School of Engineering Science • Burnaby, BC • V5A 1S6

December 17, 2009

Dr. John Bird
School of Engineering Science
Simon Fraser University
Burnaby, British Columbia
V5A 1S6

Dear: Dr. Bird and Mr. Whitmore,

The attached document presents the post mortem for the wireless single phase power monitoring system, which is being implemented in the ENSC 440 course. The product that is being designed is a home power monitoring system which will assist the user in measuring the power consumption of various appliances in their home. Moreover, this device will be able to simultaneously transmit the measured data through a wireless connection to a computer and plot a graph of energy and power consumption for the appliances under test.

The post mortem document is intended to provide the current state of the product, the deviation from our intended plans and future development for the device. Moreover, the comparison of the estimated and actual budgets and the project timeline is discussed. Finally, individually written descriptions of contributions to the project are provided.

Watt Smart Inc. consists of five enthusiastic, dedicated upper-year engineering students: Glen Nogayev, Kamyar Ghomi Osgoei, Wenqi Sun, Babak Sobhani, and Titus Cheung. If you have any questions or concerns about our post mortem, please feel free to contact Titus at tcc11@sfu.ca.

Sincerely,

Watt Smart Inc.

Enclosure: Post Mortem for Wireless Single Phase Power Monitoring System

Watt Smart

School of Engineering Science • Burnaby, BC • V5A 1S6

Functional Specification for Wireless Single Phase Power Monitoring System

Project Team:

Glen Nogayev
Titus Cheung
Kamyar Ghomi Osgoei
Wenqi Sun
Babak Sobhani

Contact Person:

Titus Cheung
Tcc11@sfu.ca

Submitted to:

Dr. John bird – ENSC 440
Steve Whitmore – ENSC 305

School of Engineering Science
Simon Fraser University

Issued date: *December 19, 2009*

Table of Contents

List of Figures

List of Tables

1. Introduction

The idea of monitoring and controlling different home appliances has been around for quite a few years. Team WattSmart has been actively working on the design and development of such a system. Over the past four months. Formed by Glen Nogayev, Kamyar G. Osgoei, Titus Cheung, Wenqi Sun, and Babak Sobhani, team WattSmart was able to integrate and put all the expertise that each member had to offer together to create a state of art system. Wireless Power Monitoring System (WPMS) is intended to monitor the power consumption of any home appliance as well as user friendly demonstration of graphs and charts of the consumption, which is accomplished by wireless data transfer from the sensing unit to a home PC unit. This will allow home owners to have a better understanding of their electricity usage and give them the opportunity to control and upgrade the efficiency of their home. The current functionality and future plans and development are outlined in this document. Also, the overall system specification, budget and timeline as well as issues that were encountered during the whole designing and implementation process are outlined.

2. Project Motivation

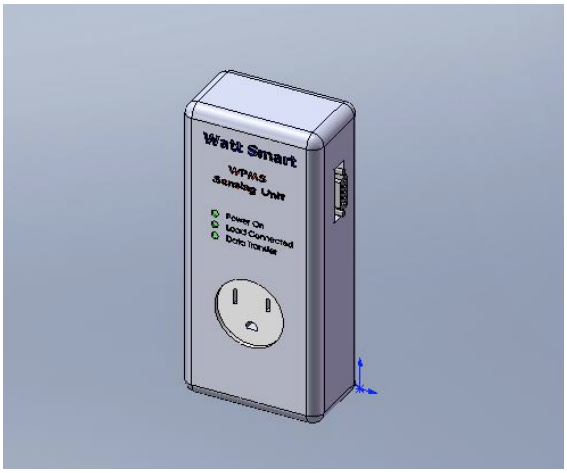
Getting Power Smart is about learning how to better use electricity and how to upgrade the efficiency of your home or business [1]; and using WPMS WattSmart WPMS is the way to do it! Average household power consumption in British Columbia is 11,000 kWh/year, which can be reduced significantly. Most hydro companies such as BC Hydro, have launched various programs in recent years to decrease the electricity waste and increase the efficiency of home and business usage. This not only will help consumers to save more energy and therefore more money, it will also help hydro companies to maintain power production and have fewer outage.

Considering our team member's background and interest, we all decided unanimously to go green and chose this project.

3. Current State

3.1 Overall System

WPMS consist of two man units: main sensing unit and central monitoring unit (i.e. PC). Figure 1 below illustrates this in a better way.



The sensing unit captures all the necessary data from power outlet, performs main calculation and then transfers the data to the main monitoring unit through our XBee Wireless module. As our developed system currently stands, all the functions and features discussed before are fully operational. Therefore our goals of saving energy for homeowners, as well as moving toward a greener planet as the result are met.

3.2 Sensing Unit

The sensing unit is responsible for measurements of drawn current and applied voltage. The appliance will be plugged into the sensing unit and then the unit itself is plugged into the power outlet. Then as the unit appliance starts working this unit captures the input current and voltage and sends them to the MCU.

Power Supply Unit

This unit provides a steady 5 volts supply for the other modules inside the sensing unit. It feeds from the main line (parallel). Output of a bridge rectifier is fed into a 5 Volts regulator to get a steady constant 5V output.

Signal Conditioning Unit

Our signal conditioning unit has two signal inputs, one from the CT that measures the current, and one from the voltage clips that measures the voltage. Both CT and Voltage Clips are set in parallel so that in an unlikely event of a shout down of the sensing unit, the appliance will keep working as usual.

ADC Unit

This unit is part of the PIC microcontroller that was used in the project. The conditioned voltage and current waveforms from the signal conditioning unit are fed to the analog pins of the ADC unit. The analog to digital conversion is performed and the resulting digital data is then transferred to the wireless module or the RS-232 port.

Wireless Module Unit

The main function of this unit is to receive data from the MCU in the sensing unit and transmit it to the PC monitoring unit through a wireless connection. As mentioned in our design specification report, we have chosen the XBee 802.15.4 module because of its simplicity, lower power consumption and larger range. This module can communicate with any device that supports UART, a circuit that translates data between parallel and serial forms.

3.3 PC Interface Unit

Our PC interface unit is responsible for data measurements and collection, and the monitoring user interface is responsible for both calculations and display. Data can be received from the sensing unit either through an RS-232 port or through a wireless connection. The user interface of the application has implemented to be user-friendly, considering that some of the end users

might not have very technical background. The GUI is based on MDI due to multiple monitoring requirements. The graphing application provides power and energy consumption graphs as well as values for voltage, current and power factor.

4. Design Deviations

4.1 Packaging

Due to the time constraint we were unable to package everything in one single box as we proposed. Our sensing unit and the actual board were separate. Instead of PCB we implemented the circuit of bread boards.

4.2 Power Supply

We achieved exactly what we proposed and the voltage supplies for all units was drawn from the line by a built in power supply module. The only difference from the original plan was that we used two transformers, one for sensing unit and one for power supply to keep the system as accurate as possible.

4.3 Signal Conditioning

The signal capture accuracy and the output signal quality was adequate but not entirely satisfactory. Voltage captured graph was not a perfect sinusoidal and we had to filter and take the first harmonic for more accuracy.

Also slight changes were made to the circuit compared to the one we proposed. An inverting amplifier and also voltage dividers were added to scale down the current and voltage to 0-5V.

The original circuit schematic for voltage signal conditioning unit was as follows:

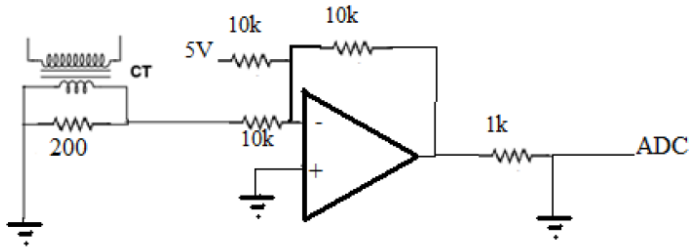


Figure 2-Old Voltage Signal Conditioning Circuit

The modified circuit is as follows:

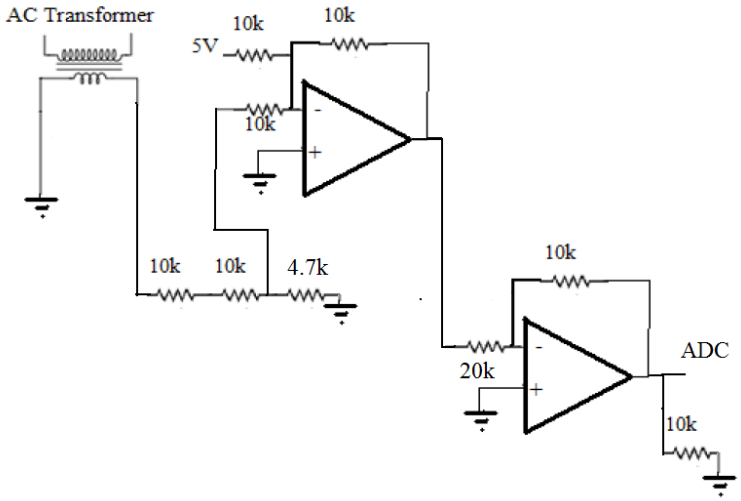


Figure 3-Modified Voltage Signal Conditioning Circuit

The op-amps originally were planned to be low voltage but since we designed a built in power supply unit that could give us 12V we stayed with higher voltage op-amp.

4.4 Sensing Unit

The sensing unit used two CT to sense the current as opposed to our plan to use one CT. The reason behind using two CTs was that for higher and lower currents we had to use different CTs for more accuracy. We achieved the accuracy that we wanted but with two CT.

5. Future Development

In this section, the potential future development and extensions for the product are outlined. These developments include various changes which will improve the appearance and functionality of the device as well as make the product more marketable.

5.1. PCB Board and Enclosure

Since our power monitor is a proof-of-concept device, the sensing unit has not been packaged and the circuit is currently set up on a breadboard. The first thing that needs to be done is the transfer of the circuit to PCB board. This will reduce the size of the sensing unit and make it look more professional. Moreover, all the components of the sensing unit should be placed in a plastic enclosure. There should be buttons installed on top of the case to control various functions of the unit.

5.2. Home Automation

The product is currently designed to transfer data from the sensing unit to the PC through a wireless connection. However, the wireless modules on both the sensing unit side and the PC side are the same; therefore there is a capability to send data from the PC to the sensing unit as well. Given this option, it is possible to implement a home automation component in the device, which would control the appliance under test from a PC through the wireless network. This feature would be very useful for elderly or disabled people, since there will be no need for them to physically go to the appliance in order to turn it off.

5.3. Internet Connectivity

Another feature which could potentially be implemented in the project is the connection to the Internet. This would be an extension of the home automation feature, since it would allow the users to control their appliances through Internet.

6. Budget and Timeline Analysis

Since there was an MCU change, and subsequently a wireless module change, there was an overrun of the proposed budget. We allocated $350 for both the MCU dev board and the wireless modules, and we ended up spending around $410 for both. We also needed to buy two additional current transformers to improve the accuracy of the project.

Table 1 Proposed Budget and Actual Spending

Component	***Expected***	***Actual***
Wireless Module	150	170.93
Current Transformer	50	250
Voltage Probe	50	
MCU-development board	200	242.63
Enclosure	50	
A/D-Transformer	30	
10% contingency	53	68
Total required	***583***	***731.56***

As mentioned earlier, the MCU was changed from TI's MSP430 to Microchip's PIC. This change led to a change in the wireless module as well. Thankfully, both the MCU and wireless module could be developed in parallel. However, there was a two weeks delay due to this change. The original schedule was set quite aggressively, and we made provisions for quite a few optional tasks. Given the absolute importance of obtaining accurate results, we decided to not pursue any of the optional tasks and focus on the circuitry.

The project timeline is provided in the figure below. The blue lines describe the tasks that were intended to be done originally and the red lines represent the tasks that were actually completed.

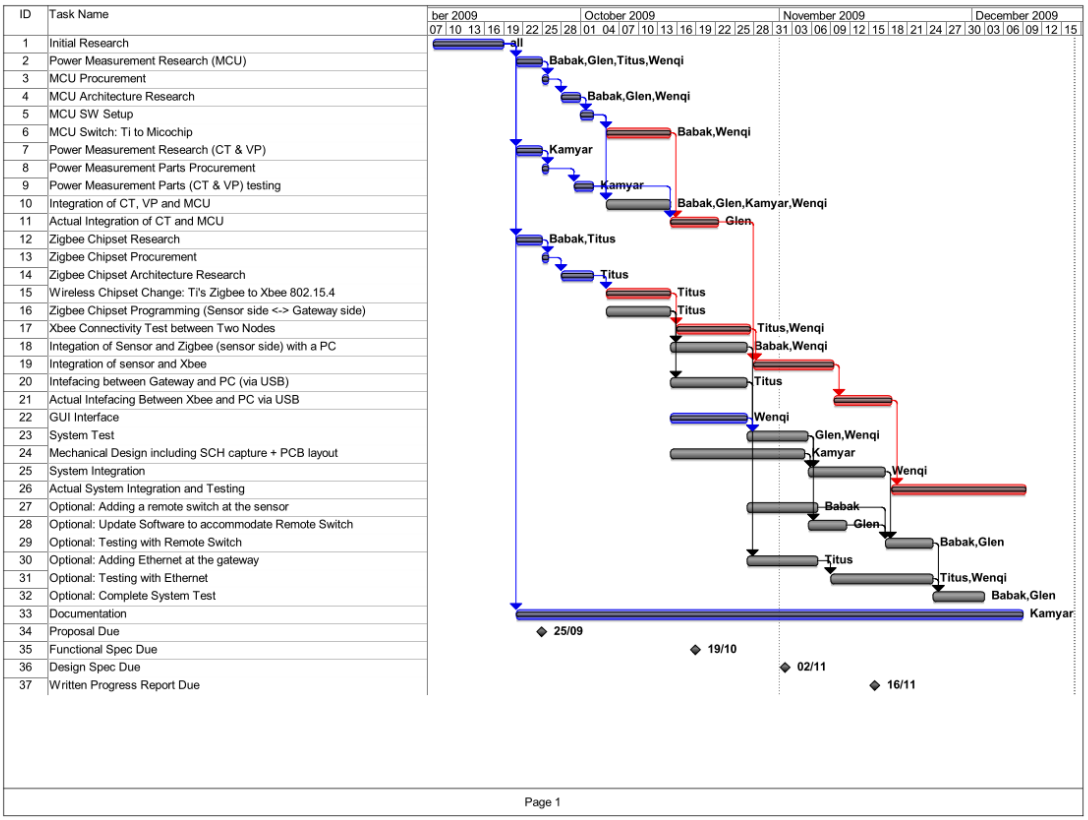


Figure 4-Proposed and Revised Schedule

7. Team Dynamics

Group projects are very different from individual projects; therefore team dynamics play an important role here. Regardless of how well we perform in the project, everyone obtains valuable experience in this course, and these will definitely help us in the future.

Our group functioned as an informal interactive organization in which there was no formal leadership, instead decisions were made as a group. Email, cell phone and MSN were the tools that were most frequent used in group meetings. On average, we had short meetings once a week, to ensure that everyone can update their current status or share any problems, which could be solved together. Work assignments were largely self-chosen and were completed on the person's own initiative.

In a group project, there will be multiple ideas presented, which can be good or bad. Since we had 5 people in our group, occasionally there were some disagreements. However, this is just a part of all the challenges in ENSC440 and it really depends on how the work is handled. We are confident that the experience gained in this course will be very useful in the future.

8. Individual Contributions and Experiences

8.1. Kamyar Ghomi Osgoei

I was looking forward to taking ENSC 440, as it is one of the main and perhaps the most important course in the whole engineering degree. At the very beginning we chose our group mates randomly, without any previous knowledge of each other. We each had different background and it seemed to be a very good team assembly. I did a lot of research at the beginning and proposed a few interesting ideas. At the end we submitted three of the best ideas to Dr. John Bird and asked his opinion, and we decided to go with the power monitoring system after that.

We started from scratch and none of us had any clear idea how to implement the whole system. I spent a great amount of time on researching with other group members since I had experience in researching from my previous co-op term at SFU with Dr. Menon. I did my research on the circuit design and circuit components, MCUs, Development boards, and CTs.

I was in charge of finding currently available products in market. I found a few similar ones and I was the one who found out that there has been a very similar project done two years before at SFU. As I was and am very eager about circuit design, I narrowed down different designs for each available product and compared to our initial design which was with TI chip. Then I analysed the schematics for the development board and purchased the necessary components. In addition, I spent a great amount of time on documentation, technical writings, editing other member's writings, making graphs and charts, and also putting different parts together at the end.

We decided to divide tasks between members and work in parallel in two stages, one working on the new PIC chip, and the other continuing the work on the TI chip and also implementing the Wireless unit. On this side we researched on compatible and suitable wireless options for our system, and decided to go with the XBee 802.15.4 module at the end.

We tested functionality of the wireless module by data transfer from computer to computer and it was successful. Further testing and debugging with the MCU unit wasn't completed due to short cooperation from the other side.

Overall this was a great opportunity for me to practice my research skills, circuit designing skills and technical documentation. I also learned a lot and became proficient in the fields of power systems and wireless connectivity.

This project potentially could be one of the most remarkable and successful projects at SFU. I will continue working on this project on my own as I find it very fascinating and also marketable. At the end I would like to thanks all the members for their efforts, and also Steve and John for their support.

8.2. Titus Cheung

As the CFO of the team, I led the effort of presenting to Engineering Undergrad Student Society (EUSS) for the Engineering Science Student Endowment Fund (ESSEF). We successfully obtained $500 from this source.

I also entered our team into a North American contest in hope of obtaining further funding. However, our school was not registered, and therefore we were not eligible for the contest. But regardless, they offered us a USD$200 voucher which was good towards a single purchase of any TI development kits.

I discussed our project with an account manager at Avnet, TI's Canadian distributor, and they sent us TI's development kit and a Zigbee demo kit. Unfortunately, we decided to choose Microchip PIC MCU over TI.

In the beginning, I co-led the system design specification effort by understanding how TI MSP430 interacts with its Zigbee chipsets. While this exercise was painstakingly time consuming, I found it to be of tremendous value. Choosing a particular chipset over another chipset demands a solid understanding of the chipsets as well as the system as a whole. Although we did not use TI at the end, the experience was invaluable.

Once the design path was changed (from TI MSP430 to Microchip PIC), the wireless chipset was changed due to the lack of SPI support from the PIC chip. We decided to choose XBee because of its known integration simplicity. However, it was not as easy as a plug-and-play solution one would expect. Full understanding on the XBee 802.15.4 module was still needed.

We tested the 802.15.4 wireless link by sending bytes from one computer to another computer via Hyper Terminal. We attempted to do the wireless test on the actual circuit, but the PIC's baud rate was not correctly setup. Unfortunately we were unable to obtain the chip for further testing, since we only have one chip. We were under the impression that the wireless module was tested working since we got the acknowledgement that the baud rate was changed. The incorrect assumption that the MCU team tested the wireless module proved to be costly. We should have set a deadline and have the chip for integration testing purposes.

8.3. Glen Nogayev

Even before the semester has begun, I was already looking forward toward taking this course. During my years at SFU, I have heard numerous stories about how challenging and at the same time interesting this course is. I was also aware of the fact that choosing an appropriate project idea and assembling a well-organized and reliable group is the key to success in ENSC440. Therefore, I decided to get an early start and helped to assemble the group almost two months before the beginning of the semester. After extensive research, I came up with the idea of a power monitoring system, which was later approved by my team members as well as Dr. Bird.

At the beginning of the semester, our group was meeting almost on a daily basis in order to fine tune our idea and straighten out all the details of the project. I spent a great amount of time researching the parts, such as the microcontroller, wireless module and various electronic components that were needed for our project. When the parts were obtained, we assigned tasks to every group member to work on. We decided to hold weekly status meetings in order to keep everyone up to date with the overall progress.

I was put in charge of all project documentation, so I was responsible for putting together the Proposal, Functional Specification, Design Specification and Post Mortem reports along with any other documentation required. Moreover, I was involved in the wireless module development. This proved to be much harder than expected. Since I was not familiar with the protocol used by our wireless module, I had to spend a great deal of time reading and understanding the product data sheets and user manuals. In addition, after replacing the TI microcontroller with the one from PIC, the ZigBee wireless module had to be replaced as well. We purchased the XBee wireless unit together with a development board. This added extra delays to the wireless part.

In the latter stages of the project, we were able to integrate the XBee module with the PC interface unit and also test its functionality. Although the receiver side was working flawlessly,

we were not able to integrate the transmitter with the MCU board since the MCU team was constantly using it and they did not think it was necessary to integrate at that point.

Overall, I definitely think that this project was a valuable experience both on the technical side and in terms of team working skills. I have gained a tremendous amount of knowledge throughout the whole semester. I believe that this project has great potential and I am considering developing a business plan for the product.

8.4. Wenqi Sun

Since the first day I was in SFU, I have already heard a lot of stories for ENSC440. Five years later I finally had a chance to experience this long awaited course. This is the most interesting course I have ever taken. We can choose our own topic, design our own circuit and come up our own method.

We come up a few project topics at beginning, after some research and discussion we finally decide working on wireless power monitor system. I guess this because it sounds easier and more useful compare to other choices, but actually building this project is much more complicate than it sounds. Since the budget is limited, lots of research has to be done before ordering any part. Tones of time were spending at the beginning of the term to do the research for the right parts.

Once we have the parts, we need learn how to put them together in order to make them works. Doing something is not just as simple as you think. We have faced a lot of difficulties in hardware design, wireless module and data analysis, actually it is everywhere, but fortunately we survived.

In this project, I worked more on GUI and data analysis. Actually I never did any GUI before. Therefore I start reading some online sources and examples at very beginning of the term. Three and half month is very short for me. Write good software required a lot of time especially in debugging. Fighting with time becomes my expertise in the past 3 months. After the hardware has been done, then we need interpret the data into some meaningful numbers or graphs. But the data is not good as we expected, because they are not perfect sinusoid wave. This is the situation that text book never mention about. Then we need use some other way to calculate the “true power factor” which is from the W. Mack Grady’s paper in 1993. Testing his method is just another nightmare, but worth it.

I paid few hundred dollars to take this course, but I think the knowledge I learn is away more than money can evaluate. Most of people will think what kind of technique knowledge they learned from a course is more important, but I think experienced in group working environment is most valuable than anything else. We are not alone on the earth, we need talk to people, but we also need learn interactive as well. Thanks for ENSC440 can give me a chance to working with a great team. It is my pleasure to work with all of my teammates together, thanks to their work.

8.5. Babak Sobhani

In designing the signal conditioning unit, I learned so much about input signal scaling and modification and filtering. The most important of all I learned that signal conditioning circuit design is very challenging and tricky. Now I am sure that if I want to be a successful circuit designer I have to work on my skills and knowledge in this area continuously.

In designing the power supply unit what I learned was that if there is a fluctuation in voltage supplied to MCU or even parts like op-amps, that fluctuation ripples through the system and causes inaccuracy. Therefore it is very important to learn how to supply constant voltage even if the input voltage to the power supply unit is fluctuating.

I implemented the RS232 communication board and I found it very interesting and useful. Prior to this project I never had worked on any project involving RS232 communication in hardware level.

I designed the circuit board for the microprocessor. I had some past experience in that area but not as deep and as involved as this project. I had never worked with PIC microcontrollers in this level and I found this learning experience very valuable.

I programmed three different PIC microcontrollers PIC16F882, PIC18F2525 and dsPIC30F3013 and I spent a huge amount of time in doing that. But now I have gained necessary skills be able to handle MCU programming in very challenging projects.

I learned an incredible amount about power calculations and power analysis. From simple computation of Irms and Vrms from a bunch of signal samples, to very complicated calculations of PF and THD factor, I learned very interesting and valuable knowledge. Now I have a very good understanding of power and very confident to take on any power related project regardless of how challenging it is.

This project helped to get my foot at the door. This experience was a very good start to take challenging projects and working on a marketable devices.

9. Conclusion

Over the past four months, we went from nothing but a simple idea to a fully operational prototype of a power monitoring system. In order to make this happen, we were required to go through an extremely work intensive period of time. We put in a great amount of effort into the research, design, development, testing and documentation of the product. The final result not only met, but exceeded our expectations and all of us are proud to have worked on this product. We have all gained valuable knowledge throughout this course, which will definitely help us in the future. We would like to thank everyone who has helped us throughout the course and assisted in the creation of this product.