Enterprise Smart Outlet

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III. Abstract

The purpose of our senior project, Enterprise Smart Outlet, is to create an electrical outlet which will allow enterprise users to monitor and change their power consumption habits on a large scale. The initial goal of this project is to allow consumers to see their power consumption per outlet in real time, and then using that information conform their future habits to help them conserve electrical energy, and more importantly, money. Three requirements for our project to meet our initial goal are, the outlet will work in a standard electrical outlet and be completely compatible with current electrical standards, the outlet will be easy to setup and monitor power consumption, and even recommend times when the outlet could be turned off the help save electricity, and third the device itself will consume a fraction of the amount of energy that the outlets are saving. Through the creation of our Enterprise Smart Outlet, we are hoping to help consumers be more informed about their energy consumption and use that information to shape future energy consumption habits.

IV. <u>Introduction</u>

Market Research

The market for “smart home” accessories has been growing for the past few years. Although the market is currently limited to home automation enthusiasts, the Enterprise Smart Outlet will branch off of the home automation market and expand into the enterprise market. The enterprise market has much more room to grow than the home automation market because businesses and organizations will pay for the extra amenities such as automation that in the long run (10-15 years) will pay itself back via saving electricity. If the Enterprise Smart Outlet was able to hit the markets before 2016, it would be possible to become the name brand for contractors building and renovating buildings. Building contractors would be the best place for this product to be marketed. Most organizations who contract buildings to be build do not care about specifics, only the total cost and maintenance costs over time. If our company could partner up with California’s top contractor firms, we would have a steady flow of customers and sales. Some of the top contractors include: McCarthy Building Cos. Inc., Kiewit Corp., Clark Construction Group, and DPR Construction.

Furthermore, because Title 24 for California has recently passed, this opens up a mandatory adoption of our product into new buildings. Title 24 is California’s efficiency code of regulations to help conserve energy and reduce carbon emissions within California. Regulations that went into effect July 1, 2014 require that all newly

constructed or renovated buildings within California must adhere to new environmental standards. These standards require more compliance, creating stricter environmental standards and regulations for building construction and renovation.

One aspect of California's Title 24 that affects our project, has to do with the mandatory installation of controlled electrical outlets. The revision has numerous requirements, but one requirement in particular is that for every uncontrolled (always-on) electrical outlet there must be one controlled outlet within six feet. This demand on renovated buildings will create a much larger demand for Smart Outlets. We are taking great care to make sure our project will meet all the required standards of Title 24 as to open up this large demand for our product. Looking into the future we will plan to update our product to continue to meet all Title 24 requirements, but these requirements have not been released yet.

There are currently many different companies that are creating products to help automate a home in many different ways. They range from very large companies that have been conducting research and this is just a small portion of their main business unit and companies who only make smart outlets. Table 1 below, the current market leaders making smart outlets along with pricing and features.

Table 1: Current smart outlet devices on the market with prices and applications

Device Name	Price	Application and Features
Belkin WeMo Switch	$49.95	Belkin is the largest company doing home automation today. The WeMo switch can be controlled remotely via a mobile application that allows the user to not only control the switch, but view power usage.
thinkeco: modlet	$50.00	After 2 years on the market, the modlet allows users to track energy usage and setup schedules for the outlet to be on and off. This smart outlet does require a USB dongle attached to a local computer to work.
MeterPlug	$50.00	After a successful indiegogo campaign, the MeterPlug has yet to hit the market. It allows the user to monitor power usage over extended periods. In addition, standby power can be monitored and controlled.
Digi XBee Smart Plug	$84.00	One of the higher end models allows the outlet to have a very powerful transmitter and receiver allowing it to be placed further from a Wi-Fi hotspot. Furthermore, the devices can use handoff to extend the network even further.
Plugwise	$149.95	Plugwise is the most expensive smart outlet that is on the market. They have many solutions from homes to enterprise operations. They are mostly used in Europe and are an external attachment for the outlet.
Kill a Watt	$24.95	This is one of cheapest options on the market, it does not have an external application and uses a build on LCD to display current usage.
Standard Electrical Outlet with USB ports	$29.99	This is a standard 15 Amp electrical outlet with USB ports attached. It is fully recessable into a standard electrical box, but features no external control or monitoring features.

The Enterprise Smart Outlet differs because it is more integrated and focused towards an enterprise application. All of the current smart outlets have different features that are helpful for specific users, but many of these features could be modified to help a facilities manager monitor and control up to 100's of outlets. The main other difference between the current market and the Enterprise Smart Outlet is the form factor. The smart outlets listed in Table 1 all require an external device attached to an existing wall outlet. Although this makes it easier for the standard homeowner to install, it is not practical in a newly constructed building or workplace. The Enterprise Smart Outlet will fit inside a standard electrical box inside the wall.

Similar to the current smart outlets on the market, the Enterprise Smart Outlet will partly rely on the adoption of smartphone operating systems such as the Apple's iOS and Google's Android. Usage has been increasing steady as shown by the Pew Research Center's Internet & American Life Project graph shown in Figure 1. Using this knowledge, the Enterprise Smart Outlet will offer select users a graphical interface (via computer and smartphone) that will allow users the ability to access the centralized server.

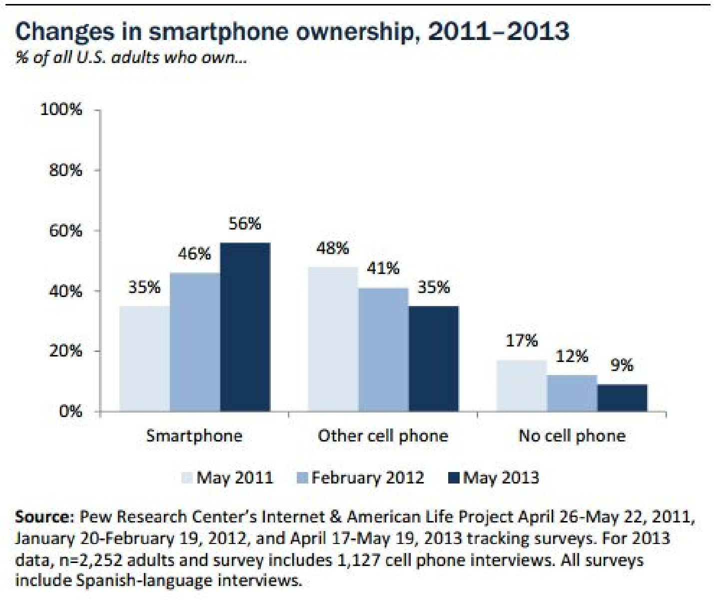

Figure 1: Change in smartphone ownership from 2011 to 2013

Furthermore, almost all home automation is very easy to use. The setup procedure takes up a couple pages of the user manual and can be controlled by a smartphone. Although our product will focus on large quantities, we would like to create a semi-automated setup that would allow contractor firms the ability to set up the Enterprise Smart Outlet without any specialty subcontractor.

Although this market may appear saturated, we believe there is a branch that has been left to hang and if we were able to go to market first, the Enterprise Smart Outlet would become the name brand.

Individual Responsibilities

1. David Faltemier
    a. Wi-Fi module
        i. Wi-Fi module part selection
        ii. Network Protocol and transmission
        iii. Interface inputs and outputs to microprocessor
        iv. Initial “easy” setup for outlet design
    b. Power Electronics Design
        i. Assist in high voltage circuit design and build
2. Matthew McGill
    a. Power Electronics Design
        i. Power measurement part selection
        ii. Power electronic controller part selection
        iii. Power relay circuit design and part selection
    b. PCB Layout
        i. Low voltage board design
            1. Wi-Fi module
            2. Microprocessor
        ii. High voltage board design
            1. Power relays
            2. USB power transformer
            3. Wattmeter design

3. Luke Stencel
    a. Microprocessor Implementation
        i. Coding
        ii. PCB integration
        iii. Power electronic control
        iv. Analog to Digital measurement conversion from Wattmeter
        v. Input and output communication to Wi-Fi module
4. Riley McGovern (Computer Science)
    a. Central server coding
    b. Smartphone application

V. Requirements and Specifications

Customer needs narrative:

There is a huge need for an enterprise solution to conserve energy around an entire building. The Enterprise Smart Outlet gives facilities managers the ability to monitor, control, and regulate power usage down to specific outlets. To achieve this goal, many requirements have been created to represent the customers needs for a product of this type. Table 2 and Table 3 list the specifications that we believe this market requires and how the Enterprise Smart Outlet will be engineered with those in mind.

Table 2: Enterprise Smart Outlet Marketing Requirements

Reference Number	Marketing Requirement
1	Network Enabled over wireless Wi-Fi networks
2	Fit inside a standard electrical box (2”x3”x2.5”)
3	Low cost $50 per outlet (comparable to current market)
4	Low power usage during standby
5	Easy setup
6	Provide two USB power ports
7	Monitorable via external device (computer app and mobile device)
8	Controllable via external device (computer app and mobile device)

Table 3**:** Enterprise Smart Outlet Specifications

Marketing Requirements	**Engineering Specifications**	**Justification**
1,5, 7, 8	Wi-Fi Module	Most commercial places have Wi-Fi networks set up and it would be easy to integrate our product to the network and connect them to a local server.
2	Components and Plug must fit within a 2-⅛”x4”x2” compartment	This is a standard deep junction box used in most commercial places.
6	Electrical socket must have additional USB ports integrated.	With mobile device so prominent in the workplace and enterprise environment, it is important to have extra features to be above the competition.
3	Cost per outlet (after development process) should be less than $50.	Contractors will spend extra money during a build so the utilities will decrease over time; however, it is important to keep the pricing as low as possible because customers will be ordering 100-1000 plugs.
5	Setup process must take less than 2 min per outlet. (Wi-Fi network must be set up).	Contractors are paid over the amount of time it takes to complete a build. They will want to be able to install outlets fast with limited connections. Furthermore, when the IT specialists come in, they will want to be able to a quick setup for all a whole building.
4	Minimal power draw from the Wi-Fi module and the microprocessor. TBA when specific parts are selected.	The purpose of this device is the save power and money from a facilities standpoint. The consumer does not want a constant high power draw from standby components.

Table 4 describes the deliverables and their due dates for this project. A few dates are still tentative until further notice. See the Gantt chart on the next page for more specific milestones for this project.

Table 4: Smart Outlet Deliverables

Delivery Date	**Deliverable Description**
October 27, 2014	Senior Project Proposal Draft Due
November 24, 2014	Final Senior Project Proposal Due
*March 12, 2015	EE 461 Demo and Report for Project
February 20, 2014	Design Review
May 29, 2014	Senior Project Analysis and Expo
*June 1, 2015	EE 462 Demo and Report for Project
February 19-20, 2015	EE Department-wide design review

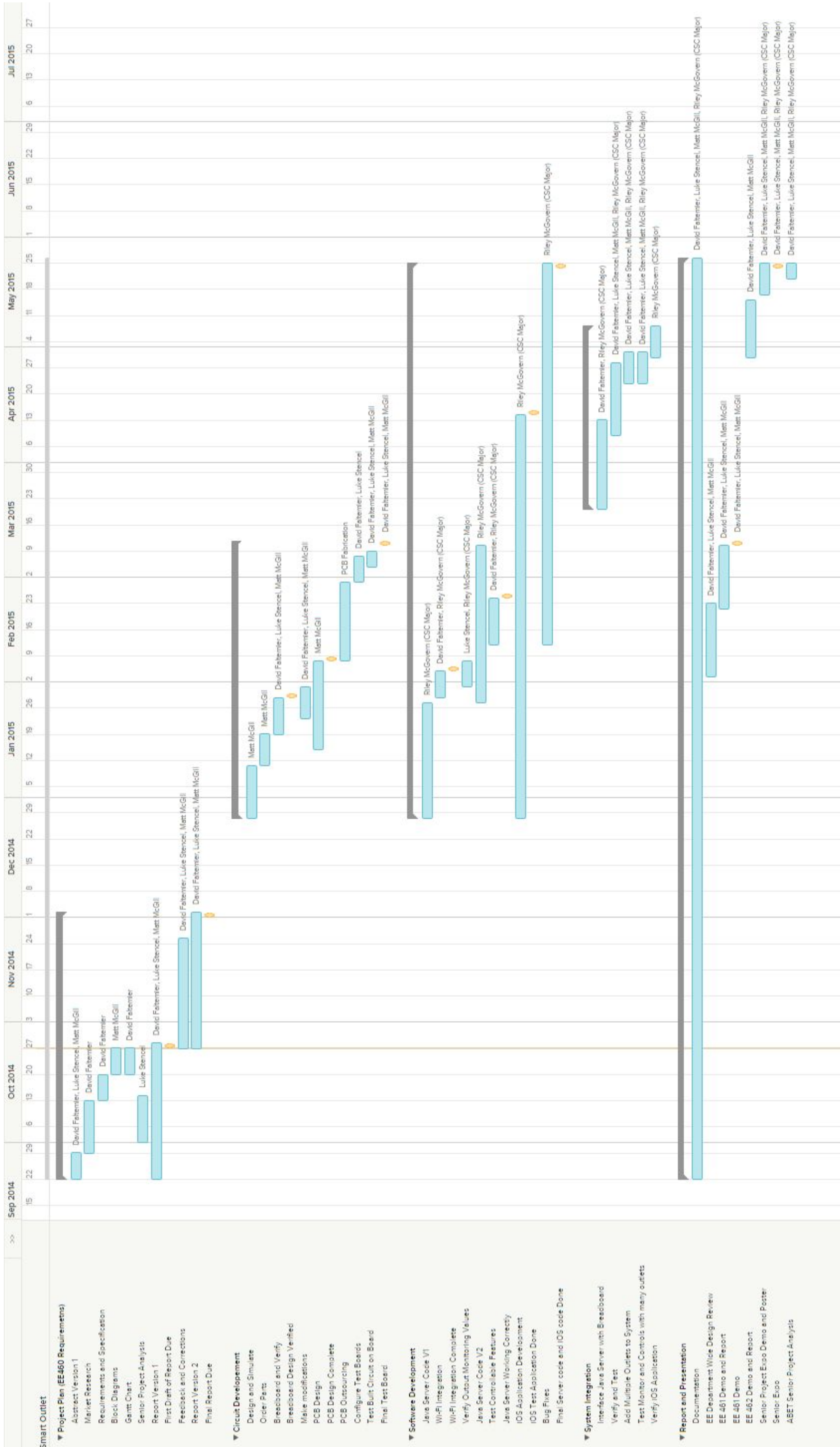

Figure 2: Enterprise Smart Outlet Gantt Chart

Cost Estimations

In Table 5, the estimated costs of the entire project are tabulated.

Table 5**:** Enterprise Smart Outlet Estimated Costs

Item:	Number:	Company:	Cost:
Custom PCB Board	2 (high voltage and low voltage boards)	Sunstone	$20 per 1 pcb ($10 per sq in)
High Voltage ADC	1	Various	$5-10
Nema 5-15 Output plugs	1	Hardware Store	$8.00
Electrical Box Casing	1	Hardware Store	$1.00
Microcontroller	1	Amtel Corporation	$3.74
High Voltage Switch	1	Various	$5-10
Wifi Antenna	1	Navo	$10
Voltage Regulator	1	Fairchild Semi.	$1.00
Low Impedance Power Resistor	1	Various	$0.50
		Physical Parts Total	$50.74 - 60.74
Labor	500 hours		$5000 ($10/hour)
		PROJECT TOTAL	**$5050.74**

Test Verification

Test verification will be done in many different parts. In Table 6, the test verification for different modules are laid out with the testing procedure.

Table 6: Test Verification

Module	Component	Test Procedure
High and Low Power PCB	N/A	Initial test procedure includes Spice simulation of circuit. Later testing includes probing of physical board and testing of individual sections of the board to ensure proper functionality of all components in design.
Wifi Module	N/A	The Wifi module testing will occur once the individual portions of the module are developed.
	Microcontroller	The communication between the Wi-Fi module and the microprocessor will be tested by probing inputs and outputs to verify the microprocessor is receiving the correct commands. Then the connections between the high voltage board will be tested to verify the power relays work as planned.
	Antenna	Antenna will be tested using standard lab equipment to ensure functionality matches that of manufacturer data sheet.
Standard Electrical Outlet	N/A	The standard Nema plugs will be tested by applying a 120V 60Hz AC signal to the input of the device and using a high power circuit on the output to ensure the

		output is the expected output.
USB Output Port	N/A	The USB port will be tested by applying a 120V 60Hz AC signal to the input of the device and ensuring that the output of the USB port is has a 5V and 2A output.
Power Conversion	Analog to Digital Converter	The ADC will be tested by inputting a 120V 60Hz AC signal and probing the output to ensure it is 12V DC.
	Voltage Regulator	The voltage regulator will be tested by inputting a 12V DC signal at the input and probing the output to ensure that it is 5V DC.
Java Server	N/A	The java server will be tested by dynamically loading and executing test classes inside the server's virtual machine. This will allow for the fullest access to the features of the server class and will also check if the server is up and live. Then communication will be tested between the microprocessor and server using the wifi signal.
Smartphone Application	N/A	The smartphone application will be tested once the java server is up and running by ensuring proper communication between the phone and the server.

VI. Functional Decomposition

Hardware

Figure 3 below shows the level 0 block diagram of the Enterprise Smart Outlet. This is a general overview of what the inputs and outputs of the entire project will be.

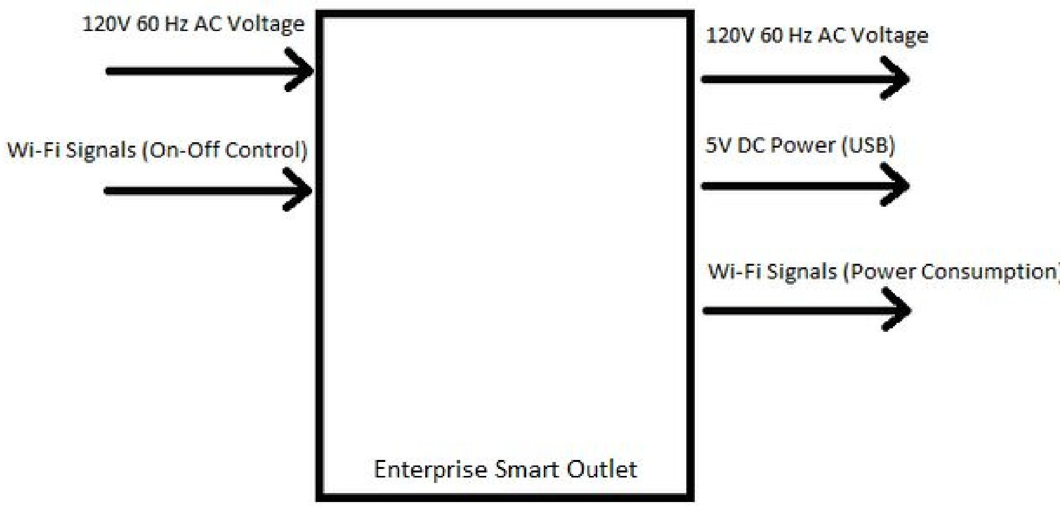

Figure 3: Level 0 Block Diagram of Smart Outlet

The first input is standard 120V 60Hz AC power the is the standard of power delivery in the United States of America. This input will be the power source for the entire project. The second input to the project will be the Wi-Fi signals that will allow the user to set when the outlet should be turned on or off. It is worth noting even when the outlet is off there will still be a standby mode to enable the outlet to be woken up when needed so it will continue to consume a small amount of power even when the outlet is off. The outputs of the Enterprise Smart Outlet will consist of 120V 60Hz AC voltage, 5V DC Power in a USB port and Wi-Fi signals so the outlet can send data back about the

power sumption of the outlet. The 120V 60Hz AC signal output will be the main output for this project, and it will be directly connected to the 120V 60Hz AC input. The second output for this project is the 5V DC power usable through a USB port. This is to address the increasing number of devices that use USB interfaces to charge. This will be a convenience to users who don't have to carry their own AC adapters to charge their devices and instead can charge their devices with just a standard USB cable. The plan for the USB port is to meet all of the current specifications for USB 3.0 charging protocols, as well as supplying the maximum amount of current allowed the charge devices as quickly as possible. The final output for the project is the Wi-Fi data being sent back to to the user about their power consumption. This data will allow users to see their data consumption per outlet in real time. These inputs and outputs are the main overview of our final project of the Enterprise Smart Outlet.

The level 1 layout of the Enterprise Smart Outlet is seen on the following page in Figure 4. This shows the basic interior components for the Enterprise Smart Outlet. While many of these components will need to be broken down further this is a good overview of the basics subsystems of our project.

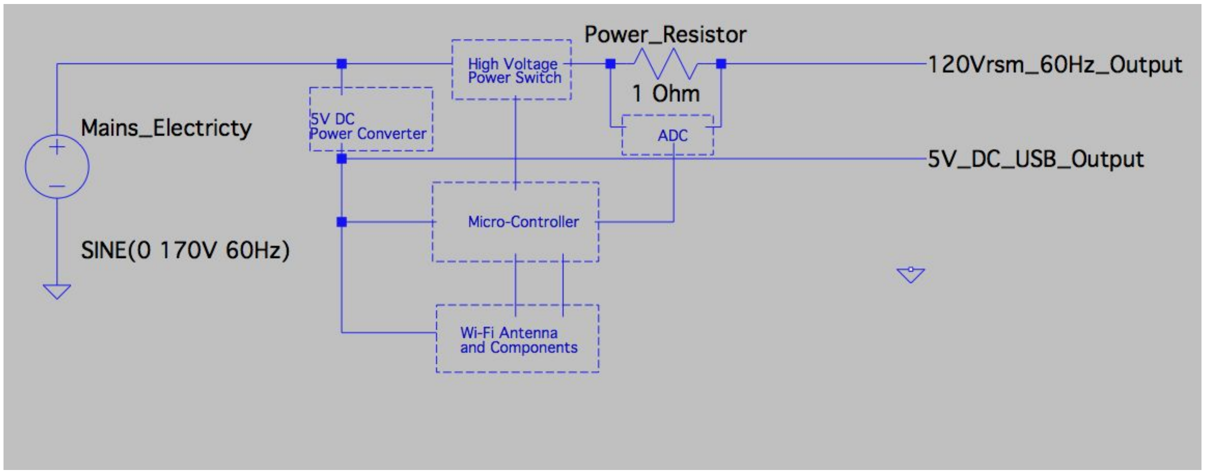

Figure 4: Level 1 Block Diagram

The main input can be seen on the left of the diagram, and is the power source for the entire project. The power supply input will be feed into a high voltage switch which will determine if the output of the system is on or off. The 5V DC Power Converter will be dual purpose. The first purpose will be to provide power to the other components in the circuit. This includes power to the micro-controllers, Wi-Fi modules, and ADC. The second purpose of this voltage converter is to provide the 5V supply to the USB output. There may need to be more regulation with the power supply to meet the USB 3.0 electrical standards. The Wi-Fi antenna will be used to communicate to and from the microcontroller. We will need to look further into the support hardware for the Wi-Fi antenna, but this will not be determined until further along in the project. Finally, the power resistor will be used with the ADC to measure the power consumption of the circuit. This power resistor and ADC method of measuring the power consumption may be replaced with a more efficient method depending on further research and development of the product.

System Specifications

In Table 7, is the specified system electrical specifications for the inputs and outputs of the entire project.

Table 7**:** System Electrical Specifications

Inputs:	Standard mains power: 120Vrms 60Hz Voltage Power Supply (+/- 5% for standard fluctuations)
	Wi-Fi Standard Protocol for communication with smart devices over a dedicated Wi-Fi Network.
Outputs:	Standard mains power: 120Vrms 60Hz Voltage Power Supply (+/- 5% for standard fluctuations)
	5V DC power supply meeting USB 3.1 charging standards which consist of (2A Max DC Charging Component)
	Wi-Fi Standard Protocol for communicating data about power consumption to users.

The following table, Table 8**,** shows other specifications for the entire project.

Table 8**:** Product Specifications

Cost:	The cost of the project will be competitive with other smart outlet products. While there is a wide array of prices and features offered, we believe that our product offered at or below $50 would be a very reasonable price point.
Dimensions:	The size of the final product will fit inside of a standard single gang electrical box. These are the sizes used in most homes and is a reasonable size to fit our project into.
Power:	As a device created to try and save consumers electricity, the device itself should use as little electrical power as possible. Our initial goal is to create the product to consume 50mW or less of power when in standby mode, and less than 1W of power when the Outlet is actively being used.
Safety:	All commercial products go under some form of outside testing to ensure the safety of the product before it is sold to consumers.

	We want to have our product meet these commercial standards, and the most common safety standards are the Underwriter Laboratory recognition standards. We will make our product meet any guidelines set forth by the UL certification so that our product would be certified as commercially safe for consumers.
Wireless Protocol:	The Enterprise Smart Outlet is going to rely on a wireless protocol using Wi-Fi to communicate data to and from the device. Our device will meet all regulatory and federal requirements for proper use of Wi-Fi transmissions.

Software

Figure 5 shows the software connections between the different parts of the Enterprise Smart Outlet solution. Our solution requires a centralized server that communicates to the outlets and then forwards information to a desktop native application. A web application may be implemented for off site control as well. Furthermore, a iOS application will be used to implement a feature that would allow employees or students the ability to quickly find an unused outlet. The server will keep all the data in a database locally and send commands through Wi-Fi protocol.

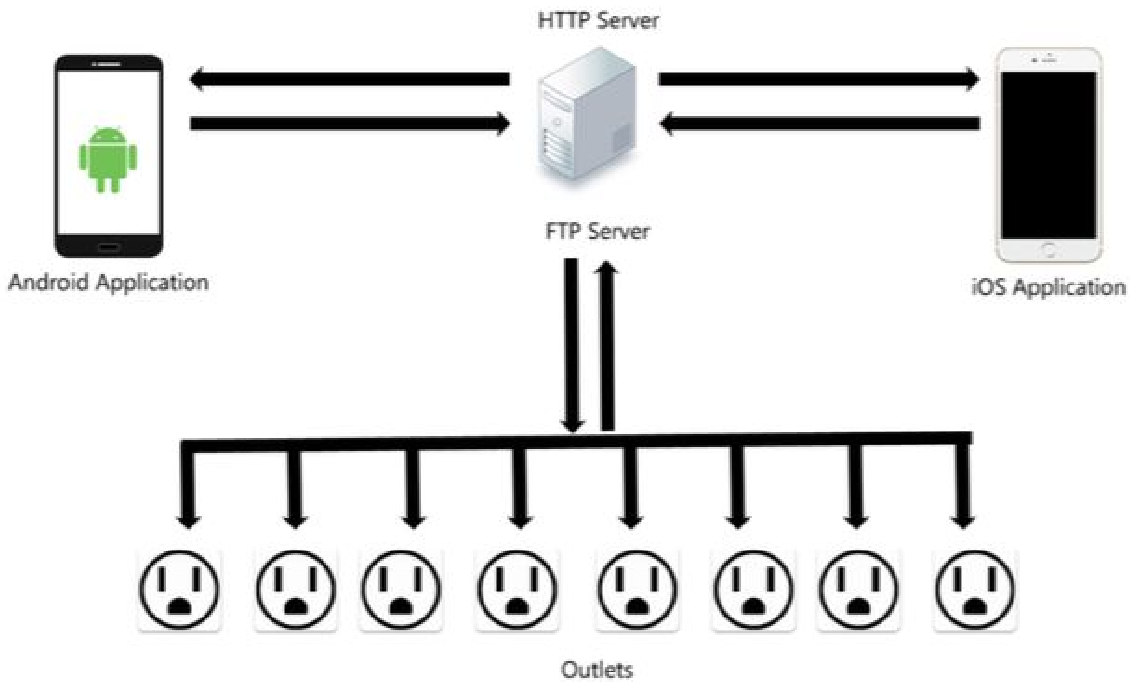

Figure 5: Software flow diagram

VII. Final Design and Test Data

The Enterprise Smart Outlet is composed of several major subsystems. The subsystems that make up the Enterprise Smart Outlet are the WiFi interface, the microprocessor, the AC to DC converter, the MOSFET solid state switch, and the power measurement subsystem.

AC to DC Conversion

When designing the AC to DC converter for the Enterprise Smart Outlet three factors influenced the design, power consumption, cost, and physical volume of the converter. The specifications of the AC to DC converter for the Enterprise Smart Outlet are to take 120 Vrms wall power and convert that into positive and negative 5V to power the microcontroller and WiFi modules as well as provide the correct voltage to switch the MOSFET switch on and off.

Since the AC to DC converter is required to power the microprocessor the AC to DC conversion will always consume power. One of the main goals of the Enterprise Smart Outlet is to save power by reducing phantom power consumption and the AC to DC converter is a critical component to achieving this goal.

Our first design of this subsystem used a transformer, a full bridge rectifier, and capacitors to turn the high AC voltage from the wall power into the 5V power supply the microcontroller required. This first design had two problems. First, from simulations, the power consumption from the conversion was over 5W. The 5W from the power consumption is larger than smaller phantom power loads, so preferably a more efficient method would be used. The second major problem with the initial design was the size of

the components required to do the conversion. The 10:1 transformer required to bring the voltage down to a reasonable level would not fit inside the standard chain gang electrical box which was our specification for the volume of the entire project. The transformer also cost $11 which was a significant portion of the projected budget for not meeting any of the other specifications. The initial schematic can be seen in Figure 6 below.

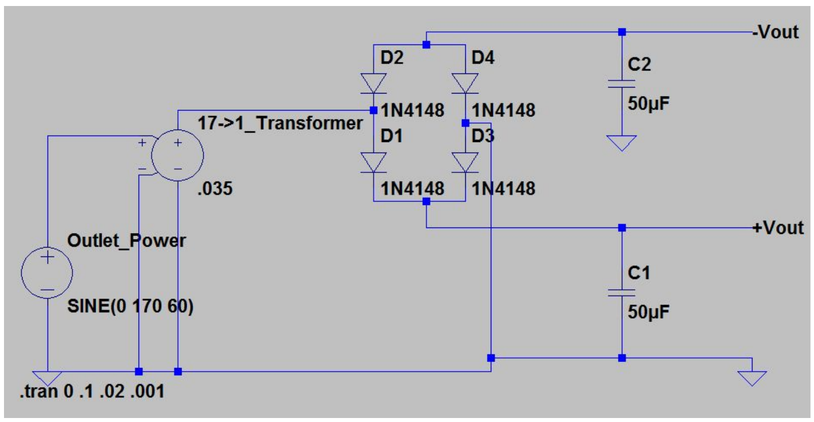

Figure 6: Initial Schematic for AC to DC Converter

The plus and minus 5V output from the AC to DC converter can be seen in Figure 7 below.

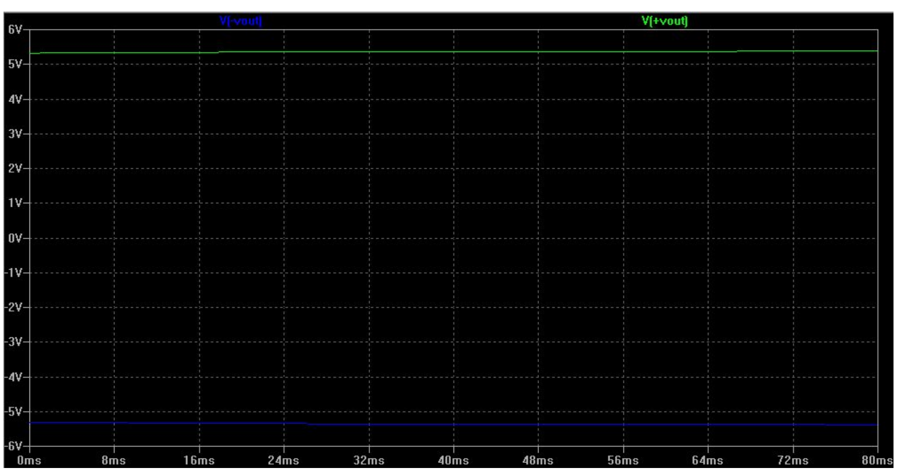

Figure 7: Initial AC to DC Converter Output Simulation

The second idea for this subsystem was to purchase a component that already met the specifications of the Enterprise Smart Outlet. Many components exist for an AC to DC converter with our specifications and using the wide range of products on the market allowed for the use of an AC to DC converter of a higher caliber than anything we were able to design during the senior project design cycle. The device we chose was the RAC04 for several reasons. The first reason was the small form factor of the converter. The entire unit was smaller than just the planned transformer for the initial design. The unit also provided both positive and negative 5V and was able to use the wall power voltage as its input. The entire converter unit cost about the same as the initial design at $12. While the cost of the unit did not meet the Enterprise Smart Outlet specifications the other design requirements allowed this unit to work as the AC to DC converter for this project. The device was much more power efficient than the initial simulations, at 98% efficiency and consuming only 4W of power. The converter unit could only supply 400mA of current which meet the requirements for the microcontroller, WiFi module, and switching circuitry. This unit did not provide enough current for the USB charging standard. This component would need to be replaced with a different converter that has the ability to source more current in order to meet USB charging standards.

MOSFET Switch

The switching MOSFETs act as an electrically operated switch which is controlled by the user signal sent to the gates of the MOSFETs through the wifi chip and inverting circuit. This switching circuit allows the user to control the flow of electricity from the mains to the load device which makes it a fundamental component of the Enterprise Smart Outlet. In order for the switching MOSFETs to function the gate of the PMOS must receive a negative voltage of at least -3V with respect to the neutral line, and the NMOS must receive a positive voltage of at least 3V with respect to the neutral line. In order to satisfy this requirement, the switching circuit must have its MOSFET gates within the range of the wifi chip 5V output and the inverting circuit output for the NMOS and PMOS respectively. In order for the switching circuit to handle a load 120VAC while still remaining at a reasonable cost, diodes were inserted between the load and the source of the FETs with the same polarity as the inherent diode of each FET. Lastly the switching circuit must comply with the 20A maximum current that can be produced by a given household load device. To satisfy this, components with a rating higher than a 20A maximum current were selected.

The switching MOSFET circuit made it into to the final design after being selected over both mechanical and solid state relays. Although solid-state relays offer a similarly reliable design, the main advantage of the switching circuit is the overall cost. Since the Enterprise Smart Outlet is designed for an enterprise consumer, it will be ordered in bulk drastically reducing the price of the components for the switching circuit and the other components required to power it. When compared with the price of an Solid State

Relay, it is only a fraction of the cost. Additionally the switching circuit operates quietly, which is a major requirement of the consumer base for this product. Since a mechanical relay does not operate silently, the MOSFET switch was the better choice. The schematic design can be seen in Figure 8 below. The 5V sources seen in this circuit diagram represent the power provided to the FETs from the wifi chip while the circuit is intended to be in its on state.

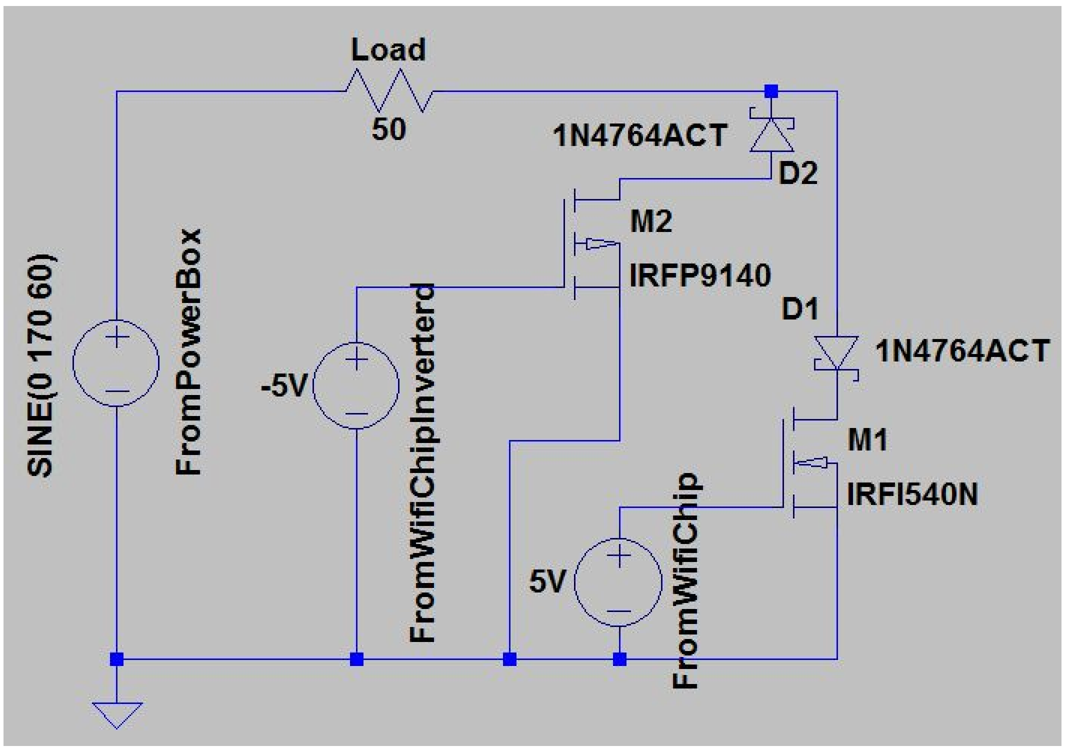

Figure 8: Schematic for Switching Circuit in ON State

In its on state, the switching circuit is designed to provide the load with maximum outlet power. Figure 9 below shows the simulated performance of the current across the load of switching circuit in the on state.

Figure 9: Load Current for Switching Circuit in ON State

The off state of the switching circuit occurs when the MOSFETs receive 0V DC from the output pins of the wifi chip when instructed by the user through the mobile application. Figure 10 below shows the circuit diagram in its off state.

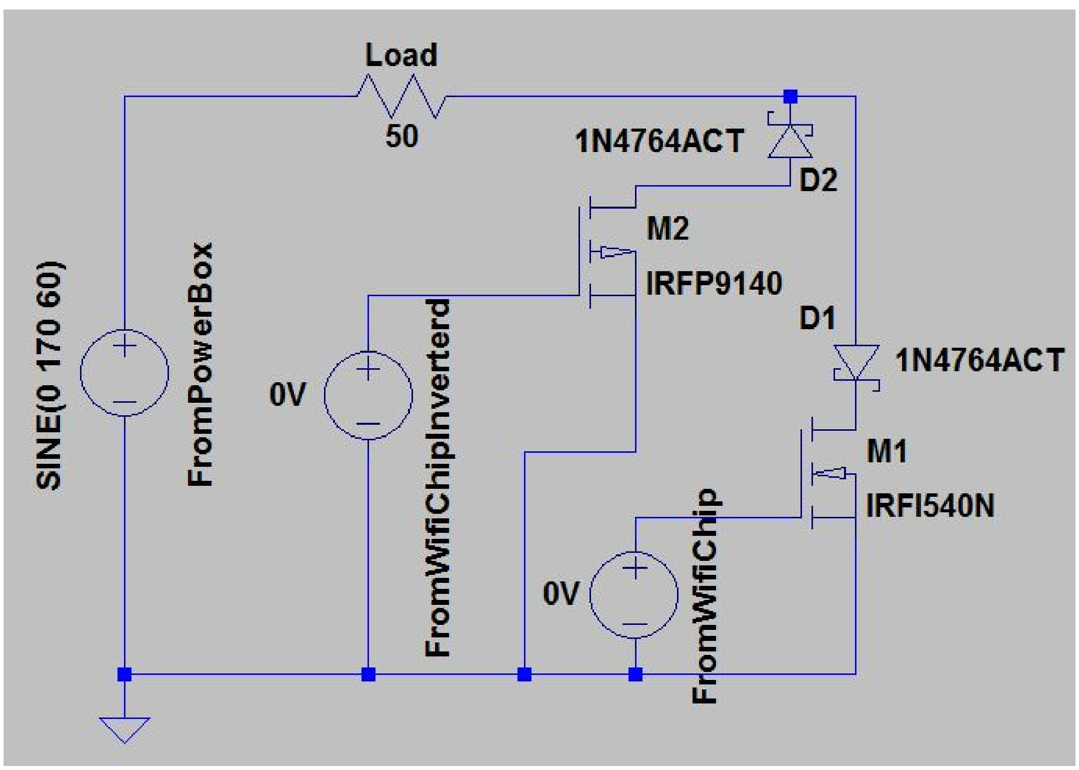

Figure 10: Schematic for Switching Circuit in OFF State

Figure 11 below shows and the simulated performance across the load while in its off state. Current in the off state is attributed to leakage of the diodes and FETs. The amount of current “allowed” through during the off state is minimal and will result in very low power consumption.

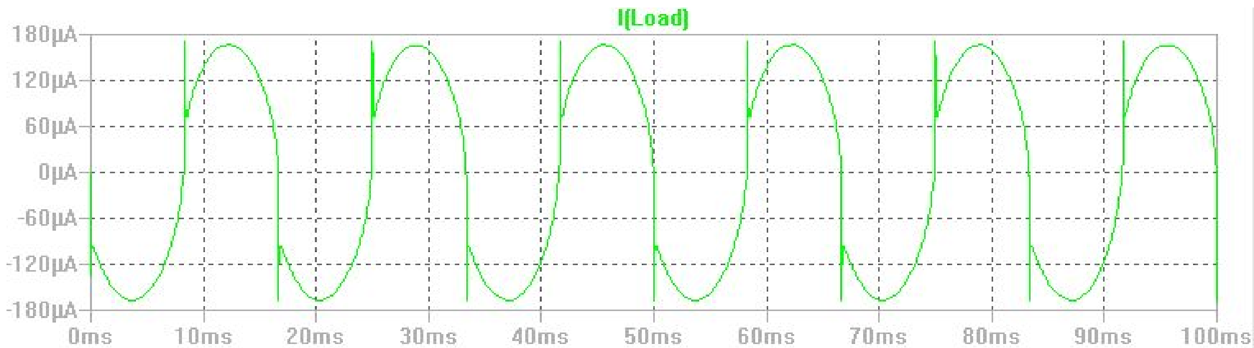

Figure 11**:** Load Current for Switching Circuit in OFF State

Table 9 below shows the selected components for the MOSFET switching circuit. One target goal of the Enterprise Smart Outlet is to provide a solution to Title 24 at the lowest possible cost per outlet. The selected parts provide adequate performance at a minimal cost, resulting in a solution that is quite suitable to the goal.

Table 9: Selected Components

Component Type	**Part Number**
NMOS	IRFI540NPBF-ND
PMOS	IRFP9140PBF-ND
Zener Diode	1N4764ACT-ND

Microprocessor and WiFi Module

There are many choices of microprocessors and WiFi modules that are available on the market. Some microprocessors are integrated, however, most are non-integrated solutions. Not being integrated was not preferable design for our project because we wanted to minimize power consumption, space, and cost. The Texas Instruments CC3200 offered the best solution that satisfied all of our design considerations. Not only is it integrated, it allows for future customization on a custom PCB. This is pivotal to the future of this project because once we were able to verify that the Microprocessor will work with the rest of our circuit design, we will be able to implement it even further. The ideal goal was to create two PCB designs for a high voltage and low voltage separation with only the required connections to minimize interference. The Texas Instruments CC3200 included an ADC that we were going to use to save additional money in the final design.

Table 10: WiFi-Chip Comparison

	Cost	Customization	Integrated	Power Consumption
Arduino and Xbee	$110	No	No	.9 Watts
RaspberryPi	$55	No	Yes	1.21 Watts
Texas Instruments CC3200	$30	Yes	Yes	0.8 Watts

Power Measurement

One proposed feature of the Enterprise Smart Outlet was to allow the user to view the power consumption of the devices plugged into the outlet. The initial design of the was to design elements which could measure the voltage of the outlet and measure the current being used through the outlet. With this information the power consumed in the outlet could be determined. The microprocessor's analog to digital converters read sensors which could convey this information.

The ADC of the CC3200 only reads voltage in a range from 0V to 3.5V. With wall power providing voltage in a range from 170V to -170V the CC3200 could not sample the voltage directly. To read the voltage a 17:1 transformer changed the 170V peak voltage into a smaller 10 V peak. After stepping down the wall voltage the waveform was rectified and pass through a resistive voltage divider to bring the maximum voltage within the range of the CC3200's ADC. Then the CC3200's ADC sampled the down sized waveform and using software conversion factors, could calculate the voltage from the wall. A schematic of the circuit used to step down the voltage can be seen below in Figure 12.

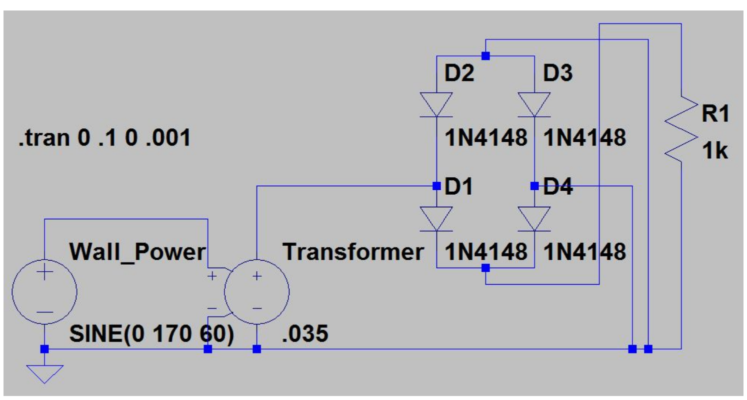

Figure 12: Circuit Used to Step Down Voltage to ADC Levels

To measure the current being used in the outlet a transducer was used to convert the current flow into a voltage output. The voltage output of the transducer could be read by the CC3200's ADC and using software could determine the amount of current flowing through the outlet. The transducer used in the Enterprise Smart Outlet prototype was the ACS709. The ACS709 is a current sensor able to measure currents up to 20A at frequencies up to 120 kHz, suitable for the currents found in a household outlet. In Figure 13 the circuit configuration for the ACS709 is shown below. The Viout pin shows the pin that connects to the CC3200's ADC pin.

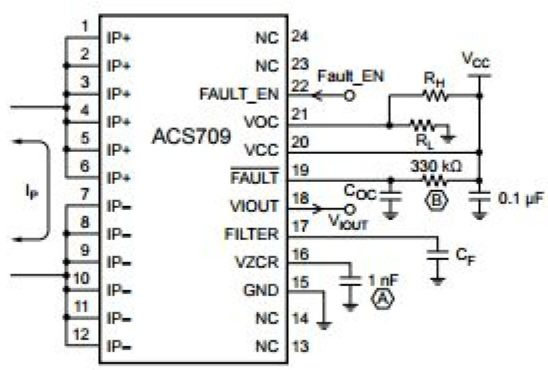

Figure 13: ACS709 Typical Configuration[1]

In individuals tests all of the sensors worked as expected. The circuit used to step down the voltage kept the output voltage below 3.5V for input voltages lower than plus or minus 175 V peak. The transducer measured current with a ratio of 85mV/A. In the prototype of the Enterprise Smart Outlet the power measurement was not a functioning feature. The issue with making the power measurement work correctly was the ADC on

[1] ACS709 Datasheet. Rev 3. Allegro Microsystems LLC. 6 June 2014.

the CC3200. To implement the two channels of ADCs to work on the CC3200 along with the WiFi functionality and the switching circuitry required multitasking functionality beyond the abilities and resources available to our group. While the individual sensors worked as planned, the programming required to constantly sample the two sensors in a periodic fashion did not get implemented in the prototype Enterprise Smart Outlet.

Analysis of Prototype

This section of the report will reflect on the initial goals of the project and how well the Enterprise Smart Outlet prototype met those goals. The goals covered in this section are passive power consumption, switching effectiveness, and AC to DC conversion.

The passive power consumption of the Enterprise Smart Outlet was comprised of the electrical elements that consumed power to enhance the functionality of the outlet. The two components that consumed power were the microcontroller and the AC to DC converter. The microcontroller, the CC3200, consumed on average 700mW of power. The AC to DC converter, the RAC04, consumed 4W of power. In total the Enterprise Smart Outlet consumed 4.7W of power of passive power consumption. This was larger than our passive power consumption goal. In order to improve this number the Enterprise Smart Outlet would need to use a more efficient AC to DC converter. A second option would be to use the CC3200 in low power mode. The microcontroller used less power than the AC to DC converter, so the main improvement here would be to improve the efficiency of of the converter.

The switching effectiveness of the MOSFET switching circuit allowed for the power to be turned on and off to the connected devices. While the simulations showed the MOSFET switch should let in less than 1μA of leakage current, in reality the switch did not perform as well as the simulations. When the outlet was connected to a light bulb, which is essentially a power resistor with a resistance around 100Ω. This load the switch blocked less than 1% of the voltage when the switch was in the on position and acted essentially as a short circuit. The problem with the switching circuit was when the

switch was turned to the off position. In this position the switch blocked only 80% of the voltage from out wall power. This meant that up to 34V peak were still able to connect to the load. This was enough power to light the test light bulb at a dim level and not enough to satisfy requirements to be a working solid state electrical switch. The main problem came from the zener diodes not behaving correctly at high voltage levels and allowing the MOSFETs to not block the incoming voltage waveforms. The switching circuitry needs to be updated in order for the Enterprise Smart Outlet to meet desired specifications.

The AC to DC conversion allowed the microelectronics such as the microprocessor and MOSFET switches to function from the AC wall power supply. The initial design with a transform, rectifier, and filtering capacitors was too large and consumed too much power to be effective. The RAC04 was a good compromise between small form factor, cost, and power consumption. The design did lack the ability to provide the 2A of current required for USB charging. Using the RAC04, a better design suited for the Enterprise Smart Outlet may be designed, but for the prototype the RAC04 worked well. The power consumption could be reduced, and the maximum output current could be increased in order to better meet the Enterprise Smart Outlet requirements.

In conclusion the switching circuitry and the passive power consumption need improving before the Enterprise Smart Outlet could be a viable product. The AC to DC converter was a good start for the power conversion, but a custom solution could provide a more efficient design suited for the specific needs for the Enterprise Smart Outlet.

Software

Server

The application and outlets require two servers to run. The first server is an HTTP server which handles requests from the app to provide the outlet data. The second is an FTP server that handles data transmissions from outlets and sending commands to the outlets to activate or deactivate. Both of these servers were implemented in Node.js, a platform for server-side and networking applications. Both servers have connections to a MySQL database. MySQL is the world's most popular open source relational database management system.

HTTP Server

The HTTP server is the interface between the MySQL database and the mobile applications and between the mobile applications and a FTP client socket to an outlet. Before the HTTP server is started, a connection is made to the MySQL database so there is never a situation where an outlet hits the server before that connection is made. The request the mobile application makes to get outlet data is simply querying the database for all outlet data and sorting the outlets based on their group in ascending order. Currently, the Android app does not support refreshing individual outlets because there wasn't a need for it with the amount of outlets we were testing with. However, the server does have a query for a specific MAC address that would return data on just that outlet. Once the database query has been formatted, it is executed and the resulting row or rows of data are directly converted to JSON using the function JSON.stringify() [9]. The JSON is packed into the response to the request.

The request to activate or deactivate an outlet is a bit more complicated. The request takes the form of a query to activate or deactivate the MAC address of the outlet. If it is an activate query, the command sent to the outlet is a ‘1’; if it is a deactivate query, the command sent to the outlet is a ‘0’. The MAC address is used to query an IP lookup table in the MySQL database and with the IP address returned, an FTP socket client is created to send the command to the outlet. If the outlet successfully received the command, then the status of the outlet in the database is changed to reflect the successful transfer.

FTP Server

The FTP server is the interface between the outlets and the MySQL database. The server does not use any form of DNS so we used static IPs for the server and outlets. The server must be running before the outlet is turned on to capture the add string that they send when they start up. The outlet sends a string that contains its MAC address, name, group, and description to the servers’ IP on startup to make sure it is always there. When the server receives this command, it adds the outlet to the table database. It also adds the MAC address of the outlet and the IP address of the outlet to a separate table to be used when sending commands from the HTTP server to the outlet. The server is also capable of receiving update strings from the outlets to update their voltage and current values.

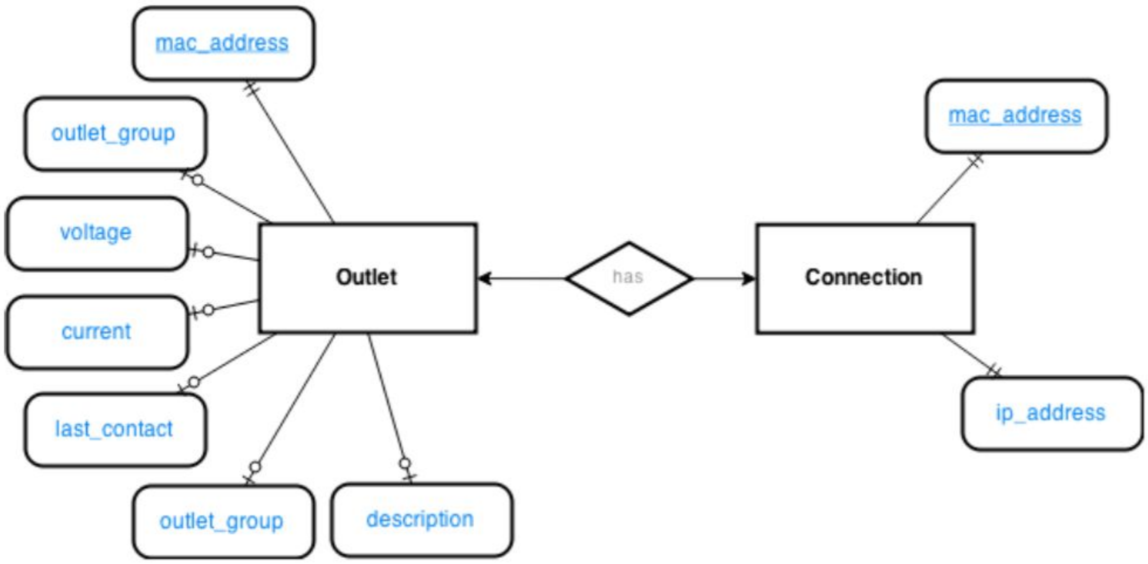

Figure 14: Enterprise Smart Outlet Entity Relationship Diagram

As shown in Figure 14, the Entity Relationship model for the database is simple, but gets the job done. There is a one-to-one relationship between Outlet and Connection. Normally, a one to one relationship would not call for a separate table, but the IP address should not be in the same table as less protected information.

Splash Screen

When a user first starts the application, they will see the splash screen as shown in Figure 15. After three seconds, the user will be taken to the main activity of the app.

Figure 15: Splash Screen

After the splash screen, the user will see the list of outlets as shown in Figure 16.

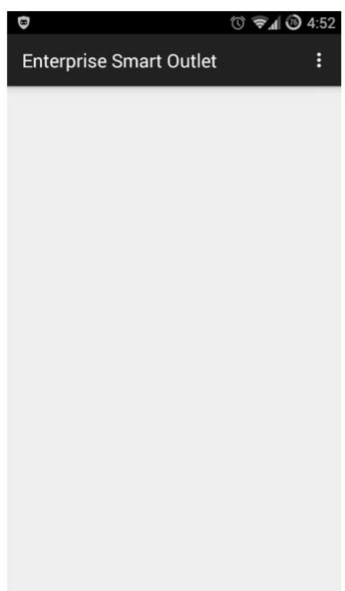

Figure 16: Empty Main Screen

This is what the app looks like if there are no outlets added to the server yet. Once outlets have been connected to the server, the list view will update and show the added outlets, as shown in Figure 17.

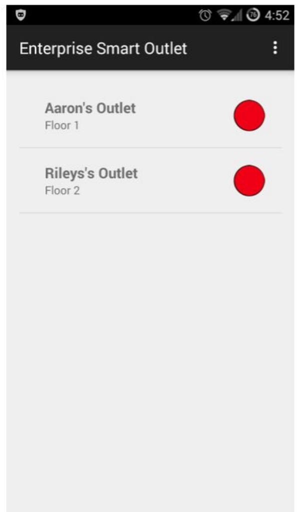

Figure 17: Deactivated Outlets Main Screen

The list view of outlets displays three pieces of data. The bolded top text is the name of the outlet. The subtext is the group the outlet is associated with. The colored circle is the status of the outlet. For the main screen of the app, the list of outlets connected to the server is displayed. On the start of the post-splash screen process, a GET request to the server is sent in the form of an AsyncTask to get an updated list of outlets on the app. The URL is built app side depending on the IP of the server. A future update to the app would use mDNS to obtain the IP of the server. Multicast DNS resolves a host name by sending an IP multicast query message that asks the host having that name to

identify itself. If the request does not return anything, nothing happens. However, if the server returns JSON data on the outlets, the Realm database is cleared and the JSON is sent to another process to be parsed and formatted into Realm outlet objects. The Realm outlet objects are stored in the Realm database.

Once the server has Outlet objects, a custom list adapter that extends RealmBaseAdapter to format my outlet data. RealmBaseAdapter is an abstract utility class for binding UI elements to Realm data. I bind the outlet name and group to the list item and, depending on the status of the outlet, display a red, yellow, or green status icon. The text items are displayed in TextViews and the image is displayed in an ImageView.

There are three possible statuses for the outlet:

- red – The outlet is deactivated.
- green – The outlet is activated but not currently in use.
- yellow – The outlet is activated and in use.

The detailed view shows information specific to one outlet.

There is an assortment of data presented on this screen:

- Name – The name of the outlet.
- Group – The group the outlet is associated with.
- Voltage – The most recent voltage reading from the outlet.
- Current – The most recent current reading from the outlet.
- Status – If the outlet is inactive, in use, or active but not in use.
- Last Contact – The last time the outlet contacted the server.

There is also a toggle button to activate or deactivate the outlet from the app.

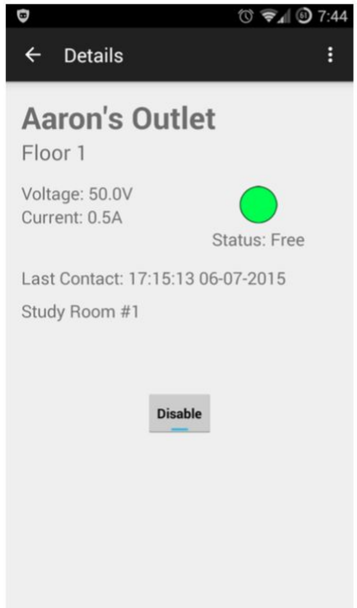

Figure 18: Detailed Screen of Free Outlet

Figure 18 shows the outlet from the list view that was active but not in use. When the toggle button is clicked, it sends a command to the server to send a command to the outlet to activate or deactivate depending on its status. When a list item is clicked, a detail screen displays all of the information on the outlet. The MAC address of the outlet is connected to the intent and query the Realm database from the detail fragment to get the rest of the information on the outlet. The outlet name, outlet group, voltage, current, last contact, description, and status texts are bound to TextViews. The status icon is displayed in an ImageView. At the bottom of the detail view is a ToggleButton. This ToggleButton sends a GET request to the server in the form of an AsyncTask to either enable or disable the outlet depending on its current status. The URL is built app side and includes a query to the server to either activate or deactivate the MAC address of

the outlet. Currently, the app will always switch from sending an enable to disable or disable to enable after a button press. Originally the send command had it based on the status of the outlet. When it was based on the status of the outlet, it required the server to receive the request, successfully send the activate or deactivate command to the outlet, receive updated data from the outlet saying its voltage and current values were lower, then update the database and send that updated data back to the app.

<u>Appendices</u>

Analysis of Senior Project Design

Enterprise Smart Outlet

David Faltemier, Matthew McGill, Luke Stencel

Advisor's Name:

1. Summary of Functional Requirements
    a. Describe the overall capabilities or functions of your project or design. Describe what your project does. (Do not describe how you designed it).
        i. The Enterprise Smart Outlet will work in a standard electrical outlet and be completely compatible with current electrical standards. It will be easy to setup and monitor power consumption and even recommend times when the outlet could be turned off. In accordance to this the outlet will have the ability to shut off for user defined times. This outlet will also consume only a small fraction of the power it is saving.
2. Primary Constraints
    a. Describe significant challenges or difficulties associated with your project design or implementation. For example, what were limiting factors, or other issues that impacted your approach? What made your project difficult? What parameters or specifications limited your options or directed your approach?

i. Physical Limitations: The Enterprise Smart Outlet must fit within the size constraints of a common house outlet box.

ii. Design Limitations: The Enterprise Smart Outlet must consume the least amount of power possible, and run using a 120V 60Hz AC input voltage. Outputs must include a 120V 60Hz Ac voltage, a 5V DC Power USB port, and follow Wi-Fi protocols..

3. Economic

a. Economic Impacts

i. Human Capital: If the design were to get picked up by a large scale company due to the manufacturing needs of the current time, it would create jobs for people including research and design engineers, installation technicians, and support technicians as well as provide business to manufacturing companies.

ii. Financial Capital: Profit is a clear possibility if this product was developed. Consumers will see monetary savings on electrical bills the will quickly outmass the price of integration of the smart outlet.

iii. Natural Capital: Product will be composed of common outlet casing, silicon, pcb boards, and possibly contain some rare-earth materials. It will be a product the will require responsible recycling and will be a sustainable product.

iv. Costs: Costs included for this device primarily from the manufacturing costs of this device. The remaining portion of the

costs come both the development and marketing of the device, with the marketing being least expensive. The profit that occurs with this device is two-fold. The company in charge of the development will make money from the actual purchase of the device, while the consumer will make money from the savings derived from the implementation of the device. Pricing for production and consumer use will be determined by component cost and retail price of rival products. Refer to Table 15 for the price of specific components.

4. If manufactured on a commercial basis:
    a. Estimated Number of devices sold per year:
        i. Initial Round of Production: approx 100,000
        ii. Later Rounds of Production: approx 500,000
    b. Estimated manufacturing cost for each device: $35.00 (when components are bought in excessive bulk price per unit will significantly drop
    c. Estimated purchase price for each device: $49.99
    d. Estimated profit per year: $1,499,000 per 100,000 units sold
    e. Estimated cost for user to operate device per unit time: TBD when specific parts are selected. Customer will significantly reduce power consumption so money will be saved.
5. Environmental
    a. Describe any environmental impact associated with manufacturing or use.

        i. The environmental impact of the Enterprise Smart Outlet will have significant environmental impact. It will dramatically decrease energy consumption which will save the users money. It will additionally decrease the demand for energy from commercial businesses which will decrease the manufacturing of energy which will decrease pollution.

6. Manufacturability
    a. Describe any issues or challenges associated with manufacturing.
        i. The challenges associated with this project include keeping the product within the dimensions of a single gang outlet, minimizing power consumption, and providing both 120V 60Hz AC, 5V DC, and wifi-outputs while keeping the price range within the range of its rivals in the competitive market.
7. Sustainability
    a. Describe any issues or challenges associated with maintaining the completed device, or system.
        i. Maintaining the completed device may have issues with regards to specific components that must constantly be running and their limitations. Components that need to be constantly running include wifi modules and microcontroller as well as the AC to DC voltage converter and voltage regulator to keep both of the previously stated units powered.

b. Describe how the project impacts the sustainable use of resources.
    i. This product significantly impacts the use of nonrenewable resources in the environment by limiting the the amount of power consumed by each electrical outlet. This in this will limit the amount of power that needs to be produced.This impact will be significantly increased with increase in product sales.
c. Describe any upgrades that would improve with the design of the project.
    i. Upgrades that will improve the design of the project include an android application for communication with the the wifi module of the outlet portion of the product.
d. Describe any issues or challenges associated with upgrading the design.
    i. The main issue associated with the implementation of an android communication is the time commitment required to design and develop an android application.

8. Ethical
    a. Describe any health and safety concerns associated with design, manufacture or use.
        i. Design: Safety concerns associated with design of the product include having separate printed circuit boards for high voltage and low voltage applications, and also having surge protection protect to ensure circuitry is not damaged in the event of a surge.

ii. Manufacture: Safety concerns associated with manufacturing of the product include ensuring connections are properly soldered and insulated to ensure proper device functionality as well as prevent undesired short and open circuits.

iii. Use: Safety Concerns for the use of this product include standard safety issues associated with outlets. These include risk of shock or electrocution resulting in serious injury or death and/or damage of equipment or circuit breakers.

iv. User Reliability: The user will be able to control their electrical outlets, but the outlets will be resistant to unauthorized users gaining control of the outlets. This will require Wi-Fi protocol security measures.

9. Social and Political

   a. Describe any social and political concerns associated with design, manufacture, or use.

      i. This project can have a direct impact politically; especially in California where Title 24 will be passed requiring new or refurbished buildings to meet new set of electrical standards where outlets must turn off at times where not in use. The Enterprise Smart Outlet can also have a social impact with regards to the green movement. People will be able to use this product to reduce energy consumption which in turn reduces the need for the volume

of energy production, which will ultimately and hopefully result in less pollution from power plants, and also lower the amount of non-renewable resources expended during the creation of electrical power at such plants.

10. Development

   a. Describe any new tools or techniques used for either development or analysis that you learned independently during the course of your project.

      i. Tools: New tools learned for the development of this project include PCB123 for the PCB board design and development. Additionally LTSpice was used to simulate circuits to ensure theoretical design accuracy.

      ii. Equipment: For analysis various equipment was used, including Oscilloscopes, a Curve Trace, waveform generators and other common lab equipment.

Program Listing

1. Microsoft Office
2. LTspice
3. Cadence OrCAD and Layout
4. Apple Xcode

References

What is the Reference:

The Pew Research Center conducted a study on the increasing ownership of smartphones in the general public and the trends indicate that smartphone ownership will only continue to grow.

Smith, Aaron. *Smartphone Ownership – 2013* (n.d.): n. pag. Pew Research Center, 5 June 2013. Web.

http://boletines.prisadigital.com/PIP_Smartphone_adoption_2013.pdf

What is the Reference:

This page offers listings of projects in California for renovation and construction and provided some information on Title 24.

"ENR California." *McGraw-Hill Construction*. McGraw Hill Financial, n.d. Web. 26 Oct. 2014.

http://california.construction.com/

What is the Reference:

This is the actual report for Title 24 in California. This is where the information states the requirement for controlled electrical outlets in renovated or newly constructed buildings.

"Table of Contents." *Polymer Contents* 27.8 (2010): 480-523. *Building Energy Efficiency Program*. California Energy Commision, 2013. Web.

http://www.energy.ca.gov/2013publications/CEC-400-2013-002/chapters/08_electrical_power_distribution.pdf

What is the Reference:

This is a listing from Post Scapes, a company that tracks current Internet of Things products. This site was a great help in our market research.

"Smart Outlets- Postscapes." *Postscapes*. N.p., 2013. Web. 27 Oct. 2014.

http://postscapes.com/smart-outlets

What is the Reference:

This is one PCB manufacturing company. We used this as a reference for how much it would cost to manufacture a PCB. The prices will change depending on our actual needs and final design.

"Sunstone Printed Circuit Boards." *PCB Prototype & PCB Fabrication*. Sunstone Circuits, n.d. Web. 26 Oct. 2014.

http://www.sunstone.com/

What is the Reference:

This is an example report posted by Dr. Derrickson. We used this report to help the formatting of our own report as well as decide what details we needed to add to our report.

Keegan, Kevin, Austin Fox, Cameron Kiddoo, and Luke Rafla-Yuan. "Exhale Breathalyzer." (2013): n. pag. *Polylearn.calpoly.edu*. California Polytechnic State University, San Luis Obsipo. Web.

https://polylearn.calpoly.edu/AY_2014-2015/pluginfile.php/304079/mod_resource/content/1/Example%20Report%20number%201.pdf

What is the Reference:

This was the datasheet used from Texas Instruments website that included all the technical data used to program and connect the CC3200 Launchpad to the rest of the design.

Texas Instruments, "CC3200 SimpleLink™ Wi-Fi® and Internet-of-Things Solution, a Single-Chip Wireless MCU," SWAS032F datasheet, July 2013.

http://www.ti.com/lit/ds/symlink/cc3200.pdf

What is the Reference:

This datasheet used from RECOM that included the technical data for the AC to DC converter.

RECOM, "Powerline AC/DC Converter, RAC04". January 2015.

http://www.recom-international.com/pdf/Powerline-AC-DC/RAC04-S_DC_277.pdf