2005, http://www.epa.gov/statelocalclimate/documents/pdf/4_20_06_EPACT_Tax_incentives_Prindle.pdf

3 System Description and Block Diagram

This system will consist of two major components, the remote and bulb. Both units will contain multiple subsystems. The interface between them is intended to be wireless, although the protocol is yet to be determined.

The remote will consist of a user interface at first implemented as a PC application, which will connect to the communication subsystem. The communication system will then interface with a communication unit in the light bulbs in the system. This will allow the user interface to change the state of the bulbs.

The enclosure or package will contain in it the communication system on the bulb's side. This system will then interface with the microcontroller; the microcontroller will interpret information received from the communication subsystem. The microcontroller will then relay this information in some fashion such as PWM to the dimming control circuit. The dimming control circuit is fed wall AC, which it modulates to be used to charge the switching converter. The AC voltage is also fed through a power supply circuit to power the microcontroller. The switching converter is then used to drive the LED's. Meanwhile any heat generated due to the LED and other circuitry is sunk through the heat sink.

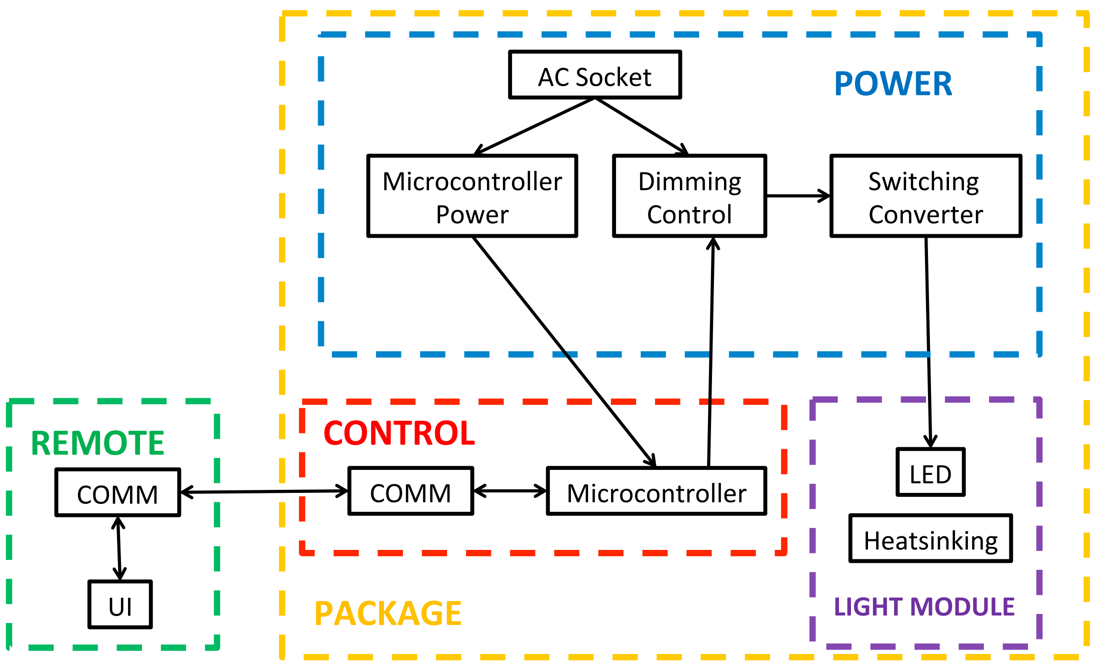

Figure 1 – System Block Diagram

4 System Requirements

4.1 Overall System

Table 1 - System Requirements

SYSTEM REQUIREMENTS	
General Purpose	Must be able to communicate with the user interface to switch lights off and on as well as have a dimming function
User Implementation	Must be able to be screwed into normal light socket and operate without any other implementation
Expected Life of Product	Must be comparable to commercial LED bulbs, i.e. have an expected lifetime of several thousand hours
Cost	System prototype must be within $500 budget to design and produce

4.2 Subsystem and Interface Requirements:

Table 2 – Subsystem Requirements

SUBSYSTEM REQUIREMENTS	
Light Module	
General	Must illuminate reasonable area Must provide consistent brightness over wide range Must dim in a controllable manner Must be able to translate PWM from MC
Package	
Safety	Must adhere to standard electrical codes Must be no danger of electrical fires Must have no exposed line voltages
Performance	Must distribute light evenly Must dissipate heat effectively
Mechanical	Must have mechanical strength when turning Must be durable to endure possible falls
Power	
General	Must be able to provide rated power to each necessary subsystem (microcontroller, light module, and communication) Must be able to transform standard U.S. line power (120 V_{RMS}, 60 Hz) to necessary board ratings (5 V_{DC}) Must minimize effects on other external devices on circuit
Control	
General	Must have internal clock Must be able to perform tasks at specified times
Memory	Must be able to store system state in nonvolatile memory Must be able to load system state from nonvolatile memory Must be able to store presets in nonvolatile memory Must be able to load presets from nonvolatile memory
Input	Must be able to receive input from remote

	Must be able to change system state based on remote signal in nonvolatile memory
Output	Must produce a PWM signal
Remote	
User Interface	Capable of taking user input from one or multiple sources Able to distinguish between input sources Able to resolve conflicting inputs in predefined manner User can specify one light bulb among many User must be able to select from preset conditions or define manually
Communication	Able to relay user inputs to microcontroller Must not interfere with other equipment on same circuit within a building

4.3 Future Enhancement Requirements

Table 3 – Future Enhancement Requirements

FUTURE ENHANCEMENT REQUIREMENTS	
Power	Custom flyback converter Power factor optimization Efficiency optimization
User Interface & Control	Mobile application Adaptive response to patterned input behavior
Ambient State	Must be comparable to commercial LED bulbs, i.e. have an expected lifetime of several thousand hours
Lighting Features	RGBW LEDs with mixing control Ability to detect ambient light levels and signal changes Ability to detect motion

5 High Level Design Decisions

5.1 Remote Control

The real essence of our project lies in the design of our control system. We intend to create a communication scheme that is entirely ubiquitous: the lamp may be controlled from any device with an internet connection. Our remote subsystem will be responsible for communicating very simple commands to a bulb: on/off state and dimming level. The exact implementation of our remote has yet to be decided; its final form depends largely on the communication protocol that we select.

However, one viable remote control method may be to establish a central server (on the internet), which is responsible for storing the current settings for any bulb. A user might use a computer program or a mobile device to send a request to the server, which will update its records and make the request visible to the bulb (which has its own wireless internet connection). An advantage of using this “central hub” will allow one to control their lighting from hundreds of miles away.

5.2 Power

The challenge of the power subsystem lies in its efficiency and size requirements. For example, the implementation of the following construction:

transformer → bridge rectifier → filter capacitor → linear regulator

would be technically trivial—but costly, large, heavy, and extremely inefficient. Out of necessity, our power subsystem will be of the switching type. Switching converters have the advantage of high efficiency (typically >80%) as well as low cost and small size. Our current research and study of the LED bulb market has shown that either a buck or flyback topology is appropriate for our design. However, the design and control methods of a switching converter are considerably involved. To wit—an emerging standard for LED switching converters is to employ active power factor correction and phase decoding to support TRIAC dimming. Though the final bulb design will likely feature a custom switching converter, alternatives have been considered.

As stated, many LED bulbs support TRIAC dimming. A perfectly viable approach to the power subsystem is to attack it from the “outside”: to implement a TRIAC dimmer that is controlled by the microcontroller. Purchasing a commercial LED bulb and placing a TRIAC dimmer inside avoids the complex task of designing a switching converter in the first prototype. However, the difficulty in this approach lies in the ability of the TRIAC dimmer to fit inside of an LED bulb. Surprisingly, this approach is quite advantageous from a cost standpoint: designing and building a TRIAC dimmer is much more cost effective than designing and building a custom switching converter. To avoid a premature investment (of both money and limited knowledge) in a custom switching converter, this TRIAC control method will be implemented in the first prototype. Should it be successful, it may be featured in the final design.

Another duty of the power subsystem is to provide power to the microcontroller. Obtaining 5VDC from 120VAC with high efficiency, low cost, and low component count is a challenge of its own. The prototype employs a capacitive current limiter with a half-bridge rectifier and a zener diode for regulation. While not pretty, it gets the job done.

5.3 Control

5.3.1 Communication

As previously stated in 5.1, the exact form of our communication system is yet to be determined and is largely dependent on the protocol we choose. The preferred method of communication would be cost efficient and aids in minimizing end product cost for the user. There is the possibility that the communication in the package may interface with a central server via Wi-Fi. If this is case Microchip and other distributors have small, low power modules that are capable of Wi-Fi such as the RN-171.

Upon receiving information from the external remote it is then necessary that the communication in the package relay this data to the microcontroller. As the type of communication protocol and therefore package is yet to be determined it uncertain at this time how this information will be relayed. Likely candidates include SPI and UART.

5.3.2 Microcontroller

The microcontroller needed in this design requires the basic ability to communicate serially with the communication module, interpret this input signal, provide a pulse width modulated signal to the dimmer, and store/load state into some form of non-volatile memory or contain a low power battery to maintain its state. The reasoning for this non-volatile memory is in the case of power loss, such as the turning off of a light switch. An initial choice for microcontroller with several timers, flash memory, use of synchronous and asynchronous communication, and pulse width modulation module seems to fit our needs.

5.4 Package

The main goal of our enclosure is to safely house all of our features into the same form factor as a standard 60W incandescent bulb. This scale restriction is not expected to be an issue, but we would consider expanding to a larger, "flood-light" type enclosure to allow more internal space for system components. The base in either case will be an E27 style socket; this is the standard 27-millimeter diameter socket used for bulbs in standard US sockets. Significant design work will need to be done before deciding on the final 3-dimensional layout of components within the package, but significant heat dissipation will need to occur both near the LEDs and power electronics. Once the locations of these system components are finalized, we can design proper passive and/or active heat dissipation to maximize performance.

Safety measures are important for devices that work with 120V_RMS signals. The E27 socket addresses the issue of high voltages by ensuring that ground is on the exterior of the socket, with connection to high voltage being made only after the ground has been established. Additionally, the high voltage contact cannot be accessed from the outside once the device has made a closed circuit. Similar safety measures will be included in our design: no high voltage signals will be available to touch from outside of the enclosure. Also, any external conducting components (such as heat dissipation hardware or metal connection segments) will be grounded to reduce the risk of electric shock. Additionally, no flammable materials will be used in the product's construction, to reduce the risk of fires caused by faulty electrical connections or component failures.

6 Open Questions

6.1 User Interface & Communication

The exact communication protocol that will be used has yet to be fully determined. The main concerns are primarily the cost and the ability to implement. Because internet connection is an attractive end goal, we are currently leaning heavily towards using Wi-Fi communication. We have discovered dedicated Wi-Fi subsystems made by Microchip that have extended documentation on their implementation. Specifically, the information on interfacing with Microchip microprocessors would be exceedingly helpful.

However, other protocols must be investigated further to see if they address the needs of our project more specifically. ZigBee has also been considered briefly, but we still have questions on how we might eventually be able to connect to the internet with this protocol. Would we be able to interface directly, or would we need some sort of "base station" to interchange between ZigBee and the internet?

6.2 Enclosure

Our proposed enclosure is possibly one of the hardest engineering challenges we face out of our specific area of expertise. It will have to be both mechanically strong and dissipate heat, all while maintaining a standard form factor. We have focused less on this aspect of the project so far, as we finalize our electrical specifications and design. However, we will most likely look to others that have more expertise in this area for assistance in designing an enclosure. We may also take inspiration from what we can reverse-engineer from existing commercial products.

7 Major Component Costs

Table 4 – Estimation of Major System Component Costs

ESTIMATED SYSTEM COSTS	
LED bulb	$10
Microcontroller	$2
Custom Printed Circuit Boards	$75
Wireless Module	$30
Power Converters (including expected cost of replacing multiple blown out parts)	$200
Enclosure	$20
Rough Expected Total Cost	**$337**

8 Conclusions

This project presents a series of design issues and engineering challenges, which must be overcome in order to design a construct a functioning prototype. In overcoming these challenges and discovering solutions, we will learn how to implement a design and become more proficient problem solvers. Our design itself will continue to be revised and tweaked in order to minimize costs and create the most efficient system. The end goal is to build a working prototype that would be marketed to individual consumers as well as to large-scale building designers.