Portable RF Light Socket Control

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Final Report for ECE 445, Senior Design, Fall 2017

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December 13 2017

Project No. 9

Abstract

A customizable, low cost and short range analog radio based design for controlling residential lighting directly at a light socket's AC mains is presented. The requirements and verifications necessary for a successful product are given and all blocks of the system are dissected in detail. Results of the prototype system are discussed and areas of future work in the lighting control problem space are identified.

Contents

1 Introduction

1.1 Objective

For residents of temporary housing like apartments there is a need for a more practical solution to customizable lighting control. Landlords often discourage modifications to wall circuitry and current wireless based options are either difficult to set up or not customizable.

The wireless based system we have developed will enable apartment residents to control their lighting from a switch with a built in transmitter that can be mounted anywhere in their home. The other component of the design is a light socket insert that receives a control signal from the switch, so the installation of the system will be as involved as screwing in a light bulb. The resident will be able to control up to 4 sets of lights and be able to customize which lighting fixtures are contained in each set of lights by turning a selector dial on the socket insert.

1.2 Background

Many college apartments do not include built in ceiling lighting for large areas such as the living room. Once additional lamps are purchased, it becomes a chore to control the lighting since the resident must approach the lamp to turn the switch. The internet of things has tried to solve this problem with light bulbs that connect to the internet and are controlled by a smart phone. These bulbs have two issues. They are either too expensive with typical costs greater than $30 and often times they require the purchase of an additional communication hub [1]. College tenants have limited budgets for such luxuries.

A further issue with bulbs controlled via wifi communication is the communication range. The smartphone switching the light could be within close proximity, but regardless of this switch to light distance there could be connection issues because of the longer range intermediate communication between router and light bulb. Routers operating in the 2.4 GHz band have a range only up to 150 feet [2], so if a wifi controlled bulb is in a far corner of an apartment the resident may be out of luck.

Arguably the biggest drawback of wifi controlled lighting is the time delay between flipping the digital switch in an app and the light actually switching on. The time delay is on the order of a few seconds [3]. Flipping a light switch is an action that should be met with instant gratification. Our radio controlled solution will reduce this time delay substantially without the user ever having to open up their smartphone.

1.3 High-level Requirements

- The system will be capable of choosing among four sets of lights which set should receive its unique on/off signal based off of the button on the switch selected by the user.
- The switch and the socket insert will be able to communicate up to distances of 30 feet but no more than 100 feet in order to not interfere with other switch systems.
- The size of the socket insert will be less than 4 in in all dimensions as to fit into light fixtures and the size of the switch will be less than 6 in in length and width for easy portability by the user.

2 Design

Our solution consists of two components, a switch box and a light socket device. The switch box will be composed of a battery power supply, a TTL unit, and a radio transmission unit. The light socket device will be composed of a power supply, a TTL unit, and a radio receiver unit. The power supplies will both power the components but in their own way. The power supply of the switch box needs to be battery powered so it's portable and the power supply of the light socket device needs to power both the light bulb, TTL circuitry, and the radio receiver parts. The TTL units will act as the brain of their respective devices but they need to work together. The two separate TTL units will be able to communicate with each other through their radio units. The transmission unit will be responsible for sending information from the switch box to the device. The receiver unit will be responsible for receiving the information sent by the switch box.

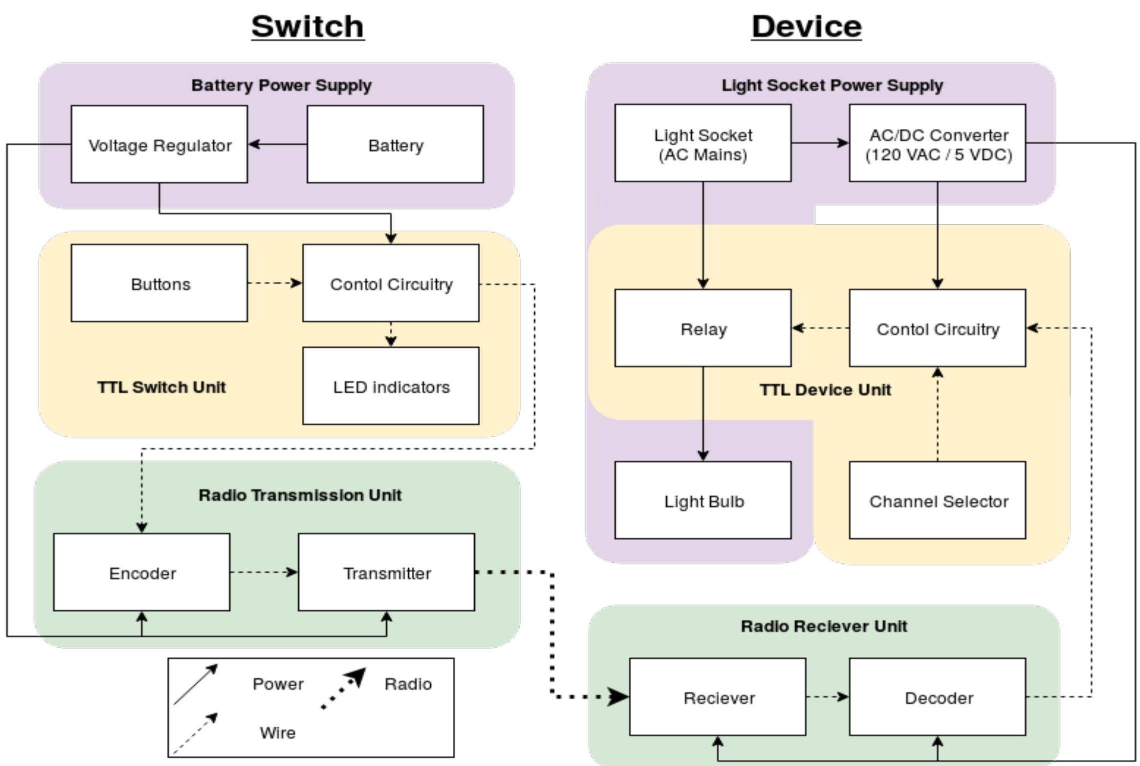

Figure 1: Block diagram of both the switch and device.

The constructed switch box and light socket device can be seen as Figures 2 and 3 respectively. The switch box is definitely small enough to be hand-held. The light socket device is small enough to fit into any light fixture as well as leave room for a light bulb to screw in.

2.1 Battery Power Supply

The portable switch box is powered by a battery pack. The battery pack has a nominal voltage of at 9 V. The battery pack will be comprised of Energizer L91 AA batteries connected in series, each rated 1.5 V. Six connected in series will produce 9 V. 9 V works well for the design because the higher the battery voltage, the more power will be lost from the regulator. The L91 batteries are chosen because they have a high capacity for their size, approximately 3,300 mAh.

Figure 2: The final, constructed form of the switch box. Figure 3: The final compact form of the light socket device.

The voltage regulator ensures the consistent delivery of nominal 5 V to the Control Circuitry in the switch box. The LM7805 is chosen to regulate the 7.5 V battery to a constant 5 V. This particular voltage regulator is rated for 1 A, which is well above our maximum switch control circuitry current of 30 mA.

Table 1: Requirements and verifications for battery power supply.

Requirement(s)	Verification
1. (3pts) The battery must supply at least 7 V and have a capacity of at least 2 Ah. 2. (3pts) The switch system battery life must be at least 150 operational hours. 3. (3pts) The voltage regulator must output between 4.8 and 5.2 V	1. Using a multimeter across the battery pack terminals, verify that the voltage is 7 V or greater. The capacity will be verified from the manufacturer datasheet. 2. Power on the system and operate with all light sets set to on. Using a multimeter, measure the current out of the switch battery power supply. Divide the battery capacity [mAh] by the measured current [mA], and verify that the operation hours are at least 150. 3. Attach a multimeter across the output of the voltage regulator on the switch box and ground. Observe for 10 seconds and verify that the voltage is between 4.8 and 5.2 V.

2.2 Light Socket Power Supply

The light socket will power the entire device as well as a light bulb. The devices TTL and radio unit will need 5 VDC so the 120 VAC provided by the light socket needs to be converted into 5 VDC. The 120 VAC comes from the socket and is passed through the relay to power the light bulb. 120 VAC is also converted to 5 VDC to power the receiver and decoder. The 120 VAC power will be accessed through an Edison screw socket adapter as pictured in Figure 3. Fuses are placed with the relay and the 120 VAC to 5 VDC power supply to protect the components from high voltage if a fault occurs.

The 120 VAC to 5 VDC converter takes the voltage from the light socket and converts it to 5 VDC which powers the control circuitry, the receiver, and the decoder. This component ensures the safe delivery of 5 VDC from the AC mains. The component will be an AC-DC Power Module, such as a deconstructed 110v/5v USB 700mA charger. Our AC/DC converter must be small enough to fit inside the housing that will screw into the light socket. With this constraint, safety, noise, and clearance between live and neutral become design issues. For these reasons, we will use an off the shelf converter to supply the 5 VDC power.

The relay will act like a switch between the 120 VAC coming in from the light socket and the light bulb. The relay takes in digital input to turn the light on and off. We drive the relay with a circuit containing a NPN transistor and two resistors. This is due to the fact that the T77S1D3-05 relay requires 40 mA along the coils. The contact current rating is 3 A, which is far above what we need for light bulbs, which all require less than one amp. We place a reverse diode between ground and power to protect the 5 V supply when the relay is switching.

Table 2: Requirements and verifications for light socket power supply.

Requirement(s)	Verification
1. (4pts) Voltage for our socket device circuitry must be taken from the 120 VAC mains by a standard Edison screw. 2. (4pts) The AC/DC Converter must output between 4.8 and 5.2 V and be rated for at least 500 mA.	1. Insert Edison screw into 120 VAC socket for device power. Insert light bulb into the device, turn the signal from the switch box on, and observe if the light bulb turns on. 2. With AC/DC converter connected to 120 VAC socket, use a multimeter to measure the 5 VDC output for 10 seconds, and verify it is between 4.8 and 5.2 V.

2.3 TTL Switch Unit

The TTL unit in the switch box will act as the brain of the switch box. It'll take in inputs from the buttons and will transmit an on/off signal to the device(s) on the channel linked to the button. The TTL unit in the switch box also has to display which channels have device(s) on and off. The control circuitry in the TTL unit will take in inputs received from the buttons and send them to the encoder to be encoded. The control circuitry will then transmit the encoded data when at least one channel is on and when the clock signal is high. The control circuity will also display which channels are on and off through LEDs.

2.4 TTL Device Unit

The TTL unit in the light socket device will be responsible for taking in the digital signal handed from the decoder and determining whether to turn the light on or off. The control circuitry of the TTL unit will store the data bits received whenever there's a valid transmission. A valid transmission will be checked on every rising edge of the clock signal. The channel determined by the channel selector will determine which data bit is used to control the relay. The relay will act like a switch between the 120 VAC coming in from the light socket and the light bulb. The solid state relay takes in digital input to turn the light on and off.

Table 3: Requirements and verifications for TTL of the switch box.

Requirement(s)	Verification
1. (2pts) Different buttons correspond with different channels of communication. 2. (2pts) Output a digital signal to turn lights on/off that can be encoded. 3. (2pts) The buttons stop bouncing within 5 ms after being pressed. 4. (2pts) The LEDs must be visible when holding the switch box and each LED consumes less than 60mW.	1. Press each of buttons and see if the light(s) on the associated channel respond. 2. Send a known digital signal to the encoder and see if the same signal is the result after decoding. 3. Measure how long the bouncing of a button goes on by observing its behavior on an oscilloscope. 4. Turn on the LED and see if it is visible from 3 feet away. To measure how much power the LED is consuming, we'll measure the voltage across the LED and current running through it. We then multiple the two to see the power consumption.

The channel selector will allow the user to select which light socket devices are on which channels. There's going to be four channels that the light socket devices can be tuned into.

Table 4: Requirements and verifications for TTL of the device.

Requirement(s)	Verification
1. (4pts) Turn on the light on/off through the relay. 2. (4pts) Correctly switch to different channels.	1. Have the device on a fixed channel and then send a turn on signal to the same channel. See if the LED connected to the relay turns on. 2. Change the channel of the device and see if the status of the light changes according to the status of the new channel it's on.

2.5 Radio Transmission Unit

The switch's transmitter unit is comprised of not only a transmitter but also an encoder that converts the control data parallel output from the switch's control unit into a data packet that can be modulated onto a 433.92 MHz carrier channel. Once the switch's control unit sends the transmit enable signal, the switch's transmitter unit will shortly after begin radiating this data packet. The transmitter used is FS1000A XY-FST, a module that is commonly used as an add on for Arduino and the chosen encoder is the Holtek HT12E.

Two alternatives were considered for the internal components of the transmitter unit. One alternative was a Linx multi chip module that contained a transmitter and encoder all within a single package. The cost of this module was in the tens of dollars which contradicted the key motivation of our design for keeping the solution low cost. The other downfall for this module was lack of access for modifications to the transmitter chain which could be essential for fine tuning our design. The second alternative was utilizing the same transmitter as our chosen design but using an ATMega microcontroller for encoding parallel data into a serial package. Once we found a $0.50 encoder, we scrapped this solution. The operation of this module and the Light Socket Receiver Unit determine the range of communication of the system.

The data packet prepared by the Holtek HT12E encoder is a 12 bits. 4 of those bits are from the 4-bit control signal originating from the switch's control unit block which indicate which set(s) of lights need to be switched on/off. The other 8-bits are address bits that serve to only enable communication with corresponding socket decoders that have the same address. We have made the design decision to maintain the same address throughout every encoder and decoder in our system and instead use the data bits as the addressing mechanism for each set of lights. A data packet of 1-0-1-0-(Constant address) instructs sets 1 and 3 of lights to be on without affecting other neighboring systems with different addresses. The encoder operation follows the flowchart operation shown in Figure 4

The data packet from the encoder is modulated onto a 433.92 MHz carrier channel in an amplitude shift key scheme and radiated using a helical spring antenna. This transmitted signal is received by the socket's receiver unit. The FS1000A XY-FST transmitter operating voltage is between 3 and 12V. Flexibility for adjusting the systems communication range is provided by adjusting this operating voltage. A helical antenna is omni-directional so the socket receives an equally strong signal whether it's 30 feet in front of, in back of or to the right or left of the transmitter. The helical shape allows the antenna to be shorter from end to end than a quarter or half wavelength.[4]

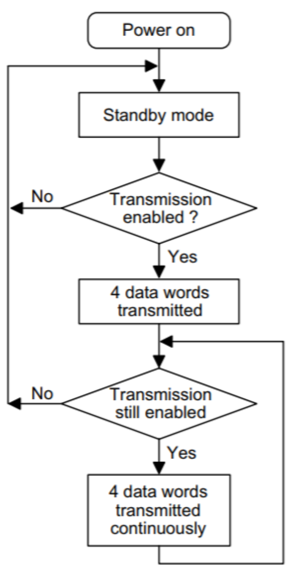

Figure 4: Flowchart of the encoder's operation.

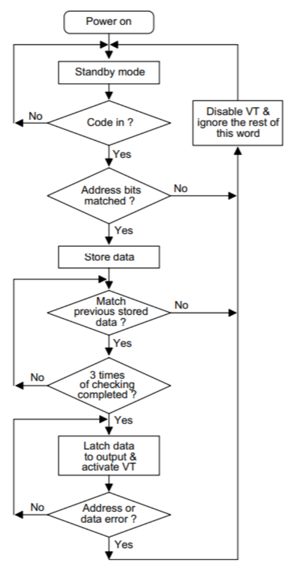

Figure 5: Flowchart of the Decoder's operation.

Table 5: Requirements and verifications for the radio transmission unit.

Requirement(s)	Verification
1. (4pts) At 100 feet away from the transmitter, the radiated signals must be less than the receiver sensitivity to prevent neighboring systems from jamming the other's decoder. 2. (4pts) Main channel emissions must be between less than 11,000 micro volt/meter three meters away from the radiator to comply with FCC part 15.231b. Outside channel spurious emissions must be less than 11,000 micro volt/meter three meters away from the radiator.	1. Set up transmitter by applying data signal to transmitter data in pin using encoder data_out with arbitrary data_in values. Set up oscilloscope with antenna connected to RF port. Orient oscilloscope antenna and transmitter antenna in same plane parallel to one another to ensure high directivity signal. Save oscilloscope screen shot of frequency spectrum and record fundamental power in lab notebook. Using the inverse square law, determine the value of the transmitted power at distances of 100 feet based off the previously measured data. 2. Set up the switch box to transmit a control signal 1 foot away from high frequency oscilloscope. Measure received power using high frequency oscilloscope RF port. Use the formula $E = ((30P)^{0.5})/d$ to determine electric field strength where P is transmit output power and d is distance from the switch box. Adjust transmitter VCC if needed to obtain desirable value for microvolts per meter, record values in lab notebook and save oscilloscope screenshots.

2.6 Radio Receiver Unit

Much like the switch's transmitter unit, this block consists of a receiver to demodulate the transmitted signal back to baseband energy and a decoder to convert the data packet to parallel data on its output pins. As explained above, the addresses of all the decoders in all the light sets in the system are the same as that of the single encoder in the switch. The state of the ith set of lights is determined by the value of the ith data bit.

The receiver contains a helical spring antenna that listens for the signal sent by the transmitter and other radiated signals in the socket's environment. An all in one receiver module will be used so there will not be a need to individually choose components such as oscillators, amplifiers, mixers and filters. The receiver chosen has a sensitivity of -105 dBm which allows for less power to be required by the transmitter in the switch's communication unit. Once the signal has been converted back to baseband energy, the output is sent into the decoder.

The input to the decoder is the receiver output. If the address section of the data packet matches the decoder's address, then the decoders output pins contain the data section of the 12-bit serial data packet in parallelized form. The decoders data out pins maintain their value until a new data packet with the correct address arrives.

The decoder data out pins are the input to the sockets control unit. If the data received is 0010 and the socket's channel selector dial is set on channel 3, then the light will turn on since the third data bit is high. The operation cycle of the decoder is specified in the flowchart pictured in Figure (5).

Table 6: Requirements and verifications for the radio receiver unit.

Requirement(s)	Verification
1. (3pts) Received signal must be at least -100 dBm (receiver sensitivity) 30 feet away from transmitter for an ideal antenna orientation. 2. (3pts) Received signal must be at least -100 dBm (receiver sensitivity) 30 feet away from transmitter even when antennas are in weak orientation. 3. (3pts) Received signals must be decoded within 200 ms to prevent noticeable latency.	1. Apply data signal to transmitter data in pin using encoder data_out with arbitrary data_in values. Set up high frequency oscilloscope 30 feet away from transmitter with antenna connected to oscilloscope RF port. Place receiver antenna to be in same plane as transmitter antenna and orient antennas in a parallel formation. Save oscilloscope screen shot of frequency spectrum and record fundamental power in lab notebook. 2. Repeat above method two times, once with oscilloscope 1 foot away from transmitter and each antenna on same axis and once more with antennas in parallel formation. Determine attenuation of weak same-axis orientation versus strong parallel orientation. Subtract this attenuation from above verification results to determine weak axis power 30 feet away from transmitter. 3. Apply data signal to transmitter data_in pin using encoder data_out with data_in values set by push buttons. Set up receiver and decoder. Set up oscilloscope with probes from button press and corresponding decoder data output pin. Record time delay between button press and decoder data update in lab notebook and save oscilloscope screenshot.

2.7 Schematics and PCB Layouts

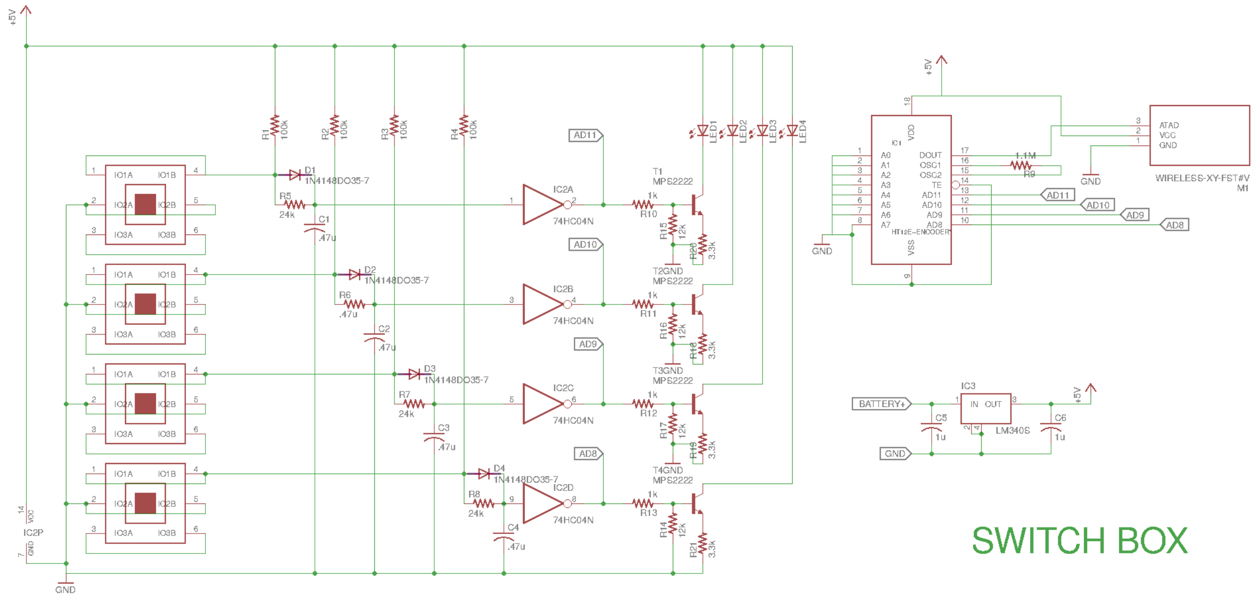

Figure 6: Schematic of switch box circuit.

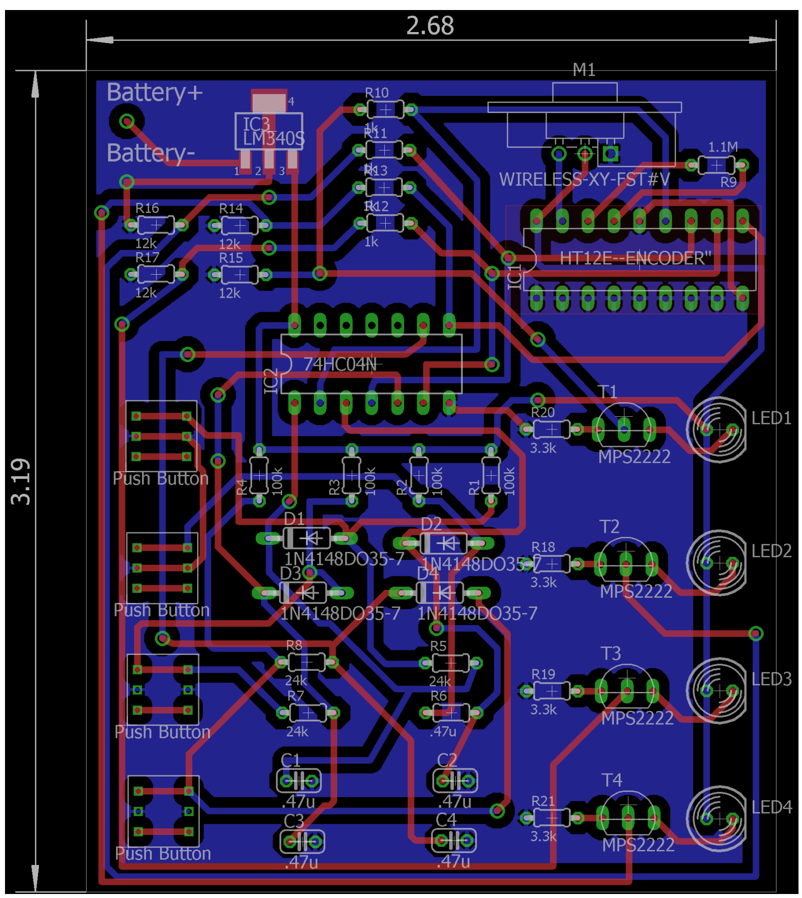

Figure 7: PCB layout of switch box circuit.

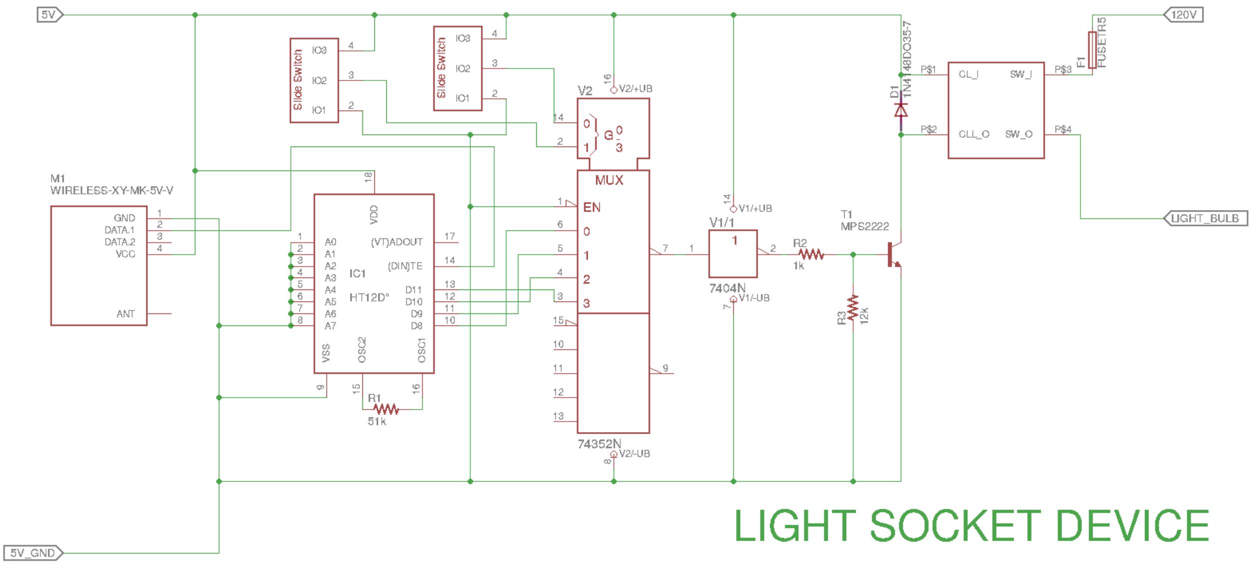

Figure 8: Schematic of light socket device circuit.

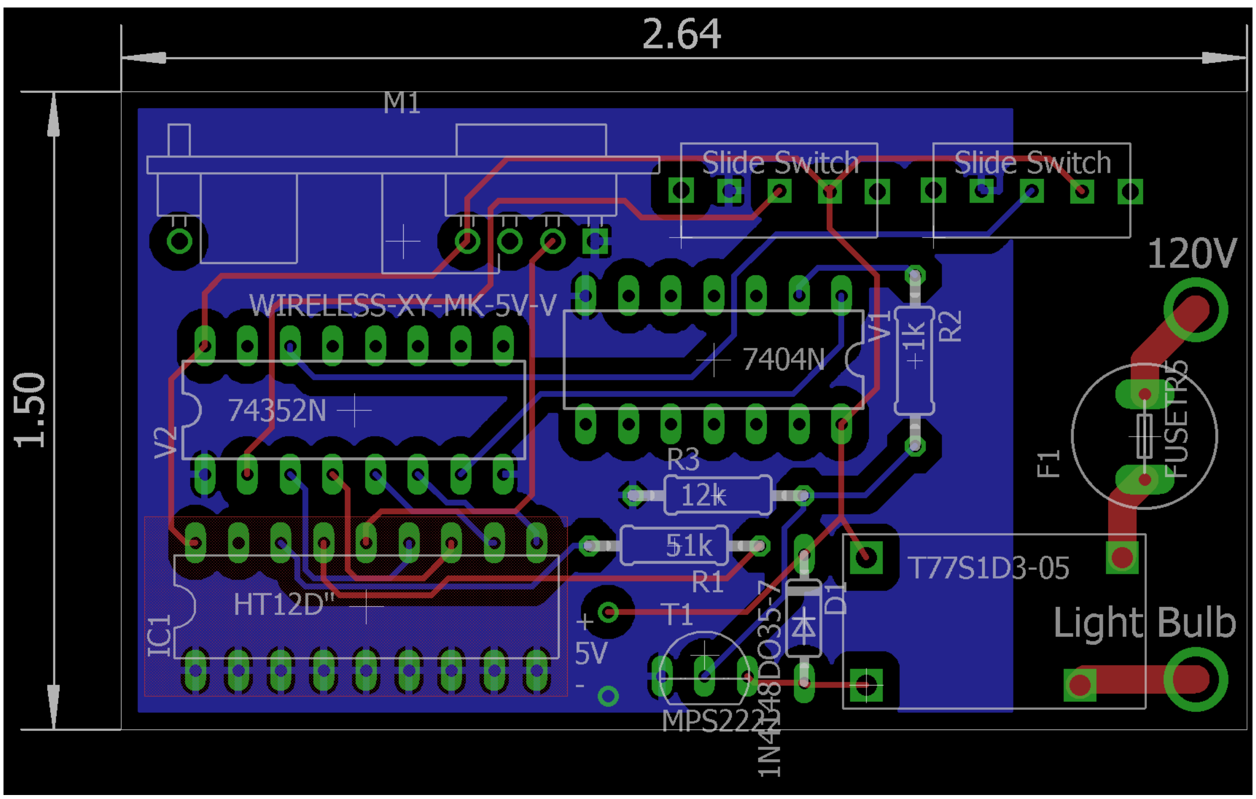

Figure 9: PCB layout of light socket device circuit.

2.8 Calculations

2.8.1 Battery Lifetime

The switch current for all four channels in the ON state is 12.3 mA. According to manufacturer data for L91 batteries, discharging at constant 25 mA down to .8 V results in a capacity of 3400 mAh. We will instead only be discharging to 1.08 V when considering our capacity, since 6.5 V is our minimum allowed battery voltage.

$$6.5/6 = 1.08V \tag{1}$$

An advantage of the L91 batteries is the discharge profile. Changing the discharge point from .8 V to 1.08 V has a nearly negligible effect on the capacity. Therefore, conservatively, the capacity of the battery pack is at least 3300 mAh.[5]

$$BatteryLifetime : 3300/12.3 = 268\ hrs \tag{2}$$

We can power the portable switch system at full operation for about 268 hours. This battery setup is expected to comply with our requirement of 150 operational hours.

2.8.2 Voltage Regulator Power Dissipation

The maximum input voltage is 9 V and the output voltage is 5 V. The thermal resistance of the junction-case is $5\frac{^oC}{W}$ and the thermal resistance of the junction-air is $65\frac{^oC}{W}$. The power calculated in equation (3) is low enough that the voltage regulator will not need a heat sink, as the 7805 can handle a maximum temperature of 125^o C, and .05 W leads to only a 3.5^o C increase in temperature as calculated in equation (4).

$$Maximum\ Power\ Dissipation = (V_{in} - V_{out}) \times I_{max} = (9 - 5\ V) \times 12.3\ mA = .05\ W \tag{3}$$

$$Increase\ in\ Temperature = (65\frac{^oC}{W} \times 0.2\ W) + (5\frac{^oC}{W} \times 0.2\ W) = 3.5^oC \tag{4}$$

2.8.3 Debouncing Circuit

The debouncer circuits that interfaces between the buttons and the ICs is constructed as in Figure 10.

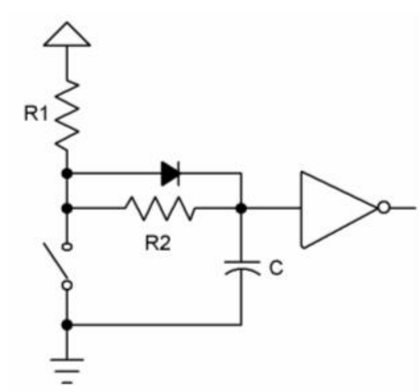

Figure 10: Circuit diagram of a RC debouncer.

The values of R_1, R_2, and C can be derived from the equations of a discharging and charging capacitor. The equation for a discharging capacitor and the rearranged form used to calculate R_2 with a chosen capacitance are equations (5) and (6) respectively where t is time in seconds, V_{cap} is the voltage across the capacitor at time t, V_{th} is the threshold voltage of the gate switches within an IC, $V_{initial}$ is the initial voltage of the capacitor, and R is resistance in Ohms, and C is capacitance in Farads.

$$V_{cap} = V_{initial}(e^{\frac{-t}{RC}}) \tag{5}$$

$$R_2 = \frac{-t}{C\ln(\frac{V_{th}}{V_{initial}})} \tag{6}$$

The equation for a charging capacitor and the rearranged form used to calculate R_1 with a chosen capacitance are equations (7) and (8) respectively where V_{final} is the final voltage across the capacitor [6].

$$V_{th} = V_{final}(1 - e^{\frac{-t}{RC}}) \tag{7}$$

$$R_1 + R_2 = \frac{-t}{C\ln(1 - \frac{V_{th}}{V_{final}})} \tag{8}$$

To fulfill the requirement that the buttons have to stop bouncing after 5 ms, t is set to 11 ms for good measure and the capacitance was chose to be 0.47 μF since they're inexpensive and easy to find. The values of R_2 and R_1 were calculated in equations (9-11) and the threshold voltage values of the 74F14 hex Schmitt inverter IC were taken from the data sheet [7].

$$R_2 = \frac{-t}{C\ln(\frac{V_{th}}{V_{initial}})} = \frac{-11\ ms}{0.47\ \mu F\ln(\frac{2}{5})} = 25.5\ k\Omega \tag{9}$$

$$R_1 + R_2 = \frac{-11\ ms}{0.47\ \mu F\ln(1 - \frac{0.8}{4.3})} = 113.7\ k\Omega \tag{10}$$

$$R_1 = 113.7\ k\Omega - 25.5\ k\Omega = 88.2\ k\Omega \tag{11}$$

Since a single resistor having either the values of 25.5 kΩ or 88.2 kΩ can't easily be bought, the closest values for R_1 and R_2 were selected to be 24 kΩ and 100 kΩ respectively.

2.8.4 Radiated Power

Equation 12 gives the relation for electric field strength as a function of measured power for an isotropic radiator, and equation 13 gives the reverse relation. In order to meet the 11,000 micro volt/meter requirement set by table 5, the radiated power must be less than -14.4 dBm at 3 meters away as given by equation 14.

$$E = \frac{\sqrt{30P}}{d} \tag{12}$$

$$P = \frac{(Ed)^2}{30} \tag{13}$$

$$P = \frac{(11,000 * 10^{-6} * 3)^2}{30} = -14.4\ \ dBm \tag{14}$$

Equation 15 gives the relationship of radiated power versus distance. As distance doubles, power falls off by a factor of four.

$$P \;\alpha\; \frac{1}{r^2} \tag{15}$$

2.9 Aftermath

In this section, the most crucial test results of the system testing are shared including battery life, transmission power, communication range and system latency.

2.9.1 Switch Box

Table 8 shows measurements of the switch box current versus time. We tested the switch box current by turning on all four channels. We then waited five minutes for the system to begin to reach steady state. We recorded the current drawn from the battery pack by the minute until 10 minutes have passed, and then we concluded testing at 15 minutes. With this data the battery lifetime is verified in section 2.8.1.

Table 8: Switch Box Current.

Time [min]	Current [mA]
5:00	12.53
6:00	12.47
7:00	12.31
8:00	12.21
9:00	12.18
10:00	12.19
15:00	12.28

The only source of radiation in the final design was the switch box. We measured the power levels at various distances and orientations of interest in order to determine compliance with tables 5 and 6. A summary of these various power levels is shown in table 9. Most notably, at 1 foot away from the switch box the power level is -30.5 dBm which easily met the power requirement given by equation 14. As for the max distance requirement of 100 feet, this was tested by observation in a large open space and confirming that at large distances the decoder pins are not updated when transmitting.

Table 9: Radiated Power

Distance [feet]	Received Power [dBm]
1 (strong direction)	-30.5
1 (weak direction)	-39.8
2 (strong direction)	-47.2
30 (strong direction)	-66.3

Two Example spectrum captures of measured power are shown in the appendix in figures 13 and 14. These captures show the measured power at about 1 foot away from the switch box for a strong antenna orientation and a weak antenna orientation.

2.9.2 Light Socket Device

The reception of the transmitted signal is a factor of antenna orientation and once again table 9 is a useful reference. For a socket insert that has its antenna oriented along the same axis as the switch box, the received power exhibits a 9.3 dB loss versus a stronger parallel rotation. This is not problematic for distances of 30 feet, because in our system testing we successfully received data at distances of 90 feet from the switch box for strong antenna orientations. Coincidentally, by the inverse square law formula given in equation 15 the loss seen from tripling transmission distance from 30 feet to 90 feet is 10log(9)=9.5 dB. Therefore, A weak antenna orientation at distances of 30 feet at worse is equivalent to a strong antenna orientation at 90 feet which has been shown to be an effective communication distance.

A large motivating factor for our design was a short lag time between user input on the switch box and light bulb output on the socket insert. Table 10 shows a summary of the latency between a button press on the switch box and data update on the decoder's output pins. These results were obtained using an oscilloscope and the screen shots for the captures are shown in figures 11 and 12. A max lag time of 115 ms is 5% of the latency that would be seen when using an Internet controlled lighting system that takes 2 seconds or more to switch lights.

Table 10: System Latency

Test type	Delay[ms]
Off to on	70
On to off	115

3 Cost

$$LABOR = 3\ people \times 38\frac{\$}{hour} \times 2.5 \times 12\frac{hours}{week} \times 12\ weeks = \$41,040 \tag{16}$$

Table 11: All of the parts and the cost of each part used in our design.

Part	Cost ($)	Quantity
FS1000A XY-FST Transmitter Module	0.83	1
XY-MK-5V Receiver Module	0.83	4
DAOKI 433MHz Helical Spiral Spring Antenna	0.55	5
HOLTEK HT12E Encoder	0.50	1

HOLTEK HT12D Decoder	0.50	4
Hex Inverter (MC10189)	0.65	1
Hex Inverter Schmitt (74F14)	0.17	4
Dual 4-input NOR (CD4002CN)	0.24	1
Diode (1N4448)	0.082	16
Quad 2-In OR (74HCT32)	0.50	1
Quad 2-In AND (74F08)	0.50	1
Dual 4:1 MUX (74LS352)	0.55	4
TE Relay (T77S1D3-05)	2.14	4
120VAC to 5VDC Supply	3.50	4
ON NPN Transistor (PN2222)	0.16	8
Littelfuse Fuse (38505000000)	0.60	8
7805 Voltage Regulator (7805)	0.48	1
Energizer Batteries (E95)	1.35	5
Switches w/ LED	0.20	4
Various RLC Components	0.10	55
Parts Total	57.65	

$$GRAND\ TOTAL = LABOR + PARTS = \$41,040 + \$57.65 = \$41097.65 \tag{17}$$

4 Conclusion

The lighting control system design by our team achieved its greatest milestones early in its development which allowed the final demonstration to include four sets of lights controlled by four separate channels. Changing the channel of each Socket Insert involved flipping two slide switches and it worked flawlessly. In most situations the communication range of the system was greater than 30 feet and was not limited by antenna orientation until greater distances were reached.

The lag time between button press and light bulb output was on the order of tenths of a second. These are results that we are satisfied with and a user of our system will be greeted with an illuminated room in a pleasingly short amount of time.

Another great success of this project was the industrial look and feel of the Socket Insert thanks to our teams collaboration with the machine shop. In our final demonstration, the design rested comfortably in a desk lamp and had a safe finish with the 120 VAC connections concealed beneath PVC material.

The communication range of the system varied greatly depending on which Socket Insert board was being tested. It remains uncertain if this behavior was a symptom of interference from nearby high voltage lines, or if it's a result of individual receivers being tuned to a passband a few KHz away from the transmission band.

In the future, further investigation on these RF communications concerns could lead to improvements in our design. Another way to improve upon our design would be the replacement of our battery pack with a rechargeable battery. This would eliminate the need to change out batteries and improve usability.

The frequency over which we transmit is 433.9 MHz which falls under FCC part 15.231 for periodic operation in bands above 70 MHz. For this project, we intend to comply by FCC rule 15.23 for Home-built devices which states "Equipment authorization is not required for devices that are not marketed, are not constructed from a kit, and are built in quantities of five or less for personal use." Should we decide to develop this product beyond the duration of this course, the necessary steps will be taken to abide by the more strict regulations for commercialized products. We would make sure our device only transmits for very limited durations of time when a flip of a switch occurs. Should situations occur where users are prolonging the very short transmission durations to unreasonable amounts by flipping the switch many times consecutively, we will ensure our system has some type of buffer to ensure transmissions qualify as periodic vs continuous as defined by the FCC. In our current design, we did ensure our design follows the respective FCC limits on power transmission for 433.9 MHz and did not increase communication range at the expense of polluting the spectrum.[8]

During this project and in preparation for our professional careers, we will follow the IEEE Code of Ethics. With every decision we make for this project, we will be consistent with Code # 1. Our actions must not only keep ourselves safe, but also pose no threat to the public or those who are exposed to our designed product. In accordance with Code # 7, we strive to learn through the process of working on our project, and will both accept and offer criticism to correct errors to the best of our ability. As we work together in a team, we will commit to Codes # 8 and # 10. Each member of our group will be treated fairly, and also all of the course staff. We seek to help each other meet individual and group goals, and support each other in following the ethical code[9].

5 Appendix

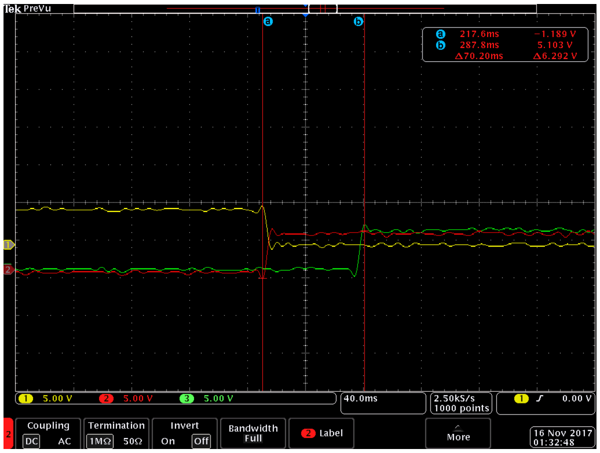

Figure 11: System Latency Test:Button off to on.

Figure 12: System Latency Test:Button on to off.

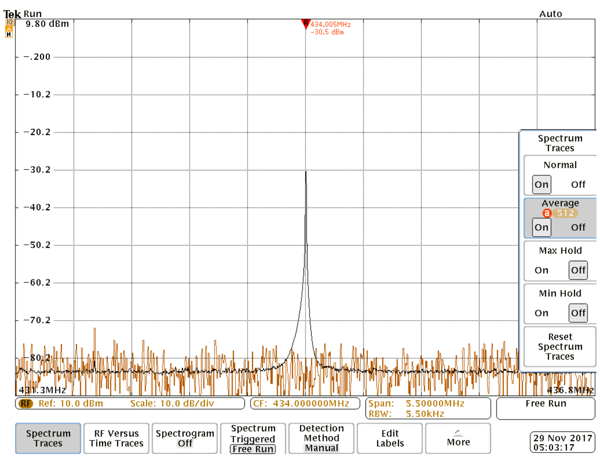

Figure 13: Spectrum of 1 foot distance strong radiation

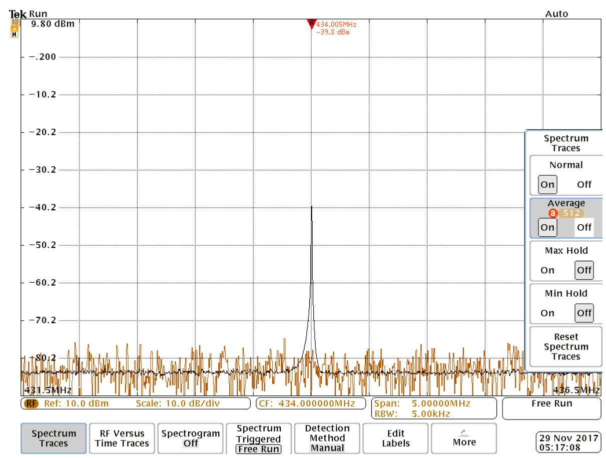

Figure 14: Spectrum of 1 foot distance weak radiation

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[8] "e-CFR: Title 47: Telecommunication , if the responsible party can demonstrate that because of price or performance the computer is not suitable for residential or hobbyist use, it may request that the computer be considered to fall outside of the scope of this definition for personal computers., in addition, devices operated under the provisions of this paragraph shall be provided with a means for automatically limiting operation so that the duration of each transmission shall not be greater than one second and the silent period between transmissions shall be at least 30 times the duration of the transmission but in no case less than 10 seconds., the double asterisks in condition three (**) shall be replaced by the responsible party with the angular pointing restriction necessary to meet the horizontal emission limit specified in paragraph (b)." authority: 47 U.S.C. 154, 302a, 303, 304, 307, 336, 544a, and 549. [Online]. Available: https://www.ecfr.gov/cgi-bin/text-idx?SID=2ca9d3fb1b02fce42a5c8f249f99e37d&mc=true&node=pt47.1.15&rgn=div5#se47.1.15_123

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