Remote Controlled Smart Socket

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Abstract

We build a remote-controlled socket which can turn on or off the plug-in device remotely through the user's computer and also it can shut down the device automatically if the device is broken. Our product can measure the voltage, current and power of that device and send those data to main system and the user's computer. Moreover, the user can set a safety range for the power supply and if our program detects that the voltage or current value is out of the safety range, the socket will automatically turn off the device.

Contents

1. Introduction

1.1 Objective

Nowadays, with the development of science and technology, electricity becomes such an essential part that we cannot live without it and thus there are many accompanied problems being induced. For example, many people get annoyed at work when they realize they forget to turn off the household appliances. It is not only money-consuming and wasting energy but also dangerous if the appliance is overheated by long time power-on. Only from January 2017 to September 2017, there are 32 civilian home fire fatalities reported by U.S. news media, which are caused by electrical malfunction or appliances [1]. Moreover, in many laboratories or hospitals electric security is a really important part. Many equipment is precision and has very strict requirements for the power supply system. Uncautious using electricity may cause a lot of problems such as damage of equipment, fire and hurt people. On January 22, 2017, an electrical worker died in Lubbock Hospital when he tested the new equipment because of the overflow current [2]. If we can monitor the power supply of the socket and alert the user in advance, we can avoid these accidents.

Our goal is to build a smart socket, which can protect the equipment by checking the power supply automatically or remote controlling by people. It can be analyzed by the core microcontroller in power and other parameters and send these data to the computer. Depending on the value of the parameters, the computer would send the signal back if something goes wrong and shut down the power to protect the socket and devices. In addition, user can manually send back the signal by computer if they want to turn off an appliance when they are absence.

1.2 Background

Internet of Things develops based on the computer and Internet, which utilize sensor, RFID and other technologies to realize the communication between physical objects. Nowadays, people's lives are already around by electronic devices and with more focus on the daily life's quality and detail, Internet of Things gets more and more attention. Based on this technology, we put almost everything in our pocket and construct a smart world [3]. Among it, smart home is a very important field and there are already series of products which can control the power supply system. But most of those products' functionality is simplex and does not fit industrial demands. Also, the smart socket will become more popular and necessary in the future. "Coming era of smart grids has implications for domestic DC distribution concepts with smarts sockets" [4].

Our goal is to fit for both household and industry use. Therefore, our socket must overcome the problems and implement multiple functions including control system, monitoring system and protection system. Also, taking account of universal practicability, the socket needs to be portable and not too expensive.

1.3 Block Diagram

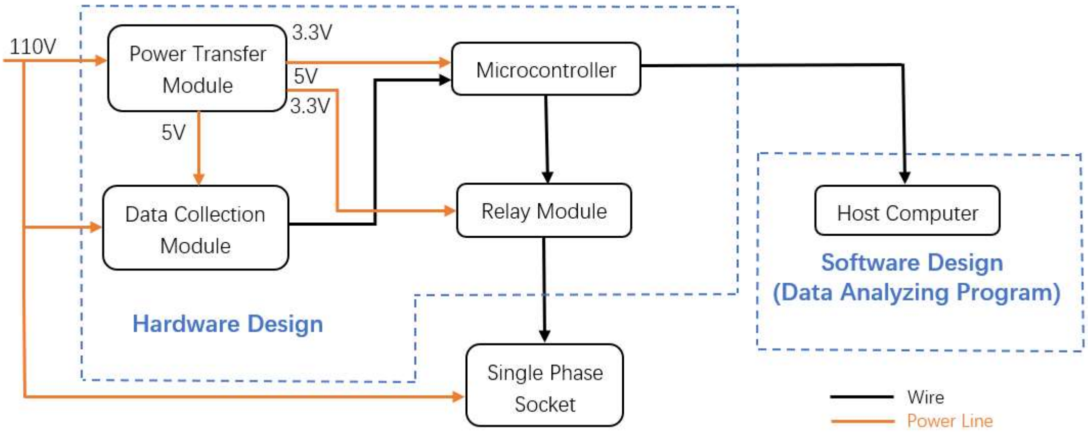

Figure 1 Block Diagram

From the block diagram above, we have five modules in our project. The first is power transfer module which transfers the wall power to two stable DC power to support other modules. The second one is data collection module which reads and writes the voltage, current and power values of the device plug in and sends them to the microcontroller. The control module can receive the data from the data collection module and transmit them to the computer; it is also used to control the relay. The fourth one is relay module which connects to the single-phase socket where the device plug in. If the circuit works normally, the relay switches off and the device keeps working but if the voltage or current looks abnormal, the relay will shut down the device on the single-phase socket. The last one is our software design module. It makes sure all the hardware design work in the right status.

2. Design

2.1 Power Transfer

Our power transfer module is used to provide stable DC voltages to other modules. For microcontroller and data collection module, the power is 5V; for the relay module, the voltage should be 3.3V. In order to realize this functionality, first, we used a potential transformer to transfer 110V AC to 15V AC which is small enough for the resistor circuit to filter the AC signal. Moreover, we used LM7805 as our first voltage regulator. LM78xx family can produce a stable DC voltage according to the last two numbers. For example, LM7815 will produce 15V DC and LM7820 will produce 20V DC. This family is one of the most commonly used regulators in many TTL. For this project, we only need LM7805 which can generate a 5V output for the microcontroller and the data collection module.

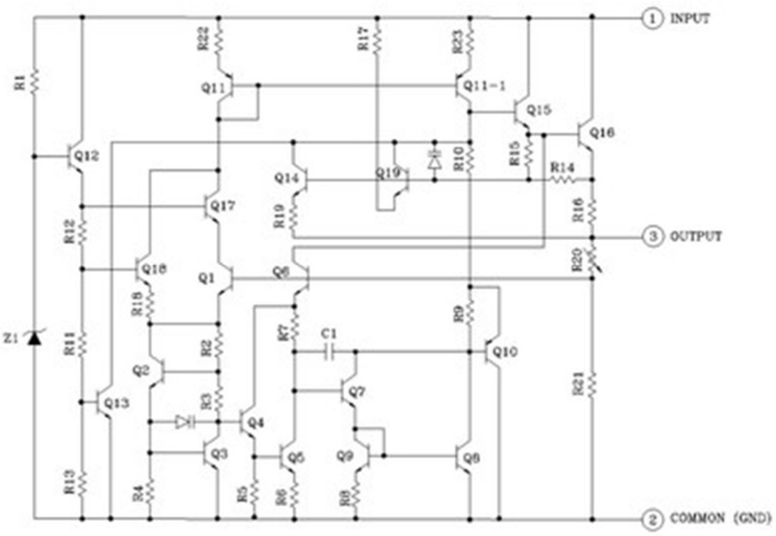

Figure 2 LM7805 Schematic

In order to get a 5V DC, first we add a bridge rectifier to rectificate the current and make the resistor to deliver a DC voltage, second, we will add a large value capacitor to wave filter the current and third we will add this voltage to the input of LM7805 pin and the output will be a stable 5V DC.

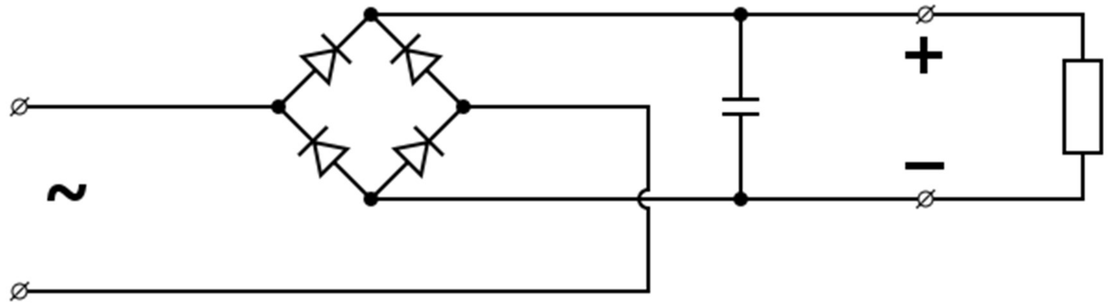

Figure 3 Bridge Rectifier Schematic

Figure 3 is the schematic for bridge rectifier. The four diodes on the left with specific directions can filter the AC signal and then produce a relatively stable DC voltage on the end of the resistor on the right. The capacitor we choose is 0.33uF which is large enough to filter the wave provided from the datasheet and the resistor we choose is 1kOhm which is also a large value to lower the current. The voltage is close to 9.55 V as shown below.

$$V_{dc} = 2 * V_{max}/\pi = 0.9 V_{rms} \tag{1}$$

$$V_{rms} = V_p/2 = 15V/1.414 = 10.6V\ DC \tag{2}$$

$$V_{dc} = 0.9 * 10.6 = 9.55V\ DC \tag{3}$$

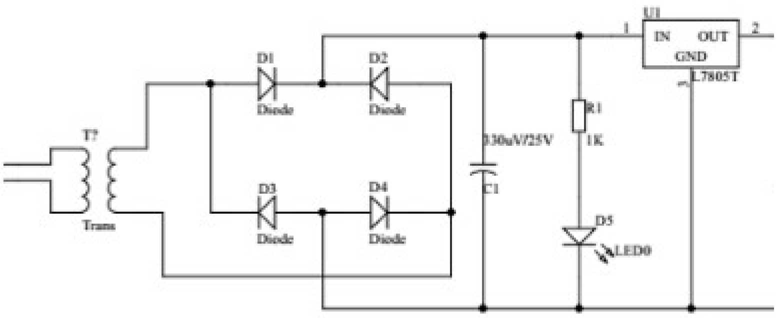

Figure 4 Power Transfer Basic Schematic

Therefore, the input voltage on pin1 is 9.55V which is good for LM7805 to generate a DC output voltage close to 5V at pin2.

Moreover, we need another chip called AMS1117-3.3 to get a 3.3V DC from the 5V. AMS1117 is a common family for DC-DC transformation. We use AMS1117-3.3 to get a stable 3.3V DC to power up relay and WIFI module.

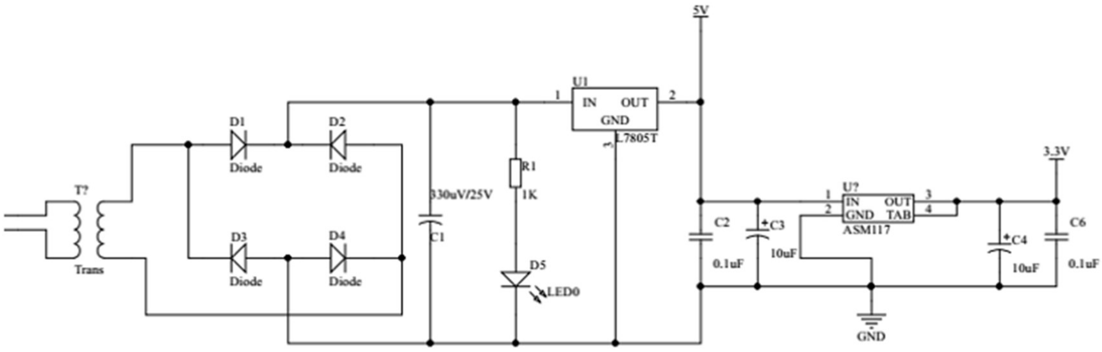

Figure 5 Power Transfer Module Schematic

This is the final schematic for the power module. The 5V DC comes out from the first voltage regulator LM7805 and goes into the second regulator AMS1117-3.3.

2.2 Data Collection

Data collection module is to measure and calculate the circuit parameters and send the data to microcontroller to analyze. In order to realize it, we will use the CS5463 power metering chip. This chip can measure small DC voltage and current accurately enough for this project. This sensor can collect the data from the current connected device. Combined with voltage divider and current divider, CS5463 can sample voltage and current and calculate the power. We will weld this chip on the PCB. Moreover, the data collected by the sensor will be sent to the microcontroller. The safety voltage for this sensor is 5V DC. Besides, CS5463 has an internal temperature sensor so it can also measure the temperature for future use.

By CS5463 datasheet [5], we know that due to the input voltage limitation, the chip cannot connect to 110V circuit directly, so we need sample circuit first.

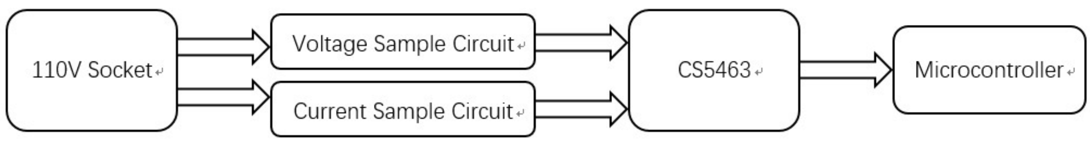

Figure 6 Data Collection Block Diagram

There are two common sampling methods. One is direct sampling and the other is mutual inductance sampling. Direct sampling utilizes voltage divider and shunt resistor to sample voltage and current respectively. Mutual inductance sampling utilizes voltage transformer and current transformer. But compare to direct sampling, it has large error, large size and poor linearity so we will use direct sampling.

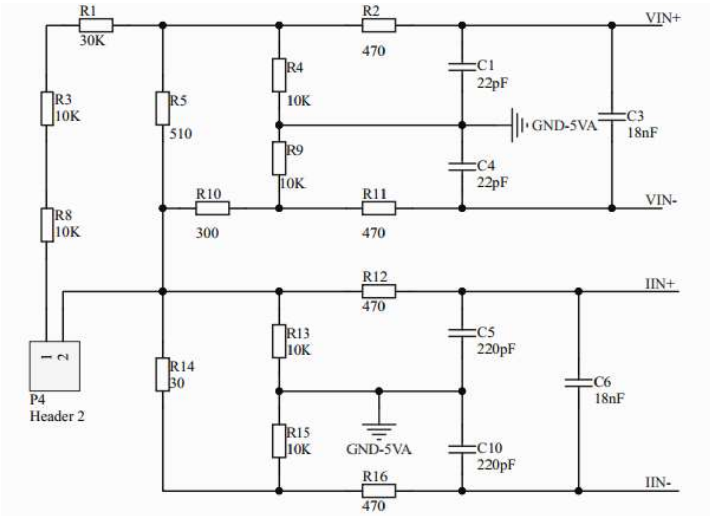

Figure 7 Sample Circuit Schematic

Voltage sample circuit is the top part of the schematic. R1, R3, R5 and R8 build the voltage divider circuit. R5 is the sampling resistor. R10 is to limit current. R4 and R9 are to control the differential voltage signal. R2, C1, R11 and C4 build a simple low pass filter. Then C3 filters the differential voltage signal again. The full-scale differential input voltage for the voltage channel is $\pm$250mV [5], so the maximum RMS voltage is $250mv \div \sqrt{2} = 176.78mv$. In our circuit, the output voltage after voltage divider is

$$\frac{1k\Omega}{(330*2+220)k\Omega+1k\Omega} * 110V = 125mV \quad (4)$$

So it is not beyond the voltage range. But we have a gain factor K_v. Let voltage before sampling to be V and voltage after sampling to be V', then V'= K_v *V, where gain factor

$$K_v = \frac{1k\Omega}{(330*2+220)k\Omega*3+1k\Omega} = \frac{1}{881} \quad (5)$$

The bottom part of the schematic is current sampling circuit, which is similar to voltage part. We use a shunt resistor to get the sampling voltage and calculate the current. And let the current before sampling to be I, voltage after sampling to be V and resistor parameter to be R, then V=I*R, where R=30Ω is the shunt resistor.

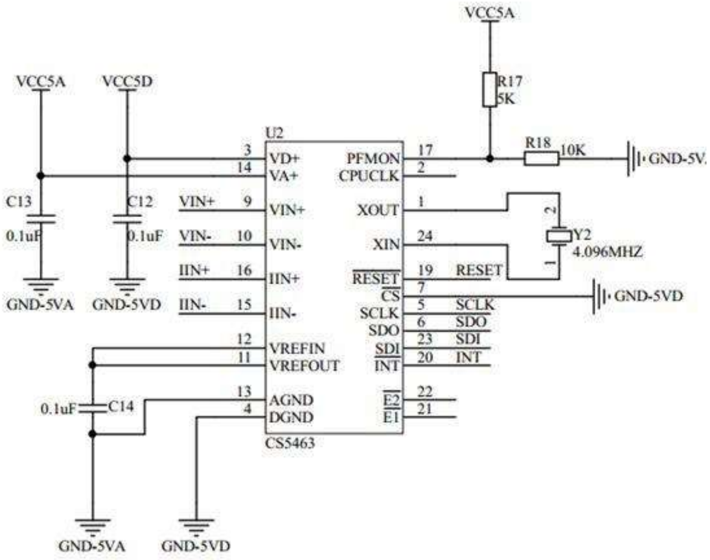

Figure 8 CS5463 Connection Diagram

VIN+/VIN- and IIN+/IIN- are connected to the output of the sampling circuit respectively. RESET, SCLK, SDI, SDO and INT are used to communicate with microcontroller.

CS5463's input signal is operated on the 110V voltage and this will result in that the common-mode level of the CS5463 is referenced to the line side of the power line [5]. It may lead to severe common mode interference, even destroy the devices. Thus, in order to ensure efficient communication between microcontroller and power metering IC, we are thinking about add an isolation circuit. We choose HCPL2631 to build the isolation circuit. It is LSTTL/TTL compatible and has very superior common-mode rejection so it can provide maximum ac and dc circuit isolation [6].

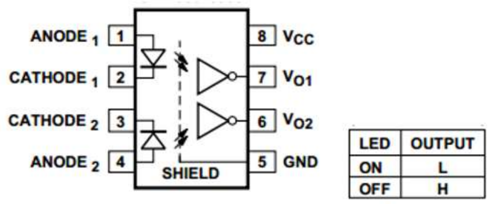

Figure 9 HCPL2631 Functional Diagram and Truth Table

HCPL2631's operating voltage Vcc is 5V and the forward input current IF range is 3mA to 10mA. We assume that the built-in potential of diode is 0.7V, so we can get the current-limiting resistor $R = \frac{VCC - VDD}{IF} \in [430,1433]\Omega$ and we choose 1KΩ. The pull-up resistor range is 330Ω to 4KΩ and we choose 350Ω. Besides, the Vcc supply to each optoisolator must be bypassed by a 0.1uF capacitor or larger [6].

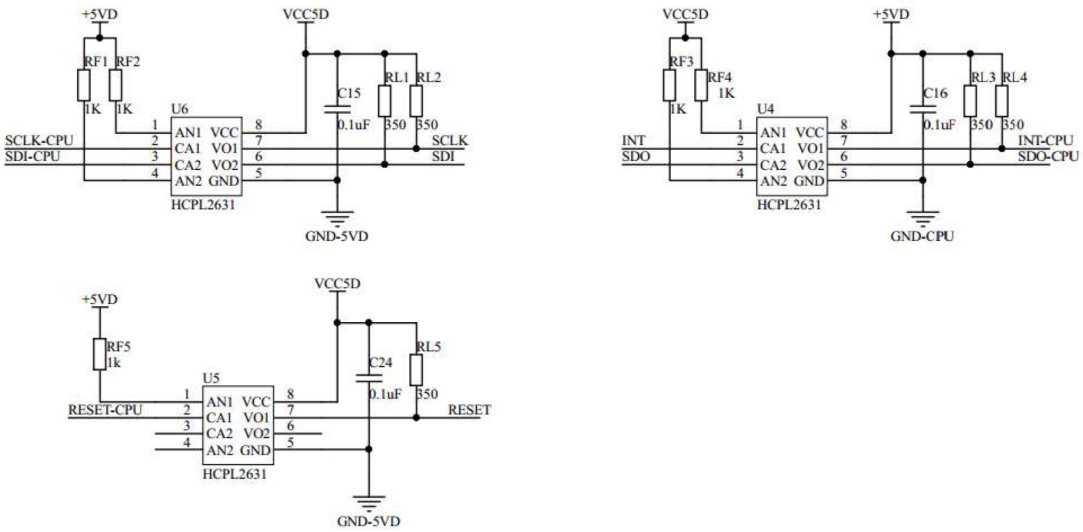

Figure 10 Isolation Circuit Schematic

2.3 Microcontroller

We use ATmega328P as our microcontroller because of four considerations. The first is that ATmega328P is a low power solution chip which can save energies. The second one is that its physical size is small enough to fit our project. The third one is that it is fast enough for our project computation and the fourth is that it can be programed on Arduino which saves a lot of time and easier for us to debug, redesign and add new functionalities on the whole program. Below is the schematic of our microcontroller (figure 11). The left side circuit design is used to stabilize the microcontroller. The top ports on the right are used to connect with the data collection module. MISO and MOSI can read and write the values from the data collection module and the CLK pin is used to synchronize the two modules. The middle ports are used to control the relay module: pin PC5 can generate a current to the relay; the bottom ports are reserved for WIFI connection in the future development; RX receives the information and TX can transmit the information.

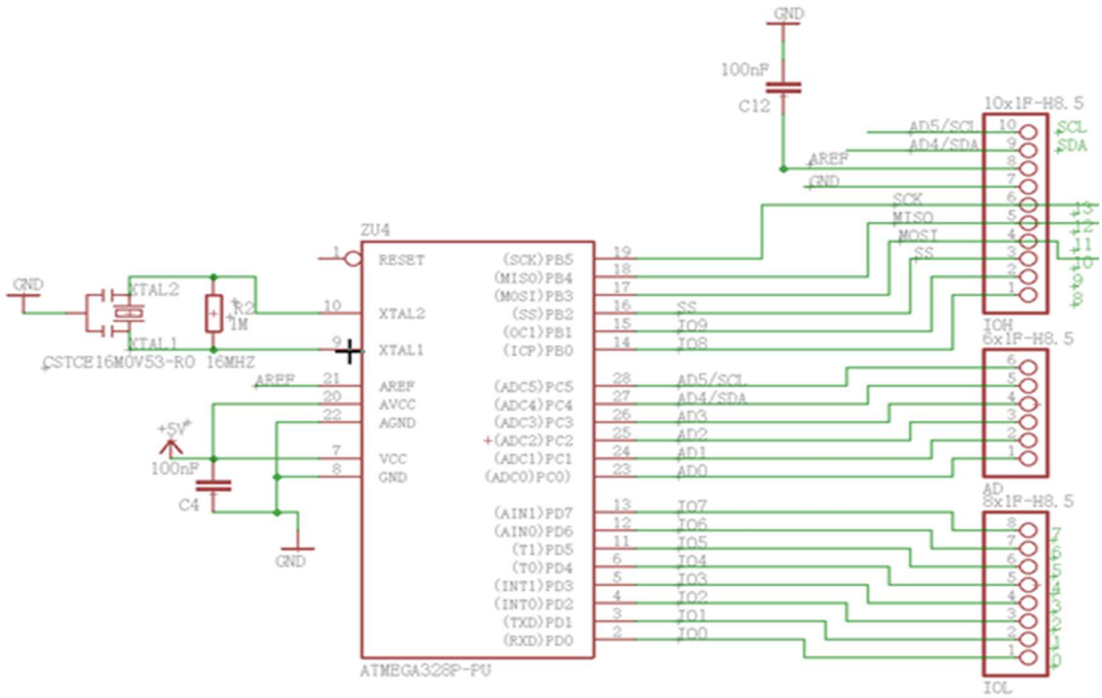

Figure 11 Microcontroller Schematic

2.4 Relay Module

The relay we use is model ODC5, which is a common used four pin relay. Figure 12 is its schematic. The upper two pins connect with our test LED and the lower two pins connect with the microcontroller. Relay module is the terminal to control the socket power supply. Everything we build above has only one purpose that is to use the microcontroller to generate a current to control the relay. On the right bottom part, there is an electrical magnetic iron. If there is a current enters into the bottom two pins, the magnetic iron will be triggered and attract the switch so that the upper circuit will be opened and stops working and if there is no current enters the bottom pins, the magnetic iron will not be triggered and thus the upper circuit is closed and keeps working.

In our project, the relay is controlled by the microcontroller. When the input voltage or current is within the safety range, the microcontroller will not send a current to the relay and the device plug in keeps working, but if the data we collected is abnormal, the microcontroller will generate a current and thus turns on the relay and the device also stops working. Because the output current from the microcontroller is too small to open and close the relay, we need to add a bipolar junction transistor to enlarge the output current.

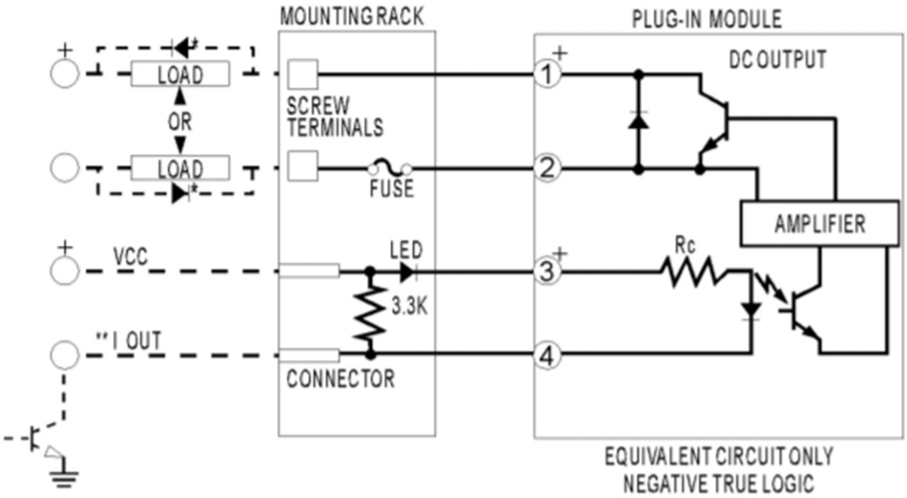

Figure 12 Relay Module ODC5 Schematic

2.5 Software

The software is to mainly deal with the wireless communication task. When the program start, the computer can monitor the socket and if it detects there is client coming, it will open the connection thread and begin to receive data. When it is done, the program will start a new monitor cycle.

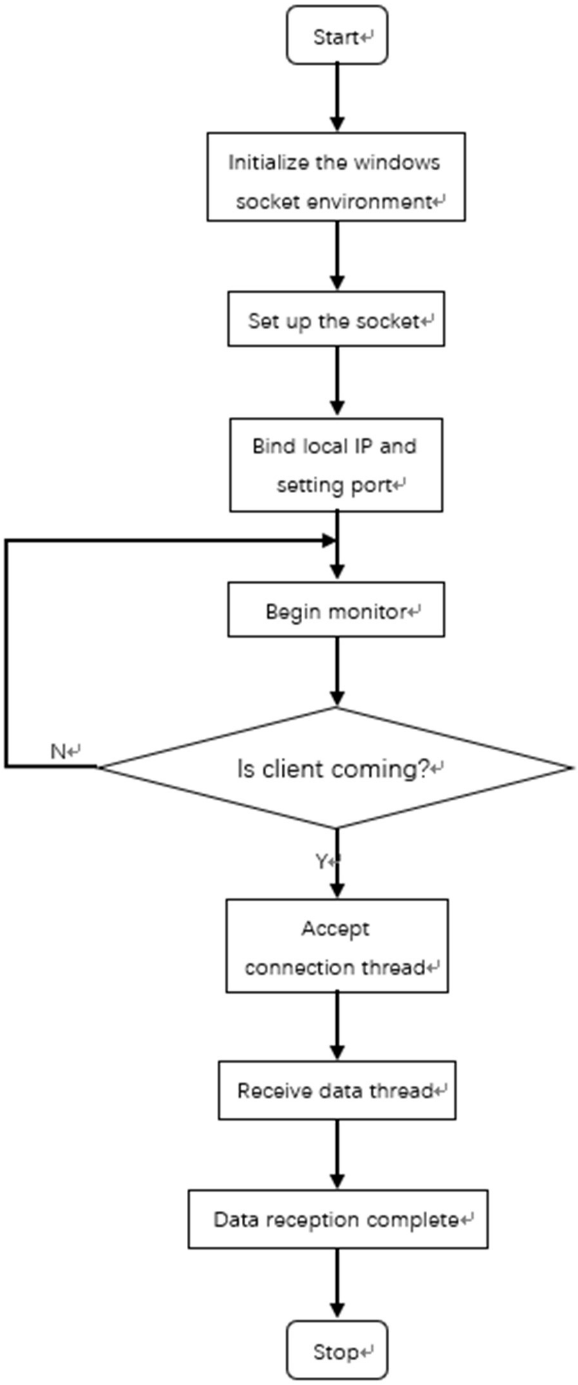

Figure 13 Communication and Data Transmission Flow Chart

3. Design Verification

3.1 Power Transfer

The power transfer module was tested under two conditions. The first one is under the open circuit condition and we used the multimeter to test the output of LM7805 and AMS1117. The voltage of LM7805 was 4.97V and the voltage of AMS1117 was 3.33V, which both were within the reasonable range. And next we connected it to other modules and tested these outputs again while system running. This time we got 4.89V for LM7805 and 3.33V for AMS1117, which were also within the reasonable range. The reason why the voltage dropped a little is that the power transfer module has internal resistance so load circuit divides part of the voltage.

3.2 Data Collection

When testing this module, we used the 15V AC signal to be the power supply for the measuring circuit. Then we connected it with the microcontroller in order to see the data directly on the computer. On the serial monitor, we found the voltage was 14.99V, current was 0.17mA and power was 2.54mW. The resistor we use in the measuring circuit is 88KΩ so the ideal current should be 15V/88 KΩ≈0.17mA and ideal power should be $(15V)^2$/88 KΩ≈2.55mV. Thus all the data met the requirement.

3.3 Microcontroller

To test the microcontroller, first, we connected all the modules together and then we used a 15V AC signal as the power supply for our measuring circuit (figure 7). Then we set the voltage safety range as Vin < 10V in the main program; finally we used the multimeter to measure the signal pin (PC5) on the microcontroller which is used to control the relay module. The result we get from the multimeter is 5.01V, which was large enough to turn on the relay. Then we changed the safety range to Vin < 16V which is larger than the input voltage 15V and the voltage of the signal pin became to 0V, which means the relay was turned off. To test the remote control system, we typed "Y" on the serial monitor to control the relay when the program asking whether to close the socket and the voltage of the signal pin became 5.00V. Finally we typed "Y" again when the program asking whether to open the socket and the voltage of the signal pin became 0.

3.4 Relay

After making sure the microcontroller met the requirements, we connected it with relay module. For testing purposes, we used function generator as the power supply instead of wall power for the measuring circuit shown on figure 7 because this way allows us to change the input voltage and current with different values. We set the safety range as Vin < 6V DC and adjusted the function generator at 5V; the LED of the relay circuit lights on. Next, we change output voltage value on the function generator to 7V and the LED turned down as expected. Below are the photos for our verification.

When voltage was in the safety range:

Figure 14 Testing Voltage 1

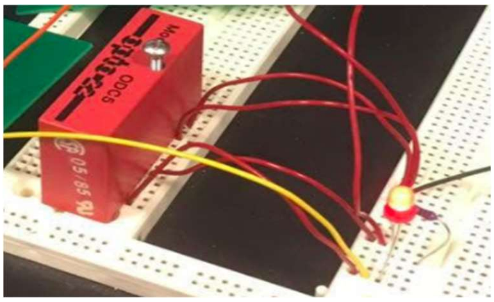

Figure 15 Relay Status 1

When voltage was out of the safety range:

Figure 16 Testing Voltage 2

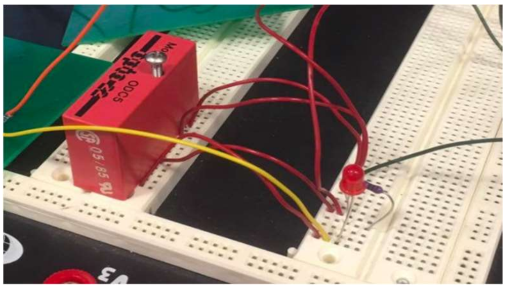

Figure 17 Relay Status 2

3.5 Software

For software part, we need to ensure that the program runs continuously. So we opened the serial monitor when the whole system was working and used the timer to measure the number of data collected in 1 minutes. Then we found in 1 minutes, there were 15 data coming in, which met our high-level requirement.

4. Costs

4.1 Parts

Table 1 Parts Costs

Part	Unit Cost ($)	Quantity	Total ($)
Atmega328p PU	26.36	1	26.36
CS5463	4.95	10	49.56
HCPL2631	2.27	5	11.37
LM7805	0.40	8	3.20
AMS1117	0.19	50	9.95
Relay ODC5	2.77	1	2.77
ESP8266	1.75	1	1.75
RCL	0.40	25	10.00
PCB	5.40	5	27.00
15V Converter	20.99	1	20.99
Total			162.95

4.2 Labor

Our fixed development costs are estimated to be $40/hour,10 hours/week for two people. The project will take approximately 16 weeks, so the total labor cost is 2*40*10*12*2.5=$24000.

5. Conclusion

5.1 Accomplishment

Our team successfully constructed a reliable remote-control socket which can automatically shut down the device if the voltage or current values are out of the safety range. Moreover, the users can use their computers to turn on or off the device remotely through the internet. We implemented all the requirements including generating stable DC voltages, controlling the relay properly and measuring the data correctly.

With the functionalities we realized, we can protect the devices, avoid electrical accidents, reduce human injuries and save the losses.

5.2 Uncertainties

The main uncertainty in our project is that our measuring circuit (figure 7) did not connect to the wall power because of the testing purposes but we are pretty sure that the capacitors and resistors are large enough to lower the input current and voltage to small enough values when they enter into the measurement chip CS5463 and this chip is capable to measure the unstable power supply.

5.3 Ethical Considerations

Our socket is a remoted controlled electric device which connects the WIFI in the room and has other control utilities. Violation usage includes stealing data, hack the devices, shut down the devices with illegal purposes and break the whole electrical circuit. Unfortunately, these possible actions are against #7 and #9 of the IEEE Code of Ethics [8]. So we want to reiterate our principle in a note while packaging, which is people are not allowed to use our product to undermine the privacy of others or use them for malignant business competition or other criminal act. We are responsible for making human's lives more safety and convenient. The main function of our socket is to control the power supply and protect both appliance and people from potential electrical fault. It stresses the importance of electronic security so it is an implementation of the IEEE Code of Ethics, #1:" to accept responsibility in making decisions consistent with the safety, health, and welfare of the public and to disclose promptly factors that might endanger the public or the environment" [8]. We want to build a safe electric environment.

5.4 Future Work

In the future development, we want to improve some points in both hardware design and software design. In hardware design, considering some countries use 220V wall power and three-phase sockets whose voltage is over 300V, we need to improve the power transformer and the relay module to make sure they can work under larger voltages. In addition, we will add a temperature sensor close to the connector on the socket. At present, we only collect the electrical data but sometimes the fire accidents are caused by overheated circuits: long time powered on devices could be burned; which under this circumstance, the voltage and current are within the safety range. Besides we want to design a WIFI connection module to make the socket be able to communicate with cell phones, which will be more convenient for users.

For software part, first we want to improve the user interface to give a better user experience. Consider the #7 and #9 of the IEEE code of Ethics [8], to avoid violation use such as turning down the device for illegal purpose we are considering adding permission code and warning system when the socket status has been changed. Furthermore, for deep use of the data, we will relate it to the energy field to do analysis on the energy consumption, such as making energy reduction plan.

References

[1] U.S. Fire Administration,"Home fire fatalities in the news", 2017. [Online] Available: https://apps.usfa.fema.gov/civilian-fatalities/incident/reportList. [Accessed: 20-Sep-2017].

[2] Amarillo Globe-News, "Electrical worker dies at Lubbock hospital after incident at construction site of Amarillo's new Xcel building", 2017. [Online]. Available: http://amarillo.com/news/2017-01-22/electrical-worker-dies-lubbock-hospital-after-incident-construction-site-amarillo-s. [Accessed: 21-Sep-2012].

[3] intel," Smart Homes with Intel® Internet of Things (IoT) Technologies", 2017. [Online]. Available: https://www.intel.com/content/www/us/en/internet-of-things/smart-home.html. [Accessed: 20-Sep-2017].

[4] Research Gate," A smart building power management concept: Smart socket applications with DC distribution", 2015. [Online]. Available: https://www.researchgate.net/publication/264977487_A_smart_building_power_management_concept_Smart_socket_applications_with_DC_distribution. [Accessed: 21-Sep-2017].

[5] Circuit Logic," CS5463 Datasheet", 2011. [Online]. Available: https://d3uzseaevmutz1.cloudfront.net/pubs/proDatasheet/CS5463_F3.pdf. [Accessed: 01-Oct-2017].

[6] Avago Technologies," HCPL2631 Datasheet", 2007. [Online]. Available: http://datasheet.octopart.com/HCPL-2630-Avago-datasheet-17702952.pdf. [Accessed: 01-Oct-2017].

[7] STC MTU Limited," STC12C5A60S2 series MCU Data Sheet", 2011. [Online]. Available: http://www.stcmcu.com/datasheet/stc/stc-ad-pdf/stc12c5a60s2-english.pdf. [Accessed: 04-Oct-2017].

[8] Ieee.org, "IEEE IEEE Code of Ethics", 2016. [Online]. Available: http://www.ieee.org/about/corporate/governance/p7-8.html. [Accessed: 20-Sep-2017].

Appendix A Requirement and Verification Table

Table 2 System Requirements and Verifications

Requirement	Verification	Verification Status (Y/N)
Power Transfer (10 points)		
1. The output of the first regulator is ranged from 4.7V to 5.3V.	1. Use multimeter to test the 5V output to see the value. (4 points)	Y
2. The output of the second regulator is ranged from 3.1V to 3.5V.	2. Use multimeter to test the 3.3V output to see the value. (4 points)	Y
3. The LED is on when the power PCB is working.	3. When the PCB is connected to the wall power, the LED is light on. (2 points)	Y
Data Collection (10 points)		
1. Able to measure the voltage from the testing power supply (the function generator).	1. Use the screen of function generator to see whether the voltage value is the same as the value on the serial monitor. The error should be +-0.1V. (3 points)	Y
2. Able to measure the current from the testing power supply (the function generator).	2. The resistor is 88K ohms. Use the voltage from the function generator divided by 88 to get the input current value and see if this current value is matched with the one on the serial monitor. The error should be +-0.005mA. (3 points)	Y
3. Able to measure the total power of the testing circuit.	3. Use the voltage value generated by the function generator times the theoretical current value to get the theoretical power (V * (V /88)) to see if the value matched with the one on the serial monitor. The error should be +- 0.01 mW. (4 points)	Y
Microcontroller (15 points)		
1. Automatically generate a current strong enough to turn on the relay when the circuit works out the safety range set by the user.	1. When the function generator turns on and the output voltage is adjusted over the safety range set by the users, use multimeter to measure the signal pin (pin 8) on the Arduino and the voltage is close to 5+-0.5V. (4 points)	Y
2. Automatically stop generating the current to the relay when the	2. When the function generator turns on and the output voltage is within the safety range set by the user in the program, use multimeter to measure the	Y

circuit works in the safety range set by the user. 3. Able to stop generating the current if the user enters "Yes" in the command line on PC when it asks whether to turn on. 4. Able to continue generate the current if the user enters "Yes" in the command line on PC when it asks whether to turn off.	signal pin (pin 8) on Arduino and there is a voltage close to 0+-0.1V. (4 points) 3. After the user enters "Yes" in the command line, use multimeter to measure the signal pin (pin 8) on Arduino and there is a voltage close to 0+-0.1V. (4 points) 4. After the user enters "Yes" in the command line, use multimeter to measure the signal pin (pin 8) on the Arduino and there is a voltage close to 5+-0.5V. (3 points)	 Y Y
Relay (10 points) 1. When the control system sends the signal (a current generated from the signal pin 8), the relay switches on. 2. When the control system stops sending the signal (the current is stop generated from the signal pin 8), the relay switches off.	1. When the circuit works over the safety range (the current is generated), the LED lights down. (5 points) 2. When the circuit works within the safety range (the current stops generating). The LED lights on. (5 points)	Y Y
Software (5 points) 1. Able to control the data collection module to measure the values 15 times per minute (115200 Bd).	1. Check the collecting page of the program on PC, and use the timer to see whether the data is collected 15+-1 times per minute. (5 points)	Y

Appendix B Full Circuit Schematic

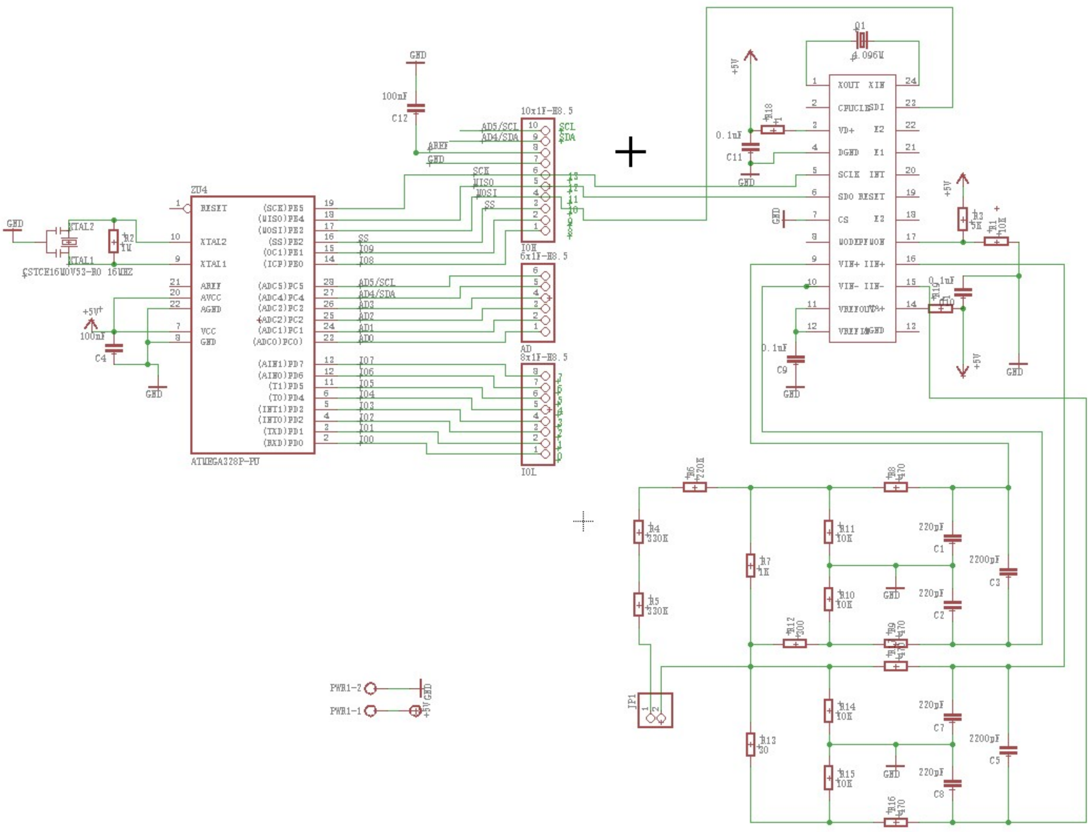

Figure 18 Schematic of microcontroller and data collection module

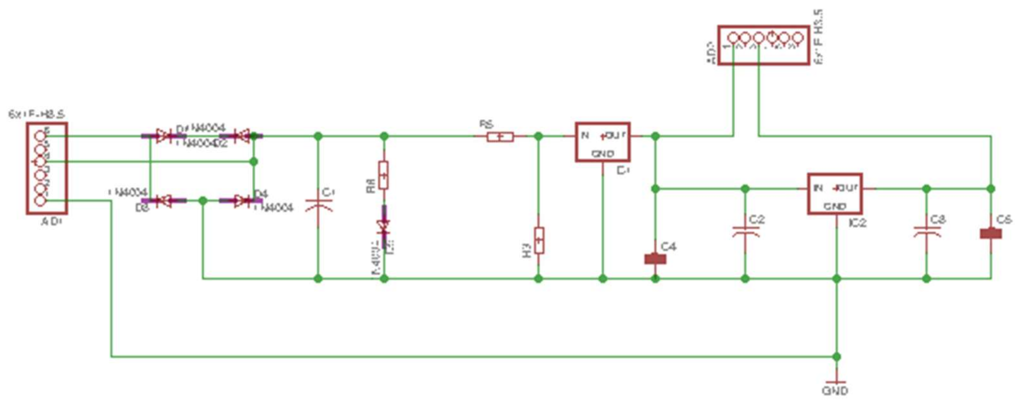

Figure 19 Schematic of power transfer module

Appendix C PCB Design Layout

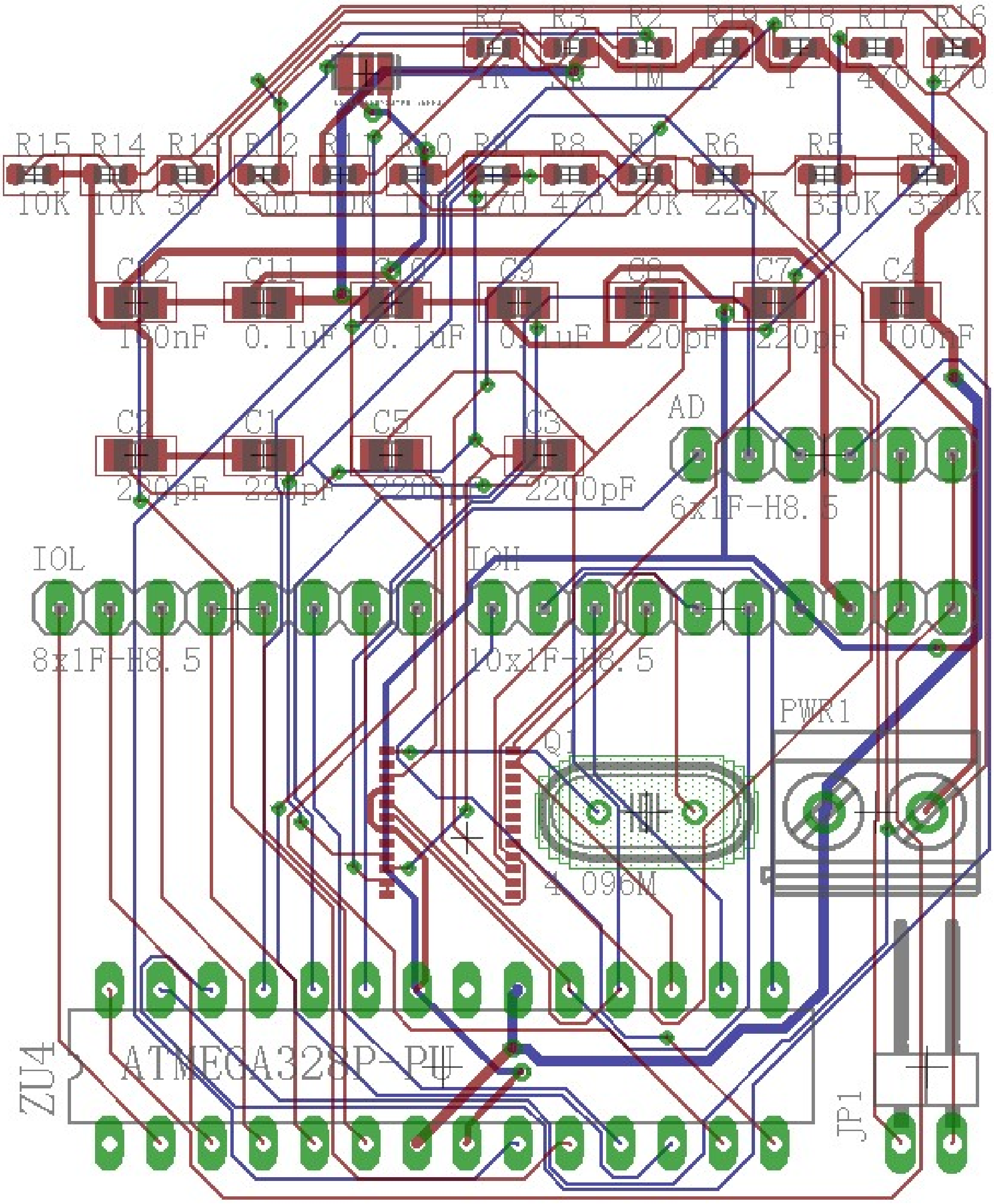

Figure 20 PCB Layout of microcontroller and data collection module

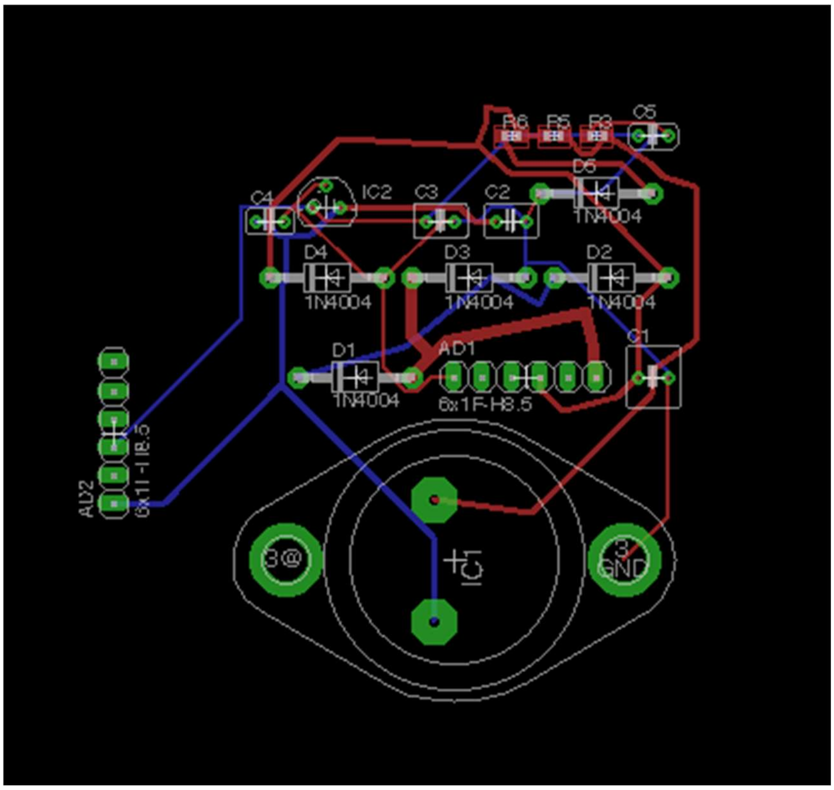

Figure 21 PCB Layout of power transfer module