Portable RF Light Socket Control

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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 are designing 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.
- The size of the socket insert will be less than 4in in all dimensions as to fit into light fixtures and the size of the switch will be less than 6in 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.

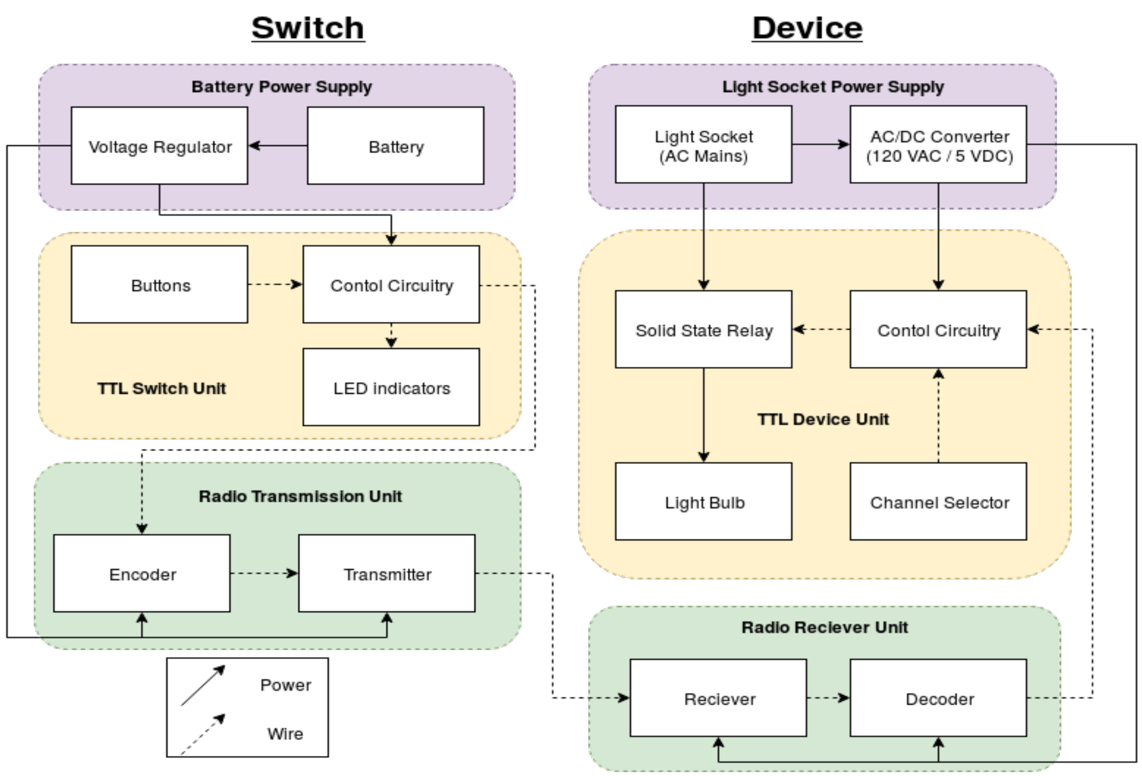

Figure 1: Block diagram of both the switch and device.

A rough idea of how these components will look like can be seen as Figure 2 for the switch box and Figure 3 for the light socket device. The switch box and device don't have physical dimensions yet because we're unsure of how large the parts that go inside each component will be, but the switch box definitely needs to be small enough to be hand-held. The light socket device needs to be small enough to leave room for a light bulb in light fixtures because the device will screw into the socket of a light fixture and the light bulb will screw into the device itself.

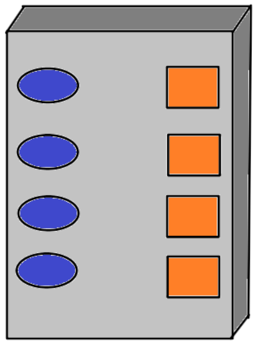

Figure 2: A rough sketch of the switch.

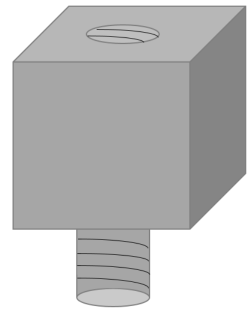

Figure 3: A rough sketch of the device.

2.1 Battery Power Supply

The battery power supply will power all of the components in the switch box as well as make it portable.

2.1.1 Battery

The portable switch box is powered by a battery pack. The battery pack contains alkaline batteries with a nominal voltage of at least 5 V.

Requirement: The battery must supply at least 5 V and have a capacity of at least 5 Ah.

2.1.2 Voltage Regulator

The voltage regulator ensures the consistent delivery of nominal 5 V to the Control Circuitry in the switch box.

Requirement: The voltage regulator must output 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 device's TTL and radio unit will need 5 VDC so the 120 VAC provided by the light socket needs to be converted into 5 VDC.

2.2.1 Light Socket

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.

Requirement: Voltage for our socket device circuitry must taken from the 120 VAC mains by a standard Edison screw.

2.2.2 AC/DC Converter

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.

Requirement: The AC/DC Converter must output between 4.8 and 5.0 V and be rated for at least 500 mA.

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 (depending whether the device is already on or off) 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.

2.3.1 Control Circuitry

The control circuitry in the TTL unit will take in inputs received from the buttons and will turn off or turn on the light(s) on the corresponding channel depending if the light(s) are already on or off on that channel i.e. turn off lights that are on and vice versa. The control circuity will also display which channels are on and off through LEDs. The control circuitry also needs to hand the digital signal that needs to be sent to the encoder.

Requirement 1: Different buttons correspond with different channels of communication.
Requirement 2: Keep track of which channels are on and which are off.
Requirement 3: Effectively output a digital signal to turn lights on/off.

2.3.2 Buttons

The buttons will allow the user to turn on device(s) tuned to a specific radio channel.

Requirement: The buttons have little to no delay between being pressed physically and a signal sent electronically.

2.3.3 LED Indicators

The LED lights in the switch box will indicate to the user what channels have device(s) on or off.

Requirement: The LEDs must be visible when holding the switch box and each LED consumes less than 60mW.

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 depending if the light is already on or not.

2.4.1 Control Circuitry

The control circuitry of the TTL unit will be doing comparisons against the channel encoded in the digital signal handed from the decoder and the channel determined by the channel selector. If the channel in the digital signal matches the channel from the channel selector, the TTL unit will change the operation of the light bulb i.e. turn the light bulb off if it's on and vice versa.

Requirement 1: Be able to interpret the digital signal handed from the decoder.
Requirement 2: Be able to compare the channel encoded in the digital signal against the channel selector.
Requirement 3: Be able to invert the light's operation after channel matches.

2.4.2 Solid State Relay

The solid state 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.

Requirement: Be able to turn the light bulb on and off reliably with a digital input.

2.4.3 Channel Selector

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.

Requirement: Be able to output at least two bits that can be interpreted by the control circuitry.

2.4.4 Light Bulb

The light bulb screws into the light socket of the device and the light socket needs to withstand the current drawn by the installed light bulb.

Requirement: The light socket of the device needs to power light bulbs of 40W rating and under.

2.5 Radio Transmission Unit

Once the digital output signal is available from the Switch TTL unit, this component handles the conversion to analog and the wireless communication of the analog signal to the Light Socket Receiver Unit. The operation of this module and the Light Socket Receiver Unit determine the range of communication of the system.

2.5.1 Encoder

The input to the encoder is a digital string of bits from the Switchs control circuit block. This string of bits represents the address of a set of lights and what the desired state change is. In order for over the air transmission to occur, the digital signal must be converted to an RF sine wave. Our design utilizes amplitude shift keying as the means for encoding information hence the need for an encoder. The string of bits are parallel input into the encoder and output as a serial signal to the transmitter.

Requirement: Encoding of signals must take no more than 1 ms.

2.5.2 Transmitter

Once the digital output signal is available from the Switch TTL unit, this component handles the conversion to RF and the wireless communication of the RF signal to the Light Socket Receiver Unit. An all in one transmitter module will be used so there will not be a need to individually choose components such as oscillators, amplifiers, mixers and filters, however an off the shelf antenna will need to be chosen. Together, it is the operation of the Portable Switch Transmitter Unit and the Light Socket Receiver Unit that determine the range of communication of the system.

Requirement 1: Antenna gain must be at least 2 dBi for signals in the 433 MHz frequency range
Requirement 2: Must be able to tune transmit power within a 10 dB range in order to determine optimum power use and adjust for higher than desired antenna gain.

2.6 Radio Receiver Unit

This unit receives the analog signal from the Switch TTL and then converts the analog signal back to a digital signal for the TTL unit.

2.6.1 Receiver

The receiver contains an antenna that listens for the signal sent by the transmitter and other radiated signals in the sockets 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. There is still a need to ensure that the chosen receiver module has operation ranges that are consistent with transmitted power levels and transmission frequency. Once the signal has been converted back to baseband energy, the output is sent into the decoder.

Requirement 1: Must have ¿10 dB attenuation of signals not in transmission channel. Requirement 2: Antenna must have gain of at least 2dBi in 433 MHz frequency range.

2.6.2 Decoder

The input to the decoder is the receiver output. Since the receiver is always listening and always outputting this decoder section must be capable of distinguishing between a control signal and lower energy signals coming from outside noise. When a signal is recognized as a control signal, the decoder will convert the Amplitude Shift Keyed signal back to a digital value on its output pins that will be further processed by the socket insert control circuitry.

Requirement 1: Must only decode signals that have power levels greater than 0 dBm as a redundancy for other radiated signals that may get through the receiver.
Requirement 2: Must decode signals within 1ms.

2.7 Risk Analysis

The delivery of 120 VAC to the light bulb is the greatest risk to the successful completion of our project. We must ensure that our device safely switches between on and off, and construct the physical socket insert and housing that fits the necessary components without risk of mishandling the AC mains. This means that we need to implement circuit protection that handles a sudden short or a sudden open. If we do not design and construct the light socket insert properly, then it could potentially cause injury.

3 Safety and Ethics

Our project has safety concerns which must be recognized and addressed. The most serious concern is the circuitry handling the 120 VAC mains. When working with 120 V, there exists the potential for both electric shock and fire hazards. Our design must present the safe delivery of 120 VAC to the bulb through a relay, as well as the conversion from 120 VAC to 5 VDC. With the proper design, handling, and safety precautions, safety concerns will be mitigated. Circuits will be arranged and soldered so that conductive contacts are safely separated and heat dissipation is managed. The one-hand method will be used when dealing with high voltages. Additionally, safe grounding will always be implemented to avoid electric shock. As a group, we will use the appropriate multimeters and measuring equipment, as well as carefully abide by rated parameters for each component used.

The frequency bands over which we intend to transmit the control signal will be within one of the several FCC assigned Industrial, Science and Medicine Bands. 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. Our device will only be transmitting 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. For the ISM band chosen, we will ensure our design follows the respective FCC limits on power transmission and does not increase communication range at the expense of polluting the spectrum.[4]

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. [5]

References

[1] "Best smart lights 2017 ultimate comparison." [Online]. Available: https://smarthomesolver.com/product/lights

[2] B. Mitchell, "How far will your WiFi reach?" [Online]. Available: https://www.lifewire.com/range-of-typical-wifi-network-816564

[3] S. Wolpin, "Heres why you never turn off a so-called smart bulb." [Online]. Available: https://www.gearbrain.com/smart-light-bulb-led-how-to-1801637028.html

[4] "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

[5] "IEEE code of ethics." [Online]. Available: https://www.ieee.org/about/corporate/governance/p7-8.html