Power Budget Automation System

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Abstract

The goal is to create a home power automatic system which allows homeowner monitor and manage energy usage through occupancy detection and energy limit setting. The system included a central hub unit which is a remote control and multiple sensor units which connecting to the outlet. The user is able to control the electric product connected throughout the sensor units. They can turn individual device on and off, enable passive infrared sensor automation, monitor power and energy usage, look back to energy usage history, and energy priority setting.

Contents

1. Introduction

Our project goal is to make a home power budget control system. This system will allow users to control electricity directly or remotely in particular rooms or anywhere in the entire house. The system includes one central controlled box (the brain of control system) and a sensor boxes. The project will focus on the processing control system. The controller will be able to navigate power consumption in the house based on the budget management (dynamic prioritization). The goal is to avoid going over a certain power limit. Supposed there are a few rooms having multiple outlets inside. We will assign priority to each room or each outlet. The rooms/outlets with lower priority will be restricted with a power limit. The highest priority room/outlet will have the power before anything happens. The sensor system will be implemented in those small boxes which placed in each room. The small boxes will be built with the microcontroller, IR sensors, current sensors, and bluetooth/RF transceivers. If someone is in the room, the sensor system will recognize and send the signal to the center box and bump up the priority a bit. And the setting will add into the schedule of the center boxes. After a certain amount of time, if there is no one in the particular area, the system will automatically turn off the power to that area. We will program the control box to remember these setting and generate a schedule to manage and distribute power efficiently. Building the brain - a control unit is the core of this project. To design the learning ability of the brain system, we will figure out the algorithm and the decision making to run on inexpensive pieces of hardware. Combining the features (Learning ability and priority setting) makes home budget saving more optimal and affordable.

1.1 Purpose

This project is to build a home power budget control system to save energy for the user. Energy is invisible to us, but we were using it every single day. We might be aware of the money we overspend each month. However, the energy we wasted daily might not be as obvious. This project can help the users to understand their power usage behavior and decide a power budget plan that fit for them.

1.2 Objectives

Goals

- User interface with the system through the controller
- Wireless communication between sensors unit and controller unit
- Home electricity automation
- Power budget saving
- Notification helps alerting user if user reach the power usage limit setting

Functions

- Sensor system can turn light on/off depend on room's occupancy
- IR sensor detecting room's occupancy
- Automatically turn off the power when the electric devices aren't used
- LCD display current power consumption, alert user, and allow remote control.

Benefits

- Reduce wasted energy
- Enable remote control to power outlet
- Save money by reducing power usage
- Allow user to manage home power usage

Features

- User remotely control through the controller system
- Learning ability on controlling
- User-friendly display and notification
- Easy and safe installation process

1.3 Block Diagrams

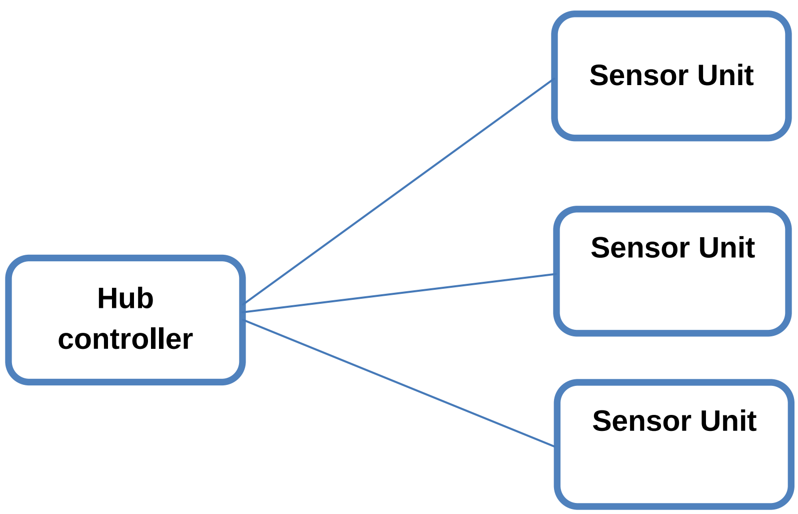


Figure 1: Top level system layout

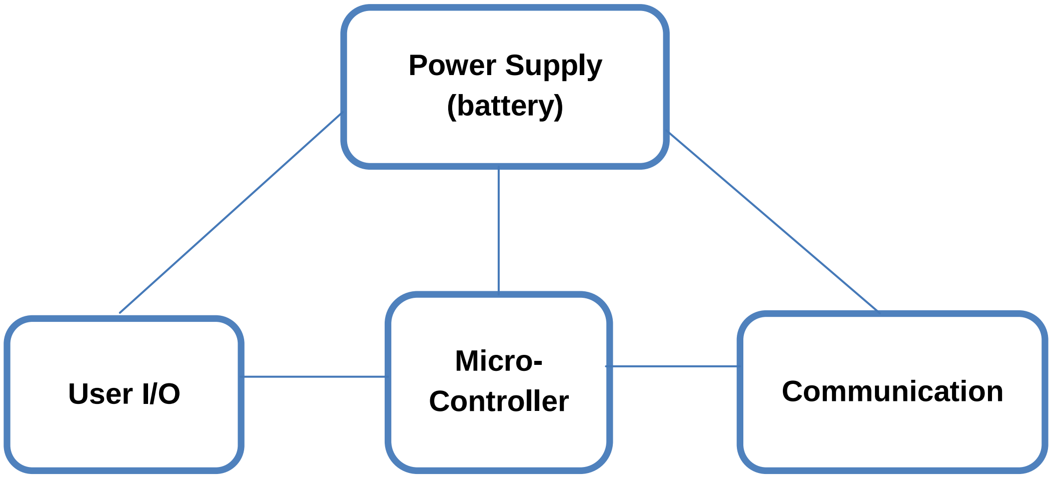


Figure 2.1: Block Diagram of Controller Unit

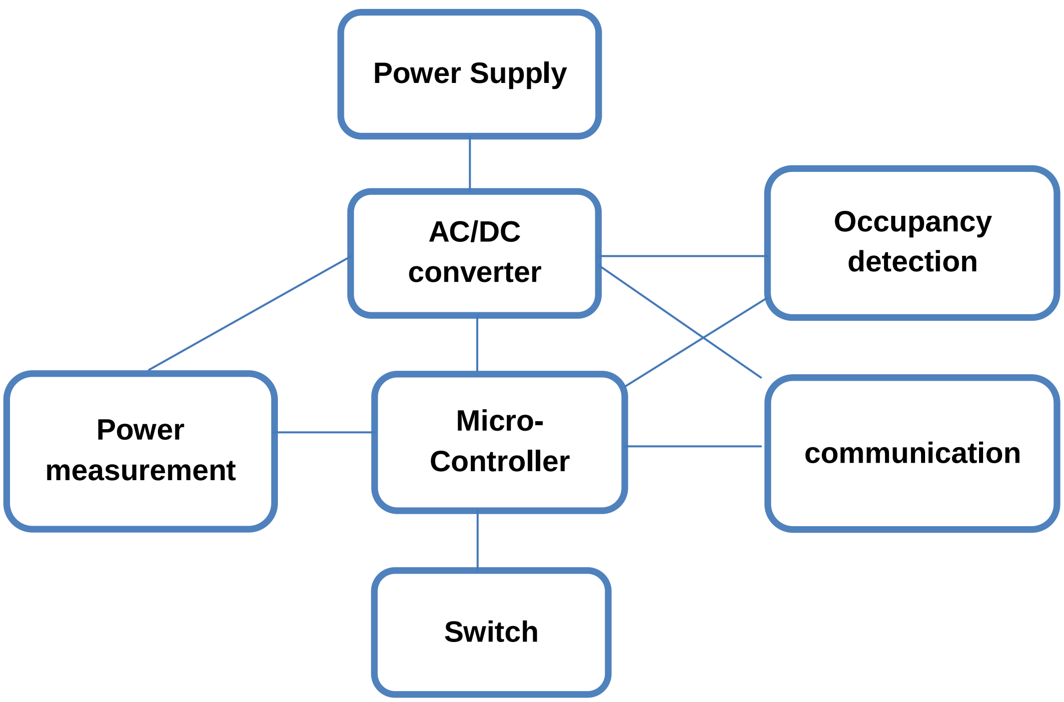


Figure 2.2: Block Diagram for Sensor Units

1.4 Block Descriptions

Controller Unit

The unit will consist of a microcontroller, RF module, power supply, and user I/O. Microcontroller in the big box will process all the data receive from small box and also commanding small box from user's input. RF module enables wireless communication between microcontroller and sensors. Power supply will be the energy source for microcontroller's operation. User I/O display information of power usage and allow user to control the power.

User I/O

A basic character LCD will be used for display and buttons for user input. Information such as power usage will be display on the LCD and user can interact with the system through the buttons. The LCD and buttons will connect with the microcontroller through a serial connection.

Microcontroller

The microcontroller receives input signal through RF transceivers and store data. When motion has been detected from the sensor system, the microcontroller will send signal to give command to start the power for particular areas. It also analyzes the users 'setting to generate a power budget management. The implemented microcontroller will be TI MSP 430. Furthermore, the MSP430 connects to the LCD through a serial connection.

Power Supply

The power supply will be a small power circuit that provides a stable constant 3V to the MSP 430, LCD display, and RF module. Small batteries will be used as the initial energy source.

Communication

The module transmits and receive radio signal for communication between controller and sensor system. These CC1101 transceiver and CC1150 transmitter modules operate in the 434 MHz which is comply with a TI MSP 430 microcontroller through SPI interface. They are an inexpensive option for high performance and price ratio of wireless transceivers implemented with PLL. We use transmitter to send command signal from controller to the switches and use transceiver to receive data signal for power consumption value and motion detection

Case Design

The case will be designed to be small and portable. It's intended to let the user to carry around the house. The body should also be insulator to prevent electrical shock.

Sensor Units

Power Supply

The power supply will be a small power circuit that provides a stable constant 3V to the MSP 430, LCD display, RF module. Small batteries will be used as the initial energy source.

Microcontroller

MSP 430 microcontroller will be used to control the unit. This device is powered by the AC/DC converter, which provides a constant 3V. The microcontroller will receive input data from IR sensors/ Current sensors to output control signals to relays. Moreover, it will analysis data, which collects from power measurement, to send to controller unit via RF transmission. The main reason for using this sort of microcontroller is the low power consumption and low cost of this device.

Communication

We use the same wireless transceiver for each unit. They will transmits the data of power usage and receive the command from the controller for the relay.

Occupancy Detection

The sensor module will detect motion and occupation. It is able to provide consistent and reliable reading. The sensor output an analog voltage will give signal to RF module as activation for starting power.

Switch

It is used as a relay which can be controlled by DC voltage. The primary reason for using this device is high rate current adoption at 120VAC. This relay is connected to microcontroller via serial data port. The relay works as a switch (on/ off) power when it receive command signal from microcontroller.

Power Measurement module

The module is a wattmeter which output a voltage that's proportional to the average power consumption in the load. Figure 26 in page 24 showed the schematic. The output voltage to power measured ratio is 0.5V/1kW. It allows power detection from 0W to 6.6kW. The module will be between the grid and the load separated with an isolation transformer. The output voltage is then send to the MCU for ADC and data processing.

2 Design

2.1 User I/O

LCD

The LCD can work within a range from 2.2V to 5V supply voltage and within a range from 4.2V to 4.8V driving voltage. The supply voltage 5V for the display is connecting to pin 2. The pin D4, D5, D6, D7, E, and RS from LCD will be connected and gotten the signal from pin P1.0, P1.1, P1.2, P1.3, P1.6, P1.7 respectively of microcontroller to be able to display information. LED backlight can be used to help LCD brighter where pin 15 and 16 are LED cathode and anode.

Button

The button will connect the multiplex DM74151 which logically send the signal microcontroller. There are 6 buttons which connect in serial to the multiplexer DM74151, then logically send the select signal to microcontroller via pin 5 or 6. Where Pin 1,2,3,4 and 12,13,14,15 are connected with the button while pin are pin 9, 10, and 11 select signal from MSP430G2553.

2.2 Microcontroller

Hub unit pin connection

The pin connections for sensor module are shown in table (number) below. In term of software, pin configures are also shown in table (number). There are also some interrupt function is used for this microcontroller such as: timer interrupt, port interrupt. (which is shown in appendix).

Table 1.1: Pin connection of Hub controller

	Hardware connection	Software configure
P1.0	-	-
P1.1	-	-
P1.2	Wire connection	P1DIR
P1.3	Wire connection	P1EN
P1.4	Data selection	P1DIR
P1.5	Data selection	P1DIR
P1.6	Data selection	P1DIR
P1.7	Output of multiplexer	P1EN
P2.0	LCD data	P2DIR
P2.1	LCD data	P2DIR
P2.2	LCD data	P2DIR
P2.3	LCD data	P2DIR
P2.4	EN	P2DIR
P2.5	R/S	P2DIR

P1DIR and P2DIR: output pin configure
P1EN and P2EN: input pin configure

Sensor unit pin connection

The pin connections for sensor module are shown in table (number) below. In term of software, pin configures are also shown in table (number). There are also some interrupt function is used for this microcontroller such as: timer interrupt, ADC interrupt, port interrupt. (which is shown in appendix).

Table 1.2: Pin connection of Hub controller

	Hardware connection	Software configure
P1.0	-	-
P1.1	-	-
P1.2	Wire connection	P1DIR
P1.3	Wire connection	P1EN
P1.4	Connect to output of PM circuit	INCH_4
P1.5	-	-
P1.6	-	-
P1.7	-	-
P2.0	Connect to output of	P2EN
P2.1	Control Relay	P2DIR
P2.2	-	-
P2.3	-	-
P2.4	-	-
P2.5	-	-

P1DIR and P2DIR: output pin configure
P1EN and P2EN: input pin configure

2.3 Communication

In initial design, we chose a radio module A110L09A which was constructed on Texas Instrument transceiver chip CC110L. The transceiver chip is wireless base RF communication protocol that is capable to work in the 433 MHz, 868 MHz, and 915MHz band. For the purpose of the project, we operated the module in US902-928MHz Ism bands, and specifically tested at 915MHz $\pm$ 10% frequency band. The figure below shows how the module is connected to the MSP430G2553 microcontroller from the LaunchPad.

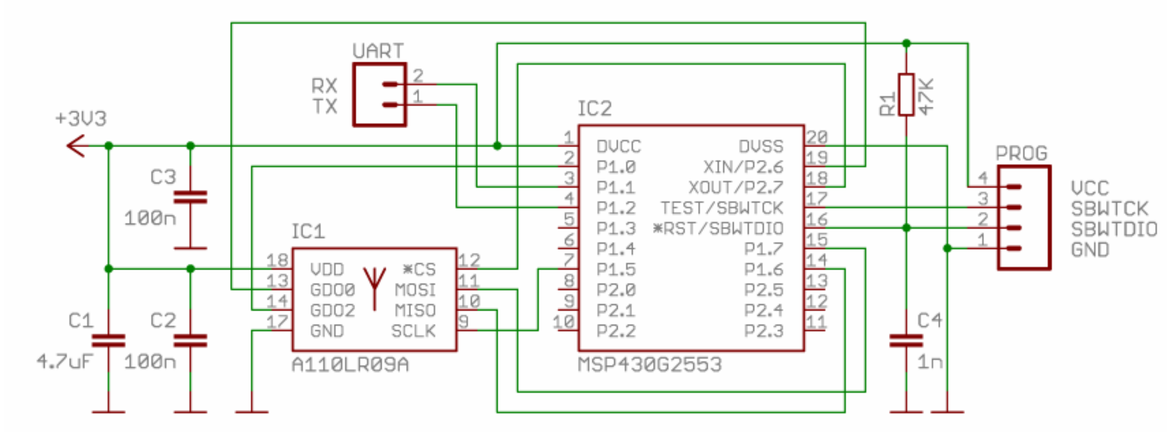


Figure 3: Basic connection of transceiver and microcontroller

Besides the SPI interface pin, the A110LR09A radio module has 2 control pins GDO0 and GD02 – configured for interrupt request by state changes of the FSM controlling modules. Simplified sequence of module operation by transmitting a packet is as flows. After waking up from sleep state, the module accesses its crystal oscillator and the PLL system for generating the carrier frequency. Due to the configuration setting, the module performs frequency calibration every packet transmission about 750us.

The initial design project included 2 of these modules: one for transmitting the data while the other one is for receiving the data. To have the wireless communication operate properly with the whole circuit design, we set up a few test for frequency operate and data transfer, power consumption.

2.4 Occupation detection

For the occupancy detection function, we implement PIR (passive infrared) motion sensor form Parallax manufacture. The PIR is a pyroelectric device that detects motion by comparing the amount of infrared radiation that reaches a pair of detectors. When the two detectors receive different values, the sensor indicates it as movement of an object as far away as 20 feet in reduced sensitivity mode. The Parallax PIR sensor has an analog on/off output. When movement is on, the sensor is detecting moving. When movement stops, the output turn off (after a fixed delay) The output of the sensor will be directly connected to TI MSP430 microcontroller, and operates as a trigger for power.

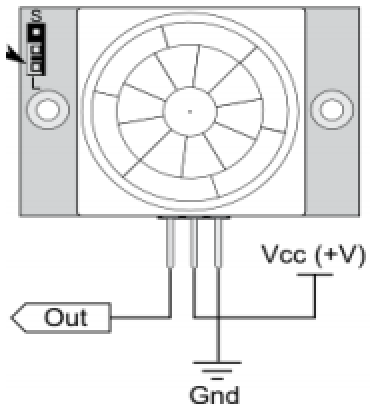


Figure 4: Passive infrared board

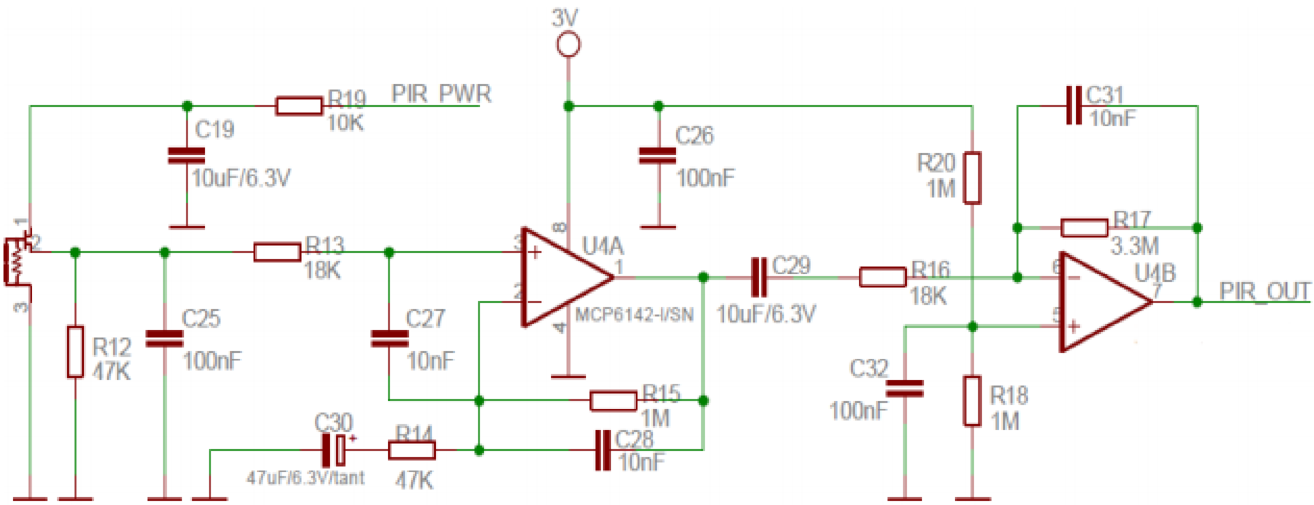


Figure 5: Passive infrared circuit

2.5 Power supply

Control unit Power supply

The Control unit is a remote that the user can carry. A portable energy source will be needed. A 9V battery is used for this purpose. Since the power needed in Control unit are the 3.3V for MCU and 5V for LCD, voltage regulators will be needed. The 9V battery will connect to both 3.3V and 5V regulator. At the stepped down output voltage, 1uF capacitors will be added to ensure a constant dc voltage supply.

Sensor unit Power supply

The Sensor unit demand ±15V for the op-amp, 5V for the relay and PIR, and 3.3V for the MCU. Since the sensor unit will be plug into the wall, using the power from the wall seem more legit. First, a transformer will step down the 120V AC voltage to ~26V AC voltage. Then the voltage will be full bridge rectifier. Two 100uF capacitor will use to smooth the rectified voltage waveform into DC-like voltage. Four voltage regulators will use this DC-like voltage as supply and product ±15V, 5V, and 3.3V respectively.

2.5 Power measurement

The Power measurement module is the core of this project. At the beginning of the design, there were two ways to measure the power. The first way is to measure voltage and current separately. Then measure their phase shift. Feed these three signals into microcontroller to calculate the average power. The second way is to built a watt meter circuit. Its output voltage signal will be proportional to the average power with a constant ratio. The second way was chosen for its simplicity and occupy less pin of the MCU.

To built a watt meter circuit, equation 1 will be essential. The integral of the product of Voltage and Current will be needed. The first design use a voltage divider circuit to sense the voltage. A shunt resistor with a differential op-amp circuit(Figure 6.1) will be used for current detection. These two signals will then feed into a multiplier IC (AD633). After that, there will be an integrator op-amp circuit(Figure 6.2) at the end to integrate for average power. The output voltage signal will represent the average power with a constant ratio. However, this first design run into a safety issue. The voltage divider circuit will share its ground with the wall's neutral. To avoid potential electricity hazard, the voltage sensing is using the differential op-amp circuit as well. The complete schematic for power measurement can be found in Appendix B.

The constant voltage per watt ratio at the end of the power measurement circuit is determine by the capacitor and resistors value. Equation 2 and 3 show how the resistors value affect the ratio of $V_{out}$for differential op-amp and integrator op-amp circuit respectively. With the final power measurement circuit in Appendix B, using a 0.15Ω shunt resistor, the output voltage per watt ratio is about 15mV/W. This ratio can be vary by changing the shunt resistor or the resistors value in the op-amp circuit.

In this module, the output voltage need to reflect the device power consumption with less than 5% error. The ripple of the output voltage need to be under 20mV for stable ADC in MCU. In the range of 0W-200W power consumption, the shunt resistor PR must be able to handle it. All the verification of requirement in Appendix A for power measurement will be talk in section 3 design verification.

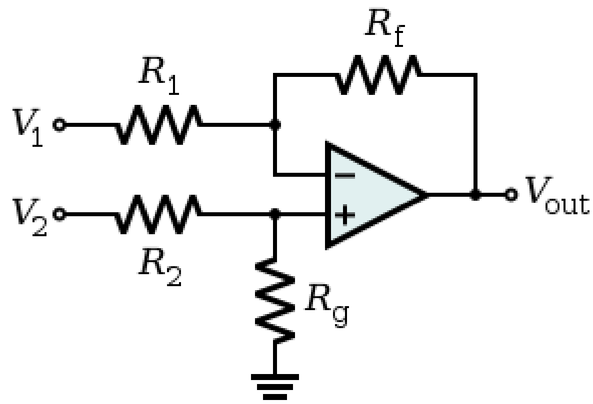


Figure 6.1: differential op-amp circuit

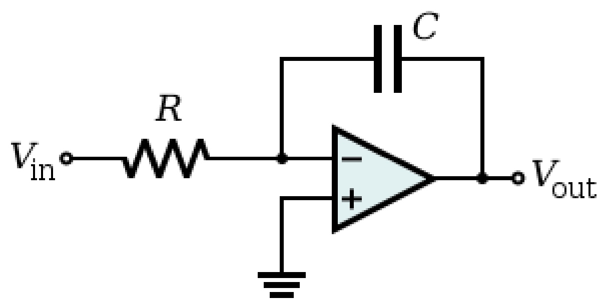


Figure 6.2: integrator op-amp circuit

$$< P > = \frac{1}{T}\int V_{instant} I_{instant} dt \qquad (1)$$

$$V_{out} = \frac{R_g(R_f+R_1)}{R_1(R_g+R_2)} V_2 - \frac{R_f}{R_1} V_1 \qquad (2)$$

$$V_{out} = \int_0^t \frac{V_{in}}{RC} dt + V_{initial} \qquad (3)$$

2.6 Case design

The purpose of the case for both control unit and sensor unit are to protect the PCB inside and prevent user to get electric shock from the circuit. The only requirement for the case design is it embrace the PCB and can't conduct any current. Cardboard boxes with electric tape covered completely were used for our case design. A picture of them can be see in Appendix C.

2.7 Relay

The signals from P14 of MSP430G2553 microcontroller are used to trigger the switches to turn on/off power. A relay T77S1D10-05 [4] is used for this circuit due to the maximum AC voltage is 120V and current is 10A. However, the lowest coil voltage for this relay is 5VDC while the output logic voltage from microcontroller is 3.3V so a 2N3903 NPN is used to translate the control signal. The operations of NPN are shown in table 1. As the results, the NPN is forward when the logic voltage is 3.3V and vice versa.

Table 2: NPN operations

Applied voltages	Mode
E<B<C	Forward
E>B>C	Reverse

3. Design Verification

3.1 User I/O

LCD

For the LCD, it should display a correct function which can be confirmed by observer LCD response after pressing button. The figure () below shows the screen display of our system.

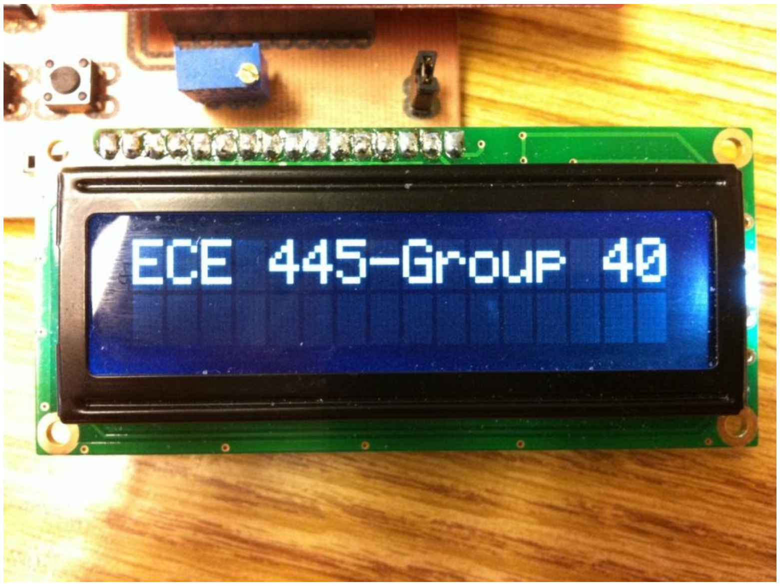


Figure 7.1: The LCD display

Button

The data selection waveform is shown in figure 7.2. The first three waveforms are the data selection from microcontroller and the last waveform is the output from multiplexer.

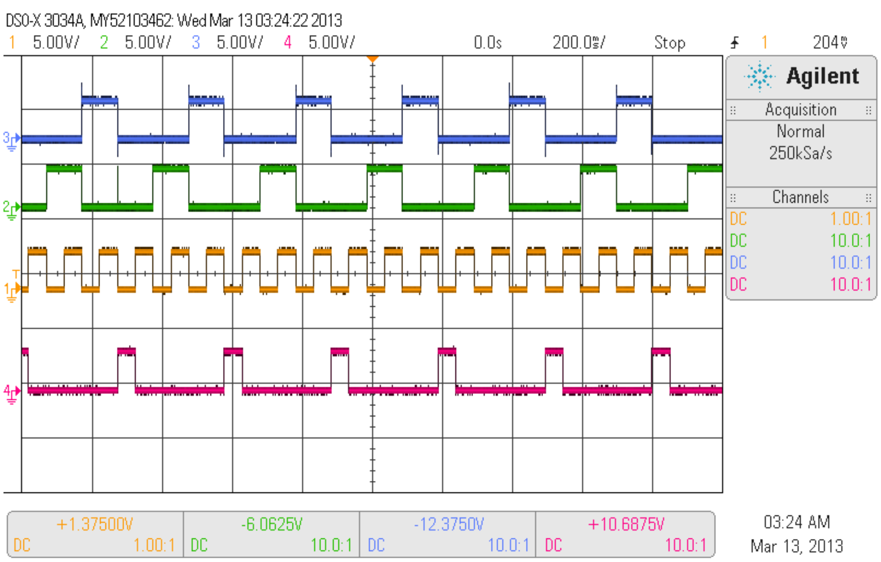


Figure 7.2: The button control waveform

3.2 Microcontroller

The power supply at 1V-4V and verify the correct input with function generator and output with oscilloscope. We connect the digital pin out of the microcontroller to the oscilloscope. Using the trigger function and sample the time in 10ms, we can see the data bits are generated. Moreover, we can also configure the logic output pin of the microcontroller, which is the logic high (3.3V) and digital low (0V), and see the LED at the output pin to check if it is on or off.

3.3 Wireless communication module

After setting up the basic circuit, we use spectrum analyze to test the module at 915Mhz frequency band, data rate 99kBaud and 7dBm for maximum RF power in order to verify the transceiver could receive the transmitted signal constantly.

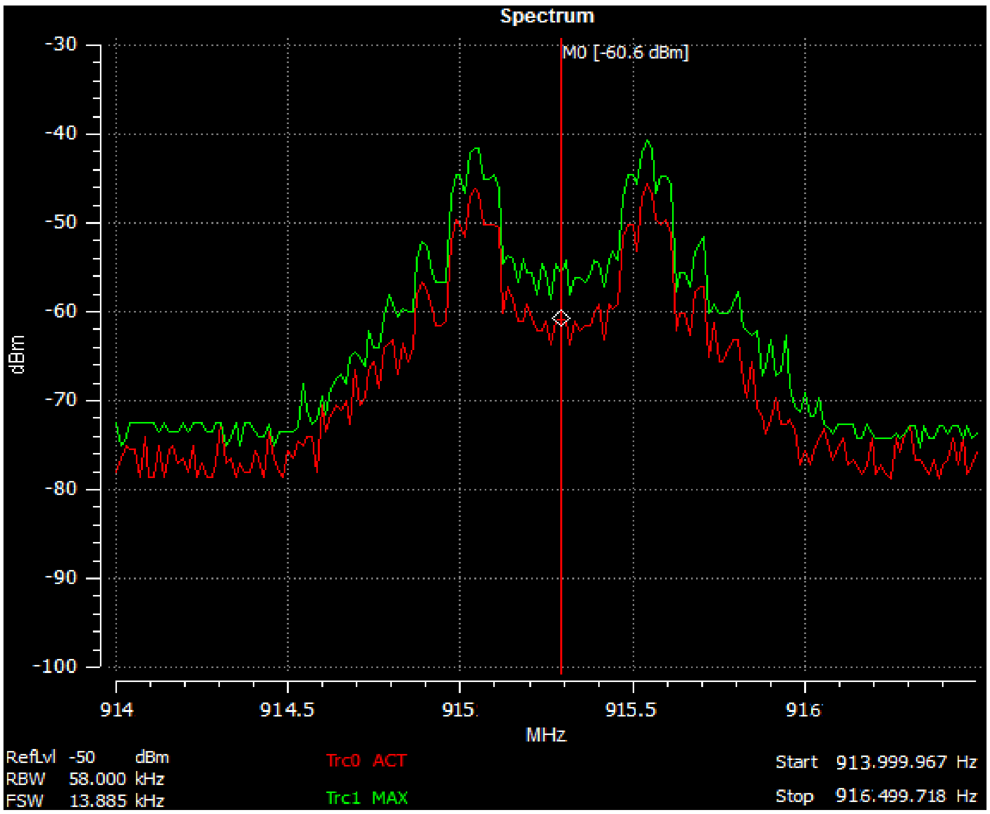


Figure 8.1: Frequency signal at 915MHz operate

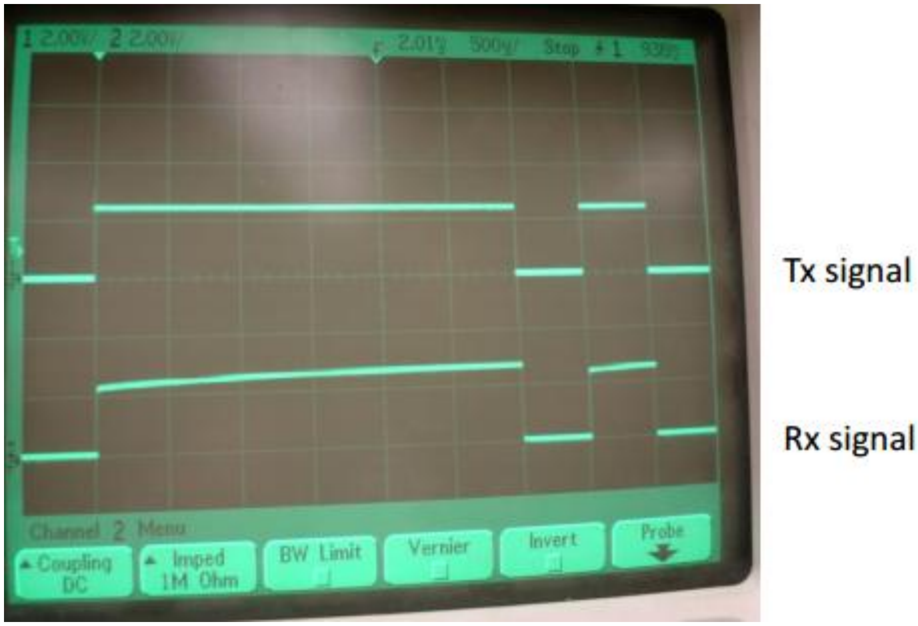


Figure 8.2: transmitting and receiving signal

Measurements result of power consumption is in a table below. Setting the transceiver transfer data with data packer per second transmission

Table 3: Measured Current at Voltage supply 3.5V

	I_{min} (mA)	I_{max} (mA)	V_{cc} (V)
Transceiver	1.78	22.2	3.44
Transceiver + microcontroller	11.23	31.21	3.44

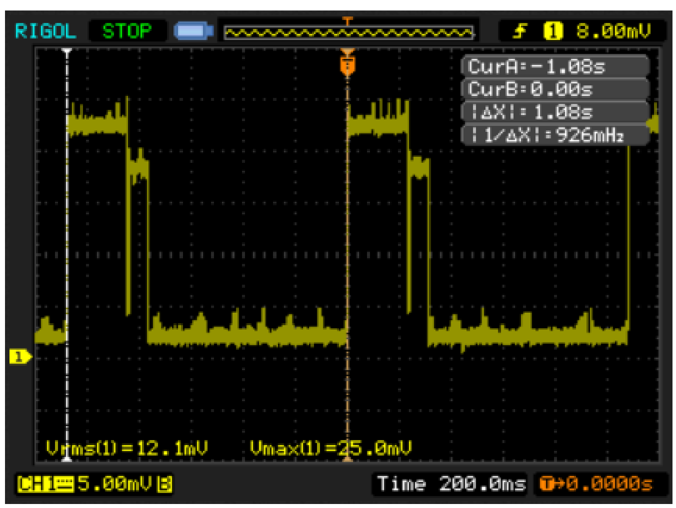


Figure 9: Current peak each second

As initial results, the transceiver is capable to transfer data packet each second at low power consumption within the needed frequency band. Unfortunately, the Pin connection of digital inputs overlap with other module in HUB control unit so that there are no further tests and calculation for data Even though there is potential solution which use software to optimize and change to pin configuration for the transceivers, it is time consumption so that we decided to use wire connection between Hub and Sensor units in order to have other function of the project work as expected.

3.4 Occupancy detection module

Since we only need the Passive Infrared Sensor detection motion up to 15 feet away by measuring change in the infrared levels emitted by surrounding objects. When motion is detected the PIR sensor output a high signal on its output pin then connected to the microcontroller. We use oscilloscope to observe the signal output the PIR sensor at difference displacement.

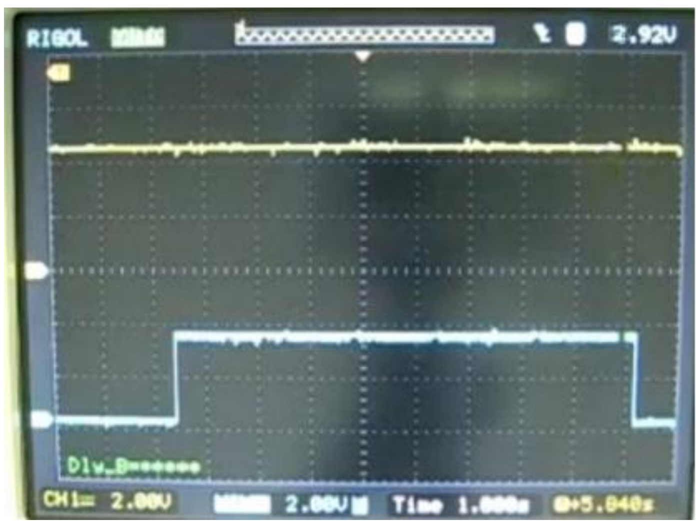


Figure 10: signal from PIR sensor

With voltage supply 3V (yellow line), the PIR sensor gives high signal output when detecting the movement and low signal output otherwise. The high signal has delay from 5-10s at default jumper setting and connect to the microcontroller in order to control the relay.

3.4 Power supply

Control unit Power supply

To verified the 9V battery can supply a stable 3.3V and 5V. We just view the waveform of the output of the 3.3V and 5V voltage regulator. It met the requirement in Appendix A.

Sensor unit Power supply

Figure 11.1 show the full bridge rectified voltage waveform after the transformer step down the 120V AC voltage into 25.7V AC. After the 100uF capacitor, this full bridge rectified voltage will be DC-like and feed into ±15V, 5V, 3.3V voltage regulator. The output meet the requirement in appendix A as Figure 11.2 shown.

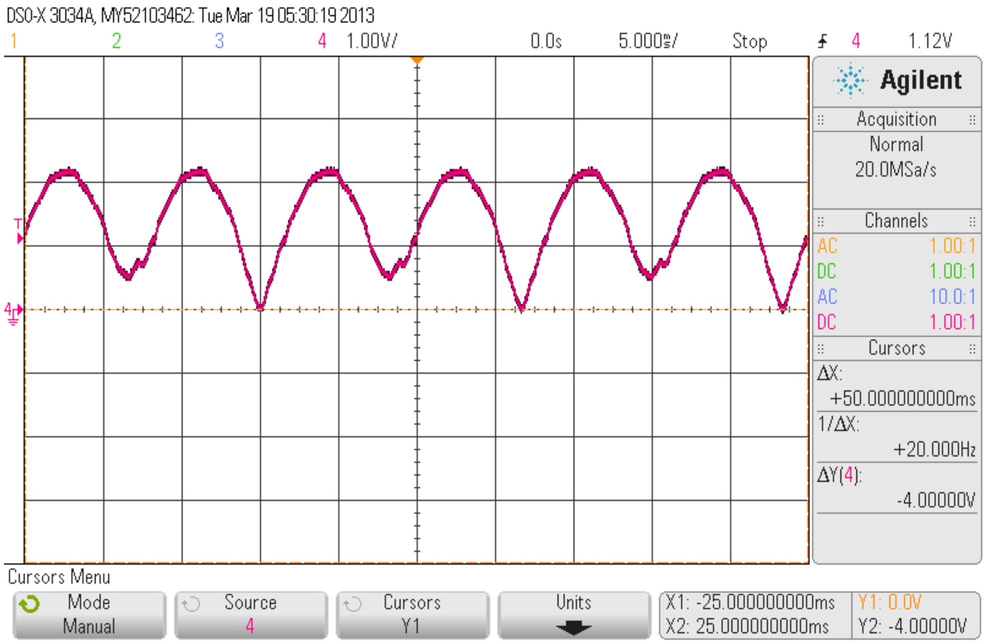


Figure 11.1: After stepped down into 25.7V AC, the Full bridge rectified voltage waveform

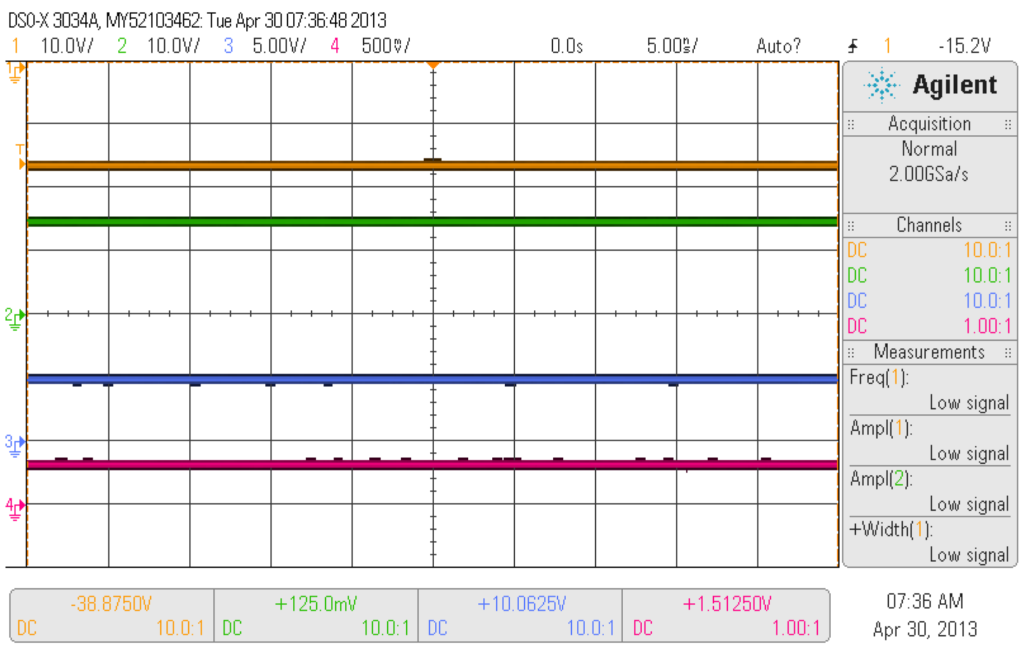


Figure 11.2: The voltage waveform at each voltage regulators output

3.5 Power measurement

The first requirement needed verification was the shunt resistor PR. The power dissipate in this shunt resistor must be under 80% of its PR. Since our design use a 0.15Ω, 0.5W shunt resistor. The shunt resistor should consume no more than 0.4W. By equation 4, that mean no more than 1.63A.

$$I = \sqrt{\frac{P}{R}} \tag{4}$$

In table 1, it showed the output voltage of different load. The Voltage per Watt ratio is constant as long as the shunt resistor is under 80% of its PR. It more obvious in figure x. As the shunt resistor reach above the 80% PR, The slope which represents the V/W ratio goes down. It showed the shunt resistor's resistance is dropping when it get too heat up.

Table 4: power measurement output voltage showing constant 15mV/W ratio

R_{load}(Ω)	Power(W)	I_{load}(A)	V_{out}(V)
500	30	0.243	0.47
250	59.5	0.483	0.85
166.7	88.6	0.721	1.26
125	117.8	0.96	1.63
100	146.7	1.2	2
83.3	173	1.43	2.39
71.43	204	1.67	2.62
62.5	230	1.9	2.79

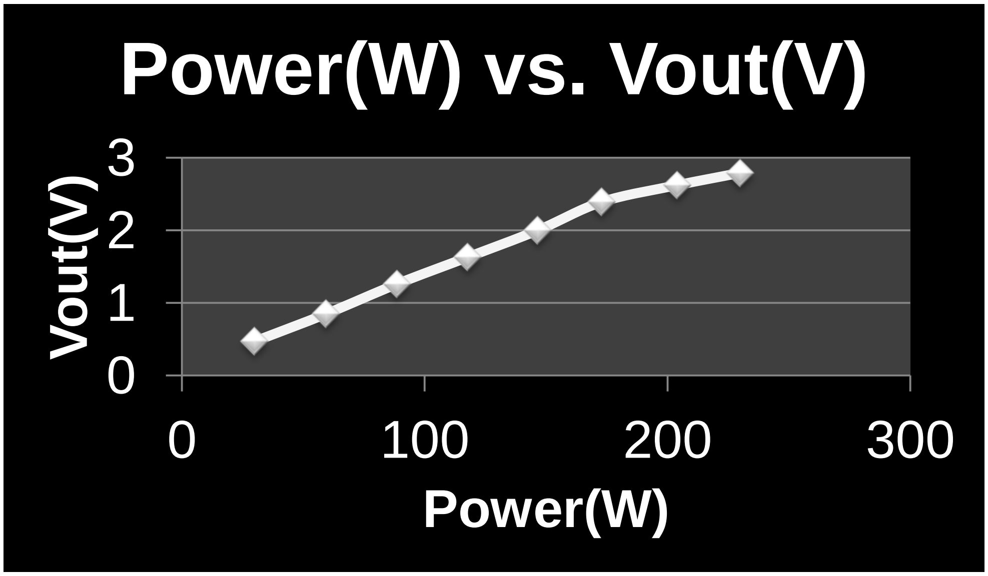


Figure 12: Plot for power measurement output voltage

After verified the detection range for a 80% PR shunt resistor, the next verification will be the percent error of the measurement. We compare the Power measure by our power measurement circuit to the watt meter in the basement power lab and we get the data in table 2. Using equation 5, the max error is less than ±2% which meet the requirement of under 5% error.

Table 5: data comparing power measure by circuit and watt meter in basement lab

$R_{load}(\Omega)$	$P_{circuit}(W)$	$I_{load}(A)$	$V_{out}(V)$	$P_{measure}(W)$
500	30.3	0.2	0.45	30
250	59.6	0.5	0.88	59
167	89.7	0.7	1.33	90
125	118	1	1.75	118
100	147	1.2	2.22	145
83	175	1.4	2.65	173

$$\%\ error = \frac{P_{measure} - P_{circuit}}{P_{measure}} \tag{5}$$

The last verification is the ripple of the output. At first, the output ripple is about 50mV p-p. After apply a RC filter and optimize it, the ripple reduce to 8.4mV p-p. The waveform can be view in figure x.

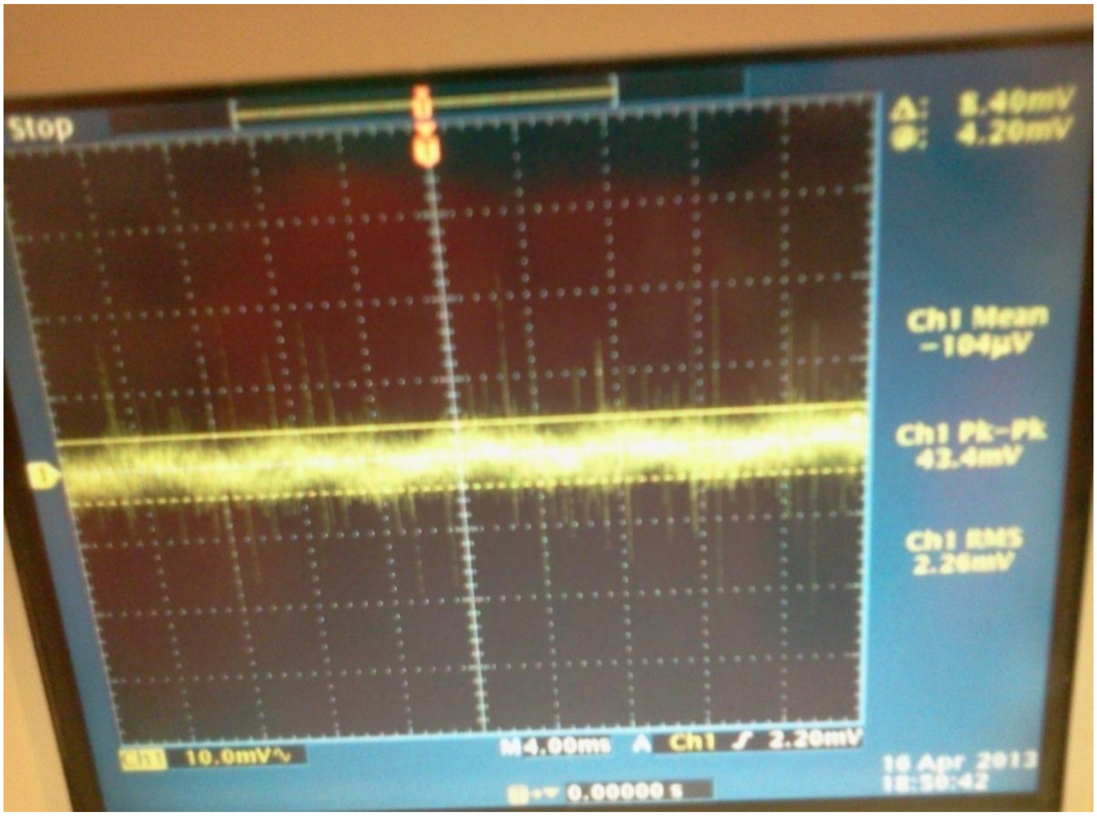


Figure 13: Wither RC filter C=1mF, Ripple is ~8.4mV

3.6 Case design

The purpose of the case for both control unit and sensor unit are to protect the PCB inside and prevent user to get electric shock from the circuit. The only requirement for the case design is it embrace the PCB and can't conduct any current. Cardboard boxes with electric tape covered completely were used for our case design. A picture of them can be see in Appendix C.

3.7 Relay

The measurements result of relay is shown in figure 14.1 and 14.2. A delay between the operations of relay and control signal is clearly smaller than 50ms so the circuit achieved the requirement.

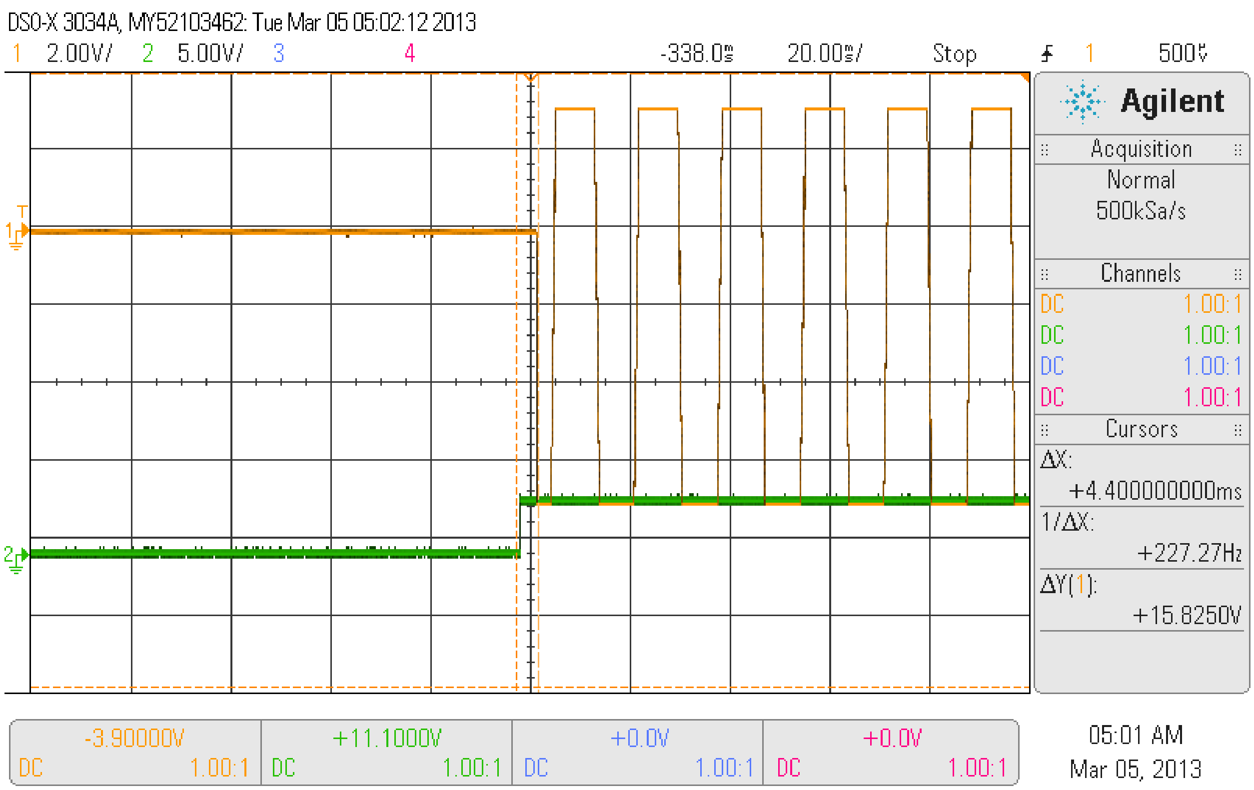


Figure 14.1: Delay between relay switches on operation and control signal

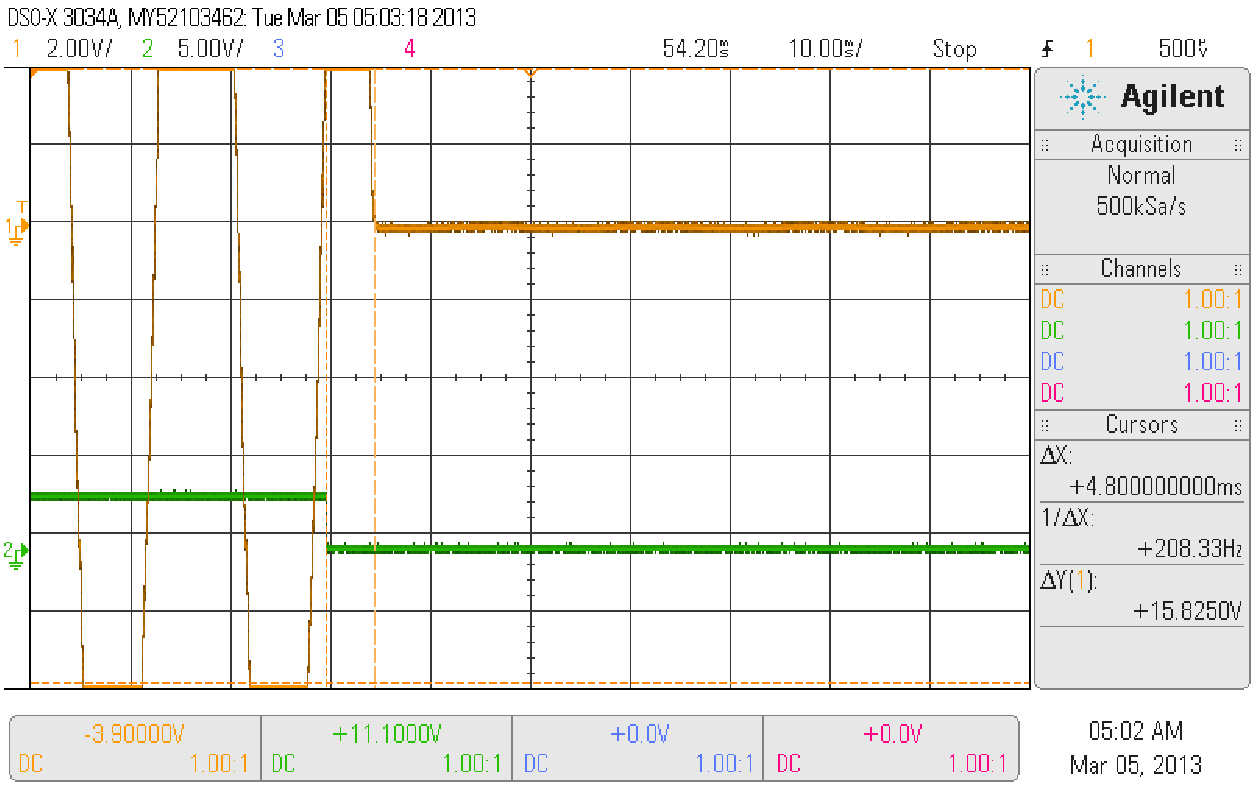


Figure 14.2: a delay between relay switches off operation and control signal

4. Costs

4.1 Part

Table 6: Parts cost approximate

Description	Part number	Quantity	Manufacturer	Cost / Unit	Total cost
Power supply					
Voltage regulator	LM7805	3	Fairchild Semiconductor	$0.67	$1.81
	LM7815	3	Fairchild Semiconductor	$0.67	$1.81
	LM79155	3	Fairchild Semiconductor	$0.67	$1.81
	UA78M33	3	St microelectronic	$0.62	$1.86
BJT	2N2222	3	St microelectronic	$0.15	$0.30
NPN	2N3903	1	National Semiconductor	$0.51	$0.51
	DM74151N	1	C&K Components	$0.80	$4.80
Relay:					
Relay	T77S1D10-05	3	TE CONNECTIVITY	$2.25	$6.65
User I/O					
16x2 character LCD	U01602D/A		Lumix	$15.00	$15.00
Microcontroller					
16 bit Microcontroller	MSP 430g2553	3	Texas Instrument	$5.00	$15.00
Communication					
RF Transceiver	cc1101	3	Texas Instrument	$1.53	$4.59
Occupancy detection					
PIR motion sensor	555-2870	3	Parallax	$4.99	$14.97
Power measurement					
Op-amp	LF411	9	Texas Instrument	$0.84	$7.56
Analog Multiplier	AD633JN	3	Sparkfun	$3.50	$10.50
push button switch	COM-00097	6	Sparkfun	$0.35	$2.10
					$111.10

4.2 Labor

Table 7: Labor Cost approximate

Member	**Hour Rate**	**Total Hours Invested**	**Total** = Rate *hour *2.5
Hai Vo	$35/hour	180	$15,750
Vi Tran	$35/hour	180	$15,750
Benny Tsang	$35/hour	180	$15,750
		540	$47,250

4.3 Grand Total

Table 8: Grand total cost

Section	**Total**
Labor	$47,250.00
Parts	$111.10
Total	$47361.10

5. Conclusion

Out project wasn't fully complete as we didn't get the wireless communication work with other modules and missing the energy priority budget function. Other than that, we have all the other modules work as we want them to. All the other basic function work well which allow user to use this system for home automation, power monitoring, and remote switch control. This meet our goal of providing a system that help user save energy and easy their life at home. The down side is our system still have a lot of space to improve. All those failures mention above can be fix, so a better and more complex system is possible to built upon our project.

5.1 Accomplishments

For this project, we get the basic functionality of remotely turn on/off device, enable/disable PIR automation, monitor power and energy usage, setting energy limit, and viewing past energy usage history. we also able to measure the power consumption with under ±2% error. Although our project didn't accomplish all the functions we promised, our project still serve its purpose of saving energy for user. With our project user can enjoy home automation and monitor his energy use behavior at the same time.

5.2 Uncertainties

We are uncertain how many sensor box can added into our system. The MSP430 we used as MCU is a limiting factor for multiple sensor units. However, we are still uncertain how many sensor unit this MSP430 can support. The reasons for the failure of one of our sensor unit PCB were still unknown. That may be due to overcrowd PCB design, but it also can be the circuit problem. Further investigation is needed to determine these uncertainties.

5.3 Ethical considerations

This project will be deal with wall power. It's our responsibility to make sure our product does not ignore safety to the public. It's consistent with the 1st code of the IEEE code of ethics:

1. to accept responsibility in making engineering decisions consistent with the safety, health and welfare of the public, and to disclose promptly factors that might endanger the public or the environment;

The intent of this project is to help the user to save money by reduce energy consumption. To achieve such goal, our system will also need energy to run. It's important to be honest about our system's energy consumption. It's stated in the 3rd code:

1. to be honest and realistic in stating claims or estimates based on available data;

While working on this the project, we will learn about ways of measuring power, wireless communication, and programming MCU. As we apply this knowledge into our project, we are learning their corresponding application and potential consequences as the 5th code:

5. to improve the understanding of technology, its appropriate application, and potential consequences;

6. to maintain and improve our technical competence and to undertake technological tasks for others only if qualified by training or experience, or after full disclosure of pertinent limitations;

There were colleagues working on different project in the lab with us. It's for our best interest to keep a good relationship with them. It's also for the best of us to seek help from them or provide support to them which form an efficient and friendly environment for us to work. These are consistent with 7th and 10th code:

7. to seek, accept, and offer honest criticism of technical work, to acknowledge and correct errors, and to credit properly the contributions of others;
10. to assist colleagues and co-workers in their professional development and to support them in following this code of ethics.

Every project have their limit and tolerance. It's important to state them honestly as the 3rd code said to avoid injury which mention in 9th code:

9. to avoid injuring others, their property, reputation, or employment by false or malicious action;

5.4 Future work

Overall, our project was successful in some functions. Therefore, there are certainly improvements that we can work on in the future work. First, the most obvious part is wireless communication. We will try to develop Bluetooth communication version for our product. With this kind of communication, we hope in the future there are more sensor modules which controlled by only one control module. Second, the priority function will be built to complete the home power budget for our system. Third, to upgrade the system which can control more sensor module, we must change our microcontroller, which is a main processing system, to a better microcontroller and add a memory module as well. Finally, to make this into a product that is good enough for consumer market, a smaller size with PCB silkscreen and some safety function will be considered.

References

"2500 mAh NiMH Battery - AA - SparkFun Electronics." News - SparkFun Electronics. N.p., n.d. Web. 21 Feb. 2012. <http://www.sparkfun.com/products/335>.

Institute of Electrical and Electronics Engineers, Inc. (2012, September 10) IEEE Policies, Section 7 < http://www.ieee.org/about/corporate/governance/p7-8.html>

" 555-28027-PIRSensor"Copyright © Parallax Inc. PIR Sensor 13 June 2012 <http://www.parallax.com/Portals/0/Downloads/docs/prod/sens/555-28027-PIRSensor-v2.2.pdf>

"Low-pass filter - Wikipedia, the free encyclopedia." Wikipedia, the free encyclopedia. N.p.,Web <>

“Wattmeter” J. B. Calvert 13 July 2008 <http://mysite.du.edu/~etuttle/electron/elect64.htm>

Web. 14 Feb. 2012. <http://en.wikipedia.org/wiki/Low-pass_filter>.

"RFcc1101 module datasheet." Texas Instruments Incorporate. n.d. Web. 12 Feb.2012. <http://www.ti.com/lit/ds/symlink/cc1101.pdf>

“MSP430G2X53 Mixed Signal Microcontroller.” Texas Instrument. Web. 20 Feb 2012. <http://www.ti.com/lit/ds/symlink/msp430g2553.pdf>

“Estimating-appliance-and-home-electronic-energy-use” U.S Depeartment of Energy. August 31, 2012 . <http://energy.gov/energysaver/articles/estimating-appliance-and-home-electronic-energy-use>

"IEEE Code of Ethics." IEEE. Web. 25 Feb. 2013. <http://www.ieee.org/about/corporate/governance/p7-8.html>.

“Voltage regulator” Fairchild Semiconductor Web. 11 June 2011 < http://pdf1.alldatasheet.com/datasheet-pdf/view/82833/FAIRCHILD/LM7805.html>

“Power Relay ” TE connectrivity Web. 11 June 2011 < http://www.newark.com/te-connectivity-oeg/t77s1d10-05/power-relay-spst-no-5vdc-10a-pc/dp/91F2922?Ntt=T77S1D10-05>

Appendix A : Requirement and Verification Table

User I/O module

Requirement	Verification	Status
LCD interface 1. Input power supply voltage 5.0V 2. Delay display time < 100ms 3. Display clear, good characters segment	1. Pin connection are tested via volmeter'buzz funtion 2. Before connecting, check input voltage by voltmeter if in range 5.0 ± 0.0V 3. Adjust the resister to have adjustable voltage in range of 4.8V to 5 (for best contrast at 5.0V)	Y Y Y
Button 1. Fast response 2. Input voltage for multiplexer 7451 is 5.0V 3. Mux 74151 is powered correctly	1. Input voltage is checked before apply to 74151. 2. The select data signals from MSP430 are checked before apply to 3 select pin of 74151 to verify that the signals go from 000 to 111. 3. Use an oscilloscope testify output waveform from the 74151. Output signal is used to compare with select signals from MSP430G2553.	Y Y Y

Power supply

Requirement	Verification	status (Y or N)
Power supply 1. Aim on voltage supply to support all the electrical components with different needs of voltage and current values 2. The power supply noise should be within 20mV pk-pk. 3. 2 AA batteries will be used to generate 6V DC input power since most of the components must have voltage range of 1.8V – 6V	1. Using a series of voltage dividers to approach multi operation voltages on each device 2. A power supply is connected directly to the oscilloscope. The peak to peak voltage is measured 3. Connect battery to volt meter and check the output voltage with voltmeter. The voltage measure should stay constant at 6 V	Y Y Y

AC/DC converter 1. Supply DC voltage to power on the board 2. Supply constant power to the board 3. Supply multiple voltages: +15V, -15V, +5V, +3.3V 4. Ripple voltage is smaller than 100mV	AC/DC converter 1. The board doesn't power off intermittently. An oscilloscope will be used to check if the voltage supply is steady. 2. The power supply tests should be done with batteries. The output of the power supply will be observed with an oscilloscope. 3. A multimeter will be used to check the voltage output to see if 5V, 3.3V, 1.8V, 1.2V and 1.5V are achieved. The error tolerance should be about $\pm 0.15V$ 4. Ensure each component is connected to its correct voltage supply by checking the voltage before connecting it to a component.	Y Y Y Y

Occupancy detection

Requirement	Verification	Status
1. Function correctly in power supply range 3V + 10%	1. Connect to power supply (3,4,5V)and read output change indicating device working	Y
2. The sensors need an accurate reading in room temperature in range 50 ℉-90 ℉ condition.	2. Changing the temperature in door or close to the sensor. Move in front of sensor ,then use oscilloscope to check if sensors give output signal corresponding to the movement	Y
3. Be able to generate voltage output at least 0V when there is no movement and 2.5V + 10% when detecting motion distance between 5-20 feet	3. Connect to power supply and vary signal when changing distance between sensor and people. Use oscilloscope to check the waveform signal	Y

Communication

Requirement	Verification	Status
1 Able to transmit and receive data in the frequency range 906-915Mhz , especially at 915Mhz +10Mhz signal	1 Set spectrum analyzer to read around the 915Mhz frequency. Send difference signal at different frequencies. Use an oscilloscope to observe the verified signal	Y
2 Certify to recognize bit pattern from microcontroller signal with less than 1% error	2 Continuously transmit data from microcontroller , use parity bit method to check the error	N
3 Communicate within 20meter ± 5 meter range indoor	3 A distance test will measure the signal strength and noise ratio of the receiver to determine the maximum RF transmission distance. Transmit data and then measure the output vs. distance. Change the distance between 2 module and check the point at which the data output cannot be recognized will be the maximum distance.	Y
4 Able Implemented with the circuit design	4 Check pin configuration	N

Switch module

Requirement	Verification	Verification status (Y or N)
Relay 1. Operate at 120V AC, with the maximum current is 10A.	1. Input +5V is checked before apply to relay circuit.	Y
2. Can be controlled with 5V DC	2. Relay is connected to DC voltage before connect to AC voltage to test the switching delay time and the switching frequency.	Y
3. Fast response which can work at 50Hz switching frequency.	3. AC connection is checked prior to turn on power. Voltmeter’s buzz function is used to check the first condition of the switch in relay. An oscilloscope will be used to check voltage waveform before apply the control signal. Voltmeter’s buzz function is used to	Y

4. The delay times with respect to control signal is smaller than 10ms	check short circuit on the hot line as well. 4. Apply a control signal to check switching delay time and switching frequency.	Y

Microcontroller

Requirement	Verification	Verification status (Y or N)
1. Function correctly under voltage range of 1.8V- 3.6V	1. Connect to the power supply at 1V-4V and verify the correct input with function generator and output with oscilloscope	Y
2. to be able communicate with RF module to send the data rate 500kbps + 100kbps a. Correctly decode one octave frequency range(262Hz -523Hz) b. The delay time between data input from sensors is less than 200ms	2. Code the microcontroller to transfer data. We connect the digital pin out of the microcontroller to the oscilloscope. Using the trigger function and sample the time in 10ms, we can see the data bits are generated	Y
3. Be able to receive the signal under 0 – 5 volts	3. Wire the digital output pin of the microcontroller to the digital high (5V) and digital low (0V), and see the LED at the output pin to check if it is on or off	Y
4. The response time of this module should be lesser than 5ms	4. A 20% duty cycle pulse is generated by function generator and is inputed into the microcontroller. The input pin which is fed with the signal pulse is connected to oscilloscope channel 1. Then, the output from the microcontroller will be connected to the oscilloscope channel 2. The time difference of both input and output signal is observed. The test is repeated with 80% duty cycle.	Y

Power Measurement

Requirement	Verification	Verification status (Y or N)
1. Able to measure load with Power range from 1W to 170W.	1. Value of components in the circuit already simulated in OrCad which can measure load with range from 1W to 170W. The actual circuit will be test with oscilloscope by placing different value resistor as load. Test will then be taken to see if the average power rescale from the output voltage is showing the average power which measured across the load resistor with a wattmeter in the lab	Y
2. The average power measured after rescaling the output voltage must not excess 5% error. (compare to the average power measure across the load).	2. The second requirement will be also test with the above method for the whole range of load resistor to make sure error is under 5%.	Y
3. The ripple of the output voltage needs to be less than 4%.	3. The ripple of the output voltage can be measure with the oscilloscope.	Y
4. The Response time for the output voltage to stabilize (reach 3dB) need to be reasonable (less than few second)	4. When testing the first 3 requirement, see if the output voltage is stable after few second	Y
5. The peak power dissipate in each resistor is less than 80% of their P.R.	5. Measure resistor's voltage and current with the oscilloscope. Then find the peak instantaneous power dissipate and make sure it's less than 80% of their P.R	Y
6. After the ADC in the microcontroller, the measured power must not excess 5% error(compare to the average power measure across the load)	6. Check the data sampled into MCU is also within 5% error in CCS.	Y

Case

Requirement	**Verification**	Verification status (Y or N)
The case should cover all external module and protect the circuit from any possible hazards, must electric shock proof	With a sealed case, all the components cannot be taken out. Measure if there is current goes through outside of the case	Y

Appendix B : Schematic & PCB

Final Circuit Schematics

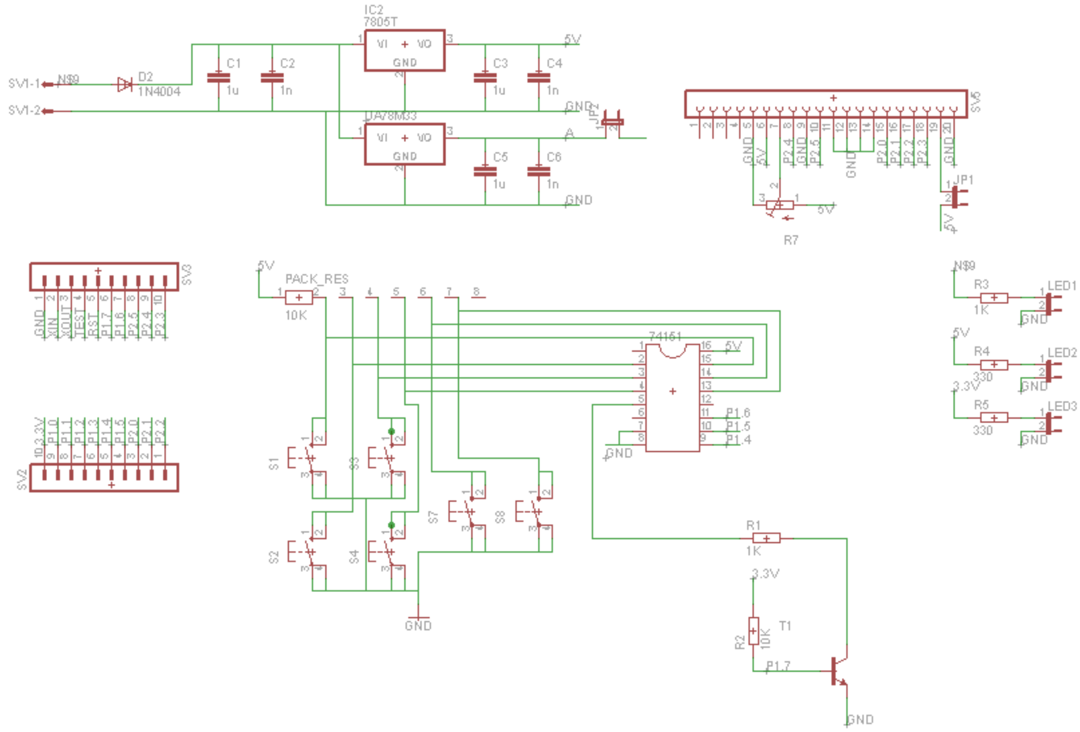


Figure 15: Control Unit Schematic

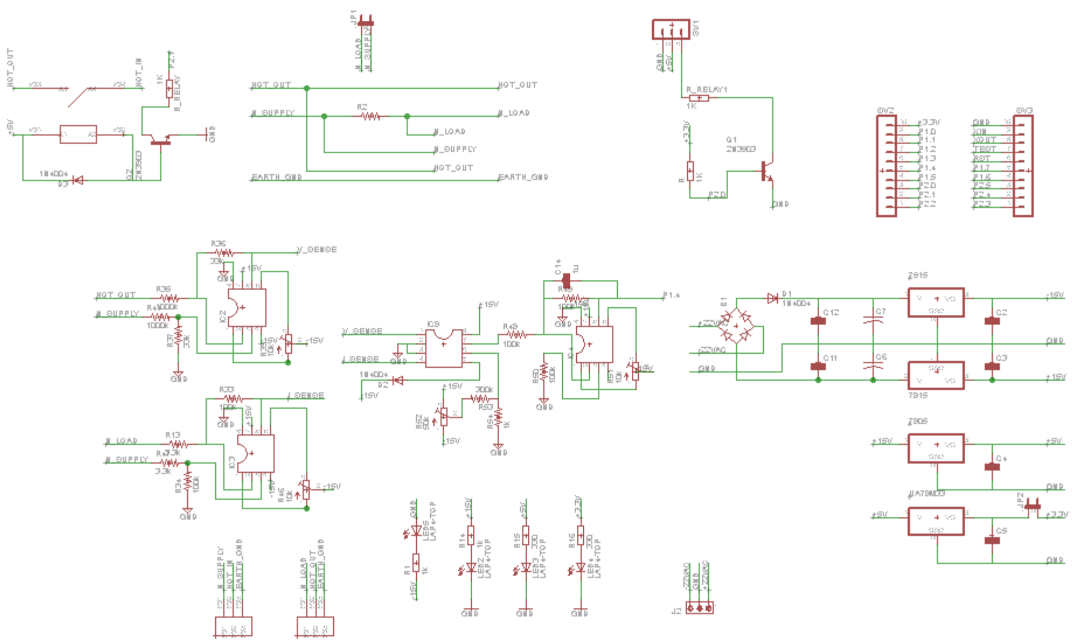
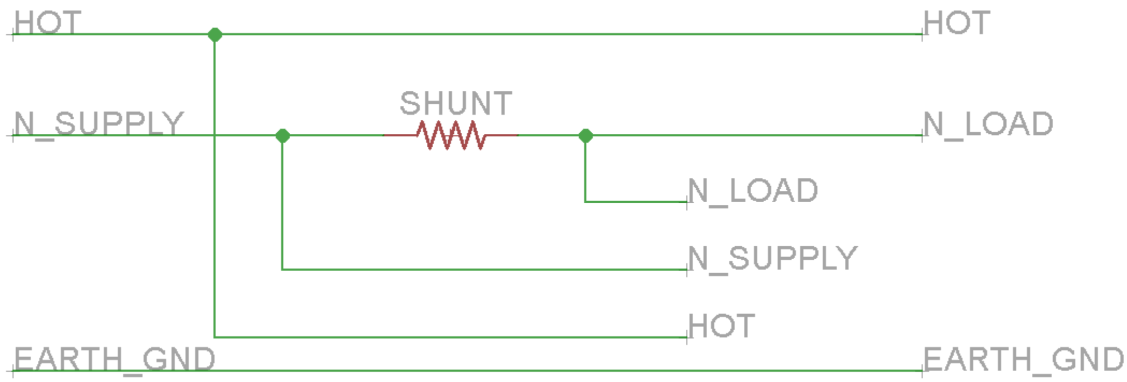


Figure 16: Sensor Unit Schematic

Power measurement's Schematics



Firgure 17.1: The wires for wall power in sensor unit

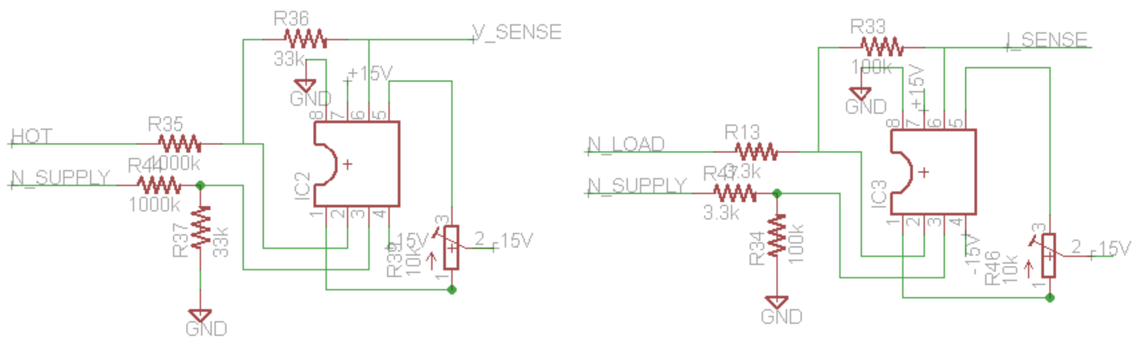


Figure 17.2: The Voltage sensing circuit (Left) and Current sensing circuit (Right)

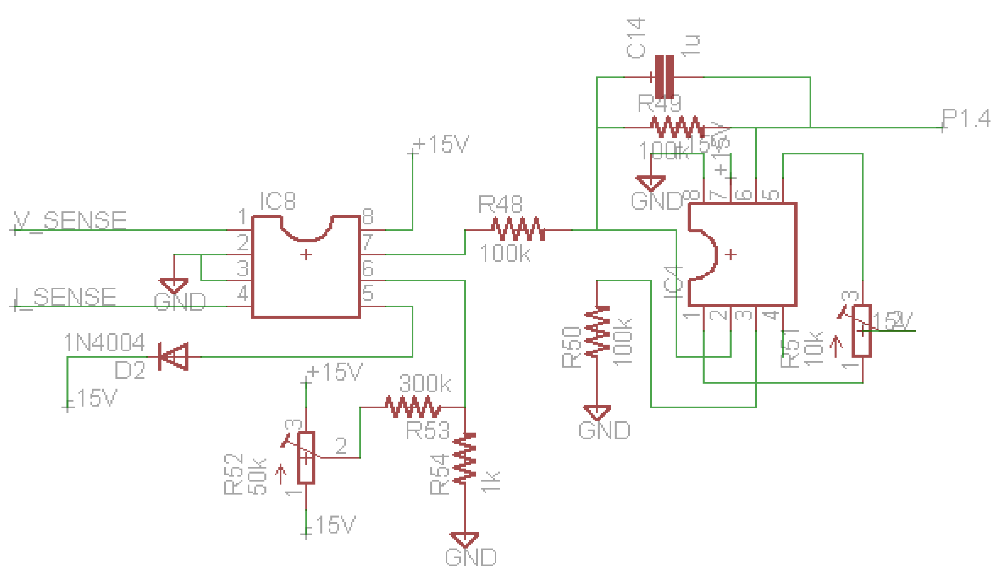


Figure 17.3: Schematic 3.B: The AD633 multiplier circuit (Left) and integrator circuit (Right)

Final PCB Design

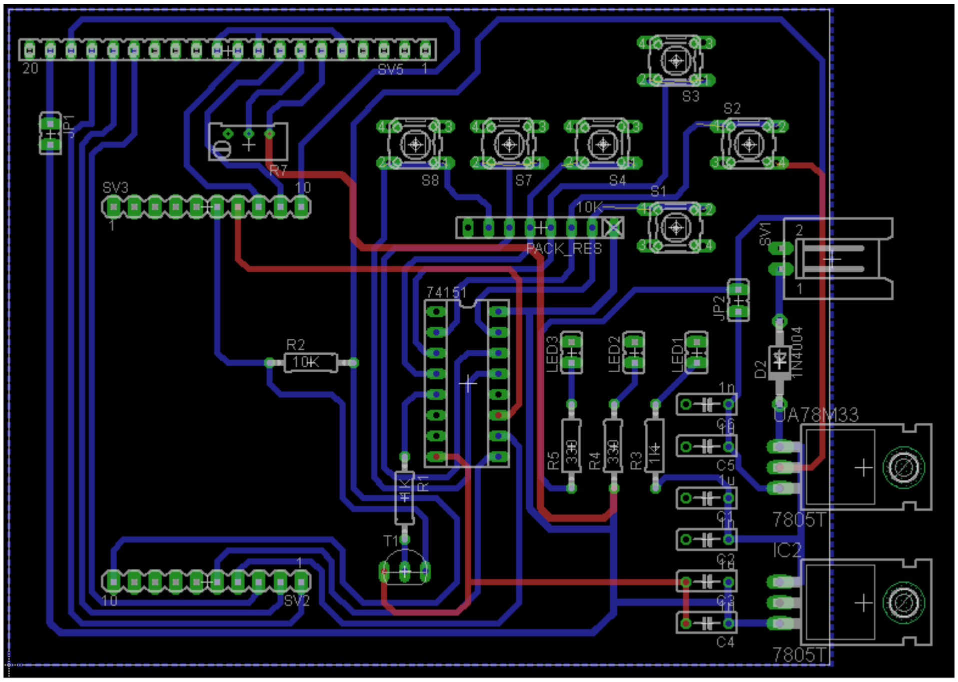


Figure 18: Control Unit PCB

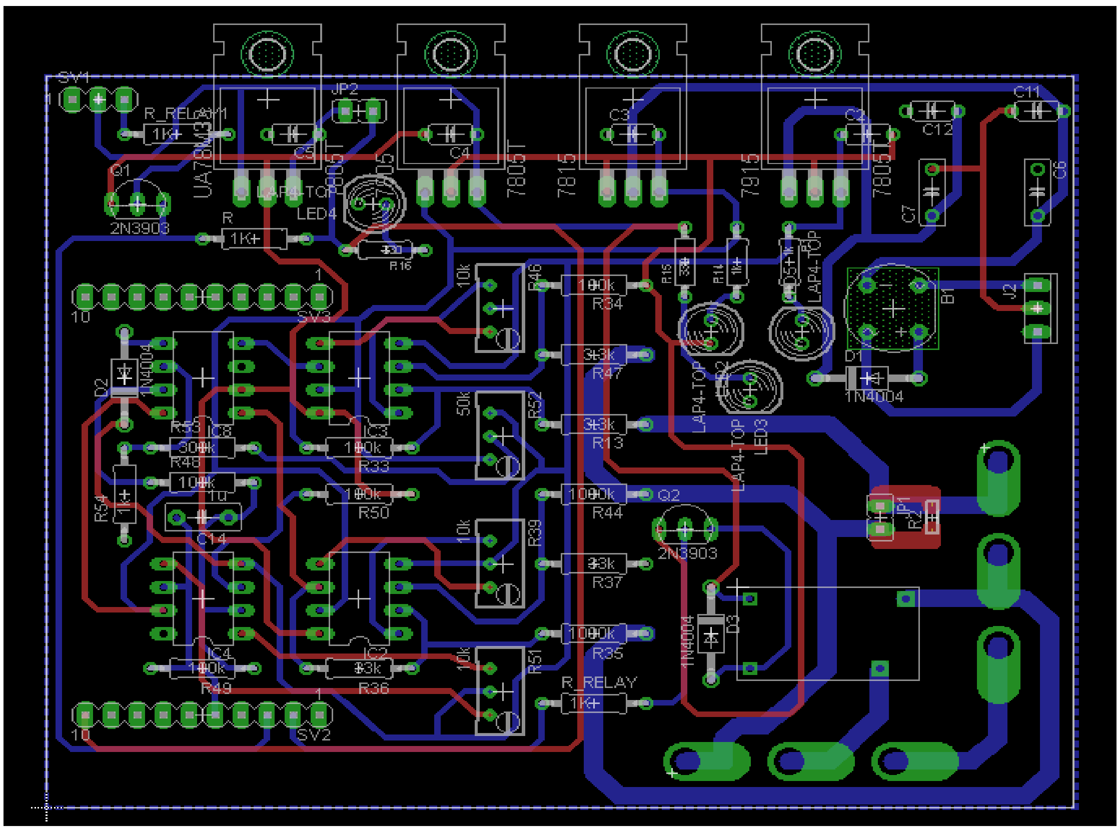


Figure 19: Sensor Unit PCB

Appendix C: Final product

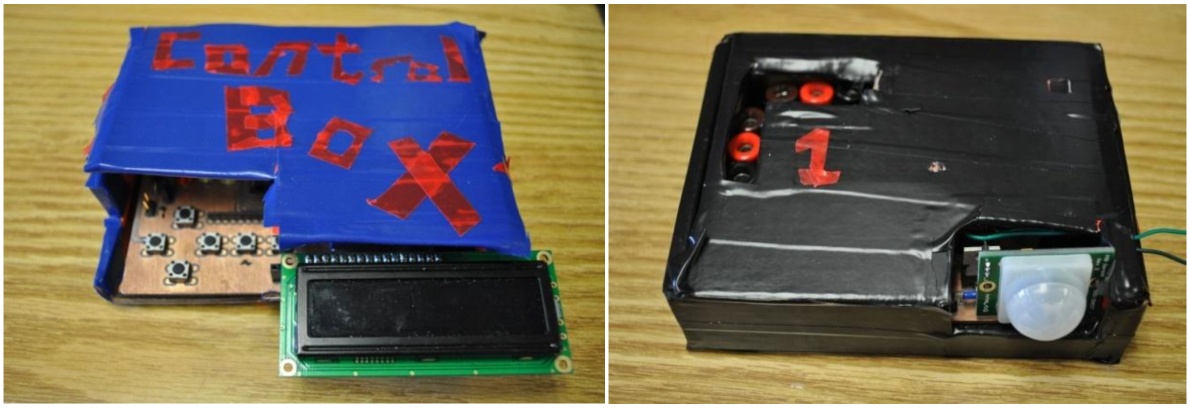


Figure 20: Control Unit's case(Left) and one of the sensor units' case (Right)

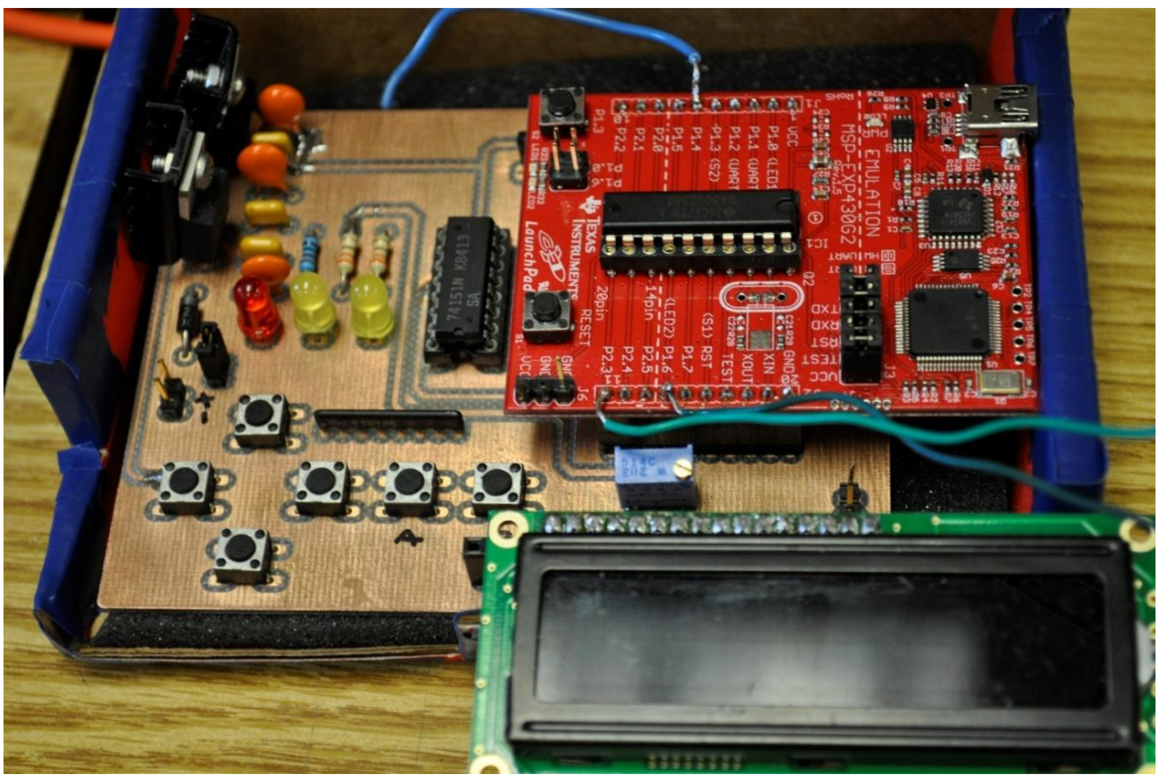


Figure 21: PCB inside control unit box

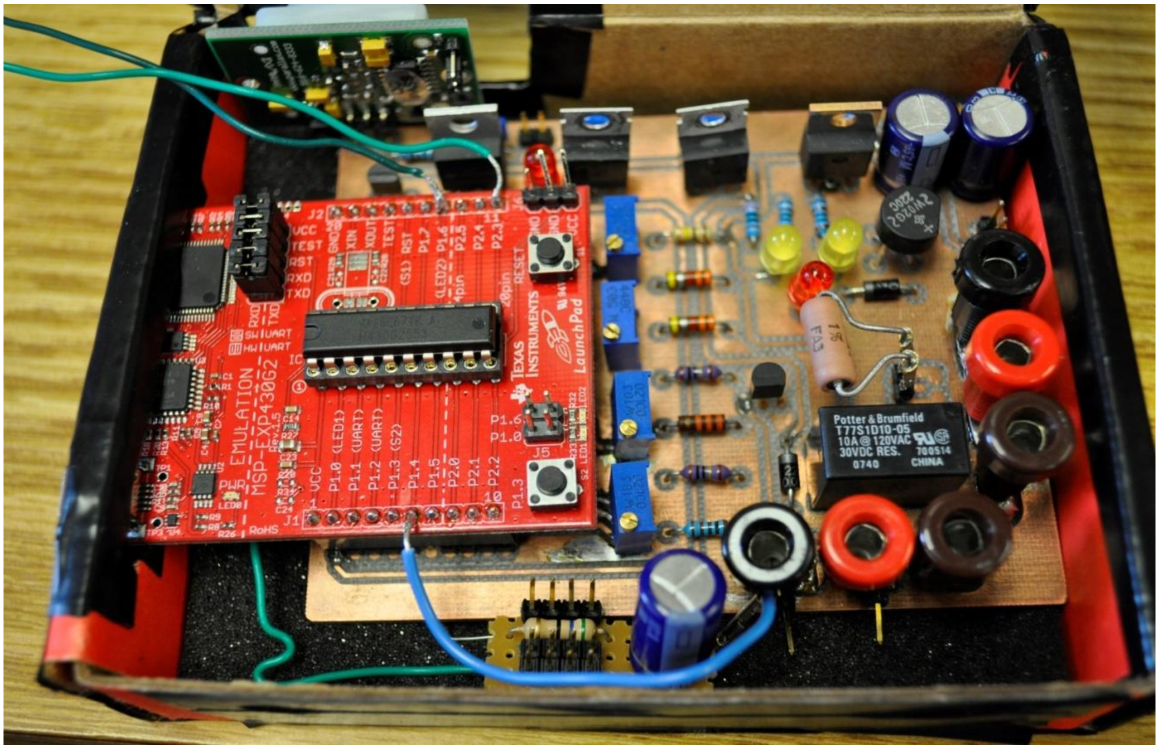


Figure 22: PCB inside one of the sensor units box

Appendix D: interrupt function code

```
// Timer A0 interrupt service routine
#pragma vector=TIMER0_A0_VECTOR
__interrupt void Timer_A (void)
{
	timecnt++; // Keep track of time for main while loop.
	if ((timecnt%50) == 0)
		go = 1; // .05s loop for button select data counter
}

// Port 1 interrupt service routine
#pragma vector=PORT1_VECTOR
__interrupt void Port_1(void)
{
P2IFG &= ~BIT5; // P1.7 IFG cleared
P2IES ^= BIT5; // toggle the interrupt edge,
}

// ADC10 interrupt service routine
#pragma vector=ADC10_VECTOR
__interrupt void ADC10_ISR(void)
{
	__bic_SR_register_on_exit(CPUOFF);	// Clear CPUOFF bit from 0(SR)
}
```