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Executive Summary

This is an era where the conservation of resources is at the forefront of most people's agenda. Some do it to save money and others have more selfless motives such as the preservation and conservation of natural resources. The environment is a topic much talked about these days and with its finite resources, it is necessary to use them as intelligently as possible. Also, the economic downturn has made people be more aware of where their money is going. The idea for this project came directly from these concerns.

The design and construction of a power meter for the household is the goal of this project. The power bill is one of the highest household expenses and anything that can make it lower is definitely welcome. The power meter can be used to measure the power consumption of any electrical device in the home that is connected with the use of a plug. The device will be connected to the power meter which in turn will be connected to the household outlet. It will then display the calculated power consumption per hour, day or month. The results will be display in a dollar amount. The information gathered by the power meter will be transmitted wirelessly to a head unit that will have an LCD display.

The goal for the project is to have an accurate measurement of power. Commercial meters have an accuracy ranging form 2% to over 10%. The goal here is to have an accuracy of at least 5%. The range of the wireless transmission should be no less than 30 feet and for that reason, the Zigbee wireless protocol will be used. The meter should be affordable so it will be built as inexpensively as possible while still maintaining the accuracy goals. It will also consume as little power as possible as that is obviously one of the goals of a consumer using it.

In order to accomplish these goals, a simple but effective shunt resistor circuit will be used to calculate the current of the appliance and the voltage will be measured directly from the household socket. The voltage will obviously be lowered to levels usable for the microprocessor. An Arduino microprocessor will be used due to its low cost and ease of use. XBee transceivers will then be used to transmit the information from the meter to the main unit. The main unit will have an LCD display that will display the recorded power measurements in terms of hourly, monthly or yearly usage. Through the main unit, the user will also have the option to turn the appliance on or off. The only information that the user will need to input is the date and the cost of electricity. The microprocessors will be coded using the C language and the circuits will be mounted in a printed circuit board that will be inexpensively constructed by a local builder.

1 Definition

1.1 Motivation

The premise of this project is having a way to measure the consumption of electricity of home electrical devices. This measurement should be in dollars and cents based on power consumption. The idea would be to measure the power on every electrical device in the house and wirelessly send this information to a head unit that will display the information gathered. Using this information, the consumption of the device in dollars per hour, week, month and year would be calculated.

Saving energy has always been the desire of anyone that has to pay a utility bill. Sometimes in an attempt to save money people will go to all kinds of lengths such as turning off lights, only turning on the water heater whenever they take a shower, keeping the home temperature as high as possible, etc. Taking these measures can be useful but there is no sure way of knowing how much is being saved or if the sacrifices are worth the effort. With a scientific way to monitor power usage in the house it will be clear to know exactly how much each appliance is consuming per pay period. It could be possible that the toaster in the kitchen is pulling more current when it is not in use than let's say, a tv set in use. There's no way to know the precise numbers until they are accurately measured. Another very useful use for a home energy measurement system is to know how much a certain appliance is costing you to use since the last pay period and how much it will cost to use if the load on it stays the same until the end of the month. The winter of 2010 in Orlando Florida was very cold compared to other years. There were record lows almost every day and this happened for quite a few weeks. Many people started using the heat in the house to try and stay comfortable. When the power bill came at the end of the month many people were shocked. There were talk of bills over $600 and as much as $800. If these people had known ahead of time or even on a daily basis how much it was costing them to use the air conditioner, many of them most likely would have preferred to set it at a much lower temperature and maybe wear warmer clothes when indoors. A system like the one being designed would have shown them that they were on track to having a very high power bill at the end of the month and they could have then make an educated decision as how they wanted to spend their money.

Another use for having an energy consumption system in the house is to corroborate claims of energy savings by using certain appliances. Many companies sell their products claiming that they will save up to 50% in their energy bills. Old air conditioning systems are said to be less efficient than a newer one. The same can be said of any home appliance. The older the unit, the less efficient it can become. A brand new toaster can toast bread in less than a minute but maybe that 10 year old toaster is taking 3 minutes and obviously using a lot more energy. Appliances that are used daily and are not efficient can consume a lot more energy over the course of a year. At the same time, some of the claims made by manufacturers can be corroborated when the new appliance is bought. If your brand new air conditioning unit is using the same amount of power as your old unit, you can be certain that a savings of 50% in your utility bill is not feasible. The same can be said of any energy efficient appliance or device. Another product that is being sold as being energy efficient are halogen bulbs. The savings by using these kind of bulb can be instantaneously calculated by using a home energy system. All the consumer has to do measure the power consumed by the old bulb and then compare it to a more efficient one. This way a person can make educated purchases and not be fooled by overzealous sales people.

Right now there are a few of this type of household meter on the market. Most of them can only measure power on devices that are powered by 120 volts. Usually these devices are going to consume the lowest amount of energy in a home. The devices that use 220 volts will use much more power and controlling their use will make the biggest difference in dollars and cents at the end of the month. One goal of the design is to make sure the system can easily be used in both 110 volt and 240 volt appliances.

Another motivating factor is to make the device as user friendly as possible. If the device is difficult to set up or difficult to read or if simply the readings are difficult to understand, the consumer will most likely not use it. That is why the system will show the consumption of the appliances in dollars and cents. Kilowatt hours don’t mean much to most people but they know what a dollar is worth. If they see that they are spending $20 daily on just their air conditioning usage, they will definitely know that they need to make a change in usage if they want to save money.

Energy usage is not only a personal problem but also a worldwide problem. The resources in the planet are not infinite. It is necessary to make sure to not burn the candle at both ends. Saving energy is not only a good way to save money but it is also a way to make sure that future generations will be able to have the energy necessary to live in the conditions presently available in the United States. Preserving the planet’s resources will have an impact for generations to come. If each person keeps track of their energy usage and makes an effort to use less energy, they will be contributing to a more abundant future in this world. The environment will also benefit if less energy is consumed. Energy production creates pollution so the less of it that is needed or used by consumers, the less polluted the planet will be. A home energy measuring system and what can be learned from it will not only benefit people in general but also their children and the ecosystem.

1.2 Goals and Objectives

1.2.1 Low Power

The main objectives of having our central device working with low power are for environmental and cost conservation. The purpose of the central device is to inform the user with how much power is being consumed so they will not get a big surprise when they get their electric bill and to control the power used on electrical appliances around the house.

1.2.2 Wireless Communications

Through extensive research, the group has decided to use XBee as their means to go about transmitting the information from unit to unit. More information will be shown later in this paper on why XBee was chosen instead of the other innumerable options. Using wireless communications between the central unit and all the other power units scattered throughout the house is the key to combing all the information from each power unit and having it all displayed on a central unit. This information will send the amount of power being consumed within each of the given power units. The central unit will not just receive data, it will also transmit a command to all other power units. The command will be to either turn on or turn off the device.

1.2.3 High Accuracy

As stated above, the purpose of the central device is to inform the user with how much power is being consumed so they will not get a big surprise when they get their electric bill and to control the power used on the electrical appliances around the house. Making sure all devices in use perform at a high accuracy is key to making the device worthwhile.

1.2.4 User Friendly

Making sure the central unit is user friendly is one the main keys to having a successful project. The power units are extremely simple to use. They will be placed in the middle of the outlet and the cord of the device, which is how the power consumed is being read. On the central unit, there will be one line that will have what kind of data is being displayed, and right below will be an LCD screen that will display data translated from the power units. Also, for the on/off capabilities, there will be 3 buttons under the LCD that we go into more detail later on in the paper. 1.2.4 Figure 1 is an example of what our device will look like from the users point of view:

Item	Hour Cost ($)	Monthly Cost ($)	Power
1	00.27	$002.30	On
2	00.43	$003.30	On
3	01.27	$012.30	On

1.2.4 Figure 1: Sample display

We will now go into a little more detail about how this user-friendly display works. Lets begin with the two buttons on the left, the top button is to scroll up to see the data from other power units, once the user is at “1”, the display will go to the highest numbered unit. For instance, if there are “20” power units and the screen has item “1” displayed, once the top button on the right is pressed, it will display the computed data from item twenty. The button left button simply does the opposite where it scrolls down and once it is all the last item, it will go to item “1” and then precede to go down from there. The only button on the right is what makes the central unit a transmitter and receiver. It merely changes whether the device is powered on or off. For the sake of a simple example, if under power, it displays “on”, once the button is pressed the central unit will tell the certain device to not allow power to flow from the outlet to the cord and then “off” will be displayed there instead. And vice a versa if the screen had “off” initially displayed. The symbol (*) is to denote the buttons on the central device.

1.2.5 Power on/off capabilities

The power on/off capabilities will simply be a 1/0 command from the central unit to the power device. The microcontroller in the central unit will send a 1/0 command to a certain power device that is chosen by the user. We will be using a 0 to allow for voltage to be sent from the outlet to the device and a 1 to cut the voltage from the outlet to the device. Even when the power device acts as a breaker between the outlet and the device, the LCD screen will still display the **hourly** cost that will read $00.00 because the device is off and will display the accumulated cost from that single device.

1.3 Requirements

1.3.1 Power Sensor

The heart of the design for the power meter device is the power sensor. A power sensor is designed to measure power over a period of time. It could also be said that it measures energy over a period of time. To do this instantaneous measurements of current and voltage are made repeatedly and the total of their product is used to make a measurement over time. To get the average power, the total accumulated power is divided by the number of samples. This average power is then multiplied by the time in order to get the total power consumed over time. Since the alternating current of household appliances will be measured, the average power must also take into account the power factor. The power factor is the relationship between the phase of the current and the voltage. The average A/C power is voltage times current times the cosine of the phase angle. For the purposes of this design, when using this formula, the rms values of the current and voltage will be used.

A direct interpretation of power can be done by accumulating an indefinitely long list of measurements but that would not be very practical. It is better to designate a set amount of measurements and increment it using a counter. This makes the data easier to accumulate and manipulate. The system could, for example, accumulate the data for .01 Kilowatt hours and then increment the counter. This would be considered the resolution limit of the meter. This is the equivalent of 3,600 kilowatt hours; in other words, as the every time the meter reaches 3,600 kilowatt hours, the counter is incremented. After that amount is accumulated, a new round of measurements are made up to that same amount and the cycle repeats itself over and over. In order to reach the accuracy goal, frequent measurements are needed. If a sampling rate of 480 Hz is used, the result would be 8 samples per every full cycle of the line frequency. This is for an A/C supply frequency of 60 Hz. This sampling rate is divided it by the amount of samples and the result will be in terms of seconds. This amount is then multiplied by the average power to get a power expression in terms of seconds. To get kilowatt hours, the result is divided by 60.

The microcontroller used in the power meter to make these calculations cannot use the direct voltage coming from the power company which would be in the amount of 120V or more. An indirect measurement needs to be made. The same indirect measurement is done for the current. Then these measurements are rescaled back to their original values to keep the integrity of the calculations intact. To do this, the voltage values are reduced to a level and dynamic range compatible with digital circuits. To implement this rescaling in the design, the derived voltage reading is multiplied by a digitalization constant and their product is divided by a voltage proportionality constant depending on the circuit design. This would give us a factor by which the voltage is reduced. For this design, the voltage will be reduced using a voltage divider. The same technique is used to get the current measurement in terms where the microprocessor can read it.

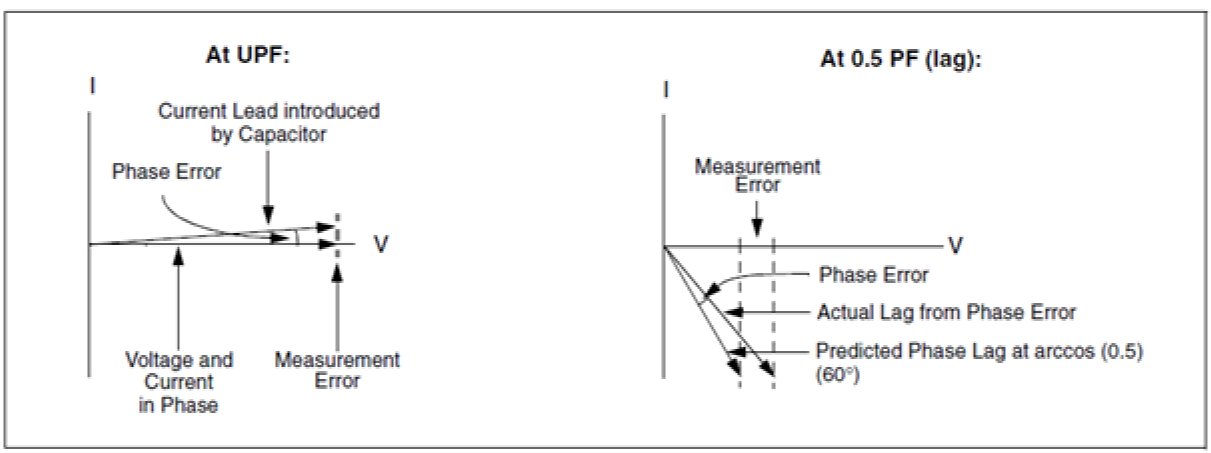
Errors in phase angle and Power Factor

When taking power measurements in A/C circuits power factor has to be taken into account. Power factor is the phase angle between the current and the voltage. Power factor can vary from zero to one with unity power factor being one. When using a current transformer in the circuit, there’s an error inherent in this device as far as power factor measurement. This is due to the phase error introduced by this device. If there is no phase error, the measured error should be constant at the various ranges of the power factor. But a current transformer will create a lag or or lead in the current. The measured error when measuring power can be significant when there is an error in the power factor measurement. When calculating this error, there will be the following equation: ((cos 0) – PF)/PF) x 100) where the angle is the difference between the theoretical phase difference and the error inherent in the usage of the current transformer.

If the current transformer creates a phase error of one angle, at unity power factor, the error will be small. But at .5 power factor, if there is a 60 degree lag, the error will be much bigger; up to 3 percent. The goal is to keep the error margin at 1% or less so power factor error is of great concern for the design. In order to compensate for this error, the error at unity and at half unity can be measured and the error for the whole range can be calculated. This calculated range error is then converted to a fixed angular phase error and compensated for by timing of the current sample in relation to the next voltage sample.

For example, if the error at unity is .2% and .7% at half unity there will be a .5% difference that needs to accounted for. Using the error equation, it is found that the error at 60 degrees will be .17 degrees lagging. So a lead of .17 degrees is needed when calculating power to compensate for the error. The .17 degrees is equivalent to 10 microseconds at 50Hz. So the voltage measurement would have to be delayed this amount of time to account for the error. If it so happens that when measuring the errors at both unity and half unity, they happen to be the same in magnitude, then no phase error correction is needed. When using a current transformer a current lag can be expected and it can be between 2 and 3 degrees. One way to make up for the introduced error is by installing a capacitor across the current transformer, which will provide a current lead that can be corrected with the aforementioned timing calculation.

1.3.1 Figure 1 shows the comparison of the measurement error for a constant phase error at different power factors.



1.3.1 Figure 1: Phase error graphs Used by permission from Microchip.com

1.3.2 LCD display

The display is what will be used to present the data output received from the individual power measuring devices. Any of the sensor devices that have power and are receiving and transmitting data will display the sensor number; whether it is supplying power to the device that is plugged into; power cost for the day in dollars; and total power cost for the month in dollars. This display must be able to large enough in individual character size as well as have the character display be dark enough so the screen could be read from a short to medium range distance from the screen regardless of the color of the output.

To do this, the display must be able to show alphanumeric as well as symbolic characters to adequately portray the information that is needed to be identified by the user. The display would also need enough horizontal space to portray all the necessary information for each sensor number on one line without loss of text or rollover to a secondary line. The horizontal space required would amount to roughly eighteen digits excluding spaces which would include: three digits for the part number allowing up to almost one thousand separate sensor devices, three digits for power status, five digits for approximate hourly cost amounting to less than ten dollars a day, and finally seven digits for accumulated monthly cost amounting to less than one thousand dollars a month. The display would need to have at least three lines of vertical text for adequate viewing of data. The Vertical lines would start with the first being the description of what is displayed such as; Sensor Number, Appliance Power Status, Approximate Hourly Cost, Accumulated Monthly Cost, etc; all of which would be displayed at all times while the sensor device is powered. The second, third and any additional lines of text displayed vertically would have data on each individual sensor. If there are fewer sensors powered than the number of vertical display lines for which the display contains, then the output display would signify this absence with the use of blank spaces.

Viewing various sensors past the number of vertical character lines would require the use of an up and a down push button which would be used to traverse through the amount of sensors, displaying no more sensors then are actually being received into the device at the given time period. The user would designate which device is currently being pointed to by the use of an arrow character pointing at the designated device, or a display such as a character alternating between a solid dark character and a space character, which will turn out to resemble a blinking action. When the user selects one of the sensors, a separate button will be able to turn the power supply of the device on or off in order to stop the flow of electricity from the wall plug to the device that is plugged into the sensor. Included along with the display will be a method of pressing buttons to enter into a setup. When this combination of buttons are pressed, it will result in a separate menu appearing, at which point the user can define the cost of power in kilowatt hours, as well as the current date and due date of energy bills, which are assumed to be repeated monthly. All buttons must have an included debouncing element within the program coding to prevent multiple button push recognitions which would create the occurrence of accidentally skipped lines or a rapid power on/off request.

This display device should come with its own microcontroller with a fairly simple method of entering in how to display text to a specific location on the output display device. The selection of location of character, as well as which character would be displayed, is to be controlled by another separate microcontroller which will be programmed separately from the display device setup. The display should also be fairly cheap to purchase as well as readily available from multiple sources to prevent the occurrences of an extended wait time in order to receive the individual parts. Since the device will be placed in a simple thermostat type box attached to the wall, it must be small in dimension as well as lightweight. Keeping within the idea of saving energy, the device must be able to run for long periods without requiring massive power usage, all while able to run on a common and inexpensive battery. Although the addition of a backlight for dark room viewing would be a plus, it would not be required for this design. As with some common displays, a backlight comes prepackaged with the display device. If this is included in the device, it would be required to be able to be turned off in order to conserve battery power.

1.3.3 Microcontroller

As there are two different uses for the microcontrollers, both have a slightly different set of requirements. Both microcontrollers must be relatively low power. The main unit should be able to have a low enough power draw to run off of battery power while all other components associated with the main unit, such as the wireless components and LCD screen, are able to run for a sufficiently long time on the same battery. The sensing unit’s microcontroller should be able to run off of wall power without greatly impacting the power consumed. As well, the sensing unit should be able to enter a lower power state once the measured device has been disconnected.

Both microcontrollers must be able to easily interface with a wireless transmitter and receiver or transceiver. Because of the complexity of the wireless communications, and the amount of data that can be transmitted and received over these devices, an adequate amount of input and output pins, both of which need to be digital, should be present on the microcontroller. The sensing unit’s microcontroller must be able to handle one wireless device which only communicates to one other while the main unit’s microcontroller must be able to handle a wireless device that can communicate with multiple sensing units at any given time.

The microcontroller should also be able to be easily reprogrammed, using either very few pins, or a USB programmer. With the main unit, the microcontroller must be able to be able to have variable reprogrammed outside of the programming environment due to the design allowing user inputs. As well, the microcontrollers should be programmed in a language that is easy to understand, easy to debug, and fairly common. Finally, the programming scheme should be able to handle mathematical operations accurately, quickly, and with relative ease.

The main unit's microcontroller will need to interface with an LCD screen. Because of this, the microcontroller is required to use a larger number of digital output pins compared to the sensing unit's microcontroller. The main unit's microcontroller will need to be controlled by buttons available to the user as well. This requirement leads to having a microcontroller with a spare pin for each of the buttons, which can be either digital or analog pins. These buttons also lead to a microcontroller that can either allow interrupting, which can be done with an interrupt pin and the appropriate software function, or allowing multiple pins to be altered at once. As well, to help with the usage of push buttons, the microcontroller must be able to realize software debouncing to prevent false triggering and potentially erroneous values.

The sensing unit's microcontroller will also be able to communicate with the power sensors. This leads to the need of either an available analog pin, which will also require an in-chip analog to digital converter, or available digital pins to take in measured values. This also means the input pins are required to be able to input the maximum output allowed from the sensor, or have it be scaled down before entering the microcontroller. The sensing unit's microcontroller must also be able to control a relay to allow the device being measured to be turned off. This must be done either with a digital output pin, assuming the relay is controlled by a voltage lower than what is deemed as a logical one or controls some other device to turn off and on the relay, or an analog output that must fall under the same limitations.

1.3.4 Wireless Transceiver

The wireless transceiver will simply play as the middleman that transports information from one device to another. This transceiver will be an XBee chip connected to all the microcontrollers. Doing extensive research on multiple telecommunication chips was the most important aspect from a telecommunications aspect. Later on, in section 2.1.2, the group goes into more detail on why the XBee was chosen over other devices. Choosing the correct chip ensures that the proper that the chip will be able to transmit and receive all necessary data within the given space and not come up short. Making sure the chip works at a relatively low power, having the proper signal strength to get to all other devices, reasonably priced and being compatible to the microprocessor used were the top priorities that came into assuring the requirements for the wireless transceiver would be satisfied.

1.3.5 Power on/off display

This power display is to be used to display the status of the power supplied to the appliances that are being measured by the sensors. The main microcontroller device, which is attached to the output display will have the ability to turn off the power supplied to the appliance plugged into the sensor. This will be done remotely though the use of the output display to select the correct device, along with the user's depression of a button labeled power. This will activate a power relay switch, which will cut power supplied to the device in order to reduce power usage. Since indicator lights are fairly cheap and common to procure they are perfectly suited for use in the prototype design. In addition they do no release much thermal energy when running, and they are very resistant to wear and tear without requiring replacement. Due to these advantages, a simple indicator light for the power display will be placed within this circuit to recognize whether power has been cut to the device when the button is depressed.

An important requirement for the project is that the specific indicator light style that the group plans to select for the power display light is easily obtainable and extremely cheap, in order to ensure low cost to the group's project for the development of the prototype. Another important aspect of this light is its simplicity, for this the group requires that the display light be connected to the power relay circuit and contains relatively few simple RLC components which are easily obtained. Power consumption is also very important due to the fact that this device will be used with power conservation in mind. The group would also not want a simple indicator light to drain too much energy from either the power outlet or the batteries. The group does not want to require the user to have to open the device and replace the device's batteries more than a few times a year. Although color or size is not of key importance, the indicator light needs to be big enough to be seen from far away but small enough to fit in with the rest of the devices inner workings. The color of the device must be of a color that can be easily seen from a distance as well as bright enough to be seen during the day and at night. Lastly, to be effective to the user the slew rate, or rate of voltage change, must be high enough that the indicator light turns off almost immediately after power had been cut from the appliance to ensure safe handling of the powered down device.

1.3.6 Software Requirements

The basic requirements of the software are very simple. The main unit's microcontroller must communicate with three different devices and one set of buttons. The wireless devices must both transmit and receive information from the microcontroller. As well, the buttons are user controlled and only function as an input into the microcontroller. The microcontroller must also output information to the LCD screen. The sensing unit's microcontroller needs to communicate with four different "devices". It must also be able to communicate with wireless devices to both transmit to and receive from the microcontroller. As well, it will need to take in a measurement from the sensor. Finally, the sensing unit will need to be able to switch a relay when given an appropriate signal.

The user button controls and its software routine has a unique and simple set of problems associated with them. This function of the software will either need to constantly be called throughout the main program or be set to an interrupt state to check if any button has been pushed. Depending on the button pushed, the microcontroller will need to either interact with the LCD screen by changing what is currently being displayed, be able to alter the values that have been inputted into the microcontroller, or send a signal through the wireless portion of the design. The buttons that don't control what is displayed on the LCD screen will need to be able to, through software, alter the initial values put into the microcontroller, such as price for per kilowatt hour, month, etc, or be able to send a signal to turn on and off power at the individual unit's source.

Another main software requirement is to have the microcontroller print out information to the LCD screen. The software will need to constantly be updating the LCD screen with updated information received. As well, it will need to display, when the appropriate buttons are pressed, a prompt to change parameters in the microcontroller. As well, it will need to be able to display different sensing unit's output when desired.

The last major software requirement is for the wireless transmission and receiving. The wireless portion of the software is the most complicated as it will need to communicate with multiple devices. The software will need to be able to cycle through all incoming signals in a reasonably fast time to be able to constantly update the readings from the sensing units while still holding communicating with each unit long enough to get an accurate reading from each of the units. As well, whenever the microcontroller needs to turn off a specific sensing unit, determined by user buttons, it will need to send a signal to turn off power on the sensing unit.

On each of the power sensors, the microcontroller's software will need to be able to take in the measured power as a digital value. This information needs to be processed in the microcontroller and sent through to the wireless transmitter. As well, the software will need to constantly be checking for a received signal from the main unit through a wireless receiver. Once a signal is received to shut off power to the item being measured, the software will need to have the microcontroller break the connection in the circuit. As well, once the connection has been broken, it will still need to measure and send any measurements.

In addition to the software requirements brought upon by the hardware, the software, for both the sensing units' microcontroller and the main unit's microcontroller, must have the ability to perform mathematical operations very accurately and quickly. This is required to adequately show results from measurements on the LCD screen as well not wasting time performing simple operations.

1.4 Specifications

1.4.1 Power sensing unit

Since this device is going to be required to disconnect the supply of power from the wall with a relay, the device will mimic a surge protector in that each appliance would connect through this device. Since the device will be connected to the power supply already, the group would like it to draw power from the connected socket. Not wanting to skew the data, the group would like the device to be low powered while draining energy from the wall so as to not destroy the accuracy of the device. The group also would like it to be able to continuously output data wirelessly to the wireless receiver unit for accurate readings. The group would like the device to not take up too much room on the socket, so the group hopes that the device is small in size with an LED light displaying power status. With these desires and needs, the group has come up with a list of specifications as described below.

- Consumes less then 10W of total real power (Approximately equivalent to 1200 hours of usage on a 9V battery).
- Measures current up to 7A (similar maximum as commercial grade “Kill a Watt” power sensor).
- Low voltage sensor measures voltage up to 125V (similar maximum as commercial grade “Kill a Watt” power sensor).
- Accuracy within 90% of power measurement.
- Able to cut 100% of power from device plugged into wall.
- Presented in a small package size less than 8” x 6” x 4”.

1.4.2 Wireless receiver unit

This device will not be connected to any power source, so the group needs the device to be connected to an external battery. With an external battery, the group does not want the user to consistently have to change the battery every few weeks, so the group wants the device to have very low power consumption. The group also would like the device to handle multiple devices’ wireless signals, with the LCD screen showing up to 3 digits worth of devices. This receiver must be able to send and receive data to the main microcontroller to store data on power consumption rates, which will be displayed as a viable output for the user to understand. With these needs, the group has come up with the following list of recommended specifications.

- Draws power from wall power
- Consumes less then 10W of total real power. (Approximately equivalent to 1200 hours of usage on a 9V battery)
- Able to read power consumption of multiple devices at once, up to 99 devices.
- Reads power consumption of a specific device at 1 reading per second for accurate power measurement.
- Able to submit collected data to the microcontroller for each specific device in a specific memory location to find out accumulated power consumption over the course of 60 minutes as well as 1 months worth of data, ensuring that no counting errors occur.
- Must be able to take collected data, and determine every 60 seconds the approximate power consumption per hour.

1.4.3 Display Screen and user interface

Since this device will be attached to the same printed circuit board, as well as within the same container as the wireless receiver unit, the group would like the LCD display screen to operate off of the same battery used within the unit, once again ensuring low power consumption to prevent a need to change batteries every few weeks. Furthermore, since the device will be required to display multiple sensors at once, the group would like the screen to be rather large in size vertically and horizontally to output the required data. The device will also need three buttons to traverse the menu as well as modify settings within the microcontroller. Lastly the device cannot be too big or heavy that it’s weight will prevent mounting the device on a drywall partition. The following list is the specifications for the device to follow in order to meet the group’s needs.

- Draws power from the same wall power used in the wireless receiver unit.
- Consumes less than 3 W of total real power which is similar in consumption to that of an air conditioner thermostat (Approximately equivalent to 2000 hours of usage on a 9V battery).
- Uses an output display, which must be able to output a total of 160 characters on the screen at one time. (4 X 40 characters)
- Will output 1 horizontal line of text for a display to help the user to understand what the output of each column means.
- Will output 3 horizontal lines of text, allowing 3 devices to be read at any time.
- With each horizontal line, the display will be able to output the device number, power on/off status, approximate power consumption per hour in terms of dollars, and accumulated monthly power cost.
- Will have an up and a down push button to navigate through the list of transmitting devices.
- Will have a power button to turn off supplied power to the plugged in appliance.

- Will have one switch to turn on, or turn off the display device’s backlight
- Will have a symbol or character which will be used to designate which power sensor is currently selected.
- Presented in a small package size less than 3” x 6” x 2”.

2 Research

2.1 Methods

2.1.1 Power Sensors

One very important part of this design is the power sensing circuit. Not only does the design need to have an accurate sensing system but it also has to work well for the application. In this case, the design has to be compact enough to fit in a small plastic box that will be plugged into the wall. It also has to be able to measure a wide range of current magnitudes and two voltage ranges; 120V and 240V. Obviously the system has to be designed to work at safe levels given the applied voltages and currents. The heat produced needs to be kept at a minimum or completely eliminated.

There are various ways in which power can be measured. Each particular method has its advantages and disadvantages. To start with, the characteristics of each system will be studied and a preferred method will be chosen. The first method would be to install an inline system for each appliance whose current will be measured. This would mean that the actual wiring in the house would have to be cut for each outlet and the system installed. The team chose this as the first one because it is the least likely to be used. For this project it is needed for the system to be user friendly. Using an inline system would definitely not be user friendly. Installation would have to be done by an electrician and obviously the reliability of the system would be compromised by the installation procedure. The system should be easy to install by the customer and be very reliable as far as installation. Obviously a system that needs to be installed by cutting wires is not going to be the best choice. There are other less invasive methods that would be much more applicable to the needs of the system.

The current can also be measured by using a unit that plugs into the wall outlet and the appliance is then plugged into the unit. Inside the unit there could be a shunt resistor that basically measures the voltage drop across the resistor and using the value of the resistor, the current can then be calculated. The problem with this system is that the appliance has to be plugged directly to the unit. This would be fine if there were only one type of plug but the plug sizes for 120V and 240V appliances are different. That would mean that the sensor could only be made for one type of connector and then an adapter would have to be used to connect the other type of connector. For example, if the unit is made to accept the more common 120 plug connector, then an adapter for the 240V connector would have to be made and added to the system. This extra adapter just adds to the complexity of the system. One goal of this project is to use the least amount of parts possible. The reason for this is that the least amount of parts the system uses means there less chances for parts to fail. The simpler the system the more likely it will be reliable in comparison with a more complex system. An adapter would add complexity to the system and could be seen as cumbersome as far as installation. Another problem with using a shunt resistor is the amount of heat generated by the resistor. Electronic parts don't like too much heat. Since the design measures the power of AC units and refrigerators, a method that can do so reliably and with the least amount of heat generated is needed. By using a shunt resistor complexity would be added to the system as it would be needed to dissipate the heat created as the current passes through the resistor. With high wattage appliances, this could become a problem and an additional factor (heat) would have to be included in the equation. Excessive heat in the system would mean having to engineer a way to dissipate this heat. This would make the system less reliable and more complex meaning that there is more chance for failure which is to be avoided. There is also the limitation of not being able to measure high current with a shunt resistor but this should not be a big problem for the circuit as the currents that will be measured should not be over 100 ohms. The shunt resistor also consumes a large amount of power compared to other methods. A smaller shunt resistor could be used and it would consume less power but if it is smaller than 125 micro Ohms, there can be a problem with the resulting low Vrms causing the analog to digital converter to not get a good signal to read. This would in turn create erroneous or false readings in the power calculations. A big advantage of the shunt resistor method is low cost and simplicity as only a resistor is needed to measure the current. This is also a big consideration as far as this project as one of the goals is to use the least amount of parts possible for the design at the lowest cost possible.

Another way to measure current would be by induction. By using this system, there is no need to cut into any wires. A sensor would measure the current flowing through the cable of the appliance by simply feeding the cable through the sensor. There is no need to cut any wires or any difficulty in the installation. For this system to work as described, an external sensor would be needed. An external unit would be used that would have a sensor attached to it. The sensor would then wrap around the cable of the appliance and measure not only the current but also the voltage. By using a sensor that wraps around the cable, the system can be used on any appliance that has a cable! Meaning of course, that all appliances can have their power consumption measured as all appliances in this time and age use cables as a means to be use electricity. Another advantage of using induction to measure current is that there is no heat generated! There are no resistors to get hot since what is being measured is the magnetic field created by the current. This current of course will only flow through the cable of the appliance and not through any internal circuitry of the unit. This is an advantage as some of the appliances that will be monitored can have pretty high wattage readings and the lower the current in the unit the safer it will be to handle and use. This of course makes the unit much more user friendly as the user is isolated from the high currents flowing through the cables.

2.1.1.1 Current Transformer

Another way to measure current is by using a current transformer. There are some very good reasons to use this type of sensing technology especially safety. The reason this system is safe is because it isolates the current being measured from the rest of the circuit. Very much like the Hall Effect Sensor. The way in which this is accomplished is by using two windings inside the transformer. The current is transferred from the primary to the secondary windings which allow total control of the amount of current going into the circuit. A large current can be transferred as a much smaller current while still being completely equivalent. Of course, that equivalency has to be established in the calculations to get the right meter readings. The transformer set up can handle much higher currents than a shunt and it also consumes less power. The downside of the transformer is that, since it is obviously more complex than a shunt, it might cost more and it also might not be as accurate. Other downside to the transformer is saturation of the core due to a current spike. When the core becomes saturated, the device becomes non linear which is something that needs to be avoided. The device needs to act in a linear and predictable manner in order to get precise measurements. One way to counter the saturation of the core is by using a Mu-metal core. Mu-metal is a nickel iron alloy that is very useful in attenuating static or low frequency magnetic fields. The problem with the Mu-metal core is that it has a higher non linear response. This non linear response occurs at lower currents and can cause errors in the power measurement. One way to compensate for this non-linearity is by compensating for it in the firmware of the system. This would be established and corrected in the testing phase of the design. Due to the transformer design, high currents can be measured accurately and with a lower degree of heat being inducted into the design. At the same time, it is still not as heat free as the Hall Effect design which also completely isolates the system from the current being measured.

2.1.1.2 Hall Effect sensor

In order for this design to work, a hall effect sensor could be used. The reasons for choosing a hall effect sensor are isolation from current in wire being measured, lack of heat production and precision. The only drawback is that for the hall effect sensor to work it needs an excitation voltage meaning that a voltage source will be needed to be implemented on the circuit. With other kinds of measuring systems, like a resistor, this is not needed but it is a small price to pay considering the advantages. The Hall Effect sensor also has the advantage that it measures current without having to break the circuit. It can be used to measure current of any home appliance. Specifically, it should help to measure the higher current appliances with ease.

There are quite a few types of Hall Effect sensors. Most of them consist of a loop or a square in which a wire is placed and as the current in the wire passes, the magnetic field is then converted to a current value. The wires being measured obviously have plugs that need to fit through the holes in the sensors. The biggest problems are the plugs for the 240V appliances as they are quite big. For this reason the easiest and most convenient type of sensor would be a round one that is big enough to fit the plug through it. There are two types of these round plugs; one that is a closed loop and the other which opens up. The ones which open up basically have two halves that open and the wire is placed inside the loop. The advantage with this type of sensor is that the size of the plug does not matter; only the size of the wire. And the wires to be measured are no bigger than 60 gauge which is small enough to fit through any of the open loop sensors on the market.

2.1.1 figure 1 shows what a hall effect sensor looks like. The wire being measured goes through the loop. These two sensors have closed loops.

2.1.1 Figure 1: Hall Effect Sensor- printed with permission from Honeywell International Inc

2.1.1.3 Voltage sensor

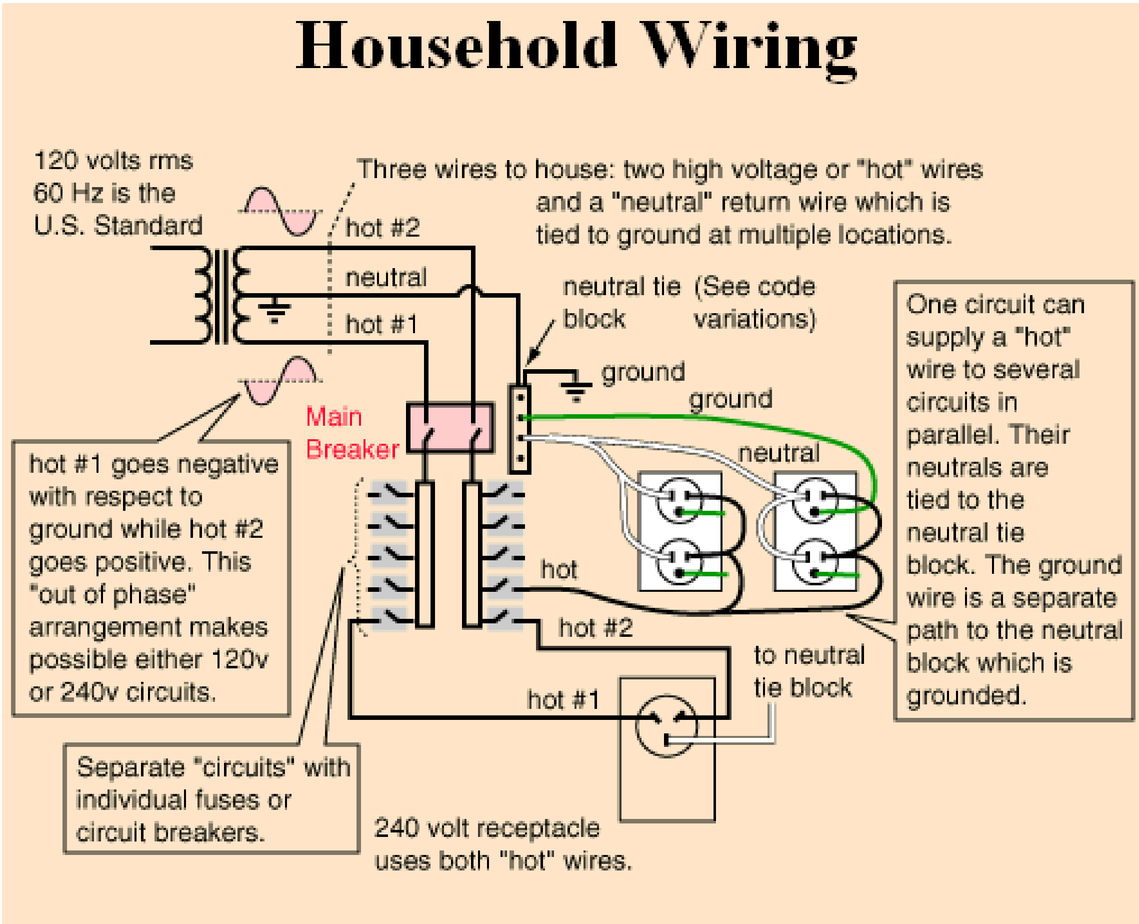
In order to measure power voltage will obviously need to be measured. There are a variety of ways to measure voltage which will be discussed later. One of the considerations for this project is where that voltage will be measured. It could be measured at the appliance itself using the voltage that feeds the appliance. This would mean that there would have a direct connection between the sensor and the appliance. This would be fine if all appliances had easy to reach connections.

Most Air conditioning systems are directly wired to the home wiring. This means that there might not be an easy way to measure the voltage at the Air conditioning unit. One of the solutions to this problem it to have the display of the system, which will be connected to the home's wiring via a plug, measure the voltage using a sensor. It can be assumed that the voltage at any sensor in the house will be the same. Therefore it would not be needed to have a voltage sensor at every appliance. This would also help us overcome the problem of the different plug sizes for 120V and 240V appliances. One method is to simply take one voltage reading and calculate the voltage at the appliances that are being measured. Then the voltage reading at the head unit can be multiplied it by two to make the power calculations.

Homes in the United States have two "hot" wires going into the electrical system. This voltage has been stepped down to 120V with a transformer. The need for two wire feeding 120V into the house is so that the addition of both of the will be able to power the appliances that need 240V. The rest of the plugs in a house are fed in a parallel fashion so that all plugs have the same voltage being fed to each. It is being assumed that all the connections at each plug are secure and have the same resistance so that the voltage is the same for every plug. For the outlets that have 220V all that is done is to take two wires that each has 120V and add them to make the 240V needed. This is of particular interest because it means that if the voltage is known at any plug in the house that uses 120V, it's possible to calculate the voltage being fed at the 240V outlets. The voltage source is the same. The transformer feeding the house with 120V feeds all outlets both the 120V outlets as the 240V outlets.

One problem to overcome is how to power the sensors at each appliance outlet. The wires for the AC unit are covered in a sheath and it is almost impossible to feed off of it. Therefore it is best if the power sensing unit is self powered so that it won't be necessary to use an outlet to power it. Current would only need to be measured at each appliance and then wirelessly send the data to the main unit and then use the voltage measured at the head unit to make the power calculation. Fluctuations in voltage are the same for every single outlet in the house as they are all connected in parallel. And even though the plugs that feed 240V have two different voltages going into them, in the end, it is the same 120V that is fed throughout the house. That means that any fluctuation in the 120V outlets will be reflected on the 240V outlets. So using any of the 120V outlets should give us a quite accurate representation of the voltage at any appliance in the house.

2.1.1 figure 2 shows the schematic of the typical home in the United States. Of particular interest is how the outlets are all in parallel and how the 240V outlets are simply two 120V live wires added together.



2.1.1 Figure 2: Household wiring schematic Used with permission from HyperPhysics.com

2.1.2 Wireless Transceiver

The group decided to use XBee as the means of wireless telecommunications. There were a few other contenders but in the end, the group came to the conclusion that XBee would be the best means of wireless telecommunications. We had a total of four possible means of telecommunications. Each form of technology was heavily scrutinized to ensure the group that, whichever piece was used, would be the best choice in many ways. The group learned a lot about the basics of different forms of telecommunication technology. From all the research on all the different kinds of technology, the group was able to understand why the XBee was the ideal choice. This choice was not easy. The four telecommunication technologies looked at were XBee, WiFi, Bluetooth, and ZigBee. After examining the four, pretty early into the research, the group was able to knock out ZigBee because that was by far the worst for them from different websites and blogs by multiple users. Bluetooth was next to be taken off the list but after nearly a week of reading up on Bluetooth, the group agreed Bluetooth was good for certain applications of wireless telecommunications, but it would not be the ideal choice for this project. For about two or three weeks, the group would read different postings on both XBee and WiFi and after making the decision based off its accessibility to more microprocessors, the XBee was chosen. Extensive research on all kinds of the telecommunication chips can be found section 2.2.4.

2.1.3 Microprocessor Programming

One of the main options for programming of the microcontroller is using MIPS assembly language. The assembly language uses a fairly simple and basic architecture. This approach requires addressing of registers for all commands. The biggest disadvantage of this programming scheme is the relative complexity; while it is very basic, as all operations are basic in the sense of a single operation occurring per code line, it seems complex compared to a more native and familiar programming scheme. As well, due to the design requiring multiple loops to be run through constantly, programming in assembly would become more complicated.

The other main option, and the one chosen to use for the designed project, is the C programming scheme. This programming scheme allows for a much less complicated overall program which is more versatile. As well, C programming is a much more native programming language, allowing it to be easier to create, follow, and debug if needed. Further, to simplify coding, C programming includes many standard libraries, allowing operations to be manipulated more easily.

Many of the functions that will need to be constantly called throughout the program are made easier through C as well. This is because the simplified looping schemes, as well as different types of looping that can easily be implemented in C. As the microprocessor will need to constantly be printing out to an LCD screen, it is also easier to perform a print in C rather than in assembly code.

2.1.4 LCD Interfacing

This section of the documentation will discuss how the LCD with be interfaced with during its use, as well as how it will interface with other devices. The first section of this section will be concerned mainly with how the LCD will be interfaced with the micro-controller and will describe some of the instruction set of the HD44780. Then this section will describe in detail how the device will interface with the user, allowing such actions as letting the user enter a initial set up menu where they would be able to enter the current date and the cost of power per kilo-watt hour. In addition, the user interface will allow the user to be able to turn on or turn off the LED backlight, browse the list of appliances currently being monitored, as well as turn on or turn off the supplied power to those appliances.

The most commonly used microcontroller in a character liquid crystal display is the Hitachi HD44780 microcontroller. This microcontroller is set up to operate a max of a 40 characters by 2 line array of characters on an LCD screen. Almost every other microcontroller that is used in other brands of character LCD uses a similar or compatible scheme for implementing characters on an LCD. For character LCDs with more than 40 characters and lines, they implement the same scheme of control for the microcontroller, but have a second microcontroller with a second enable bit to operate the second microcontroller using the same data bits that come from the main device's microcontroller. The main differences between the HD44780 microcontroller and those that use the same scheme of control are the producer and developer of the device, the power / temperature characteristics of the LCD, as well as the pin placements for each of the required data entry pins.

Having a 40 characters by 4 lines device, which is what will probably be used within this project requires an input of eighteen pins for power, data, and logic of the device. In each device that is HD44780 compatible, there are eight pins for data input called DB0 through DB7. These eight data inputs will be connected to the output of the main device's microcontroller and will be used to transmit first the specific location selection for each individual character location on the device. Once that information has been loaded onto the device, an instruction is operated to point the devices memory to that location. Then the main microcontroller will transmit which specific character, received via the data bits, is required to go into that character location and another instruction is operated and the device will output that character.

The following two charts below, 2.1.4 Figures 1 and 2, display which bits mean which characters according to the programming scheme followed by the HD44780 LCD microcontroller. This chart is arranged to show which character is represented by which logic digits, the top row represents the upper 4 bits of the device, while the leftmost column represents the lower 4 bits of the device. The programmer would use this chart to represent words by picking the character required, and then the programmer would find the upper 4 bits, then the lower four bits to find the logic input bits required to go into the device to represent the character. This chart will give the reader insight into how the device actually recognizes the inputted data logic, and outputs understandable data to the LCD device.

2.1.4 Figure 1: Character charts of HD44780 compatible controller- provided by Newhaven Display International

Lower 4 Bits \ Upper 4 Bits	0000	0001	0010	0011	0100	0101	0110	0111	1000	1001	1010	1011	1100	1101	1110	1111
xxxx1000	(1)		(	8	H	X	h	x			ｨ	ｸ	ﾈ	ﾘ	√	x̄
xxxx1001	(2)		)	9	I	Y	i	y			ｩ	ｹ	ﾉ	ﾙ	⁻¹	y
xxxx1010	(3)		*	:	J	Z	j	z			ｪ	ｺ	ﾊ	ﾚ	j	千
xxxx1011	(4)		+	;	K	[	k	{			ｫ	ｻ	ﾋ	ﾛ	×	万
xxxx1100	(5)		,	<	L	¥	l	|			ｬ	ｼ	ﾌ	ﾜ	¢	円
xxxx1101	(6)		-	=	M	]	m	}			ｭ	ｽ	ﾍ	ﾝ	£	÷
xxxx1110	(7)		.	>	N	^	n	→			ｮ	ｾ	ﾎ	ﾞ	ñ	
xxxx1111	(8)		/	?	O	_	o	←			ｯ	ｿ	ﾏ	ﾟ	ö	█

2.1.4 Figure 2: Continued character charts of HD44780 compatible controller - provided by Newhaven Display International

There are also various logic pins that are required by the device to operate and output a correct string of characters onto the display. One of these pins is the read / write select signal pin, called R/W, which tells the device whether to read from the main microcontroller, or to write to the main microcontroller to give feedback regarding the status of the device, as well as letting the LCD device be able to tell the main unit what is printed onto the device at any point in time. For this project, the device will mainly be reading from the main microcontroller, and this logic bit will be set to read. Another logic based pin is the register select pin, called RS, which selects whether the device will be computing an operation or whether the device will be outputting data to the LCD. If the pin is set low, the device is operating a command that the LCD is going to be instructed to do. However if it is set high, then the device is ready to place one of the character from the charts onto the selected location based on the bit selection on the data pins. Lastly, there are two enable pins E1 and E2 which activate a given command on each of the upper 2 lines and the lower two lines, respectively.

To fully understand how the logic operates, here is an example to quickly understand how the device works. If the command is to put a letter on the 1st row or 2nd row, any column, a location is set by the data bits in RS = 0 mode and enabled using enable bit one, and data is entered in RS=1 mode and enabled using enable bit one, resulting in a character displayed in the 1$^{st \text{ or } 2nd}$ row, and the specified column. However if the location is in the 3rd or 4th line, the same procedure is to be followed using the enable bit two as opposed to the enable bit one. These instructions will be covered in more detail later on in this section.

The chart below, 2.1.4 Figure 3, shows the address locations of each individual character locations within the LCD screen. The first and second row of this chart is controlled by the enable bit one, while the third and fourth row are controlled by the enable bit two of the LCD device's pin setup.

Display position

1	2	3	4	5	-	-	-	-	-	-	-	-	-	-	36	37	38	39	40
00	01	02	03	04	-	-	-	-	-	-	-	-	-	-	23	24	25	26	27
40	40	41	42	43	-	-	-	-	-	-	-	-	-	-	63	64	65	66	67
00	01	02	03	04	-	-	-	-	-	-	-	-	-	-	23	24	25	26	27
40	40	41	42	43	-	-	-	-	-	-	-	-	-	-	63	64	65	66	67

DDRAM address

2.1.4 Figure 3: Address values of the HD44780 compatible controller – provided by Newhaven Display International

The remaining six pins of the device are either not connected, or are the power sources of the device, and therefore will not interact with the main microcontroller of the circuit. One pin, VDD, is the main power supply for the two HD44780 compatible microcontrollers. The logic of the device is typically set to generally be around 5V, which is usually what the VDD is set to. Another pin, LED+ is the main power supply for the LED backlight, and therefore will also generally be around 5V. The last power supply pin is VO, which is the power supply for the contrast of the device which is set at .5V. The remaining two pins that are actually connected to the printed circuit board include the ground power supplies, which are the pins named LED- and Vss. The last pin discussed here is not connected to anything and is labeled NC; this pin is here for purposes of evenness of the layout of the device to enable the mounting the device to a printed circuit board much easier.

After conducting further research into the project, the group has decided that they will use a character LCD from Newhaven Display International. The device, the NHD-0440AZ-FL-YBW, is a yellow / green LED backlight display that is a 40 character by 4 line character LCD which is driven by two built in SPLC780D microcontrollers. As later discussed in detail in section 3.1.1, this device meets all the requirements laid out in the requirements section of this documentation and uses a HD44780 compatible driver for a decent price.

The pin layout is similar to the Hitachi HD44780, however the order is rearranged. The pin layout is as follows in 2.1.4 Figure 4 below. The leftmost column of the figure is the pin number as outlined on the LCD display itself. The center column lists the names of the pins to help the reader understand what each pin means, and the rightmost column signifies what the device is going to be connected to on the printed circuit board.

Pin No.	Symbol	External Connection
1-4	DB7-DB4	MPU
5-8	DB3-DB0	MPU
9	E1	MPU
10	R/W	MPU
11	RS	MPU
12	V0	Power Supply
13	Vss	Power Supply
14	VDD	Power Supply
15	E2	MPU
16	NC	-
17	LED+	Power Supply
18	LED-	Power Supply

2.1.4 Figure 4 – Pin layouts of the HD44780 compatible controller provided by Newhaven Display International

There are several different instructions that the device can be ordered to operate. All of these functions can be found in the datasheet from http://www.newhavendisplay.com listed under NHD-0440AZ-FL-YBW. In addition to information about the possible commands including those that are not used, all the details regarding the pin status will can be located on the same datasheet in page 6 under the list “Table of Commands”. The important commands that will be used within this project will be described in detail in the next few paragraphs.

The most important instruction that will be used within this device is to turn the device on, labeled the “Display ON/OFF Control”. This is so important because without this command the device will not display anything. This command will be started during the initialization section, when the main console begins receiving power from the battery. This command will be sent from the microprocessor to the LCD display’s two microprocessors and will be implemented one after the other, allowing both LCD screens to turn on. For a better user experience the cursor and the cursor blinking action will not be shown to the end user, and the device will be instructed to turn on without the cursor showing. While initialization is still occurring, the “Clear Display” command will also be sent to clear the display, which will delete all data that is output to the display. This will be used during initialization of the device to ensure that all data is cleared from the device and no memory is stored within the microcontroller.

Also during initialization, the “entry mode” command will be implemented to ensure that the cursor will be set to move in an increasing fashion with display scroll off. This will allow the user to type in a letter into a specific address, and then the cursor will move to the next address to implement a character. With this setup, the main microcontroller would only be required to select one address to allow the main microcontroller to type out an entire line with only one character address selection, which will help to speed up the process and will simplify code development. Lastly the “function set” command will be implemented to secure that the program is running in 8 bit mode, with 2 full lines of display per microcontroller, at 5 pixels by 8 pixels per character. This will allow the programmer to display and control all 4 lines of text for a full functioning display. All of these commands must be done in initialization to both of the microcontrollers, one after another, to ensure that each microcontroller will operate properly.

For this projects method of programming style, after initialization is complete there are only two extra commands that would need to be implemented at any time. The first command that would be used would be the “write data to RAM” command. This command is implemented to actually display a character from the data bits onto the LCD for viewing by the user. When the first “write data to RAM” is activated by the enable bit one, the first character location on the LCD screen will output whatever character is represented by the triggered bits. Then the cursor will move to the next location on that line, and each and every character of the top line will be placed into RAM, allowing the user to see the entire top lines display. The last command is the “set DDRAM address” command will be implemented to move to the beginning of the second line, located at address 40. The device will then output the data from the second line via the “write data to RAM” command as described above using enable bit one. Then the device will output the data from the third line using the same method of DDRAM address selection of location 0, followed by writing data to the RAM by the described method but triggering it with enable bit two. Lastly the device again sets the DDRAM address to 40 using enable bit two, and outputs data to RAM as before. After this entire setup has occurred, the entire LCD will have output displayed onto it. Using these commands, the information displayed can be updated for new data very quickly, and can be updated at least every 60 seconds, as stated within the LCD display requirements.

With the microcontroller interfacing fully explained, the user will be able to see the total amount of power cost that they will receive for a given appliance. However each area of the country has a different power company and different power costs associated with them. When the user first receives the device he must input the cost per kilowatt hour that the power company charges. For the user to input this data, the group has decided that the user must press and hold both arrows buttons at the same time to enter the setup mode. The mode will display the words setup which will follow with a display of a dollar sign followed by three digits, a point symbol, and two more digits to signify cost. The user will then cycle through these digits with the power button as the cursor blinks’, showing which digit has been selected. When the user finds a digit that he would like to modify, he would simply press the up or down arrow to increase or decrease the value of the digit displayed. When the user finds a price that correlates to his current power costs, the user will then hold the power button down for a short period of time.

After the microcontroller recognizes a held power button, the device will ask for the current month and day. Similar to entering the price of the electric bill, the user would use the up and down arrows to select the months and day, and cycle through the list of digits to be able to edit both the month and the date. When the current date has been input, the user will then hold the power button again for a certain period of time to input the due date of the power bill so the device can track monthly accumulated costs. Once again the user will enter the bill's due date using the same method described above. Finally after data entry is all finished, the user will hold the power button for the last time and the user will leave the setup mode. The microcontroller itself will store data on the order of the months and the days each month contains, excluding leap year, in order to keep track of when the accumulated monthly cost portion of the device will reset to zero. The information that is inputted will be stored within the main device microcontroller for calculation and display of power costs and monthly costs.

Once the device has been set up to display data, and the microcontroller has stored the cost of power per kilowatt hour, the device will display an arrow to point to the device which is currently under user control. The user can then press the power button to turn off the supplied power to the appliance being monitored, or traverse the various other sensors using the up and down arrows. When a device is chosen to be selected that is past device number three, the screen will output devices four through six, and several devices can be monitored at any time by searching through the list of available sensor units. If, for example, only devices 1,3,13, and 180 were operating; the device would display devices 1,3, and 13 on the first screen and the device 180 on the second screen after the user has scrolled down. This will prevent the user from having to search for a long time through the list to view the correct data. Lastly a switch on the side of the device will allow the user to turn on an LED backlight for nighttime or bright conditions to allow the user to see the data output to the LCD screen.

2.1.5 Circuit Board Fabrication

The design of the project has enough complexity that it warrants using a printed circuit board. The printed circuit board will be a 2 layer board. Although this slightly complicates the design of the circuit board itself, it reduces the overall size and improves the capabilities of the printed circuit board being designed. This overall circuit board design will be produced using a program such as Eagle. Once a schematic has been created, the layout for the circuit board should be created.There are two main approaches to creating a printed circuit board. The first would be to manufacture the entire board by hand. The second method is simply ordering the board from a printed circuit board supplier, such as ExpressPCB.

To manufacture the circuit board by hand, quite a few things are needed for the process. A drill with fine bits for drilling lead holes for parts, a copper board for each circuit board needed, and etchant to take away unwanted portions of the copper board on the final board are a few of the items required. This approach to creating a printed circuit board comes with a few drawbacks. The first is safety associated with it, as it required handling an acidic substance. Secondly, this approach is very easy to make mistakes which can include etching too much of the copper board away, not etching enough of the copper board away, and drilling a hole too large or too close. Finally, as this design will utilize two layer circuit boards, the copper layers must be perfectly aligned for the circuit board to function properly. This does have a rather large advantage over ordering a printed circuit board of easily altering the board as needed, as all the leads are exposed and able to be changed on the surface of the board.

The other main approach is to order a printed circuit board through a vendor such as ExpressPCB, PCB123, or 4PCB. This approach has the advantage of being a high quality, two-layer circuit board with potentially no flaws from the manufacturing process. However, this process does have a few disadvantages. The first is the potential price difference, as a vendor ordered printed circuit board may be more costly than creating one. As well, the designers are subject to shipping times. Finally, the worst drawback to ordering a printed circuit board is the potential design flaw, as it can't easily be fixed as a handmade circuit board would be.

Of these two approaches, it was decided to purchase a printed circuit board from a vendor. This mostly is due to the fact that little to no manufacturing flaws will be made to the circuit board, potentially become more expensive as well as requiring more time to produce.

2.1.6 Surface mounting procedures and methods

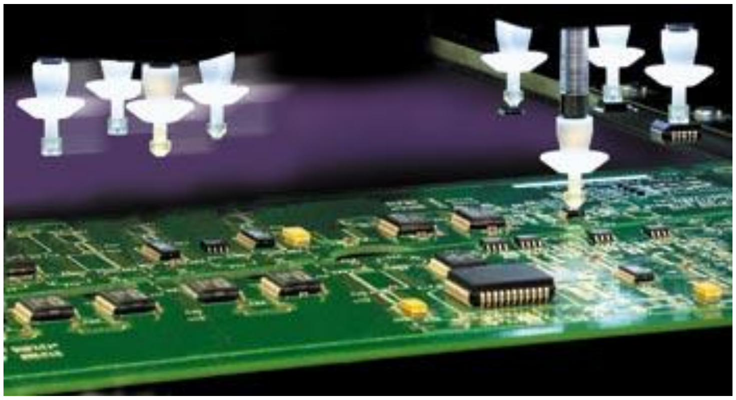
There are two types of widely used common methods for surface mounting parts directly onto a printed circuit board that you have created. The first, through-hole technology, is widely used for prototyping devices since it is generally easy to use, handle and solder. The other more commonly used among production ready devices is called surface mounting which offers a lower profile design which doesn't interfere with other layers of the printed circuit board.

Through-hole technology is a type of mounting scheme used for almost all electrical device construction from the 1950's to the 1980's until the invention of Surface-mount technology. Although it is no longer the most widely used method for mounting components and devices to printed circuit boards, it is used by electronics design engineers for early prototyping of devices. This is done because of the simplicity of soldering devices to the printed circuit board. Thru-hole technology incorporates the use of drilled holes directly into printed circuit boards into which components to be mounted are inserted. After the components have been inserted into these holes, the design engineer would flip the board over and solder the components directly onto the device. It is a technology similar to that of a common breadboard or perfboard in which components are inserted into holes to connect components and therefore is more comfortable of a technique for inexperienced electrical engineers to use.

This method provides a stronger attachment between the components and the printed circuit board and is largely used for installing larger components such as some capacitors, inductors and large sized semiconductors. The downsides to using the through-hole method are the fact that it is more expensive to produce. This is due to the fact that the device developers must get the printed circuit board developers to drill through the boards for the holes to be located in for each and every design, ensuring that no wires are destroyed. In addition to this, layers below the top layer of silicon can be affected by the drilling, which causes considerably less efficient use of real estate that the silicon could actually provide. Lastly, through-hole devices have a significantly larger height above the silicon when compared to that of a surface mounted device. This is a problem when making low profile devices and is one reason as to why through hole technology has slowly phased out of production.

Surface mounting has become the most widely used type of attachment method for bonding circuit components to printed circuit boards ever since it became widespread in the late 1980s. It utilizes a production line style of placement in which components are placed in their appropriate locations atop solder pads, or copper pads filled with solder paste. Solder paste is a material filled with floating powdered metal fragments in a temporary adhesive which is used to hold the components in place temporarily. The components are then deposited atop the copper solder pads using a device known as a pick and place machine. This is currently done via an array of suction cup tipped devices which pick up the correct part needed from a tape dispenser of sorts lined with these parts. It then photographs the components and aligns them according to the operator's instructions, which are taken from the original PCB design. After the components have been properly aligned, they are placed upon the copper pads, ensuring that all leads have a connection to the solder paste.

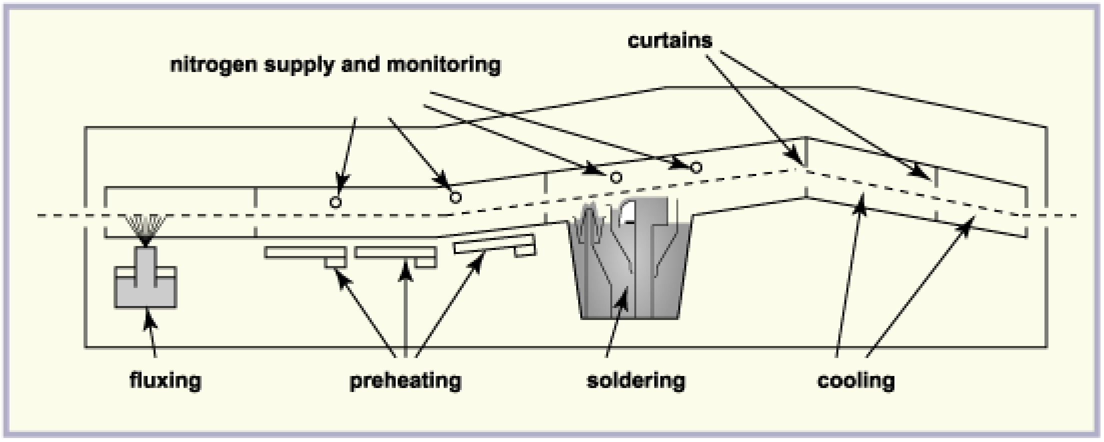
Displayed below is 2.1.6 Figure 1, this figure displays a diagram which details the suction cup tipped devices grabbing the required components from the line and properly aligning them to the surface of the printed surface board. The diagram shows the pick and place machine in a working status, and the image is shown as if a time lapse photo was taken to fully illustrate the fact that this device moves extraordinarily fast and far exceeds the speed and quality of a typical worker's skill.



2.1.6 Figure 1: Pick and Place diagram printed with permission of John Pompea, Contact Systems, under the creative commons license

In large industrial facilities that use surface mounted devices, the entire circuit board is warmed slowly until it reaches a temperature where the metal liquidizes and forms a proper solder to the device, ensuring all connections have been made. The leftover solder paste adhesive is then chemically removed to prevent any unwanted connections with other parts, leaving the components bonded to the printed circuit board. To ensure correct soldering, extensive thought is put into the locations and depth of the solder pads to ensure that the device will automatically fall into the correct location. All devices are visually inspected for unwanted connections and can be "reworked" using professional systems or simple soldering irons with experienced workers. These workers would be required to remove the existing solder and manually replace the correct amount of solder to ensure the connection is perfect. Most current technology involves the use of wave soldering which is used for both thru-hole technology as well as surface mount technology. This is done by applying flux to the device. Flux is a type of adhesive that allows solder to attach to other metal components which would then be connected to the ends of the leads of the attached device. After flux is applied, the entire printed circuit board would be submersed in molten solder, which would only attach to the leads that have flux applied, creating hundreds of connections simultaneously.

The image below, 2.1.6 Figure 2, shows a simplified, yet detailed diagram to help explain the working of a wave soldering machine and its process. As shown, it displays the idea that the printed circuit board get sprayed with flux on the appropriate locations for solder to attach to. The device being worked is then preheated before entering the soldering area to prevent cracks from forming in the device due to problems stemming from the instant heating and expansion of the circuit board when place directly into the molten solder. The board then continues down the conveyor belts and is dipped into the molten solder, at which point the connections are made between the board and the chips that are placed on the board. The device then continues down the line to be cooled down slowly for a fully finished and fully soldered final product.



2.1.6 Figure 2: Wave Soldering Diagram printed with permission Martin Tarr, University of Bolton, under the creative commons license

Due to the fact that these components are handled mainly by machines, the components can be extremely small, with some devices becoming less than one millimeter squared. The miniscule size allows more components to be placed on a given printed circuit board, as well as the use of double sided printed circuit boards for even smaller device construction. In addition to this, there is a faster assembly of the circuit components because it is done by machine control and the error margin is considerably smaller than that of a through-hole style of construction. Also the printed circuit boards are generally more rigid because their structural integrity has not been depleted due to the drilled holes in the silicon. Since these parts have smaller leads, they have a reduced resistance, inductance and capacitance and generally have fewer electromagnetic noise problems and electromagnetic interference. In addition, since this method of surface mounting is a much more widely used process, most parts can be acquired cheaper than their through-hole counterparts.

The negative aspects of the surface mounting of parts is the requirement of large expensive machinery which cannot be easily acquired by small scale project designers and is generally used mostly in the post development stage of design. This method requires a printed circuit board for every prototype because quick and easy repairs cannot be made without excessive skill and concentration as well as specialized tools. Since there is only a small amount of solder connecting the devices to the printed circuit board the components are more prone to falling off or losing strength. This results in generally flatter, lighter components that are wider with more connections in order to ensure the device components stay connected. There are those who attempt to apply surface mount parts to a printed surface board using a traditional soldering iron and solder. However, typically inexperienced people will have little success due to the difficulty of the application of the solder to the board and each chip's small leads.

The use of surface mounting would be the ideal choice of the soldering and connection method, however the group does not know exactly what parts are to be used and whether the group will have access to the particular machinery for easy surface mounting use. More than likely the group will be utilizing some through-hole technology methods due to its simplicity and ease of use by hand. However since the project requires the use of some various surface mount parts, the group will have to start practicing their soldering skills to prevent the problems that could occur.

2.2 Components

2.2.1 Display screens

There are many different technologies out there that are used in the display industry to enable users to view material. These include LED, OLED, LCD, CRT and countless others that are used for televisions, streetlights, as well as lit up advertisements. The most commonly used Technology used for displaying data from an IC is LED, OLED and LCD technologies. In this section the group will go over each technology style, learning its advantages and disadvantages and give more in depth information on the technology that will be implemented in the group's design based on those that have the most advantages and the least disadvantages.

The first style of technology that is to be reviewed for potential use in this project is that of light emitting diode displays. As anyone who has been shopping for televisions these days can tell you, the advantages of LED displays include the fact that the emitted light can be of any color, and can be considerably small in size allowing a higher resolution image. They also have very quick response times, which are the time it takes a device to go from fully on to fully off, allowing speedy imagery to be seen without any blur. These devices also emit their own low power, low heat light. This allows LCD screens to not require its own backlight for viewing. The disadvantages of light emitting diodes are the fact that most LED displays come in the form of seven segment displays, allowing only numbers to be represented on the device. The LED displays that have pixels for character realization, allow words to be represented which are either very large, used primarily in outdoor marketing displays, or are very expensive. Therefore, this form of technology will not be used in this project due to the fact that it is very difficult to find small LED display as well as the fact that these displays are very expensive.

The next style of display is the organic light emitting diode display technology that is up and coming in the high definition television market. The advantages of OLED displays are the fact that they can be essentially printed onto the substrate, lowering cost of production. Similar to typical LEDs, they have a quick response time and they emit their own light, allowing high contrast ratios per pixel and waste no energy when the pixel needs to be dark. Disadvantages of OLED displays are the fact that their brightness lifetime is one quarter that of LEDs and LCDs. In addition, screen burn-in occurs, along with the fact that certain colors in

OLED displays fade quicker than others, resulting in odd color combinations. Most small scale OLED displays can be purchased relatively cheaply and can be integrated into integrated circuits with ease. The inherent problem lies in its use of individual pixels for output of data which requires many pin wirings for input selection, along with difficult program coding to output a single character. Due to this difficulty problem, the group has decided not to use OLED displays in the design of the project.

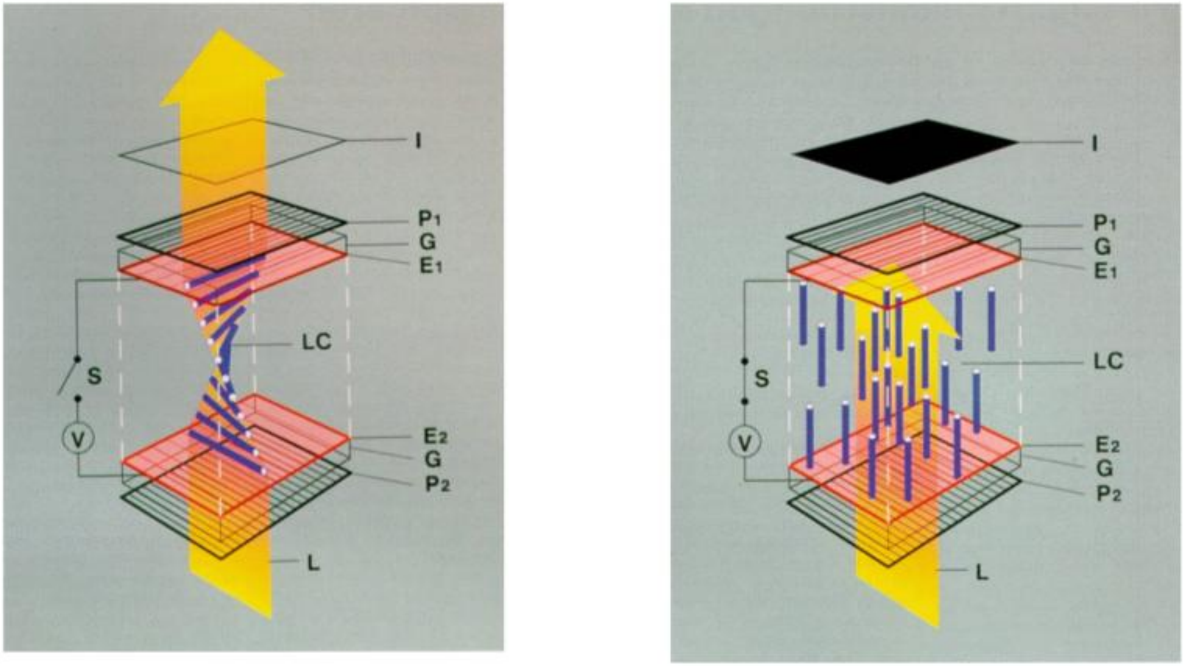
Last in the list of integrated circuit output displays, is called a liquid crystal display. This style of display is very commonly known and used in the television field, but is even more widely used in the display of information in the device engineering field. LCDs have advantages in the fact that they are widely used, and therefore are easy to obtain and implement cheaply. Also, LCDs are frequently made in the form of a “character LCD,” which makes implementation of a device to output words and symbols very simple. The drawbacks of LCDs are the fact that they require additional backlighting to be accurately seen, along with the fact that at certain angles, the LCD’s image quality deteriorates rapidly. Lastly, they have slow response times resulting in bleeding images for fast movement. Since the group’s main goal is accuracy, ease of use, low cost and easily available, the group plans on using LCD technology. This is due to that fact that character LCDs are able to accurately and easily display words and symbols, for a low price. In the next few paragraphs, the group will describe how LCD’s work along with the different types of LCD technologies out there for use.

Liquid crystal displays or LCD’s operate through the specialized use and manipulation of the polarization of light through the use of a twisted nematic liquid crystal display. Light, as everyone knows, is transmitted in the form of photons which move in a sinusoidal movement which is perpendicular to its direction of travel and can therefore be envisioned as a thin long plane. For normal light, the direction is completely random and distributed uniformly with the sinusoidal movement projected in every direction. Polarized lenses have the unique ability to block all light except those photons that are moving in a particular sinusoidal direction, which allows only a certain amount or a certain style of light to escape through the medium.

The way that most liquid crystal devices work is through the use of a twisted nematic display. In a twisted nematic display, light is initially polarized in a horizontal direction, blocking all light that enters in except the light which is moving in horizontal sinusoidal direction. After passing through the horizontal polarization panel, there is one end of an electrode which is see-through for all incoming light. Liquid crystals are then arranged such that the molecules within the device cause a 90 degree twist of the polarized light from one end of the liquid crystal to the other. On the other end of the liquid crystal medium is another electrode, which is again a see through material. This is then followed up by a vertical polarization lens, which will polarize the light vertically, again eliminating all other light passing through the device. In devices with a backlight, the incident light originates from the LED or other light source within the device, however with liquid crystal displays that contain no backlight, there is a reflective material located at the back of the device which incoming light rebounds through and makes the non-powered LCD viewable.

When the power is turned off, with no voltage applied across the two electrodes between the liquid crystals, the incident light can easily pass through. When the power is on, and the electrodes have enough voltage to create a strong electromagnetic field, the liquid crystals then align along the electromagnetic field and prevent the twisting action of the original display. This action causes all incoming light to be blocked by the two perpendicular polarization shields which creates an opaque section of the LCD's screen. As LCD displays are commonplace, everyone knows that this opaque section can then be formed into letters and words as well as separate pixels for common communication in everyday life. This electromagnetic field is strong enough to twist the molecules of the liquid crystals but is also weak enough that it drains very little power for simple LCD screens and can be powered through common small voltage batteries. The electromagnetic strength can be tuned along with variation of styles of liquid crystals within the device to create different light intensities as well as color combinations for viewing. Due to the need for the liquid crystals to return back to their original positions, there is an induced lag time associated with liquid crystal displays which explains the drag or ghosting of images seen on older LCD monitors or televisions. This problem however is of little importance to this design due to the relative slow changes in characters for the projects display.

Shown below is 2.2.1, Figure 1 which shows a diagram of the working LCD in the OFF state on the left and the ON state on the right. On the left incoming light (yellow arrow) enters through the polarized lens, passing through a clear electrode (colored red) and getting twisted by the liquid crystals. Then the light leaves through the other end of the electrode and passes through a polarized lens which shifts the light 90 degree from the opposite lens. The image on the right hand side of the figure shows the same incoming light going through the lens and electrode but not being shifted due to the electric field affecting the orientation of the liquid crystals. The light then passes through the electrode and is blocked by the 90 degree shifted polarized lens on the other side of the LCD screen. This application of electricity produces a blackened or darkened output on the front of the screen.



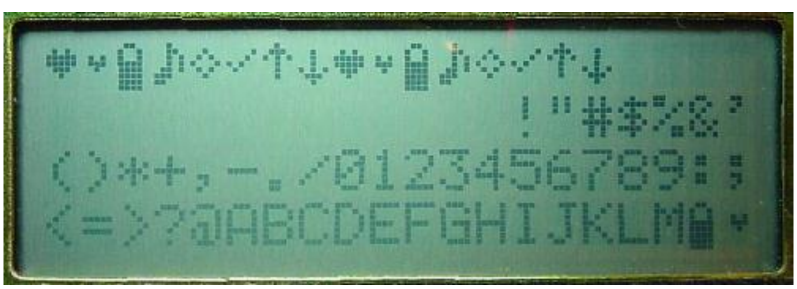
2.2.1 Figure 1: Example of off/on characteristics of TN LCD printed with permission of GNU Free Documentation License, under the creative commons license

Since the construction of these devices only requires that there is enough liquid crystal material in the display for a 90 degree shift of the incident photons, these devices can be made relatively small if there is not backlight attached. This causes these devices to be very lightweight increasing their feasibility. Early innovation with the LCD went into seven segment displays that could easily display every numerical digit, which is the main reason behind the massive amount as well as the early adoption of liquid crystal technology into watches and alarm clocks. For a seven segment LCD used commonly in wristwatches and alarm clocks there are only seven different electrodes for every digits used. When a number is inserted to be displayed, the device’s microcontroller then selects the right combination of electrodes to properly represent the number. This style of LCD is very successful in detailing numbers, but does not work well with other characters and is used mostly for alarm clocks or digital calculators due to the inability to form other characters.

For character LCDs, certain combination of pixel selections will result in what appears to be a continuous character for the user. This combination of pixels is usually done using a passive matrix technology in which each pixel has a vertical and a horizontal address to be selected. At the point when the microcontroller is given a command for a certain character, the microcontroller then identifies each and every pixel that is required to be set to on and turns the device to on. The clarity and complexity of these devices is simply limited by the number of pixels on the device and can produce any image if programmed properly with enough pixels. Lastly there are graphical liquid crystal displays, which are designed similar to the character LCDs, and use the passive matrix technology to select an individual pixel location to be turned on or off. Then, through a combination of pixel selections, can make any combination of characters or pictures to illustrate an idea. The amount of material which can be displayed can be incredibly vast due to the fact that to add more elaborate information, all one would need to do is to increase the resolution of the LCD. Having a larger number of pixels displayed upon the screen does this. This is done solely by adding more electrodes, along with connections to said electrodes, which is how most character or graphical LCDs can have such a vast selection of data to be output. The downside to this style of display is the sheer difficulty of creating an understandable output because of the complexity of the pixel selection, requiring difficult algorithms, multiple wire connections and extensive coding to implement. Color displays, while not being used in this project are usable with the simple addition of filters to allow only certain colors such as the primary colors red green and blue to exit, which when paired together in pattern creates a seamless color effect.

Based on the research into how liquid crystal displays work along with the different types of LCD screens, it looks like the device will make use of a 4 x 40 character LCD in order to present the data. The group needs the length and width to be as large as possible in order to contain all the information that the group needs to display without the need for horizontal scrolling or excessive vertical scrolling. The project also specifically needs a character LCD in order to display a dollar sign as well as other symbols for data separation and device selection. For the design, the LCD does not require a backlight; however the addition of the backlight would make for a more finished and polished looking project.

Displayed below in 2.2.1 figure 2, is an image of a 4 x 20 character LCD that is of the same type that will be used in the project design. The image below shows a small variety of the types of symbols that can be displayed by using this type of an LCD screen, and gives the reader a rough idea as to what a potential output could look like.



2.2.1 Figure 2: Example of 4 x 20 Character LCD printed with permission of David Cook, Robot Room

2.2.2 Power Sensors

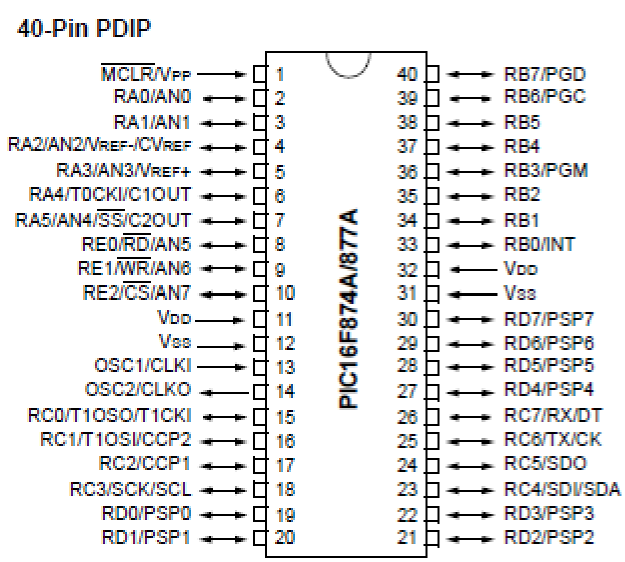
Part of this circuit is a microcontroller. There are a myriad of microcontrollers to choose from. There are many different options and brands. To choose the microcontroller for this design, many of these variables have been weighed. Since this is the heart of the design, the microcontroller is a vital and crucial part. The design has certain characteristics that need to be addressed by the microcontroller. For example, the design has an analog input as previously mentioned and a digital output is needed to perform calculations and to pass on the information to other parts of the circuit. This and a few other considerations have gone into the decision of which microcontroller to choose. One of the main considerations is price. Microcontrollers appropriate for this design can go from two dollars to more than ten dollars. Considering that the finished design will have at least 3 sensors and maybe 4, the price of the microcontroller can add up. One of the goals of the design is to spend as little as possible in the compononents of the circuit. Not only is the amount of sensors to be considered but also the possibility of design errors that could end up destroying the microprocessor. Experience has taught the team that when building circuits, especially complicated and new circuits, one of the most fragile components is the microprocessor. The team can’t overlook the possibility of needing more than one microprocessor due to errors during the build up of this design. Obviously a less expensive microprocessor will not only help keep the cost down for the design but also for the design process as a whole.

Another consideration is availability. If it is decided to use an obscure brand of microprocessor or one that is not well known, there is a chance that valuable time could be lost if a replacement is needed. Part of the plan is to buy back up components but there is a possibility that due to unforeseen circumstances, there could be a need for a component with little time to lose. To this end the microcontroller for this meter needs to be widely available. Not only is availability a consideration but the use of a well known microprocessor almost assures the availability of information on how to use it. Most low cost or amateur projects are built with certain microprocessors as a base due to the resources available for this components. This is definitely a prime consideration for this project. This could also be considered ease of use. The more information available for the components, the easier it will be to implement the design. This design has a certain amount of inputs and outputs. For each of these, there needs to be a pin on the microprocessor. Some microprocessors are very small which limits the amount of inputs that can be used. In this case it is better to err on the side of having extra pins available than not enough. With this consideration in mind, the microprocessor that better fits the design will have at least 5 inputs and 5 outputs minimum. As the design develops, this could change but that would be a start.

There is also the need for a quality part. If the best design is implemented with low quality parts, there is a good chance of hardware failure or simply inaccuracies. Some of the best known brands are microchip with their PIC series of microprocessors, Atmel and even Motorola or Texas Instruments. These are all brands that have passed the test of time and have been used in many projects and a huge variety of designs. Sticking to a time tested component is definitely high on the priority list. Due to these and other considerations, the design will use a microprocessor from microchip.

After deciding on a microchip microprocessor, there's a need to choose from one of their many options. Again, it's better to have a microprocessor that has more options than needed for the project than find that it doesn't have the necessary options causing a loss of time in the design. It's better to have extra memory which can be used to expand the design than have too little which could limit the goals of the design. The microchip corporation has a variety of energy meter designs that are offered in their website. They actually have designs built around particular microprocessors. Since the design will be based on the microchip brand, it would be advantageous to implement a tried and true design by the makers of the microprocessor. One of the designs is implemented using either the PIC16F873A or the PIC18F2320 microcontrollers. Both of these two should be more than enough for this design. Since the PIC16F873A is the less expensive of the two and it meets all the requirements for the design, it will be used for this design.

2.2.2 figure 5 shows the pin layout of the PIC16F874A. This processor has 40 pins that might prove to be much more than is needed in the design. A smaller processor will definitely be considered.



2.2.2 Figure 1: PIC16F874 microprocessor Used by permission from Microchip.com

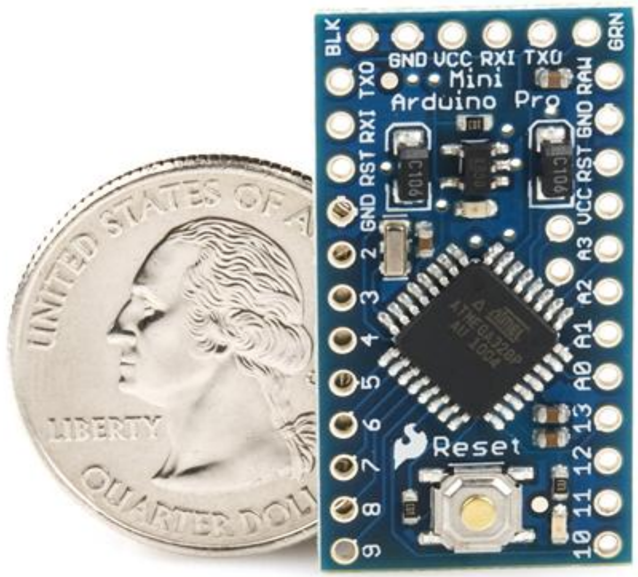
Microchip also makes integrated circuits specifically made for the implementation of power meters. This could be added to the design and could help with the accuracy of the measurements. It only adds 2 dollars to the design and could make the circuit much simpler to build in the end. The advantage of such an integrated circuit is that it is designed for the types of inputs and outputs that will be implemented in this design and will also have all the components needed to calculate all the parameters that are required. As a bonus, the energy meter specific microcontrollers are inexpensive as they only have what's necessary to implement a power meter design and don't have extras that might be needed for other types of designs. It's price per part is a little more than 2 dollars and it has everything that is needed for a succesful power meter design.

The MCP3905A supports the IEC 62053 international metering standard specifications. This is very important to the design because the component is more likely to meet the design accuracy considerations. From the microcontroller data sheet itself: "…it supplies a frequency output proportional to the average active real power with simultaneous access to ADC channels and multiplier output data….the 16 bit ADC outputs allow for a wide range of IB and IMAX currents and/or small shunt meter designs". One feature of this energy meter centric microcontrollers that won't be needed for the design has to do with tamper detection. A lot of the commercial power meters have as part of their design a tamper sensing feature that allows them to work even if someone tries to disable them by various methods. Since this design is geared primarily for the home consumer, this tamper sensing feature is not necessary. The drawback of using an additional IC is that it adds complexity to the design. The physical design would not change much but the complexity of having to program an additional IC could add to the amount of time building the design. These integrated circuits, even though they are very accurate, can also be very complex. The most likely course of action is trying to build the design without the IC and using the firmware to accomplish the project's accuracy goals. If that proves to be difficult, then the added complexity of the integrated circuit might be necessary. Most of the power meters on the market do not use these specialized integrated circuits so it should be possible to design the meter to be as accurate as anything on the market. Some of these specialized IC's are made to be used with mechanical counters. This makes the mechanical counters much simpler to build. Since this design will use an LCD, the energy centric IC might not be the best choice for it.

After some more research, it has been found that there is another option to consider as far as the microprocessor used in the power meter and even the display itself. A company named Sparkfun Electronics makes a board called the Arduino Pro 328. This board comes complete with analog input and digital output ports and with an embedded microprocessor. The advantage of the board is that it saves time and money as far as fabrication. Since the board has the inputs and outputs already connected to the microprocessor, there is no need to send all these components away for assembly. The board comes with an ATmega 328 microprocessor which has all the specifications necessary for the power meter design. It also has a built in port to program the microprocessor. This design also allows the use of regular C computer language to program it so it is very student friendly. Some other microprocessors use languages that might not be as well known making them more difficult to program. One great advantage to this board is it's price. It costs less than $20! Making it very economical when considering that the system will use four sensors. If all the parts on this board were to be bought separately and sent out to be assembled, the price could be over $50. The board also is available in a Mini package which also works perfectly for the design. As far as size it is slightly bigger than a quarter making it very easy to fit in a compact assembly. The relay that will be used to turn the appliance being measured on and off will have to be added in a separate board but it can still be controlled by the Arduino board so it should not be a problem to configure. Obviously the design to measure current and voltage still needs to be added to the input side of the board. This board simply makes the design much easier to build and saves a lot as far as components and assembly. Some of the features of the board are as follows:

- ATmega328 running at 8MHz external resonator
- Low-voltage board needs no interfacing circuitry to popular 3.3V devices and modules (GPS, Accelerometers, sensors, etc)
- USB connection off board
- 3.3V regulator
- Max 150mA output
- Over current protected
- Reverse polarity protected
- DC input 3.3V up to 12V
- Resettable fuse prevents damage to board in case of short
- Power select switch acts as on/off switch

Due to the advantages of this board, it will most likely be implemented in the design. Since the financial goal of the design is to spend as little as possible while still maintaining the integrity and accuracy of the design, the use of this board will help the design achieve these goals. Since the board comes with the aforementioned microprocessor already embedded in the system, the PIC microprocessor will most likely not be used. For the needs of the project, both microprocessors will work very well and since part of the design is keeping a balance of quality and price, the use of this board can only help with the successful design of the meter. 2.2.2 figure 2 shows a comparison of the Atmel microprocessor next to an American quarter. The size is obviously very compact and will serve well in keeping the size of the sensor as small as possible.



2.2.2 Figure 2: Arduino board Used by permission from SparkFun Electronics

Choosing a PCB board and builder

Once the parts for the design have been chosen, they need to be installed on a printed circuit board. This part of the project like any other has certain constraints. The main one is price. These boards can be built by a variety of vendors. Many of these vendors have student prices. The student prices are quite affordable; they can start for as little as 3 x $51 (ExpressPCB). Here's the description of the PCB service provided by Express PCB:

- 2 or 4 layer boards
- Tin/lead plating
- Board size must be 3.8 x 2.5 inches
- $51 for three 2-layer boards, $98 for three 4-layer boards

The goal would be to make the board as cheaply as possible so builder's with student discounts will be given priority. Another very important factor in choosing a builder is turnaround time. In finding out more about how to build this design, the team has talked to other senior design teams in their construction phase and it is evident that many times, the first prototype will not work. Therefore, a builder with a fast turnaround can really make a difference as far as achieving the scheduling goals of the project. For this reason, a local builder might be the best choice for the board. A local builder will not only be easier to contact as they could be visited in site, but their turnaround time should be faster than if the board is being built in Seattle. Again, a local builder will better accommodate time constraints. Experience also comes into the equation for the build. The builder should have good references. It is imperative that they can have the experience building a design such as the power meter being built. The power meter design is quite straightforward in comparison to other electronic builds so most any builder of PCB's should be able to construct it. Obviously, this is something that needs to be addressed with the builder being chosen. The easiest way to find a builder who can be relied on is by talking to other teams to see who they have used. This would give invaluable insight on the quality of the build and on the turnaround time. Since this is a crucial part of the design, choosing the right builder will help make the design a reality in a timely and affordable manner. A company in the Orlando area is Conelec of Florida.

Another route to making the PCB is having the team make it. The problem with this route is twofold. The first is lack of experience and the second is cost. The construction of a PCB is a process with many steps that need to be done precisely. There are do-it-yourself kits sold but they cost over $100. For that amount an experienced builder could build three PCB's or more. And experience is another factor. If the team were to build the PCB, not only would the circuit itself have to be troubleshooted if something went wrong but also the build technique. That could really put the team behind schedule. It's better to have an outside source build the board so that the design itself is the only thing that will need to be looked at in case of a malfunction. The more elements added to a problem, the more difficult it is to solve and it would simply be smarter and cost effective to have the board made by an experienced builder.

There are some guidelines that will be used to build the board. Following is a list of the main build practices that will be followed:

1) When placing components on the board, careful consideration will be given to which components need to be connected and they will be installed close to each other. This will minimize the distance of the traces so that it will be much easier to build the traces efficiently.
2) When arranging IC's, they will all be installed in the same direction; either top to bottom or left to right. And pin one will always be at the top and in most instances, on the left.
3) Polarized parts will be oriented with their positive leads on the same side and square pads will be used to mark the positive side.
4) There needs to be sufficient space between components to allow space for traces. It should be around .350 to .500 inches of space and a little more for big components.
5) When working with ICs it is necessary to have solid power and ground lines. Wide trace will be used to connect common rails for each supply.
6) The signal traces for these low current digital and analogs signals will have a width of .010 inches.
7) Traces that have a significant amount of current will be wider than signal traces. A table of common rule of thumb width is as follows:

0.010"	**0.3 Amps**
0.015"	**0.4 Amps**
0.020"	**0.7 Amps**

0.025"	**1.0 Amps**
0.050"	**2.0 Amps**
0.100"	**4.0 Amps**
0.150"	**6.0 Amps**

8) Between traces, there should be a minimum distance of .007 inches and .010 is preferred. This is especially true for high voltage traces.
9) The traces should be horizontal, vertical or at a diagonal angle of 45 degrees. As with the circuit itself, these guidelines will be used with the mock software used to design the PCB. The dimensions just outlined will then be implemented on the physical board. This guidelines should make sure that the board is laid out in a logical, efficient and easy to follow pattern.

2.2.3 Microcontroller Component Research

The main logic of the entire design is the microcontroller. Within the microcontrollers, all commands, both pre-written with code and given from the users are put into place. Certain parameters/variables should be able to be inputted through hardware (buttons) and implemented on the microcontroller. The main purpose of the microcontroller within the central unit is to take in all information given from the wireless receiver, translate this information into power being used by any specific device, and displayed on the LCD. As well, the microcontroller must be able to send a signal to a wireless transmitter to be able to turn off and on devices from individual measuring units.

The designed controller must use low power to allow the entire central unit to be powered from battery power or be able to run off of wall power, along with the measured device, without greatly impacting the power consumption. Adequate input and output pins must be available for use by the LCD screen, wireless components, and all push buttons that are used to interface with the user directly.

2.2.3.1 Microchip PIC32 series

The Microchip PIC32 microcontrollers start with a minimum 258 KB of flash memory. As well, the microcontroller has an allocated 12 KB for the bootloader. All data given into the microcontroller is either 8 or 16 bit. One large disadvantage of the Microchip microcontrollers, the 5XX, 6XX and 7XX more specifically, is that the microcontrollers are programmed with MIPS32 architecture. While this may not seem a rather large problem, it may create difficulties when interfacing with either the LCD screen or the wireless transmitter, receiver, or transceiver.

The Microchip microcontrollers operate at an input voltage range of 2.3 to 3.6 Volts and maximum current of 200 mA through most pins , resulting in a relatively low power microcontroller. Each PIC32 microcontroller has a minimum of 64 pins. These pins including 5 pulse wave modulation pins, 5 16-bit timers, and digital output pins; however, only some of the pins are 5 volt tolerant.

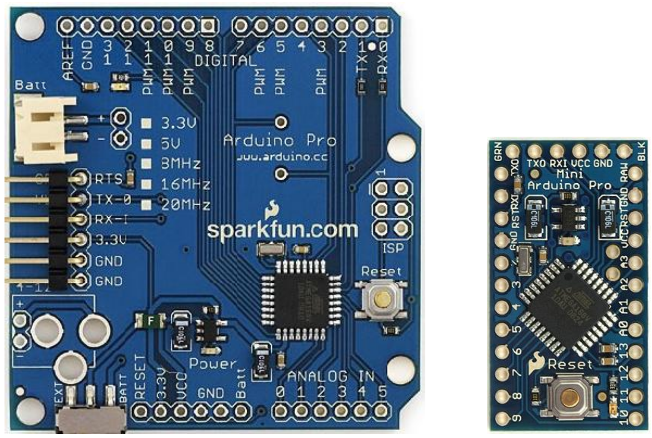
2.2.3.2 Arduino Pro and Pro Mini

The Arduino microcontrollers are preassembled with either Atmel ATmega168 or ATmega328 microprocessors, depending on the model. The Arduino Pro and Pro Mini have a built in 16 KB of flash memory; however, if the ATmega168 processor is used for the Arduino Pro and 32 KB if the ATmega328 processor is used. While both microcontrollers have the capability of having a minimum of 16 KB of flash memory, all models have 2 KB reserved for the pre-programmed bootloader. Because both microcontrollers operate on 10 bit accuracy for the analog pins, a fairly high degree of accuracy can be expected when reading in any values. The 3.3 Volt version of both the Arduino Pro and Arduino Pro Mini come with an 8 MHz clock, while the 5 volt varieties come with a 16 MHz clock Both microcontroller models use an open source C/C++ programming scheme which can be programmed with a USB programmer.

Both the Arduino Pro and Pro Mini use an input voltage of either 3.3 or 5 Volts, depending on the individual model, which can be obtained through a battery, DC power supply or the ‘RAW’ pin to input an unregulated voltage and use the on-board regulator. As well, each pin draws a maximum of 40 mA, resulting in both models being low power. The Arduinos also have a total of 14 digital input/output pins, which can be set as an input or output within software, and 6 analog inputs. As well, if needed, both have the option to use pulse wave modulated signals on 6 of the 14 digital pins. If a serial input or output is needed, both boards also have Rx and Tx pins. One feature the Arduino Pro has that the Pro Mini doesn’t is an “AREF” pin which allows a separate analog reference voltage for the analog inputs.

Of the two options of the Arduino Pro and Pro Mini’s, the 3.3 Volt versions were chosen. This was decided for power usage reasons, as the 3.3 volt version will draw less power than the 5 volt version, and can last longer on battery power. While this decision limits the available space for programming to 14KB, the code required shouldn’t exceed this. As well, between the Arduino Pro and the Arduino Pro Mini, the Pro Mini has been chosen. While the Arduino Pro has an analog voltage reference pin, it should not be needed for any operations in the microcontroller.

As the name suggests, the Arduino Pro Mini is much smaller than the Arduino Pro. The Arduino Pro has a physical size of 2.05 inches by 2.1 inches, while the Arduino Pro Mini is less than half the size at 0.7 inches by 1.3 inches. Both are presented side by side for size comparison as showing in 2.2.3 figure 1.



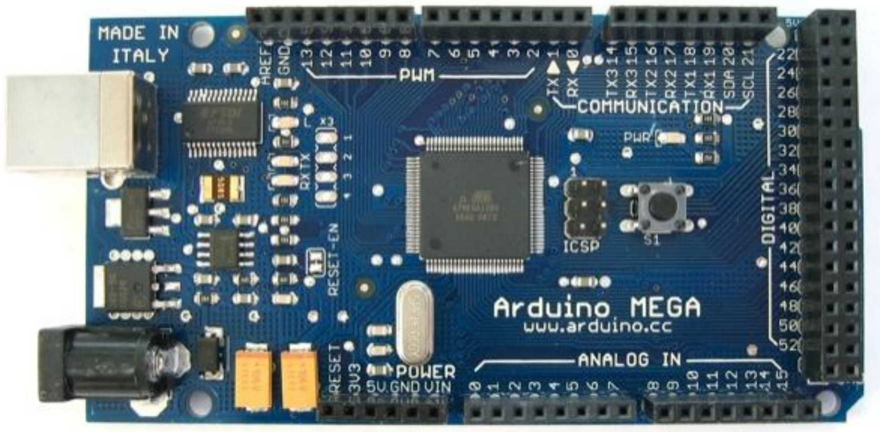
2.2.3 Figure 1: Arduino Pro and Pro Mini microcontrollers used with permissions from Arduino

2.2.3.3 Arduino Mega

The Arduino Mega, unlike the Pro and Pro Mini, comes preassembled with an ATmega1280 chip. Because of this, the Mega has 128 KB of flash memory; however, 4 KB of the 128, compared to the 2 from the previous Arduinos, are reserved for the bootloader. Much like the other Arduinos, it comes with a 16 MHz clock, though without the option of the 8 MHz one, and is also programmed in C.

The largest drawback of utilizing the Arduino Mega is the supply voltage of 7 Volts, with no other options for a lower voltage board. Compared to the 5 and 3.3 Volt Pro and Pro Minis, the Mega draws more power while it is operating. Each Input/output pin allows 40 mA of current. Because of this relatively low, constant current between the Arduinos, the rise in power between the boards isn't too great. As well, to make utilizing the Mega easier, the board comes with a barrel plug for power, along with on board voltage regulators, which regulate voltages to both 5 and 3.3 volts, allowing other devices that need regulated voltages to run off of the regulate voltage.

The biggest advantage of the Arduino Mega is the abundance of digital input or output and analog input pins. The Mega comes with 54 digital pins which can be assigned as either input or output pins through software. Of these 54 pins, 14 of them can be utilized as pulse wave modulated outputs, if required. This board also comes with a total of 16 pins available to use as analog inputs. As well, like the Pro and Pro Mini, the Mega comes with three serial input and three output pins, TX and RX. Finally, as with the Arduino Pro, the Mega comes with an "AREF" pin to use as a separate analog voltage reference. As seen in 2.2.3 Figure 2, the size of the Arduino Mega is larger board, nearly twice the size of the Arduino Pro, at 4 inches by 2.1 inches.



2.2.3 Figure 2: Arduino Mega microcontroller used with permission from Arduino

2.2.4 Wireless Transceiver

Below, in 2.2.4 figure 1, is a portion of a table from a sparkfun electronics website which scaled many types of wireless telecommunications based on seven categories; power, distance, data rate, data delivery, cost, learning curve and size, respectively. The scales were all based on how the matched up relative to the others and also the scales were of different meaning, clearly specified in the table. There were seven forms of technology used in the table; however, the group only used four, the four that were taken a look at. If the group were to narrow down a few f the columns to the ones that were the most important, the columns would be the learning curve, cost and distance columns. All of the columns were taken into consideration but the three columns mentioned previously had the greatest effect of the decision.

	Power	Distance	Data Rate	Data Delivery	Cost	Learning Curve	Size
Bluetooth:	3	3	2	4	3	5	3
Zigbee:	4	1	4	2	4	2	3
XBee:	3	3	3	3	4	4	3
WiFi:	2	3	1	5	2	3	3
	5-1 lowest to highest	5-1: longest to shortest	5-1 lowest to highest	5-1: guaranteed delivery to may not get there	5-1: cheapest to most expensive	1-5: hardest to easiest to learn	5-1: smallest to largest

2.2.4 Figure 1: Scaling of different variables associated with a wireless telecommunication chip

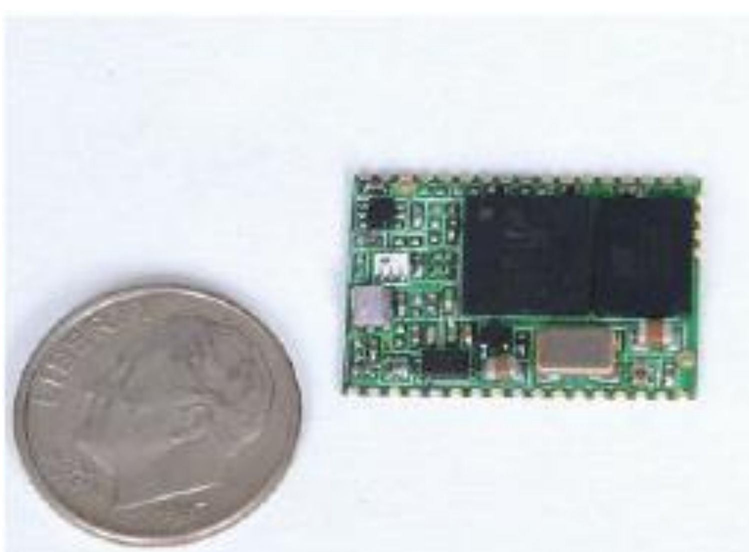
2.2.4.1 Zigbee

Our first option for wireless telecommunication was Zigbee communications. This option showed many pros but the cons overwhelmingly dominated our perception of the technology. The range is exceptional; Zigbee could potentially send wireless signals for up to one mile. Zigbee has also very fast communications but once the group had read that a separate Zigbee modem was needed, we crossed it off the list and read many opinions on Zigbee and how unnecessarily expensive it is compared to a technology like Bluetooth whose overall performance is better and cheaper per unit.

2.2.4.2 Bluetooth

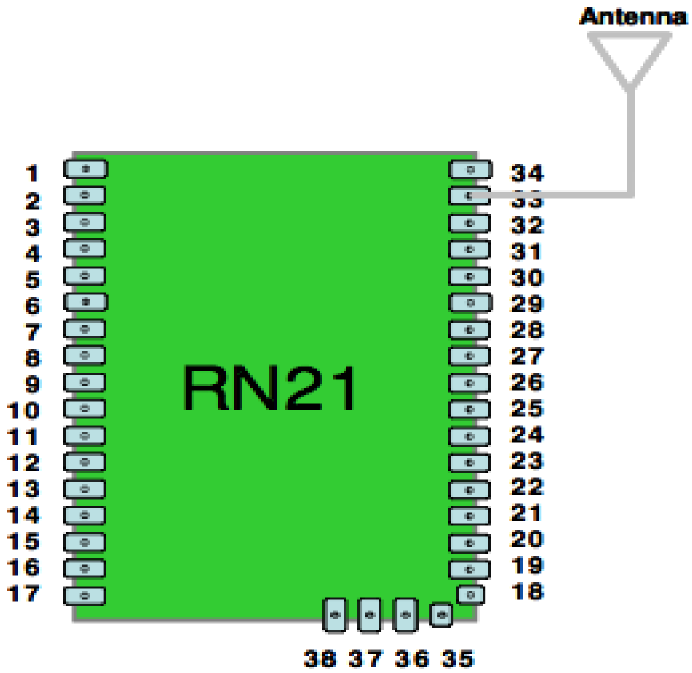
Another viable option taken into consideration was using Bluetooth technology. Unlike the Zigbee, there seemed to be a reasonable amount of pros but also a reasonable amount of cons. The reason WIFI/XBEE was chosen over this was because when it came to the big picture, this technology didn't match up when considering all the important topics. Bluetooth's high-speed, which is up to 200 Mb/s in the draft IEEE802.11n version, enables sufficient bandwidth for web browsing, file transfer and even data streaming between computers.

When assessing each piece of wireless technology, the group would take an in-depth look at an add-on chip of a whole set of components. The group found, on the DigiKey website, a Bluetooth RF/RFID chip named RN-21. RN stands for the vendor, Roving Networks. This is what the device looks like and like most electronic devices the group has seen, it is placed next to a coin, in this case a dime, for the customer to see how big it is. The dimensions of 2.2.4.2 figure 1 are 21.8x12.5x2.2mm.



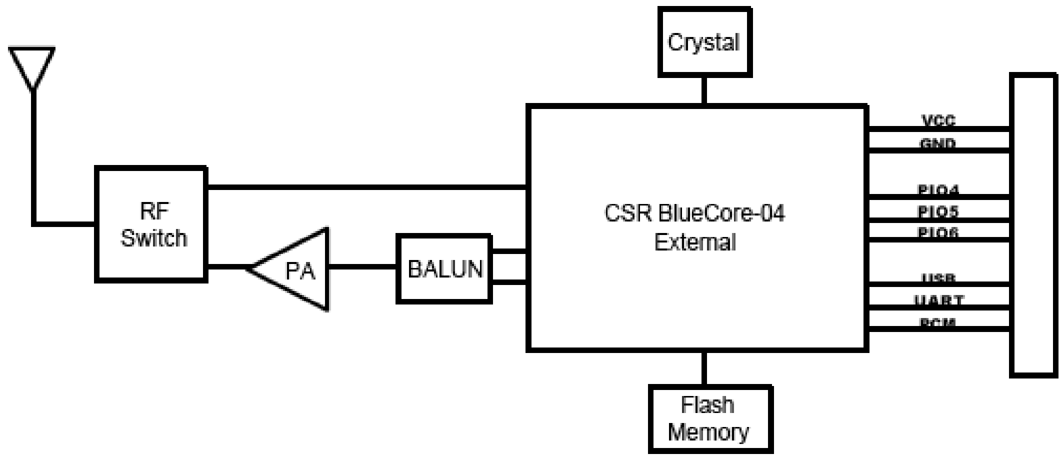
2.2.4.2 Figure 1: Bluetooth chip Used by permission from Sparkfun.com

The current flowing through the device while it is in sleep mode is 90 µA. The RX supply current is typically 35mA with a max at 60mA and the TX supply current is typically 65mA with a max at 100mA. When it is discoverable, it run about 1ma through and when it is connected and running, it will have approximately 40ma running through. The supply voltage runs between 3.0 and 3.6V with a temperature range of -40*C to 85*C that works as long as the humidity is sub-90%. It runs at 2.4GHz that seems standard at all levels of wireless telecom chips.



2.2.4.2 Figure 2: Pin Assignments for Bluetooth Awaiting permission from Roving Networks

From a hardware standpoint, there are 38 pins in total where there are 5 output pins, 5 input pins and 11in/out pins, which can be seen above in 2.2.4.2 figure 2. In the data sheet, the group was given a well-described schematic as seen below in 2.2.4.2 figure 3. Looking at that figure from right to left, we see the inputs in three different sets. We have the voltage input, and a ground in the first set. The second set includes PI04 (pin27), which is used as the factory reset, PI05 (pin26), which used for the status LED, and PI06 (pin 25), which is said to be the auto master. For the third set of pins, the schematic begins with the input USB, which would be assigned for two pins (23 and 22); USB-/+, respectively.



2.2.4.2 Figure 3: Flow chart for Bluetooth chip Awaiting permission from Roving Networks

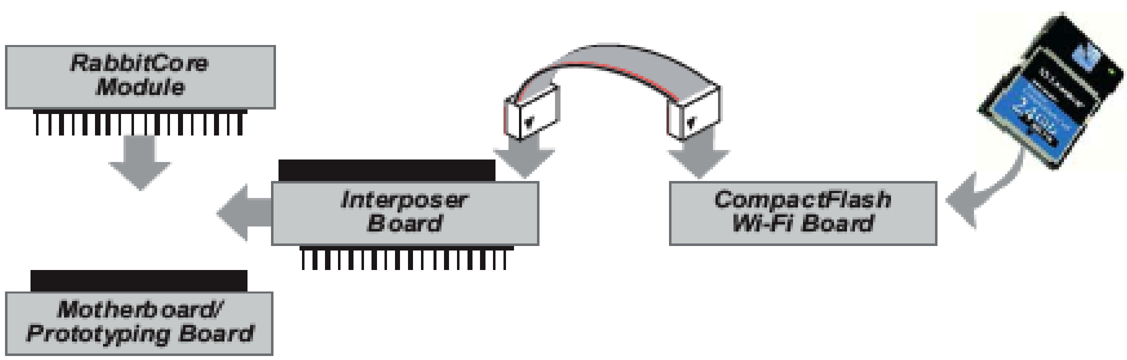
Most all of the information above about Bluetooth made it seem like a viable option for the groups project, however, the negatives the group read on line made them hesitant on choosing Bluetooth. A con such as reading it consumes a high amount of power relative to other options was a turnoff. The main con was reading about the learning curve. On many websites the group had visited, they read the learning curve is extremely high relative to other options and with only 12 weeks to construct the device as a whole, an unnecessarily high learning curve is not needed when there are so many components that need to work for such a project to be completed in such a short period of time.

2.2.4.3 Wi-Fi

The grouped looked into a Wi-Fi add on chip made by Rabbit Semiconductors as a possible means for the wireless telecommunications. On the Rabbit Semiconductors website, there was a great amount of information on the add-on kit available. The chip given on the add-on kit is an IEEE 802.11b, 11 Mbits/s, 2.4 GHz linksys chip. The dimensions of the Compact Flash Wi-Fi Board are 55x66x11mm and the dimensions of the RCM3000 RabbitCore Board are 55x41x14mm. In this case, the group looked at possible microprocessors for the chip such as RCM3000 and in most cases on the user manual; the RCM3000-RCM3300 carried many of the same features. Shown below in 2.2.4.3 figure 1 is the add-on kit along with the Wi-Fi chip.

2.2.4.3 Figure 1: Add-on chip for Wi-Fi communications Awaiting permission from Rabbit Semiconductors

The current running through the kit is approximately 285mA at 3.3V, which, for the sake of comparison, runs on the same voltage but has much higher current than the Bluetooth chip. The operating temperature between 0*C to +55*C and the storage temperature has a range of -20*C to +65*C. For the device to work properly, the humidity ranges between 10% and 90%. Looking at 2.2.4.3 figure 2, we see that all the equipment needed to work the chip with the add-on kit. As shown in figure 2 shown below, one can see how the basic assembly takes place. One would begin with a Linksys Wi-Fi chip, then one would mount it on a CompactFlash Wi-Fi Board. Then to combine the Interposer Board with the CompactFlash Wi-Fi board, a ribbon cable would be used to connect the Interposer Board to the CompactFlash Wi-Fi Board. All of the pieces above combined with the RabbitCore Module would need to be assembled properly n the motherboard to work properly. The programming program necessary, as said on the User Manual, would be Dynamic C®.



2.2.4.3 Figure 2: Basic illustration of add-on chip Awaiting permission from Rabbit Semiconductors

The chip the group took a look at was the Linksys 2.4GHz WCF12, Wireless CompactFlash Card 2.4GHz shown above as the chip on the right in 2.2.4.3 figure 1. The price we found for this chip was $69.99, which is relatively high when compared to the other devices. The group went to this website called "MobileTechReview" and on it said, "I was able to roam 100 feet from the nearest base station indoors and outdoors, through walls, glass and concrete." This quote from the review only strengthened the perception of WiFi to the group. Knowing that, through all of the materials stated above, each power unit could be up to 100 feet away from the central unit, including through walls and such, the group felt comfortable with WiFi with respect to its signal strength and distance.

2.2.4.4 XBee

As stated above, when the group was looking up our device that was an XBee, the group realized that the choice would eventually narrow down to WiFi and XBee. Both had really good qualities about themselves and it was evident when the group read many of the reviews on multiple sites from different users breaking down the pros and cons of each.

The following are some basic facts of the chip seen below in 2.2.4.4 figure 1. It is an RF transceiver. It runs at 2.4 GHz, which is what all the devices run at that the group has examined. The max data rate is 250kbps with a range of the voltage from 2.8-3.4V. The current when it is receiving data is 50mA, while it is transmitting information, the current is flowing at 45mA and while it is in power-down mode it runs below 10µA. Its sensitivity is at -92dBm. The chips operating temperature has a range between -40* and +85*C, the humidity lever was not specified. A big positive was that even the most basic of the chips has a range of up to 100 ft, 30 meters, which is more than necessary to make sure all the power units reach the central unit.

2.2.4.4 Figure 1: XBee chip Awaiting permission from Digi International

There were a few negatives about XBee that the group read. One negative read was related to a 2mm pitch connector. Also, price and power consumption were two topics that drew concern from numerous users. Size, as well, was a concern brought up; not seen as much as usual, but the group appreciates all kinds of pros and cons to make sure they make the best assessment on what piece to use because the wireless telecommunication involved is extremely important for the project to work.

The pros read about XBee were innumerous. The most important pro/con about each chip was if the configuration software was easy to manage. The group was happy to read that there were many compliments related to the simplicity of the programming involved to make the chip work properly. In one article related to the different kinds on technology, it claimed the max range for XBee could be about 100 feet, which is the distance the group was happy to read.

2.2.4.5 Shield for XBee chip

After running through different forms of boards that would complement the XBee chip properly, the group decided to go with the Arduino XBee shield shown below in 2.2.4.5 figure 1. There are two ways one can purchase the device. One way is, for $73.00, to buy the shield fully assembled with the chip already assembled. This shield is set to 9.6kbps but will allow up to 115.2 kbps transfer rate. A positive about ordering the shield this way is that it’s fully assembled and tested so any problems with soldering would be alleviated. Another way, for $24.00, would be to simply purchase the Arduino XBee shield without the chip. From a workload standpoint, it would seem the group would have more control with the programming of the XBee. However, the amount of work, given the time needed to assemble it all; having the chip assembled and tested on the Arduino would alleviate any stress with assembling the two parts together.

2.2.4.5 Figure 1: Arduino XBee shield
alex.. I got this figure from the arduino website, I didn’t send out a letter for this one tho.. would this be included?

2.2.5 Input Switches

For the group’s project, the user needs four separate switches to manipulate data and enter setup information into the microcontroller. The buttons that are required in this project are as follows: an up arrow, a down arrow, a power button and a backlight power switch. To implement this, the user needs to activate a switch within the internal electric components, which will affect a setting in the microcontroller enabling separate settings. There are countless types of switches for affecting electrical components to allow direct user input into a device. For the project's application, the most commonly used switches include pull switches, toggle switches, touch and push to make switches.

Pull switches are what people have used for years to control devices and are similar to the cords which are pulled to change the fan speed or turn on and off a light on a ceiling fan. Pull switches are usually spring-loaded, where the user has to make a significant amount of downward force to overcome the spring force. Once the user pulls down on the cord, a connection is made allowing electricity to flow through the now connected wires. After the initial pulling of the cord, the switch is now locked into the "on" state and current flows continually. When the user wants to turn off the device, the user simply pulls the cord again unlocking the device allowing the spring the pull back. With the spring force pulling the circuit apart, the device is set to its initial state. In this state, the wires' connection is open, which prevents the flow of electricity. This type of switch would work for the backlight of the LCD screen because once it is on; it would want to stay on until otherwise told by the user to be turned off. The other buttons in this project do not need this type of connection style, and this style of switch would only be used for the LCD backlight. The use of a pull string does not look very professional from the outside appearance, so this would most likely not be used.
Toggle switches are very similar to a common household light switch on the wall. The device works by the use of a user's manipulation of a mechanical switch that turns a device from a conducting state to a non-conducting state. This switching mechanism, along with the pull switch, stays permanently on once the switch is toggled and does not change state unless it is further acted upon. Once again, this style of switch would not be used as the sole type of switch in this project due to the fact that some devices need to only be activated for a short period of time such as the power off input. This type of switch will be used however for the LED backlight display of the LCD device, since once this device is turned on, it stays on until the user wants to turn it off, and this style of switch will work best with this style of input.

The last type of switching mechanism is a push switch in which the user depresses a button to allow current to either flow, or stop flowing. The two main types of push button switches are called the "push to make" or tactile switch, and the "push to break" style of switch. The push to make switch is essentially two wires separated by a distance of air or other dielectric, which prevents the wire from conducting. In this switch, there is a conducting material connected to the button which is separated from the two wires by a separate specific distance. When the button becomes depressed by the user, the wires connect through the conducting material attached to the button of the button, resulting in a current flow which essentially turns the device to an "On" state. When the user releases the button, the device once again stops conducting and turns off. A push to break switch is similar to a push to make switch expect that the device starts out connecting, allowing current to flow. Once the button is pushed the circuit is broken, creating an open connection.

Problems can arise if the user holds down to long, the microcontroller can recognize the input as multiple “On” states essentially causing the device to flutter its state. For example if a device was a counter, and counted every time the device recognizes a connection, the microcontroller might recognize 50 connections before the user releases the button on the device. This problem is the reasoning behind why the group will need to implement a de-bouncer, which is a circuit or a part of a device program coding, which will prevent this multiple recognition from occurring. This will work fine for the devices that are pushed once and it performs the action; such as sending the signal to turn off the power in the sensor device. However for the LCD backlight power button, this would have to be implemented within the microcontroller to keep the backlight on after the button is pressed and stay on after it is released, within a second press of the button turning the device off. With the addition of a de-bouncer within the code of the microcontroller and special integration with the microcontroller, the group has decided that push button technology will be the type of input used in the system for the up, down and power buttons, which will allow the group to save money by purchasing multiple buttons of the same type. As stated above, for the LED backlight, the group plans on using a toggle switch.

2.2.6 Power indicator light

For the project, the group will need a set of three indicator lights to go onto the power sensing units. These indicator lights will help the group to identify whether or not power is flowing into the appliance that is being measure by one of the sensing devices. There are really two different types of indicator lights that would actually have a feasible integration into the group’s project. These indicator light styles are that of a light emitting diode, along with that of a low power incandescent light bulb.

The first style of indicator light out that that is to be reviewed is that of a low power incandescent light bulb. This style of indicator light was very common in user products up until the late 1980’s when LED indicator lights began to take over the market; however it is still used frequently in the auto industry. A disadvantage of using this style of light is the fact that it costs more than a typical LED light would cost the producer, with a cost of up to three dollars per bulb compared to less than a dollar for a typical LED light. Furthermore the device drains a large quantity of energy, has length of life issues, and can be prone to breaking, which can cause glass to be spread about. Lastly the incandescent light bulb must have an additional light bulb holder attached to the device for the light bulb to screw into. This additional item will increase the size of the device and the scope of material needed for the project. The advantages of this style is that it gives out a decent quantity of light and due to its larger size and brightness, can be seen from far away at any particular angle. Despite this admirable quality, it has lost its hold on the market when LED became brighter and cheaper to produce, and therefore is not cost effective for the project.

The other style of indicator light that is to be reviewed is a light emitting diode. This style of light came onto the scene in the 1960's but was not used for indicator lights until the early 1970's due to their expensive price and low light quality. This has improved since then and now low power LED's with low light output can be purchased relatively cheaply. The disadvantages of this style of light are that it cannot give out a truly "white" light which is a problem within the lighting community. In addition the light that is output is not as strong as a typical incandescent light bulb and the light might have problems with outdoor applications. Despite these small problems, LEDs have succeeded in becoming the most widely used light source for indicator lights. This is because they are extremely efficient with power use, can be made extremely small. They also have low heat radiation and can last a long time in use, especially due to their ability to take massive amount of shock without fear of shattering or being destroyed.

With both styles in mind, and comparing the advantages and disadvantages of each, the group has decided that a light emitting diode would be more suited to the project. In addition to all its advantages with efficiency and lifetime, the fact that it does not need a special screw in holder to be powered is very important to meet the specification of a small package size for the sensor device.

2.2.7 Power relay

One of the features of the power meter is the ability to switch the component being measured on and off. The user can do this by going to the head unit and pressing a button. The main concern in choosing a relay is having it rated to handle the kind of current and voltage that will be measured. For this reason the Sharp S216S02 solid state relay will be used. This relay is optically isolated and rated for 240 VAC and 16 A. The relay will be installed in series with the components A/C line.

2.2.8 Batteries

To prevent the designed project from becoming too costly, it will partially be ran from battery power. These batteries will only be used on the main unit because it will be able to stand alone without any physical connection to a wall or may be needed to be away from a power outlet. The batteries will be two nine volt batteries placed in parallel. This will allow both batteries to be "drained" evenly, and allow both to produce a smaller current. As well, another smaller battery may be used to be used as a low voltage reference while still being able to run off of this battery in the case of changing a battery.

2.3 Previous Works/ Similar Projects

2.3.1 Commercial power measurement products

There are a variety of home power measurement devices available to the general public. This project will be similar in function to some of these with certain extra capabilities. The best known one is “Kill A Watt”. This sensor plugs into the wall and the device that is being measured is plugged into it. It has an integrated LCD display and 5 buttons to navigate the different options. This sensor displays its readings in kilowatt-hours. It starts monitoring power from the moment it is plugged in and the customer can use the readings to calculate power for the day, month and even year. The sensor is rated for 125V and a maximum current of 15A. The manufacturer claims .2% accuracy. The good thing about this sensor is that it is very simple and easy to use. But at the same time, it might be too simple. The device will only display kilowatt hours consumed and it leaves the calculations in terms of dollars and cents to the consumer. Also, it is not rated to read power on devices running on 240V. This means that the consumer won’t be able to measure how much power the most power hungry devices in the house are consuming. The device also displays power factor, rms voltage and current but such measurements are not exactly useful for the regular consumer. It does not have wireless capabilities. Overall it is a nice inexpensive sensor. 2.3.1 figure 1 shows the Ryobi power meter with is similar to the “Kill A Watt” meter.

2.3.1 Figure 1 Ryobi Power Meter printed with permission from Jason Swanson of Ryobi Tools

Efergy is another company that makes power monitors. Their monitors also measure kilowatt hours and it is also capable of displaying actual cost. It also can historical usage. The manufacturer claims around 5% accuracy. The reason for the lower accuracy seems to be that the sensor does not use a voltage reference. Therefore it only uses a current measurement and decides on an estimate as far as voltage. One nice thing about the sensors this company uses is that they are wireless. There is a sensor at the device that is being measured and there is a separate display for the measurements. They have two models; the Elite and the e2. Both models have comparable features. The main difference is that the e2 comes equipped with PC software to a graphical display of the readings and will also calculate the carbon footprint of the customer. This is a very nice unit but it seems to lack in the accuracy department.

Another similar product is the Wattson. This device will also make its power measurements and relay them wirelessly to a base. The Wattson is made to measure the power consumption of the whole house and not necessarily that of a particular appliance. This sensor actually glows with different colors depending if the home is consuming less than average, average or more than average power. The manufacturer also sells computer software that will make calculations and show graphical representations of the data. The current sensor uses batteries and then their duration depends on the refresh rate of the measurements. Measurements made in closer intervals will be more accurate but at the cost of battery life. The installation of Wattson is not as user friendly as other sensors. Since it measures the power usage of the whole house, it must be installed on the main wiring going into the house. Since this wiring is not usually easily accessible, it is better for it to be installed by an electrician. This obviously adds to the price of use and might also make it difficult to change its batteries once these run out. The accuracy of this device as stated by the manufacturer is also 5% due to the fact that it measures current and assumes the voltage reading. It does not directly measure voltage. This device is not as accurate as the meter reader at the house but it is useful in comparing usage from day to day.

The 3 designs just described are the most common ones in the marketplace. There are also power meters that are either homemade or are redesigns of the ones for sale to consumers. As noted, the designs all have some advantages and disadvantages. The most obvious disadvantage for some of the sensors is their accuracy. Since they might not be as accurate as what the power company uses to measure power consumption, their readings are approximations that cannot be used to precisely compare what the power company charges for usage and what the sensor is actually reading. The advantage of some of these sensors is their capacity to communicate wirelessly to the main unit. This is very useful since it makes the system much more user friendly. The user can purchase various sensors and monitor their usage from one main display instead of having to read the display of each unit connected to each appliance. Another disadvantage of some of the designs is that they cannot measure current of levels below 40 watts. The Wattson is one of them. Since the Wattson is supposed to measure the consumption of the whole house and many of the appliances in the house use much less than 40 watts, the system won’t be able to account for them and that will make the measurements even less precise. This is definitely not the system to purchase if you want a power meter that measures what the power company is measuring.

One of the most complete and useful power meters available is made by TED (The Energy Detective). This design is not only simple but extremely accurate. What makes this meter so much different and better than other designs is the way it reads voltage and current. The system has a sensor that is attached directly on the main lines of the house and the information is sent through the house wiring! The system is mostly geared for the measurement of the energy consumed by all the appliances in the house although they do sell individual sensors for appliances in case the owner wants to know how much a certain appliance is using. The accuracy comes from the fact that the system measures both the actual current and voltage being fed to the house. Other sensors take a guess as to what the voltage is or should be and derive the results from an assumed voltage making them much less accurate than the TED system. The way it reports the readings through the house wiring is also unique to this system. By sending the information this way, there's no need for any kind of wireless technology and the problems that could be encountered with them such as the deterioration of the signal the farther away the transmitter is. The system reads the current using a Hall Effect sensor. It comes in a variety of models and displays. Most of their displays look like the display in an A/C digital thermostat. TED also displays its measurements in terms of dollars so the customer will know exactly what the measurements mean. Due to this system being so accurate and the fact that it takes its readings directly from the home wiring makes it useful to compare it's readings to the what the power company charges. Due to its sensing arrangement TED is not as easy to install as other systems. In order to install it, an electrician is recommended but once it is installed, it doesn't need any maintenance. It is powered by the home wiring and it only costs about 8 cents per month to use. Another of its advantages is that it can sense all the way down to 10 watts. This also helps it be so accurate as far as how much exactly the home is consuming in energy. Other meters will only go as low as 40 watts. Since it is intended to give the customer an idea of total home energy consumption, it is very important that it reads as low a wattage as possible so even the smallest appliance usage will be accounted for. Another reason for TED's accurate readings is that it measures power every second. That means that what you see on the display is a very accurate reading of what is being used at the moment. Other than the installation difficulties that this system might incur, it is definitely one of the best household power management systems available.

These power measurement systems are what is available to the public. Obviously every home is equipped with a power measurement system used by the power company. The design of this project will be the equivalent of a consumer oriented system and not a commercial system as used by the power company. Therefore no commercial power sensing systems are included in this discussion.

It seems that as consumers have become more conscious of their power usage, more companies are coming out with different approaches on how to best measure power on the home. The above devices are not the only ones available but simply a sample of what can be purchased. Just as consumers are demanding cars with better miles per gallon ratings, it is possible that in the not so distant future, they will be demanding different appliances based on the power consumption they measure on their personal power measurement systems. As people also become more aware of the impact of their energy use on a global scale, many of them will also find use for power measuring systems for the home.

2.3.2 Previous Senior Design projects

Listed below will be a review of Senior Design projects worked on by other students at other universities who attempted to design similar devices. Each design will be reviewed for its failures and successes and will be used as a guide to learn what to do to have a quality finished product.

The first Senior Design project being reviewed is from the University of Illinois during fall of 2009, and is titled *“The Power of Control: Energy Efficient housing.”* The team of students includes Steve Granda, Ariel Moctezuma and Katies Snell. Their Senior Design project is similar to this group’s project, and has been reviewed for relevancy, as well as a method to learn from previous mistakes. The group also hopes that by reading about their design, the group will be able to apply additional cool features to the design. Their project’s purpose is to monitor the use of power consumption in the electronics around the home and be able to control the devices to reduce power. They plan on reducing power through the use of microcontrollers which are instructed to turn off devices that are currently in the standby, or idle position. They use power monitoring circuits as well as analysis of previous idle states, to be able to tell which devices are currently in standby mode. The would then power off the devices in standby mode based upon when the user’s has listed for a time where the devices can be set to be turned off. Their plan is mainly to actually save money by turning off these electronics, and the power measurement data can be viewed from a secure website within the network. In addition, they would like to implement a new type of networking to allow one device to receive and resend data from a device that is located farther away to allow a seemingly limitless distance for the devices to be from the receiver if other devices are nearby.

After completion of their Senior Design project they discovered that their device provided an accuracy of 90% of the energy reading. They also noticed a 76 cent per year decrease in power consumption per device plugged into the wall by measuring and powering down devices. They also proved that timed shutdown and power on of devices was possible, and selection of times for each device also proved feasible. They failed however to get the mesh networking to work, therefore requiring that the devices be within 20 feet from the receiver for quality wireless communication. In the future they stated that they would include features for implementing power/damage protection of devices, as well as the ability to dim lights, email power data to the user and export the data to excel spreadsheets.

Having read over their successes and failure the group felt that this percentage is good, however it should be improved to help users understand how much they would actually be saving. Furthermore, it seemed the saving of 76 cents a year was rather low and potentially not worth the actual cost of the devices and this needs to be improved. It also seemed that checking the internet for the power cost information would seem to be difficult, and all data would be lost if wireless internet connectivity was cut. In review, the group felt that the project as a whole was a success, but it could be improved. The group also felt that the addition of an external reader similar to the group's device is the best method for reviewing power consumption on a daily basis. This is, in the group's opinion, the best method to actually have the users reduce their actual power use.

Also from the University of Illinois during fall of 2009 is Gerald Nilles and Stanton Cady with a Senior Design project titled "*Power Monitoring System for measuring Consumption in Multiple Remote Modeules."* Their Senior Design project is similar in nature to that of the previous design's approach in that a voltage sensor and a hall-effect current sensor will collect all data. This data is then frequency modulated and sent on the house's existing power line, to another modem using power line communication. This is done to remove unnecessary use of wireless communication to transmit the data. After the signal is received at the other power line modem, the signal is demodulated and then analyzed on a microcontroller in the receiving setup. This then connects to a PC and outputs the data as a measure of watts of power used in a graphical form. This graphical data is then broadcast onto a website on the internet, allowing full access to view the data anywhere that is connected to the internet.

The group succeeded in accurately sending their information over the power lines of a residential house, which allowed the use of no wireless communication. They also succeeded in logging and graphing the data onto the website, however, the group noticed a large quantity of noise from their device which may have affected the data's accuracy. The group wanted to improve upon the noise problems experienced, as well as implementing an error checking mechanism to test the accuracy of power line communication.

After reviewing this project the group learned some interesting new ways to consider using for signal transmission. Once again, the group did not like the fact that their project did not use an external reading device to measure the power output. An improvement between this method and the previous method is through the use of an internet approach, where the user can look up his data from anywhere. This will also the user to do power analysis at work or even on the couch with an Iphone. The group is are a bit worried that this method may be bad due to potential problems with security, where an end user might be worried that unwanted people could pry into the owners power use infringing upon a users privacy rights. Lastly the group felt that it would be nice if their data would output data in actual spending due to their power use as opposed to power use in the form of kilowatt hours. The group feels that this is the best method to help people control their power use, cutting back unneeded costs as well as helping to save the environment at the same time.

The Last project to be reviewed is "*Power Monitoring System for Residential Use"* from fall of 2005 Drexel University students Walid Jebbari, Melvin Mathew, Joshua Nguyen, Bradley Stewart and Kai Chung Wong. This group chose to go with a computer based method of monitoring power consumption in the home along with every other group. The team planed to monitor the power consumption of the house using a power measurement chip, attached to a microcontroller in the sensor. The microcontroller then computes the current data regarding power consumption, which is sent wirelessly to a receiver. The wireless transmission will be specialized to handle multiple sensors' transmission and allow the receiver to interpret it correctly. This receiver takes in the data sent from the sensor devices and outputs the data graphically using a Visual Basic based program on the computer, which allows the user to view their power consumption and its costs.

This group did a very similar design approach to the monitoring of power conversion as Steve Granda, Ariel Moctezuma and Katies Snell's Senior Design project. They decided upon an on the computer, in home only review of the power that was measured. This approach is good, but as the group discussed earlier in this paper, its feasibility to actually lower power use is limited because you have to actually run the program to collect and review the power output of the appliance being measured. The computer based analysis will likely not occur as often as the ability for someone to look at a physical device that displays the cost. It is also interesting to see that they used a chip to measure power as opposed to the typical hall-effect sensor that most every other design uses. They provide a graphical display of the cost of the appliance, which is a much better approach then simply data output like the group's project is using. The group has looked into it and has found that to output the data in graphical form onto the liquid crystal display, would require a higher resolution LCD which would increase the overall cost of the project beyond the reasonable need.

3 Design

3.1 Component Selection

3.1.1 Display Screen

There are several requirements for an adequate display interface that the group's project needs fulfilled in order to output all of the required data for the user to see. These requirements were discussed extensively under section 1.3.2 of this document; the basic requirements however will be discussed here. Moreover, the choice for what style of display device was made in section 2.2.1 of the research section and this will be slightly discussed in the section. Finally, the exact device selection will be made in this section based of the requirements section stated earlier, along with other important factors such as cost, size, availability, and ease of implementation.

The style of screen that was selected in the project is that of a character based liquid crystal display. This was the style that was selected because of the ease of finding liquid crystal displays through various online resources, each containing various devices that follow the needs of the group. LCDs are also relatively low priced which can help to reduce overall project costs, and they are widely used, allowing research into device problems or integration questions very simple to obtain. In addition this style of display commonly comes in the form of a character LCD that allows for easier device implementation and setup.

The project has several requirements that will be satisfied through the use of a character LCD to display the data. One of these requirements is that the device displays a minimum of 18 alphanumeric and symbolic characters with 3 blank-space characters for a total of 21 characters per horizontal line. The device must also be able to have at least three lines of vertical text for the user to accurately read and understand what they are seeing, as well as allow the user to compare one device to another. The device must also come with a simple microcontroller for an easy method of character displaying. Furthermore, the device must be low power with a backlight for low light viewing of the display. Lastly the device must also be cheaply priced, and in stock at a distributor.

Since the design needs a horizontal width of 21 characters long, the group will need to find a character LCD that is larger than this number. The minimum size of the character LCD that fits this format is 40 characters long by 2 lines vertical and 40 characters long by 4 lines vertical. Since the device also needs to have at least three vertical lines of space, the only format character LCD that the group can use is the 40 character by 4 line style of LCD. Under the search criteria required above, a simple Google search resulted in numerous different styles of character LCDs that could be feasible for use within this project.

The main similarities of every search were that each and every device found with a cost of fewer than 60 dollars was compatible with the HD44780 microcontroller scheme of outputting data. These different devices used the same coding scheme for outputting character, with the only difference being the pin layouts were in a different order. The HD44780 microcontroller and its other similar microcontrollers have a selection of around 208 characters that are composed of a five pixel by eight pixel dot matrix. The HD44780 device driver is only capable of providing output to a screen size of 40 characters by 2 lines long. Therefore each of the devices requiring more than 40 characters by 2 lines will have a second HD44780 or compatible microcontroller attached together within the device, with two separate enable bits to add data to the upper and lower line sections. These two microcontrollers are attached to the LCD display and are instructed to do tasks by an additional microcontroller controlling the device. This outside microcontroller must have enough output pins to allow the user to be able to manipulate all of the pins in parallel.

After much research into the varieties of character LCDs available on the market, the group was only able to find a select few different character LCDs on the market for less than sixty dollars. The ten or so different varieties of LCD all were compatible with the HD44780, and only varied in the price of the device as well as the color. Since color was of no importance to the project, the group looked and chose solely on the cost of the device. Based on this new filter for selecting an LCD display, the group decided that the part that will be included within the project will be the NHD-0440AZ-FL-YBW from Newhaven Display International.
This LCD device is a 40-character by 4 lines long that uses two SPLC780D microcontrollers. The SPLC780D microcontroller is backwards compatible with the industry standard HD44780. This is great for the project in that the group will be able to find more information about problems or areas of interest from outside sources. In addition, this product also has some free to use C-code based programs to help you learn more about the device through testing, and these programs will come in handy for the integration of the LCD and the microcontroller. The device additionally has a yellow/green LED backlight, providing additional viewing ability at night or within a bright room. The fact that the device is LED powered is an additional bonus in that they are lower powered compared to a traditional backlight style and will not drain the entire device's power too quickly if left on throughout the day.

The device runs off of a 5V power supply to power the microcontrollers to run the logic of the device as well as the LCD itself with the current entering into the device typically around 3.5mA. These voltage values can run between 2.7V and 5.5V, and must have a max current of 4.0mA for the device to function properly. For the LED backlight on the device, it also requires an additional 5V power supply for the LED backlight, with a current typically around 360mA with a max of 480mA. This point shows how important it is to have a power off button for the LED backlight, due to the fact that the power drain of the LED backlight is 1.9 W, while the drain for the entire logic unit is .0175 W of power, showing just how much of a drain to the battery this device would be if it were left on at all times. For a pin to be recognized as high on the input of the device, the voltage must be between 2.2 V and the rail voltage of 5V. However for the pin to be recognized as low, the microcontroller will only recognize values between 0V and .6V. These are important numbers to have in mind when the device becomes implemented into the microcontroller circuit in order to prevent issues with the device not recognizing input values. The chart below, 3.1.1 Figure 1, explains the temperature ranges as well as the power supply requirements that were explained above.

Item	Symbol	Condition	Min.	Typ.	Max.	Unit
Operating Temperature Range	Top	Absolute Max	-20	-	+70	°C
Storage Temperature Range	Tst	Absolute Max	-30	-	+80	°C
Supply Voltage	VDD		2.7	5.0	5.5	V
Supply Current	IDD	Ta=25°C, VDD=5.0V	-	3.5	4.0	mA
Supply for LCD (contrast)	VDD-V0	Ta=25°C	-	4.5	-	V
"H" Level input	Vih		2.2	-	VDD	V
"L" Level input	Vil		0	-	0.6	V
"H" Level output	Voh		2.4	-	-	V
"L" Level output	Vol		-	-	0.4	V
Backlight Supply Voltage	Vled	-	-	5.0	-	V
Backlight Supply Current	Iled	Vled=5.0V	-	360	480	mA

3.1.1 Figure 1: Electrical Characteristics of NHD-0440AZ-FL-YBW Printed with permission of Newhaven Display International.

This device will be viewable for a total vertical range of 85 degrees of vertical viewing, and 120 degrees of horizontal viewing, which is within a tolerable viewing angle for most users operation and is therefore acceptable in the design of this project. The device can do all operation in less than .5 microseconds, and therefore can operate fluidly with the microcontroller. The only thing to keep in mind with this device is the delay that some instruction might have, and this must be dealt with when designing the code for the devices output display. Also, it must be known that each character has to be changed less than once every 150 ms for changes of values to become unnoticeable; this characteristic is suitable for the group's needs because the device will only reasonably be updated every 60 seconds or so. The two charts below list the details of the NHD-0440AZ-FL-YBW that was previously explained in the above paragraph, including viewing angles as well as response time of the LCD display within 3.1.1 Figure 2, and the amount of time a pin must be set to a certain level to obtain an input within 3.1.1 Figure 3.

Item	Symbol	Condition	Min.	Typ.	Max.	Unit
Viewing Angle – Vertical (top)	AV	Cr ≥ 2	-	25	-	°
Viewing Angle – Vertical (bottom)	AV	Cr ≥ 2	-	70	-	°
Viewing Angle – Horizontal (left)	AH	Cr ≥ 2	-	30	-	°
Viewing Angle – Horizontal (right)	AH	Cr ≥ 2	-	30	-	°
Contrast Ratio	Cr		-	2	-	-
Response Time (rise)	Tr	-	-	120	150	ms
Response Time (fall)	Tf	-	-	120	150	ms

3.1.1 Figure 2: Optical Characteristics of NHD-0440AZ-FL-YBW Printed with permission of Newhaven Display International.

Characteristics	Symbol	Limit			Unit	Test Condition
		Min.	Typ.	Max.		
E Cycle Time	t_C	500	-	-	ns	Pin E
E Pulse Width	t_{PW}	230	-	-	ns	Pin E
E Rise/Fall Time	t_R, t_F	-	-	20	ns	Pin E
Address Setup Time	t_{SP1}	40	-	-	ns	Pins: RS, R/W, E
Address Hold Time	t_{HD1}	10	-	-	ns	Pins: RS, R/W, E
Data Setup Time	t_{SP2}	80	-	-	ns	Pins: DB0 - DB7
Data Hold Time	t_{HD2}	10	-	-	ns	Pins: DB0 - DB7

3.1.1 Figure 3: Timing Characteristics of NHD-0440AZ-FL-YBW Printed with permission of Newhaven Display International.

With the device meeting all of the group's requirements, far surpassing the requirements in some cases, the group has found this device to be suitable to the groups needs. Furthermore the price of around $25 meets the expectations for this project and is one of the lowest prices around for an LCD screen of this size. After many careful considerations, including price and functionality, the group has decided to use this device as the LCD output screen.
If this device is not in stock, the group plans on ordering a similar device from the same company, with the same specs, but with a different LED backlight color. This device number is NHD-0440WH-ATFH-JT# and is a comparable unit to our device

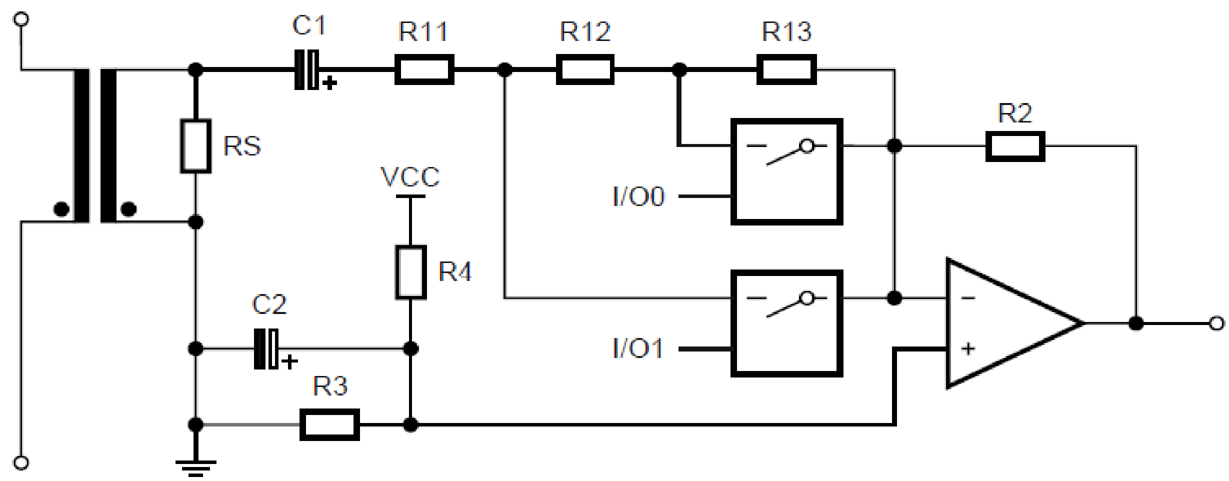
3.1.2 Power Sensors

The sensor circuit has two basic sides to it, a front or analog side and a back or digital side. The analog side is where the A/C voltage and current to be measured reside and the digital side is the side where these measurements are converted to voltages that can be read by a microprocessor. And that is the main reason why there are two main sides to the circuit. The voltages and currents in the analog side are very high in comparison to what the microprocessor can handle without being destroyed. So the first step is taking the voltage and current from the A/C side, measuring it and bringing those levels down to something a microprocessor can handle. The simplest and most efficient way to downsize the voltage is using resistors. For this design, a resistor ladder will be used which is a fancy way of describing a voltage divider. Part of this circuit design is the careful reduction of noise. Since the voltages in the front end of the circuit have a high amplitude, they can be a source of noise. This noise will particularly affect the current measurement portion of the circuit and will interfere with its actual values. This interference will be most notable at non unity power factors and at small signal amplitudes and it will show as a non linear error. At unity, the current and voltage are in phase and the error shows up as a gain error. This error is easily compensated for and calibrated. But when the voltage and current are out of phase, the non-linear error created cannot be calibrated. To minimize the interference, the use of filters will be crucial for the accuracy of the meter. Of particular interest in the meter design is the placement of a relay that is controlled by the user that can turn the appliance on or off. The relay will be place in the series with the live wire coming from the mains. The reason for the option to turn on or off the appliance is so that if the user decides that the appliance is consuming too much energy, there is an option to shut it off. This relay could also be used to shut down the meter in case of a spike in current or voltage that could compromise the proper functioning of the meter.

The measurement of the current is more complicated than that of the voltage. The reason for this is that the voltage will stay constant throughout the measurements. The current on the other hand, varies depending on the load. The current can vary from a few milliamperes to well over 10 amperes. This broad range of values makes the current measuring circuit more prone to error and needs more care when designing. In order to be able to stay within the accuracy goals, the circuit will need a gain stage to amplify the smaller signals. This gain stage is programmable and will be handled by the microprocessor. The gain stage needs to amplify signals by up to one hundred times. The catch is that it should only amplify the A/C signal and not the D/C signal. The reason for this is that an amplification of the D/C signal could create a saturation condition that needs to be avoided. Again, in order to keep the accuracy goals, this gain stage needs to also be able to settle in less than a second and as mentioned before, it should be programmable. The simplest way to achieve these goals is using operational amplifiers. There are a variety of operational amplifiers available and choosing the correct one is of critical importance. To start with, the non inverting amplifier will be of no use on this design due to the fact that one goal is for high amplification of the A/C portion of the signal and no amplification of the D/C signal. The reason for not being able to use the non-inverting amplifier is mainly difficulty of use. For the frequencies that the meter will be measuring, the non-inverting amplifier would need very big capacitors for the D/C coupling phase. This large D/C coupling capacitor will slow down the switching times of the gain.

The best operational amplifier for this circuit is the inverting amplifier. It will still need the use of a capacitor but it will be a much smaller capacitor than if a non-inverting op amp was used. Gain configuration resistors will be used in tandem with switches. The topology just described has a fast switching time while being able to create the needed gain in the A/C phase while creating very little D/C gain. The switches used are from the 74-HC logic design.

3.1.2 figure 1 shows how the schematic of the gain portion of the design.



3.1.2 Figure 1 Gain phase schematic Used by permission from Microchip.com

The gain of the op amp in this case is A = -R2/R3, where R2 is made up of resistors R11, R12 and R13 in series. The gain is accomplished by shorting out resistors R12 or R13 using the switches and the switching is controlled by the microprocessor using the connections I/O0 and I/O1. Using R2=470 kOhms, the gain of the op amp is controlled using the values found in 3.1.2 figure 2.

I/O0	I/O1	Range	R_1 Impedance	Gain
Low	Low	Low	R11+R12+R13 = 6.8k+39k+330k (2)	-(470/375.8) = -1.25
Low	High	Medium	R11 + R12 = 6.8k+39k	-(470/45.8) = -10.26
High	X (1)	High	R11 = 6.8k	-(470/6.8) = -69.11

3.1.2 Figure 2 Resistor Values Used by permission from Microchip.com

Shunt resistor RS and the current transformer are of such size as to not permit more than 1V of peak to peak amplitude at the amplifier output when the maximum amount of current is moving through the current transformer and there is a minimum amount of gain. In order to D/C decouple the input signal of the op amp, capacitor C1 is used. The DC level at the non inverting input of the op amp is stabilized with capacitors. This DC level must be half of the reference voltage at the analog to digital portion of the microprocessor. If the voltage reference is 1.1 volts, the voltage divider created by resistors R3 and R4 must supply a voltage of .55 volts. In trying to keep noise to a minimum, the voltage divider will have a high impedance which keeps current consumption low.

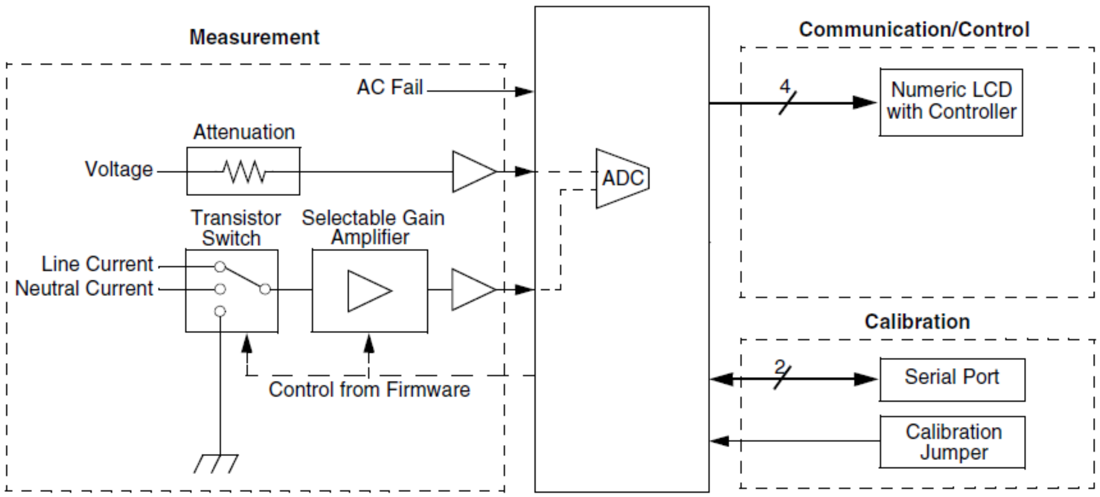
The tolerances for the components used to make the meter circuit will usually be around 5% meaning that the meter has to be calibrated in order to account for the error caused by the tolerances. This is a critical step in getting accurate readings. There are different ways to make up for these errors. Some of these ways can be done physically on the circuit or via software. If the calibration were to be performed manually, trimming resistors would be needed which would not be very efficient. A better solution is to do the calibration through software. Software calibration has the advantages that it will not degrade over time and it is quick. To do this, the calibration coefficients are calculated for the meter and then stored in memory.

As mentioned before, the current transformers, filters and the multiplexing of input channels can alter the phase of the current and voltage signals. The phase displacement caused by the current transformer can be up to 5 degrees and the multiplexing can cause a time difference in all the channels that will be inversely proportional to the sampling frequency. For example, at 2400Hz the time delay would be 1/2400Hz that comes out to .42ms. This causes a phase difference of 7.5 degrees at a main frequency of 50Hz. A simple, accurate method to compensate for this phase displacement is linear interpolation. The only problem with linear interpolation is that it causes a time delay to the signal so the phase can only be adjusted for one frequency. This means that harmonics cannot be adjusted for phase using linear interpolation. For this design's purposes, this should not be a problem as most of the signal energy lies within the first harmonic. The algorithm used for this purpose uses two additional samples to find an intermediate point when using interpolation. The result of this is that the higher the sampling frequency, the lower the margin for adjusting the phase displacement.

Errors of magnitude are created due to the tolerances of the component values but this can be accounted for by using sets of gain calibration coefficients. Gain coefficients will be needed for both the voltage and the current. Each current sample will be passed through a filter, the phase will be calibrated and the data is then accumulated. When calculating power, the current readings are multiplied by the voltage readings and then accumulated. When the calculation cycle ends, the registers are normalized and the resulting values are then multiplied by the gain coefficients. For the current channels, there are 3 different gain coefficients depending on the need for low, medium or high amplification. When calibrating the voltage, a similar method is used. The difference is that since the voltage is constant at all readings, only one coefficient is needed. These coefficients are stored in memory.

In order to calibrate the meter, it needs to be connected to a computer. Then the computer is used to write the firmware unto the FLASH memory of the microcontroller. The once the calibration is complete, the calibration data is written into the EEPROM of the microcontroller. In order to connect to a computer, an RS-232 interface is added to the circuit.

3.1.2 Figure 4 shows the general layout of the design.

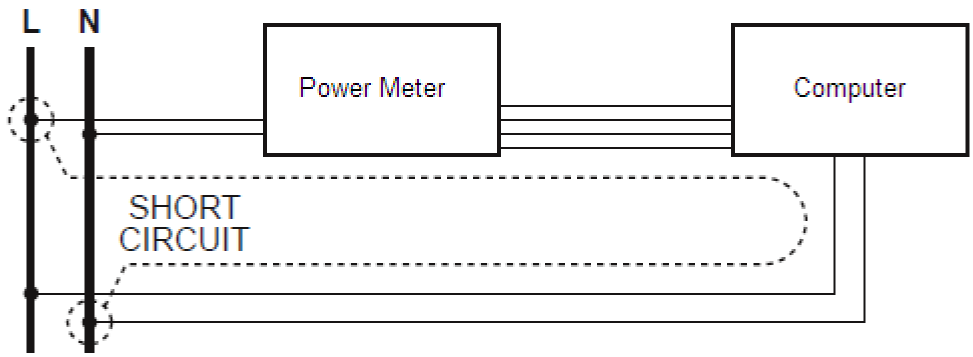


3.1.2 Figure 3 General Sensor Schematic Used by permission from Microchip.com

Setting up the meter

To install the meter, all that is needed is for the sensor to be connected to an outlet and the appliance to be measured. When it is in calibration mode, it will be connected only to a computer via the serial interface. In order to program the meter it must be connected to a computer using the In System Programming interface or ISP for short. For the safety of the meter and computer, opt couplers can used to isolate the meter from the high voltages and currents of the analog side. An opt coupler uses a short optical transmission path to transfer an electric signal from a transmitter and a receiver but it keeps them isolated from each other. It is an integrated circuit that prevents the analog signals to destroy the digital components of the design. The electric signal is converted to a light signal that is then again converted to an electric signal hence keeping the two sides from affecting each other. They are usually very inexpensive (as little as $1) and are a nice addition to the design for safety and protection purposes. When the meter is connected to the high voltage lines it is vital that care is taken if a computer is connected to it. The reason for this is that the meter has no galvanic isolation from the high current main lines. Since the meter and the computer would both be connected to ground and live wires, the computer could cause a short. In essence, the computer serves as a short between ground and the live wires and the destruction of the computer but be all but guaranteed.

This next figure shows a computer connected to the power meter and clearly shows the real danger of shorting it.



3.1.2 Figure 4 Short Circuit Schematic Used by permission from Microchip.com

In order to keep the computer from shorting, a galvanic isolation barrier needs to be created between the meter and the computer. To do this, the previously mentioned opt couplers can be sued at the ISP and USART interfaces.

In order to use the meter, it is connected as previously described and it automatically will start to measure power and displaying the results on the LCD screen. The first time the meter is used, it needs to be calibrated. To calibrate it, the meter is connected to a computer that is used to write the firmware into the FLASH memory of the microprocessor in the meter. Then the firmware will take readings of the actual power measurements and will then write calibration data to the EEPROM of the microprocessor. After the meter is calibrated, it is ready to use. The calibration parameters should last years and the meter won't need to be recalibrated after the first time it is used. Once the meter is calibrated, it can be used to display all the power parameters it is designed to measure.

3.1.3 Microcontroller

As there are two different main requirements for the design of this project, two different microcontrollers have been selected to be used. The first of which is the Arduino Mega, which will be used for the main unit's microcontroller. The other is the Arduino Pro Mini. The Pro Minis will be used in all of the sensing units.

3.1.3.1 Arduino Mega:

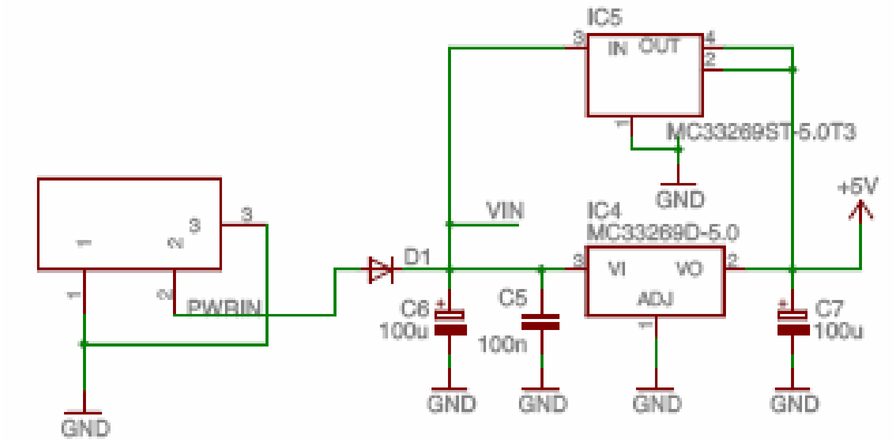
The requirements of the design of the main unit's microcontroller will be met by the Arduino Mega. As stated above in section 2.2.3, the Arduino Mega is built with a total of 54 digital input or output pins, which can be assigned to either mode as needed, as well as 16 analog inputs. Some of these pins on the microcontroller also have special functions or have multiple functions. 3.1.3 Table 1 shows the pin assignments and any special notes regarding them. The design of the Arduino Mega board itself with such a large input and output pin count allows the microcontroller to interface with multiple devices, such as the LCD screen and wireless components associated with this design, simultaneously. In addition to these devices, the Arduino Mega board has enough input pins to allow multiple used controlled push buttons to be used as a means of allowing the user to manipulate information while the microcontroller is in use. Along with the amount of digital and analog pins, the Arduino Mega serves for ease when using shields. This is beneficial due to the design utilizing the Arduino XBee shield. While these shields have been designed with other models of Arduino boards in mind, the Arduino Mega accommodates the shields as well. The disadvantage of the quantity of digital and analog pins is a sacrifice in physical size. Because of amount of usable pins on the Arduino Mega microcontroller, the board is 4 inches by 2.1 inches.

The external interrupt pins carry quite a bit of significance with this design. The external interrupt pins can potentially be used to aid in the "reprogramming" state of the microcontroller to allow changing of variables while the microcontroller is still in a stable, running state.

Total Pins	Primary Usage	Special Uses
Rx0-Rx4	Serial Communication Receive	
Tx0-Tx4	Serial Communication Transmit	
Digital Pins 2, 3, 18, 19, 20, 21	Digital Input / Output	External Interrupts
PWM pins 0-13	Digital Input / Output	Pulse Width Modulated Signals

3.1.3.1 Table 1: Pin assignments on the Arduino Mega microcontroller and any special notes about the pins

As the main unit's design will be powers by nine volt batteries and the supply voltage of the devices being used are either 5 or 3.3 volts, the input voltage will need to be regulated. To reduce the necessary excess components needed to realize the design, the Arduino Mega utilizes a 5 volt voltage regulator, which can be seen in 3.1.3 figure 1. This regulated voltage, along with another regulated voltage produced by the Arduino Mega board of 3.3 volts, can be used throughout the main unit as a supply voltage for the other main components. However, due to its own power supply voltage being 7 volts, another external regulator will need to be implemented. As the Arduino Mega requires a 7 volt power supply voltage, the microcontroller does consume more power than other options; however, the microcontroller also has the ability to supply the rest of the design with power. The Mega may also take an input voltage up to 12 volts and be stable. Along with this, each pin on the microcontroller can output, or input 40 mA of current.



3.1.3.1 Figure 1: Voltage regulator on board the Arduino Mega used with permissions from Arduino

The Arduino Mega microcontroller utilizes serial transmission and receiving pins to perform wireless communications between the main unit and the sensing units. As seen in 3.1.3 Table 1, the Arduino Mega microcontroller comes with 4 serial transmit and receive pins. Because of this, the design could be expanded to support more devices to receive information from more sensing units.

From the programming stand, the Arduino Mega satisfies the requirements for the main unit's microcontroller. This Arduino board allows easy reprogramming which is aided by the bootloader, which is already preloaded on the microprocessor. As well, because Arduino Mega is programmed in C/C++, programming the designed software will not be complicated. To further simplify coding, the predefined functions to allow easy assignments of pins are already preloaded onto the board. To support the majority of the coding for the entire design, and to handle all information coming into the microcontroller from all other devices, the Arduino Mega has 124 KB of unused flash memory, also allowing for expansion into a larger environment.

3.1.3.2 Arduino Pro Mini:

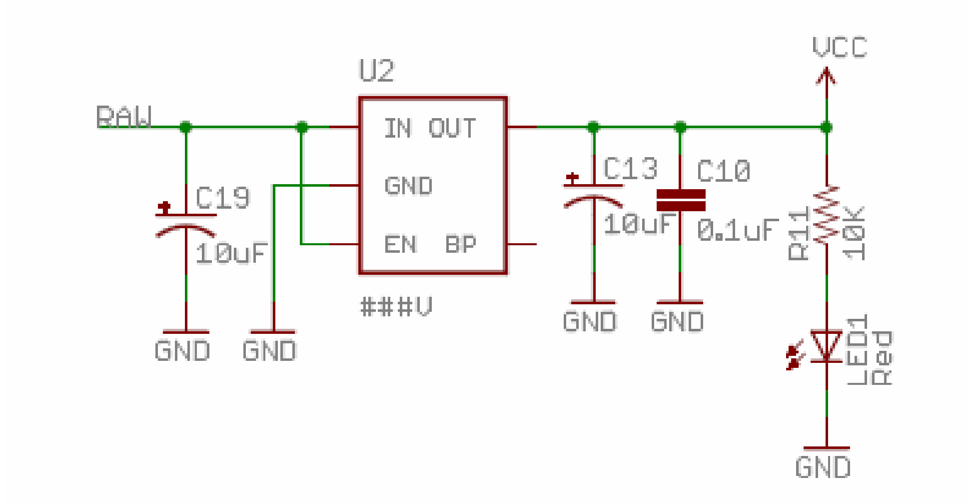
The design requirements for the sensing units will be met by the Arduino Pro Mini microcontrollers. Also stated above in 2.2.3, the Pro Minis come with 14 digital pins, which can be set to either input or outputs, and 6 analog input pins. Similar to the Arduino Mega, some of the Pro Minis' pins have multiple uses, or special functions which can be utilized in the design as shown in table 2. While the Arduino Pro Mini has the pins required to be used by the XBee, the Arduino XBee shield does not properly fit due to the Pro Mini's small size of 0.7 inches by 1.3 inches. This can be bypassed by still using the Arduino XBee shield and simply manually bridging the connection though the use of printed circuit board designs or even simple wires.

The external interrupts on the Arduino Pro Mini could also be implemented in the design of the project. As a possible way to conserve power, the Arduino Pro Mini may be forced into a sleep mode once the user turns off the measured device. Once in this sleep state, the Arduino could be “woken” from this state by the external interrupt pins.

Pins	Primary Usage	Special Uses
Rx	Serial Communication Receive	
Tx	Serial Communication Transmit	
Digital pin 2	Digital Input / Output	External Interrupt
Digital pin 3		External Interrupt
Digital pin 3	Digital Input / Output	Pulse Width Modulated Signals
Digital pin 5	Digital Input / Output	Pulse Width Modulated Signals
Digital pin 6	Digital Input / Output	Pulse Width Modulated Signals
Digital pin 9	Digital Input / Output	Pulse Width Modulated Signals
Digital pin 10	Digital Input / Output	Pulse Width Modulated Signals
Digital pin 11	Digital Input / Output	Pulse Width Modulated Signals

3.1.3.2 Table 2: Pin assignments on the Arduino Pro Mini microcontroller and any special notes about the pins

Also similar to the Arduino Mega, the Arduino Pro Mini allows unregulated voltages to be inputted into the board through the “RAW” pin. This is allowed by a less complicated voltage regulator, seen in 3.1.3.2 figure 2, which is built into the Pro Mini, turning the raw voltage to the power supply voltage needed for the Arduino to operate. This also allows the Arduino Pro Mini to produce the supply voltage for the wireless components, provided the XBee operates at the same voltage, as the Pro Mini only produces one voltage. This microcontroller can also handle up to 12 volts, after which the microcontroller no longer remains stable. As well, the Arduino Pro Mini can draw and produce a maximum of 40 mA of current through each input or output.



3.1.3.2 Figure 2: Voltage regulator on board the Arduino Pro Mini, shown to compare complexity used with permissions from Arduino

Unlike the Mega, the Pro Mini only has a single serial communication transmission and receiving pin. This allows a single XBee to be attached to it and communicate, resulting in an idea microcontroller for the sensing units.

Also like the Arduino Mega, the Pro Minis are preloaded with the bootloader to aid in the reprogramming of the board. The Pro Mini also uses the C/C++ programming language and utilizes the same predefined functions for using the physical pins. Unlike the Mega, the Pro Mini only has 14KB of free, usable flash memory. This memory is more than enough though, due to the fact that these microcontrollers will only be collecting data temporarily and transmitting it to the main unit, requiring a much smaller memory space than what is provided.

3.1.4 Wireless transceiver

The wireless transceiver the group decided to use was the XBee OEM RF 802.15.4 as shown above, in 2.2.4.4 figure 1. As stated above, the range was good enough for the group having a max range of 100ft (30m). While 250kbps might seem small for a commercial product, for a simple project like the power units with the central unit, it will be sufficient to work properly.

The XBee piece the group examined was an XB24-AUI001-ND from digikey.com costs $19.00 per unit. For the project, since it consists of a central unit and multiple power units scattered through a house and, for experimental sake, the group will purchase one for the central unit and four because the experiment will consist of four units scattered through the house, which would run up the price to $95.00. During the experiment, the XBees will be communicating to each other, where the central unit will be telling the power outlets to turn off or turn on and the power outlets will be sending data of how much power is being consumed.

3.1.4.1 Modes:

The XBee RF module works in five modes. These five modes are idle, transmit, receive, sleep and command mode.

The XBee chip is in idle mode when the chip is neither receiving nor transmitting information. This mode is connected to all other modes meaning that each mode can go straight to idle mode and when in idle mode, it can instantaneously switch to the other four modes when certain conditions are met.

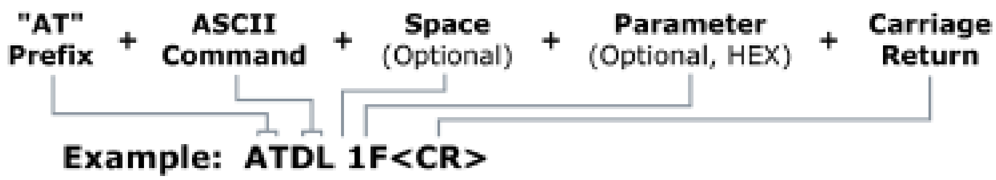
The transmitting and receiving modes are very similar to each other. Data going in and data being compiled to send out can be classified as one in the same. There were two distinctive forms as means of transmitting information. The main difference between the two forms, one being direct transmission and the other being indirect transmission, is that the direct transmission has the cyclic sleep period set to zero and where the indirect transmission, the coordinator is set to have the longest sleep value than any of the end device. When the XBee is in direct transmission, the time before sleep command on the coordinator is set the same as the end device. Also, if the coordinator has indirect transmission, it will switch to direct transmission if the end module is awake. Once the coordinator wakes, it polls to see which end device is awake.

Sleep mode is when the XBee is consuming very little power. One of the following conditions must be met. If pin 9 is either set to one, two or five, the XBee will be in sleep mode. When pin 9 is set to one, it is said to be hibernating. At one, it consumes the lowest power and works under 10µA with a wake up time of 13.2 milliseconds. When pin 9 is set at two it is at a doze setting, this setting has the fastest wake-up time at 2 milliseconds. At five, this mode makes the XBee wake up at a pre-determined time to await any data being sent in.

Finally, command mode is used to the XBee understands its parameters. One can work the XBee with either of the two command modes, one being an AT command mode and the other being an API command mode.

- The AT command mode is simple where the product manual shows clearly the format how commands are to be sent. Seen below in 3.1.4.1 figure 1, one can see the set way to send AT commands to an RF module. All values can be modified due based on what the user prefers. An example at the bottom of figure 1(same as above) shows how the code would look like to execute a command. All commands must be put in the using the write command (WR) or else, once the next command is written, the module will reset.
- The API mode makes the transition from information coming in from the DI pin to the DO pin much easier. Once RF transmission is set straight, the same information will be sent out to the DO pin. This works best in a point-to-point situation because the receiving device inherently knows

where the information is coming from. In the case of this project, the group is dealing with a point-to-multipoint. For a point-to-multipoint system, additional information must be sent with the existing data so the power outlets are aware of where the data is being sent. From this to work properly, RO is to be set to zero, the data sent in is less than 100 characters, and the command mode sequence is set properly.



3.1.4.1 Figure 1: Basic example of how to write an AT command Awaiting permission from Digi International

3.1.4.2 Peer-to-Peer Network:

All RF modules made by XBee can work in a, what's called, peer-to-peer network. This feature is fairly self-explanatory where each chip could communicate to each other. This feature is extremely important because one could confuse the peer-to-peer feature with a master-slave relationship. In a master-slave system, the master would act as a transmitter and the slave outlets would simply be a receiver. The peer-to-peer network allows each device to act as a transceiver. Being a peer-to-peer allows faster communication and a shorter start up time. One could point out that in this type of network; each outlet acts as a master and a slave.

3.1.4.2 DC Setting:

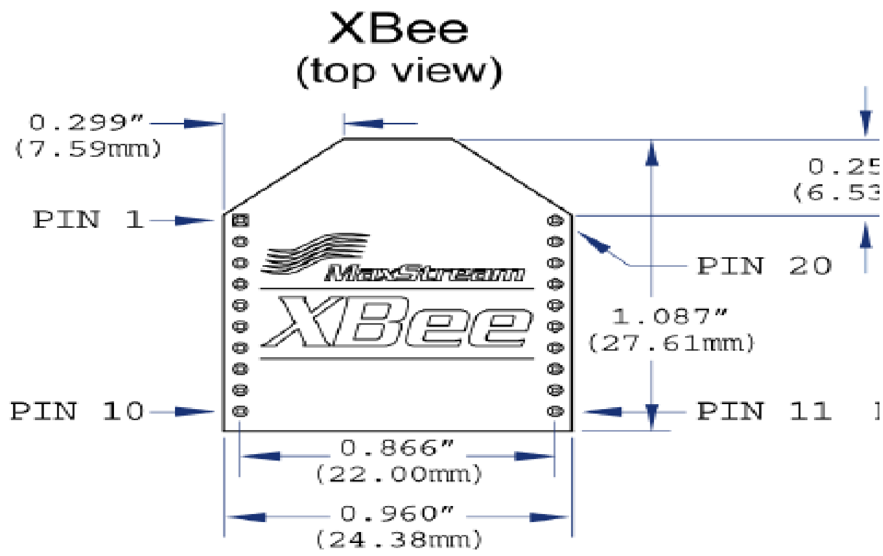
When in DC, the following are a few facts abut the voltage and current going through the XBee assuming the XBee has an input voltage (V_{cc}) anywhere between 2.8 and 3.4V. Some values will be relative to the input voltage. From the stand pint of the input voltage, the chip has an input low voltage has a maximum voltage of ($.35xV_{cc}$) V and its input high voltage has a minimum voltage of ($.7xV_{cc}$) V. From the stand pint of the output voltage, the chip has an output low voltage has a maximum voltage of .5V and its input high voltage has a minimum voltage of (V_{cc}-.5) V. Now, to look at the transmitting and receiving currents, all values are assuming V_{cc} are 3.3V. The transmitting current runs at about 45mA, where the receiving current runs at about 50mA.

3.1.4.3 Pin Assignments:

Now, 3.1.4.3 figure 1 is a drawing of the XBEE with the pin assignments and dimensions to the chip. The pins will be carefully placed in the microprocessor. The microprocessor used will be the Arduino XBee Shield that will be mentioned later on in the research portion of this paper. Pin one begins on the top right and goes down to the tenth pin that is labeled ten. Then the pin count continues on the bottom right and goes to the top from eleven to twenty.

At minimum, VCC, GND, DOUT and DIN are to be connected to work. Also, a 50kΩ pull-up resistor is to be attached to pin five when used. Lastly, any unused pins are to stay disconnected. The pins are assigned for the following commands with the set up beginning with the pin number, followed by the title, in parenthesis will be the direction and then will be followed by a brief description of the pins.

1. VCC (no direction) power supply
2. DOUT (output) sends the data out
3. DIN/ CONFIG (input) receives the data
4. DO8 (output)
5. RESET (input) module reset
6. PWM0/RSSI (output) receiver signal strength indicator
7. PWM1 (output) PWM output
8. Not to be used
9. DTR/SLEEP_RQ/DI8 (input) pin sleep control line
10. GND (no direction) ground
11. AD4/DIO4 (input or output) analog input 4 or digital I/O 4
12. CTS/DIO7 (input or output) clear-to-send flow control
13. ON/SLEEP (output) module status indicator
14. VREF (input) voltage reference for A/D input
15. Associate/AD5/DIO5 (input or output) associated indicator or analog input 5 or digital I/O 5
16. RTS/AD6/DIO6 (input or output) request-to-send flow control, analog input 6 or digital I/O 6
17. AD3/DIO3 (input or output) analog input 3 or digital I/O 3
18. AD2/DIO2 (input or output) analog input 2 or digital I/O 2
19. AD1/DIO1 (input or output) analog input 1 or digital I/O 1
20. AD3/DIO0 (input or output) analog input 0 or digital I/O 0



3.1.4.3 Figure 1: Drawing of XBee with dimensions and chart to show pin assignments and distribution. Awaiting permission from Digi International

3.1.4.4 Programming Commands for the XBee:

In the product manual for the XBee, there is a plethora of information on the programming on the XBee and also, extensive explanation on what each of the commands mean. This is one of the most important sub-sections relating to the XBee because the commands sent to the XBee set up the basic make up for the chip; it also sets the proper commands necessary to check how it is working and its proper connection to its peers, other XBees. To implement any of the code, Digi's X-CTU software must be installed and the interface board must be connected via a USB port. Also, an important thing to take into consideration is that for the AT command mode is running at the desired bit rate.

There is a breakdown into several categories based on inherent differences between the commands. Just notes to differentiate between hexadecimal and decimal, the hexadecimal values begin with "0x" and a decimal value begins with a "d." There are eight categories of commands, there are basic AT command options, diagnostics, input and output settings, network and security, RF interfacing, serial interfacing, sleep mode, and "special" commands which are all equally important to the completion of the project.

3.1.4.4.1 Basic AT commands options:

These commands, as stated in the title, are the basic commands used to program in the command mode. The commands range from being the beginning and end of the command mode to changing commands and to make sure commands are not interfered with. The following is a list of the basic AT commands options with its full name in parenthesis followed by a brief explanation of the command.

- CT (command mode time): This command reads the time elapsed from when the XBee exits the command mode and enters an idle mode.
- CN (exit command mode): This command is rather self-explanatory that once used, it exits the command mode.
- AC (apply changes): Allows the module to change the previous parameters set up and once these changes are entered, they will be implanted.
- GT (guard times): Sets a time-of-silence so the data coming in has no interference with other commands.
- CC (command sequence character): This lets the module know that there will be ASCII characters entered between the general command sequence "GT+CC+GT." Also, this command informs the module that the data entered is from the host and is not payload.

3.1.4.4.2 Diagnostic commands:

The following commands either displays faults in the executions of commands or states basic information of the module. The following is a list of the diagnostic commands with its full name in parenthesis followed by a brief explanation of the command.

- VR (firmware version): Reads which firmware version is stored in the module. There are either three or four hexadecimal characters and if there are only three characters, the last character is assumed to be a zero.
- VL (firmware version-verbose): Shows information on specifics of the RF module like the date the application was built, the bootloader version and built date.
- HV (hardware version): Indicates which version of the hardware is being used.
- DB (received signal strength): Used for read the signal strength received in dBm of the last RF signal received. There is an inherent range in the module from -40 to -96 dBm. If there is no signal sent in, "0" will be displayed.
- EC (CCA failures): Reads the amount of failures through each of the modules. A failure in this case is when the RF module does not transmit a packet due to the detection of energy that is above the CCA threshold level (set with CA command). When the user wants to reset the count, the user must set the parameter to zero.
- EA (ACK failures): Reads the amount of failures through each of the modules. A failure is when the module expires its transmission retries without receiving an acknowledgement on a packet transmission. When the user wants to reset the count, the user must set the parameter to zero.

- ED (energy scan): Finds the max energy in (-)dBm in each channel followed by a carriage return with an extra carriage return to signify the end of the command.

3.1.4.4.3 Input and Output Settings:

The input and output commands very important because they have a direct connection most all pins and make sure that the settings are set correctly. All pins that will be outputs are set to be outputs, inputs set to inputs and the proper pin set to be the analog to digital converter. The following is a list of the input and output settings commands with its full name in parenthesis followed by a brief explanation of the command.

- D8 (DI8 configuration): With a proper parameter, activates pin 9. Its default parameter is zero, which disables this pin. However, if three is set at the parameter, it activates the pin.
- D7 (DIO7 configuration): Based on what the parameter is set to, it can set pin 12 to different functions. Its default parameter is one, which enables the CTS flow chart. However, when set to zero, the pin is deactivated. When three through five are activated, certain input and output settings are activated and when six and seven are activated, the RS485 TX is enabled.
- D6 (DIO6 configuration): Based on what the parameter is set to, it can set pin 16 to different functions. It shares most all of the commands from a parameter standpoint as D7. The only differences between D7 and D6 is that D6 has the default parameter is zero and there is no six or seven parameter and has no control over the RS485 TX is enabler.
- D5 (DIO5 configuration): This command controls the settings of pin 15. By default, it is set as the associated indicator that makes the LED blink. Similar to all previous "D" commands, zero disables the pin. When set to two, it actives the analog to digital converter, and when the parameter is set between three and five, depending on what it is, sets of the digital input or output.
- D0-D4 (DIO configurations): The reason all four of these commands are bunched together is because they all have the same default parameter, zero, and their parameters all mean the same thing. D0 is set with pin 20, D1 with pin 19, D2 with pin 18, D3 with pin 17, and D4 is with pin 11. When the parameter is zero, the pin is disabled, one is not an acceptable parameter, two deals with the analog digital converter and three through five deal with the digital input and outputs.
- IU (I/O output enable): Either enables or disables the UART output. This command is key because all line data, whether input or output, go through the UART. The default parameter is set to one that enables the UART to send out the line data and when the parameter is zero, the UART won't send out any received line data.
- IT (samples before TX): Before transmitting data, this command is used to set/read the amount of digital input and outputs and analog to digital

conversion samples. The module will stay awake until sample is completed. The acceptable hexadecimal parameter range is between 1 and 0x0FF with the parameter's default at one.

- IS (forced sample): Forces all digital input/output and analog to digital converter lines to be read and returned the through the UART. This command has a default parameter of one.
- IO (digital output level): Sets the level of the digital output. This can be changed through the command mode. There is an 8-bit bitmap parameter with this command.
- IC (DIO change detect): With a bitfield range, each bit monitors of any changes made in D0-D7. With change, there will data sent with the DIO data. This command has a hexadecimal parameter range of 0 to 0x0FF, automatically set at zero.
- IR (sample rate): Will sample all digital input/output lines and analog to digital converter line as long as the module is not in sleep mode. Suggested to set IR less than 0x14 to ensure the command works properly.
- IA (input/output address): Used to mesh an output to an address. Can be used for 16 or 64-bit addresses.
- T0-T7 (output timeout for D0-D7): When a timeout value is given to any of the pins related to D0-D7 that if an invalid parameter is entered is invalid, once the time is up it will go back to its default parameter but the timer will be reset when and valid packet is received. When the parameter is set to zero, the command is disabled. There is a hexadecimal range of 0-0x0FF. The default parameter is set to 0x0FF.
- PO (PWM0 configuration): This allows incoming data to go through a PWM1 (pin6), a pulse width modulation output, and be converted to an analog form. When the parameter is set to zero, this command is disabled. At one, its default parameter, it becomes a receiver signal strength indicator and at two it would be set to PWM0.
- P1 (PWM1 configuration): Same as P0 with same parameters but it goes through PWM1 (pin7) and its default parameter is set to zero, which disables the command.
- M0 (PWM0 output level): Reads and/or sets the output level of PWM0. Before this command can be executed, one must have PWM0 set to two and either command CN or AC must be set.
- M1 (PWM1 output level): Same applications as the command above, M0, but instead it goes through PWM1.
- PT (PWM output timeout): sets and/or reads timeout values for PWM0 and PWM1 outputs. The parameter range is from 0 to 0x0FF and has a default setting of 0x0FF.
- RP (RSSI PWM timer): Enables the PWM output to the RF module. Shows the level of strength over the sensitivity of the module. Zero percent would mean it is inactive and anything under 24% means it's below the module's sensitivity. The parameter range is from 0 to 0x0FF, which is 100 milliseconds. The default is set at 0x028 (40).

3.1.4.4.4 Network and Security:

These commands are important in the sense that all some make sure the modules are communicating at the right channel so they can communicate to each other properly. They also ensure the nods available to ensure proper communication. The following is a list of the network and security commands with its full name in parenthesis followed by a brief explanation of the command.

- CH (channel): Sets the channel that the XBees' communicate to each other. The channel value can range from 0x0B to 0x1A with a default parameter value of 0x0C (12). To calculate the center frequency, the equation is: center frequency = 2.405 + (channel – 11(d))*5MHz. (Where d is the decimal value of the parameter.
- ID (pan ID): Reads the personal area network (PAN) ID of the module. If, and only if, all the PAN values match then the modules could communicate with each other. It has a default hex parameter of 0x03332 (13106) and a range of 0-0x0FFF.
- DH (destination address high): Will set and read the upper 32 bits of the 64-address. Has a parameter range of 0x0FFFFFFFF.
- DL (destination address low): Will set and read the lower 32 bits of the 64-address. Has a parameter range of 0x0FFFFFFFF. When DH and DL are put together, one can see the 64-bit combination that is the address. This address needs to be the same for all other modules to communicate to each other.
- MY (16-bit source address): Sets and reads the 16-bit source address of the RF module. When the MY is set to 0x0FFFF, the 16-bit packet received is disabled and the 64-bit packet is enabled.
- SH (serial number high): Reads the 32 high bits of the 64-bit address. This value cannot be changed and is a read-only value.
- SL (serial number low): Reads the 32 low bits of the 64-bit address. This value cannot be changed and is a read-only value.
- RR (XBee retries): Accounts for the amount of tries past the standard three retries inherent to the module. The parameter range for this command is from zero to six.
- RN (random delay slots): Accounts for the exponential value of the carrier sense multiple access – collision avoidance algorithm.
- MM (MAC address): Displays the MAC mode value. With a default parameter at zero, there are four parameters from zero to three. Zero meaning the use of the Digi mode that includes the 802.15.4 RF packet, one is just the 802.15.4 packet without acknowledgment, two is the 802.15.4 packet with the acknowledgment and three being solely enabling Digi mode without acknowledgment.
- NI (node identifier): Identifies particular nodes using solely printable ASCII data that doesn't start with a space the ending has a carriage return command and once the maximum bits have been entered, the command will

automatically end. This command can accept anything up to a 20-character string of ASCII values.

- ND (node discover): This parameter value is the same as the 20-character value given in the NI command. This command goes into each module and demands an ND command packet that is 64 bits long.
- NT (node discover time): The NT command will, once the parameter is set, give a specified time for whichever RF module to respond back with its 64-bit address. The parameter range for this command is 0x01-0x0FC (1-100 milliseconds)
- NO (node discover options): Will decide, based on its own parameter, whether or not to have its own ND response. The parameter values are either zero or one. Zero being that there will not be an ND response and with a one, there will be an ND response.
- DN (destination node): This command will convert any NI string to a physical string as long as the DL and DH are set to the NI and the RF module cannot be changed at the time.
- CE (coordinator enable): Reads the behavior between the end device and the coordinator of the module. One being the coordinator and zero being the end device, which happens to the default parameter.
- SD (scan duration): reads or sets the exponential value of the scanning time through multiple devices. The scan time can be calculated as with the following equation: scan time = ((# of channels to scan)*(2^SD)*15.36 milliseconds). SD has a parameter range of 0 – 0x0F with a default value of four.
- ED (energy scan): Displays the max energy is each channel. The value that is displayed is the energy level in –dBm. The scan time can be calculated as with the following equation: scan time = ((2^ED)*15.36 milliseconds).
- SC (scan channel): This command is very important for the two commands above, SD and ED. This command is used to display and or set which channels the energy scan and scan duration will be used in.
- A1 (end device association): Uses a combination of bits in a certain order to set certain behaviors for the end device. The parameter range is from zero to 0x0F with a default parameter value of zero. Bit zero deals with whether or not the coordinator will associate itself on PAN ID with others based on the NI command. Bit one deals whether or not the coordinator will associate itself with others based on the channel settings. Bit two deals with whether or not the device will attempt association and deals with only non-beacon systems. Bit three deals with whether or not the pin wake will pole the coordinator for any pending data. Bits four through seven are reserved and pre set.
- A2 (coordinator association): Uses a combination of bits in a certain order to set certain behaviors for the coordinator. The parameter range is from zero to 0x7 with a default parameter value of zero. Bit zero deals with whether or not the coordinator will perform an active scan to locate available PAN ID. Bit one deals whether or not the coordinator will perform an energy scan. Bit two deals with whether or not the device will attempt association with any other devices. Bits three through seven are reserved and will not be changed.

- AI (association indication): Checks to see if there are any errors while the RF module was trying to associate. The parameter range for this command is from zero to 0x013. This value is a read-only value.
- DA (force disassociation): Disassociates the coordinator and the end-device and then tries to re-associate them.
- FP (force poll): Requests indirect messages from the Coordinator.
- AS (active scan): Sends out a Beacon request to each channel. Indicates the time set for each Beacon with each channel.

3.1.4.4.5 RF Interfacing:

The RF interfacing commands read the power level and make sure that the energy and voltage going through the modules is the correct value the user would like to use. The following is a list of the RF interfacing commands with its full name in parenthesis followed by a brief explanation of the command.

- PL (power level): Selects are reads the power level of the RF module. The parameter range is 0-4. The default parameter is set at four. At zero, the XBee would have a maximum transmit output power of -10dBm. At one, the XBee would have a maximum transmit output power of -6dBm and as the parameter increases by one, the dBm value increases by two until when parameter is set at four, the maximum transmit output power of zero dBm.
- CA (CCA threshold): Can set or read threshold value for any given channel. Before this value can be sent, an energy scan must take place. The parameter range is 0 – 0x050 (-dBm). The default parameter value is 0x02C (-44dBm). If the detected energy value is lower then the modules value, the command will not be executed.

3.1.4.4.6 Serial Interfacing:

Serial interfacing commands control the rate at which data is being sent. Also, these commands can set the flow of information coming in and can change the form of commands coming in. The following is a list of the serial interfacing commands with its full name in parenthesis followed by a brief explanation of the command.

- BD (interface data rate): Sets and reads the data rate for communication between RF modules and the host. The table below, 3.1.4.4.6 figure 1, shows the relationship with the parameter and the configuration in bits per second.

Parameter Range:0 – 7 (standard rates)
0x80–0x3D090 (non-standard rates up to 250 Kbps)

Parameter	Configuration (bps)
0	1200
1	2400
2	4800
3	9600
4	19200
5	38400
6	57600
7	115200

3.1.4.4.6 Figure 1: Parameters with the data rate for the BD command
Awaiting permission from Digi International

- RO (packetization timeout): Sets the break between characters sent through the DI buffer. If the parameter is set to zero, there will be no bundled RF packet, all characters will be sent as received. There is a parameter range from zero to 0x0FF with the default parameter being three.
- AP (API enable): Enables the RF module to operate in a frame-based API instead of the AT mode. The parameter range is from zero to two, with zero disabling the command, one enabling the API mode and two enabling API with escaped characters. The default setting has this command disabled.
- NB (parity): Sets and reads the parity setting for the module. This command only one bit. The range is from zero to four. At zero, the default setting, configures the setting to be an 8-bit address without parity and 7 bits with parity. The rest have an 8-bit address with one being set to an 8-bit even address, two to an 8-bit odd, three to an 8-bt mark and four with an 8-bit space.
- PR (pull-up resistor): Reads the bit field to configure pull-up resistance. Has a default setting that enables all pull up resistance. At zero, the pull up resistance is disabled. When the hexadecimal is expanded to its 8 bits. From left to right, the bits go from bit7 to bit0 and if there is a one in that spot, the resistor will be enabled and if there is a zero, it will be disabled. Below, in 3.1.4.4.7 figure 2, shows the bit assignment correlated with its pin assignment.

bit 0 - AD4/DIO4 (pin 11)
bit 1 - AD3/DIO3 (pin 17)
bit 2 - AD2/DIO2 (pin 18)
bit 3 - AD1/DIO1 (pin 19)
bit 4 - AD0/DIO0 (pin 20)
bit 5 - AD6/DIO6 (pin 16)
bit 6 - DI8 (pin 9)
bit 7 - DIN/CONFIG (pin 3)

3.1.4.4.6 Figure 2: Pin assignment based on the bit

3.1.4.4.7 Sleep Mode:

All these sleep mode commands entail all the different sleep modes the XBee goes through to lower its power usage. The following is a list of the sleep mode commands with its full name in parenthesis followed by a brief explanation of the command.

- SM (sleep mode): This is used to set the module to different modes based on the parameter entered. The parameter range is 0-6. Defaulted at zero, which disables the command. At one, the pin hibernates, at two, the pin is in pin doze mode, three is reserved, four is a cyclic sleep remote option, five is like four but with a pin wake-up and six is a sleep coordinator.
- SO (sleep mode command): Two bit command where bit zero deals with the poll wakeup disable and bit one deals with the analog to digital converter and the digital input/output wakeup sampling disable.
- ST (time before sleep): Sets and/or reads the time of inactivity before going to sleep. The parameter range for this command is 1-0x0FFFF. The ST values have t be the same for the coordinator and the end device to work properly.
- SP (cyclic sleep period): Sets the sleep time for the module. Once it wakes up, it will check for data and if there is none found, it will go back to sleep. The longest time the device can fall asleep is 268 seconds. The command has a parameter from 0 to 0x068B0.
- DP (disassociation cyclic sleep period): Sets and reads the time for the cyclic sleep period for an end device. The longest time the device can fall asleep is 268 seconds. The command has a parameter from 0 to 0x068B0 with a default parameter is set to 0x03E8.

3.1.4.4.8 “Special” Commands:

These “special commands” are for making sure whatever command is written stays in the module’s memory. One command resets all the parameters put in and the other restarts the module. The following what are known as “special” commands with its full name in parenthesis followed by a brief explanation of the command.

- WR (write): Uses the non-volatile memory of the module to set parameters. This ensures all changes will still apply is the module is turned off, the changes will still be there when their turned on.
- RE (restore defaults): This resets all the parameters to their default parameters that are shown in the description of each of their command that has parameters.
- FR (software reset): Forces a reset of the software in the module that will turn off then restart the module.

3.1.5 Push buttons and switches

The main receiver and LCD display screen device will need to have several different buttons and switches in order for the user to be able to turn on the backlight as well as interface with the screen for menu operation, device selection and power on/off features. As stated in the component research section, the device needs to be able to consume very little power, and be used for turning devices on and off.

For the LED backlight display, the project will need one power switch so that when the power is turned on it stays on until the user turns the backlight power off. There are many types of switches to turn off power which all have a relatively similar price range. These styles include push buttons, buttons that hold in the on or off state, physical switches similar to a light switch, and rocker switches. The main problem with buttons is that they must be attached to a microcontroller that will take up vital input pins on the microcontroller. In addition to this, light switch style switches do not look very good on the outside while buttons that hold a state will confuse the user as to their function due to the similar look to the regular buttons on the device. Finally, the group has decided that the use of a rocker switch will look more refined and sleek for an outward appearance and will be used in this design. There are different places on the internet to look for these switches, but most of the time it requires the purchaser to buy the amount in bulk and they charge shipping, increasing the total cost of the device. For example, a switch purchased online will cost the group $2.14 at Digikey while a similar model purchased at RadioShack can be purchased for $2.99. Therefore since there is such a small difference in price, the group has decided to play it safe and purchase the rocker switch from RadioShack so that the group will not have to worry about getting the devices on time. This switch, which will be used for the LED backlight for the LCD screen, is a ¾ inch circular red rocker switch with serial number 275-694, and can withstand a voltage of 250V with a current of 10A which is way more resistant to fluctuations in current and voltage than the device will need to withstand.

For the LCD operation, the user would need three buttons to operate the menu, traverse the list of sensor devices and remove supplied power from the connected appliance. Since the user will be pushing the button multiple times, the device will need an actual button to press as opposed to a switch, or a state holding button. As above, the buttons can be purchased online at Digikey for the price of $1.80, while a similar button can be purchased for $2.49 at RadioShack, where the group can pick it up at any time. Due to the ease of acquiring the devices from RadioShack as opposed to waiting for the mail to arrive with the buttons, the group has decided to purchase the push buttons from the local RadioShack. This button is a red ½ inch circular pushbutton with serial number 275-646, which can withstand a voltage of 125V and a current of 3A, which is way more resistant to voltage fluctuations than is needed for the devices functionality. Since the specifications of this button are similar to most buttons on the market, the group has deemed this style of button an adequate purchase.

3.1.6 LED Power Display

For the light emitting diode power indicator, the group does not need to look too deep into the type of LED that the group is going to choose for their design. This is so because most LED indicators lights function the same as any other, but with very small differences in specifications. The project does require that the device be relatively simple to install onto the printed circuit board, without requiring complex components beyond a typical selection of RLC components. Since most of the LEDs on the market just require a simple voltage to be turned on, the device will not require any more components than a simple voltage divider to achieve the correct operating voltage of the device. This voltage divider and LED circuit will be hooked up to the power relay switch and will have its power cut when the power from the device is cut. The group selected a green color for the LED output to display due to the fact that most indicator lights on current technology devices that signifies power supplied are colored green. This will help the user understand the meaning of the powered on LED indicator without having to look into an instruction manual. Since most LEDs on the market all consume around the same power when operating, power consumption will not be much of an important requirement, since almost all LEDs are relatively low power. With all other problems out of the way, cost and device availability therefore are the major elements to help decide which LED device will be used in the design of the project.

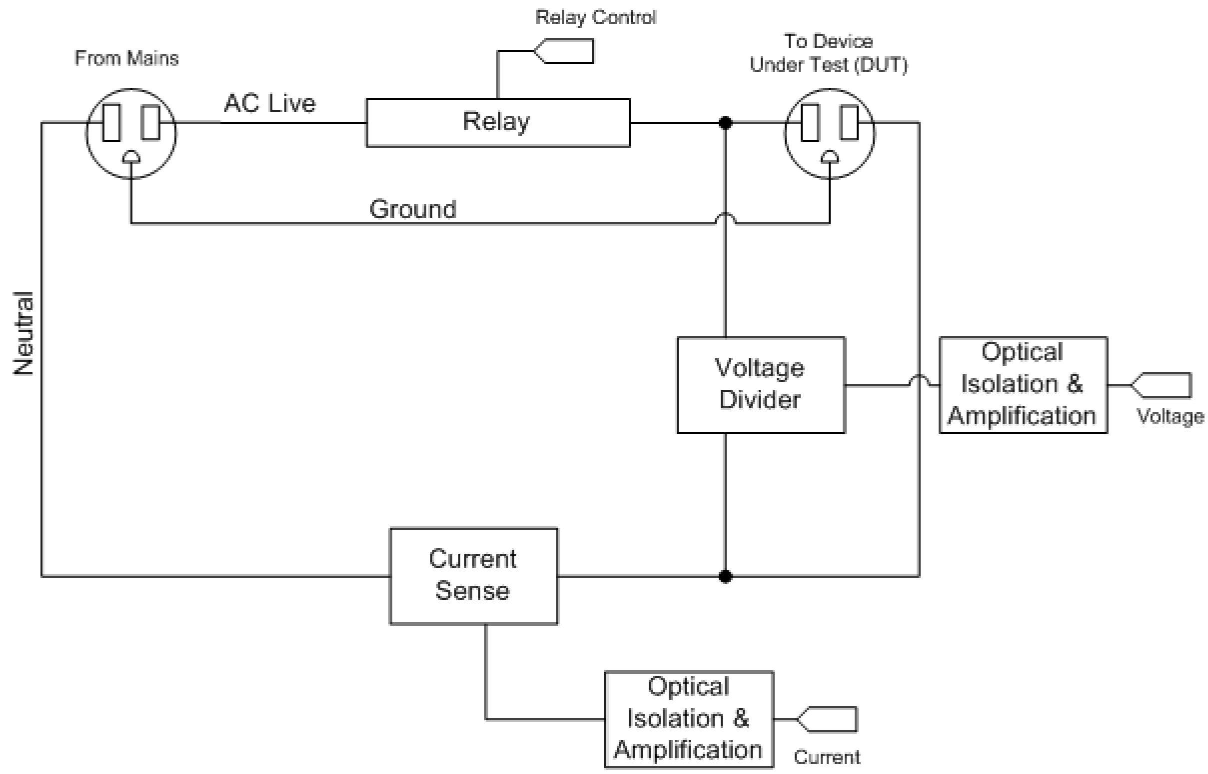
Having looked online for resources, most internet websites selling LEDs sell for under a dollar an LED. However in order to get that price you have to either wait a few weeks for shipping or order LEDs in bulk. Since the design is only requiring three LED lights, ordering them in bulk or having to wait a few weeks for a device to come in does not seem like the ideal approach. Therefore, the group has decided that instead of ordering the LED indicator lights online and being forced to wait, pay shipping, or order more than needed, the group plans on going to the local RadioShack to obtain the three indicator lights.

The particular LED light that the group is choosing is RadioShack 276-022 which is a 5mm in size Green LED easily acquired from RadioShack. This LED shines out light with a typical wavelength of around 565mm, and has a viewing angle of

30 degrees. It draws a typical current of 10mA at a typical voltage of 2.2V, with a max of 2.4V for device operation. This device will consume .022 Watts and therefore can be considered to be relatively low on the power consumption end. With a cost of two lights for $1.50, this LED meets all the requirements that the group decided was necessary for a chosen LED indicator light.

3.1.7 Power relay

The implementation of the relay, as seen in 3.1.8 figure 1, in the design could be very close to the one used by the students at the Cornell University. They take the live line and install the relay in series with the main outlet and the appliance being measured. This would be the most logical implementation of the relay in order to have complete control of the current flowing into the load.



3.1.7 Figure 1: Relay Circuit Design Used by permission from Bruce R Land, Cornell University

3.1.8 Basic Components

Basic components needed for the implementation of the design include resistors and capacitors. The capacitors will be used strictly for filtering. These will be used for both filtering of signals between different devices and for power supplies. Resistors will also be utilized as well. These resistors will be used for simple voltage dividers as well as amplifiers. Further, the resistors will also be used as pull up and pull down resistors. Both the pull up and pull down resistors will be used on any pins on the microcontrollers which will have either a button or switch attached. These will prevent floating pins, and potentially false values, on these pins whenever a button or switch is disconnect from the microcontrollers. As well, most resistors, except for those needed in any amplifiers or otherwise appropriate, will be 1000 ohms, for simplicity.

3.1.9 Amplifiers

The basic design will use amplifiers mostly to increase the strength of any given signal. This mostly will be used for any signal outputted from the microcontroller that needs to be boosted. These signals may be the signal to control the relay, or a signal that needs to be boosted from the output of the microcontroller into the wireless communication devices. As well, these amplifiers can be used to boost a low sensed value to produce a higher accuracy output for low power values. These amplifiers will be made of operation amplifiers, when applicable, as well as BJT's and MOSFETS.

As well as basic amplifiers, attenuators and regulators will be used in the design of the project. The attenuators will mostly be used to limit the input from the sensors into the microcontroller. This will be done to limit the signals into the microcontrollers to input a maximum of their tolerated value to protect the chip. These attenuators can be realized using simple voltage dividers through resistors, or with operational amplifiers, when applicable, with a grain of less than one. The voltage regulators will be used in both the main unit and sensing units to limit the input voltage, either from battery or from a wall voltage, and power all appropriate chips, such as the microcontrollers, the LCD screen, and all wireless components. These regulators will regulate the voltages to either 3.3 or 5 volts, depending on whichever is needed for the specific device.

3.1.10 Filters

As all the signals within the designed project are non-ideal and have noise associated with them, filters for the signals will have to be implemented. At all junctions of power supplies and the power supply voltage input on any device will have a filter. This filter is to prevent any random voltage spikes, which can occur while putting in or replacing a battery. As the noise associated with these signals are very high frequency and all values, the power supply in this case, needed are fairly constant, first order, low pass filters are used. These filters will be made of capacitors in parallel with the signal to allow DC and low frequency signals to pass.

The other main purpose of the filters in the design of the project is to prevent bouncing. Because push buttons are being utilized by the user in the design to control functions on the microcontroller, and therefore the entire system, debouncers will need to be implemented. These debouncers are in place to prevent false, rapid inputs into the system when a button is pressed and bouncing occurs. These filters will be in place as hardware debouncers while software debouncers are also being implemented. All filters for debouncing will need to be first order, low pass filters. The filters will also be realized with capacitors in parallel.

3.2 Methods

3.2.1 Coding

As stated in 2.1.3, C will be the most appropriate programming scheme to utilize in the design due mostly to its familiarity and ease of use. As well, to go with this, both the Arduino Pro Mini and the Arduino Mega utilize a C/C++ programming scheme. A large portion of this ease of use is because of C's standard libraries, some of which are listed and further explained in detail.

- **stdbool.h:** This library is used for Boolean type of variables. This mostly will be used for push button operations, as not being pushed will be a 0 or false and pushed will be a 1 or true. This will be used to implement all user controlled functions.
- **string.h:** This library is used to manipulate strings. This library will be used to handle all information going to be displayed to the LCD screen. This will help to format all information to be displayed in an orderly, logical manner.
- **stdio.h:** This is the standard library for input and outputs. This will be used throughout the entire designed program. The stdio.h library also contains allows usage of the printf statement. This can potentially be used both for implementation of the LCD screen as well as used for debugging purposes.
- **stdlib.h:** Among other functions, the stdlib.h library allows the usage of the absolute value function. This will allow the microprocessor to handle any negative values it may come across use them appropriately.
- **math.h:** This is the standard math library. This library allows functions such as round. The round function will mostly be used to make the raw data given by the main logic steps, converting the inputted power measured into kilowatt hours, into a more manageable value. These rounded values will be the values that are to be outputted to the LCD screen and are the ultimate output of the design.

Along with all standard C libraries that come with both the Arduino Pro Mini and Arduino Pro Mega, both microcontrollers come with a separate set of functions.

These functions enable the programming of the microcontrollers, as well as utilizing all of their features, much easier. These libraries are functions as well as benefits and uses they provide.

- **pinMode():** This function has two parameters, the pin's variable and the mode it is to be set. The pinMode function is to set any digital input/output pin as either the input or output. This will be used to help read in data from the sensors in the sensing units, disconnecting the power with the relay switch in the sensing units, reading in whether a push button has been pressed in the main unit, outputting information to the LCD screen in the main unit, and both transmitting and receiving information through the wireless components.
- **digitalWrite():** The digitalWrite function allows any digital pin that has been assigned a variable to be set to "HIGH" or "LOW". The high signal corresponds to either 5 volts or 3.3 volts, depending on whichever the input voltage of the microcontroller is. This can be used for all wireless communications. As well, it will be used for all data going out into the LCD screen and control the relay switch for power connection to measured devices.
- **digitalRead(): T**he digitalRead function reads in any digital value on any digital pin that has been assigned as an input from the pinMode function. The first main use for this function will be for the push buttons. This will allow the microcontroller to read in the digital values associated with the push buttons, as they will connect, or disconnect, a 3.3 or 5 volt line to the microcontroller. The second main purpose of using this function is to read in information from the wireless receivers on both the sensing units and main units.
- **analogWrite():** The analogWrite function allows the generation of pulse width modulated signals. This function allows any digital pin, which has the capability to be used for pulse wave modulation, to be set with a desired duty cycle. This pulse wave modulated signal may be used for wireless communications.
- **analogRead():** The analogRead function allows an analog value to be inputted into the microcontroller when it on an analog input pin. The inputted value will be stored in the defined variable as a value from 0 to 1023, as the signal goes through a 10 bit analog to digital converter. The resolution of these stored values is dependent on the microcontroller used; the Arduino Mega and the 5 volt version of the Arduino Pro Mini will have a resolution of just under 5 mV per number, while the 3.3 volt version of the Arduino Pro Mini will have a resolution of roughly 3.3 mV per number. This function will be used almost exclusively for the sensing unit's microcontrollers, as they will allow analog voltages to be inputted, stored, and transmitted to the main unit.
- **delay():** The delay function acts as a no-op command and simply pauses the microcontroller for a specified amount of time in milliseconds. While in the delay state, the microcontroller holds all pin out values, including the

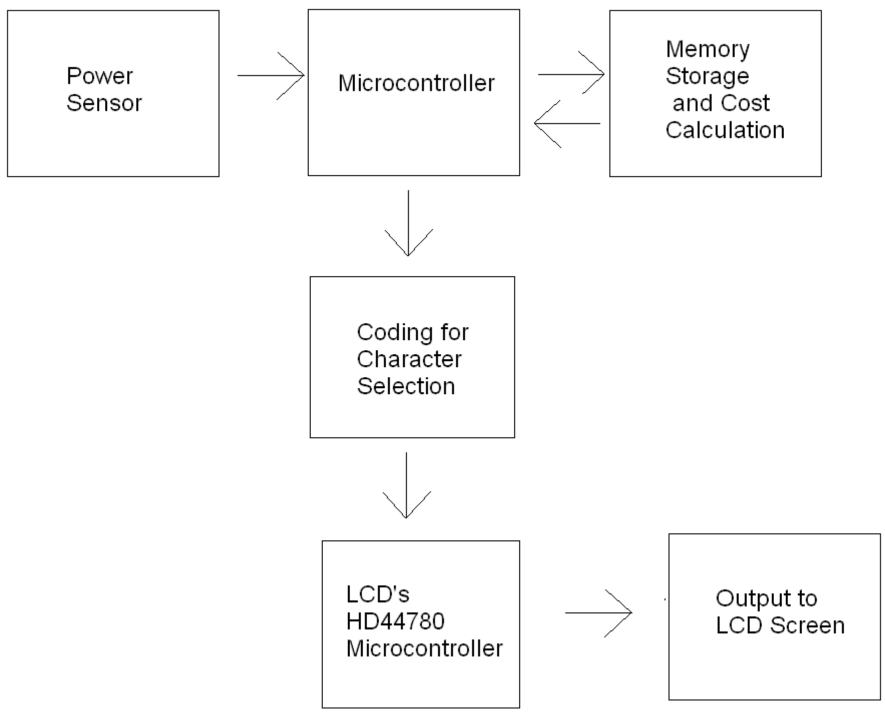
pulse wave modulated output signal. As well, the microcontroller's Rx serial communication pin still records information as it is received. Because of this, the delay may be used as a pseudo sleep state, allowing very little interaction with the rest of the design while still checking to see if the relay switch needs to allow power to pass to the measured device again.

- **attachInterrupt():** The attachInterrupt function allows external interrupts to be used when mapped to the appropriate digital input pins. This interrupt can be triggered from a low voltage, a change in voltage, a rising edge or a falling edge Once the interrupt has been triggered, the attachInterrupt function calls a specified function given within the attachInterrupt command. This function can be utilized to allow the user to alter variables in stored in the microcontroller.
- **analogReference():** The analogReference function allows the programmer to set the analog reference voltage for analog inputs. This can be done with the default voltage, which is the voltage required to power the specific Arduino, an internal voltage, which is dependent on the microprocessor built into the Arduino and ranges from 1.1 volts to 2.56 volts, or the voltage supplied on the "AREF" pin, on those Arduino boards which have such a pin. The biggest application of this function would be if the design were to implement a low battery feature.

3.3 Block/ Schematic Diagrams

3.3.1 LCD Block Diagram

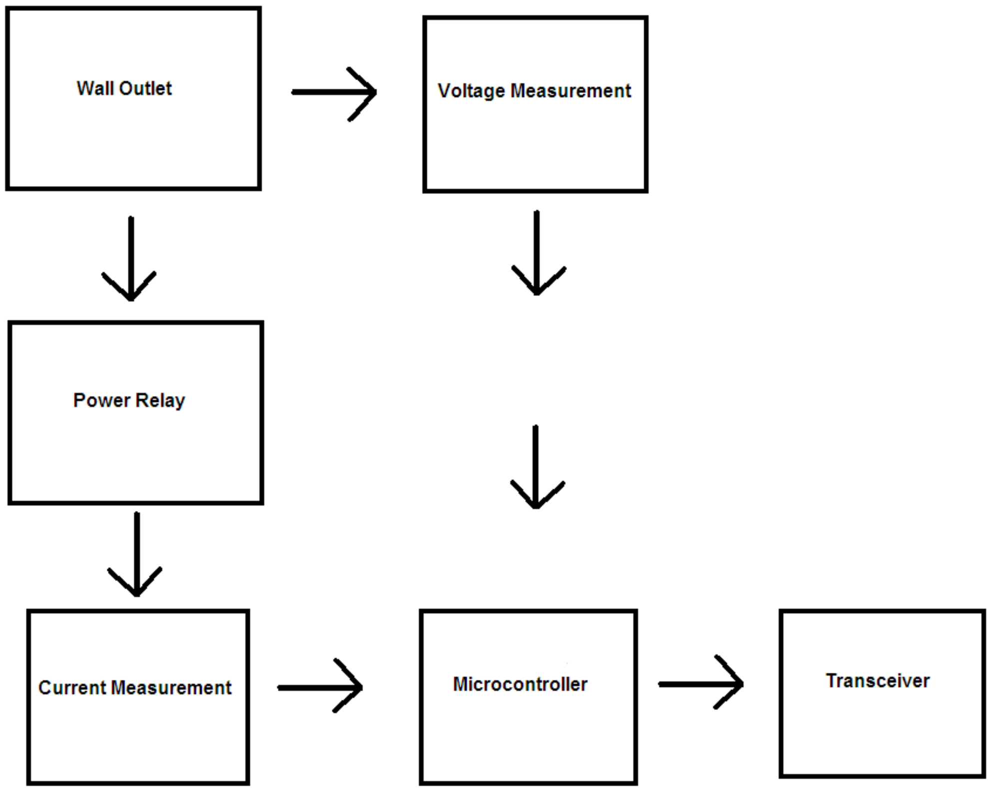
The following figure below is the block diagram for the plans set up to operate the group's LCD screen. As portrayed in figure 1 of section 3.3.1, the power sensor first sends its collected data wirelessly to the microcontroller on the group's main receiver device. At which point, the main microcontroller will calculate the power consumption cost of the particular device that the sensor was reading, and store the data for the calculation of monthly accumulated power consumption. Then the calculated power costs of the appliance being measure will be sent to the microcontroller for processing. The microcontroller then puts the data measured through coding to select what bits will represent the needed information. These bits will be sent through the data pins on the LCD's HD44780 microcontroller. The HD44780 microcontroller than is instructed to output the character by the microcontroller at a specific location, which then outputs the data to the LCD screen.



3.3.1 Figure 1: LCD block diagram

3.3.2 Power Sensor block diagram

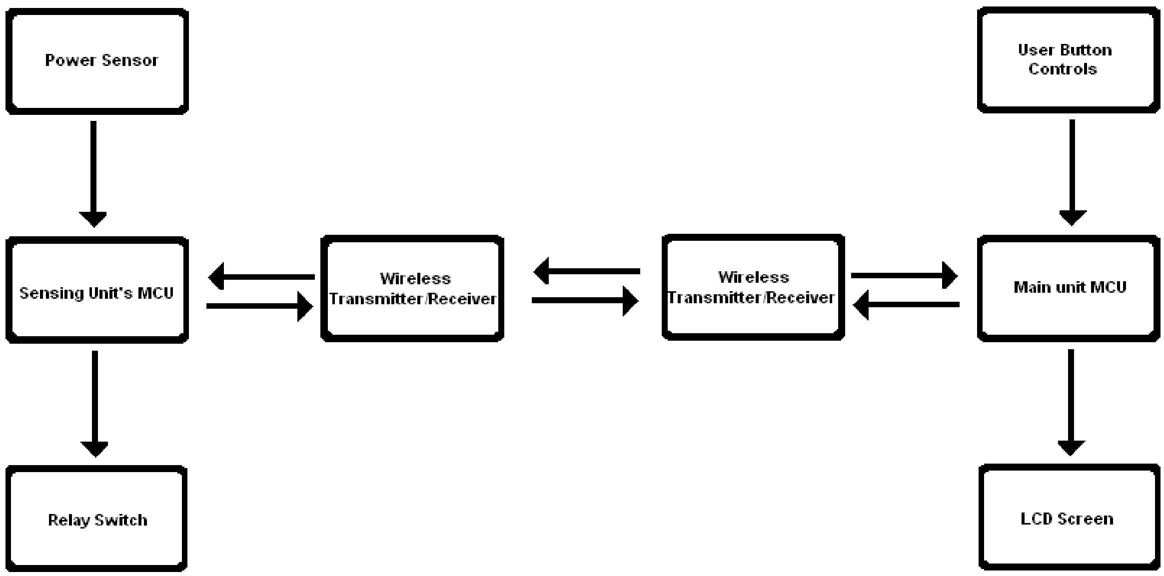
The following diagram shows the basic functions of the power meter sensor. The sensor takes the voltage and current measurement from the wall outlet, the microprocessor takes those measurements and calculates power and the information is sent through the transceiver over to the main unit. Another detail of the diagram is the power relay. The power relay will be used to turn the appliance on and off.



3.3.2 Figure 1: Power meter block diagram

3.3.3 Microcontrollers

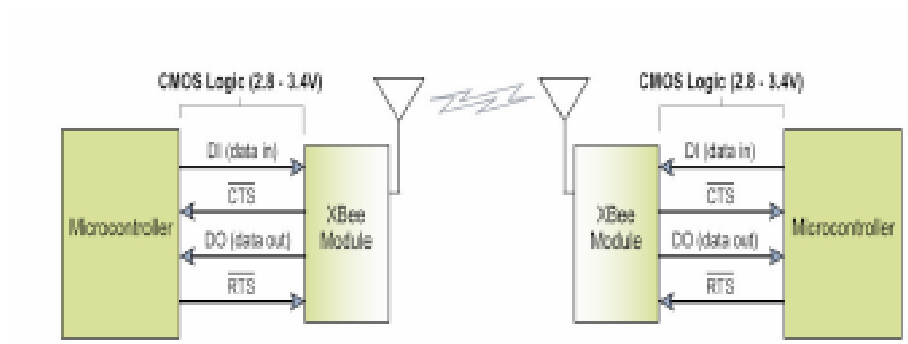
The following figure shows the communications through the entire design of the project. In 3.3.3 Figure 1, two different microcontrollers are seen, each with different tasks to perform. Initially, a value must be inputted into the main unit's microcontroller to allow calculations and all outputs to be relevant. Power will be sensed by the appropriate components in the sensor portion of the design. Once the value has been read by the microcontroller, it will be transmitted wirelessly from the sensor end to the main unit's end. After it sensed power has been received by the main unit's wireless receiver, along with all other sensing unit's sensed powers, which are not shown to simplify the block diagram, it will be evaluated by the main unit's microcontroller. This information will then be displayed on the LCD screen. The data displayed on the LCD screen can then be cycled through by the user controlled buttons. The buttons will send a signal to either display new information, or to disconnect any device that is being monitored. If the microcontroller has been told to disconnect a device, it will output a signal across the wireless transmitter from the main unit to the appropriate sensing unit. This signal will then be processed by the sensing unit's microcontroller and then will turn off the device by a controller relay switch.



3.3.3 Figure 1: Block diagram of microcontrollers

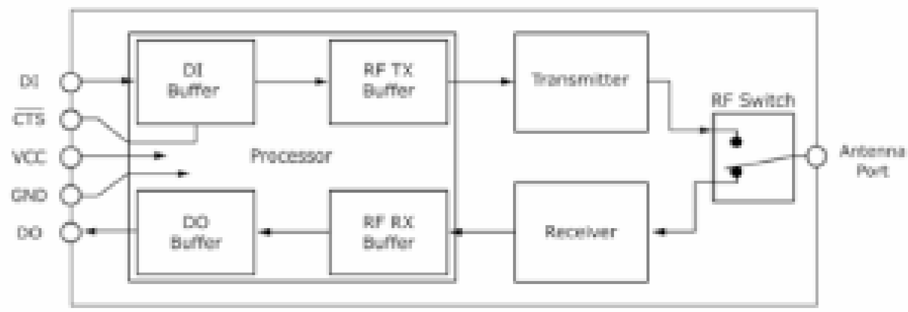
3.3.4 Wireless transmission

The way the XBee and its respective microcontroller communicate to each other is shown in 3.3.4 figure 1. Also shown in this figure, it is shown that the XBees in the network communicate with other XBees on the same network through the antennas. The microcontroller transmits the data it would receive from the power sensor that will send a certain number to the XBee module. Also the microcontroller will command a request-to-send flow control to the XBee module, where the XBee will send the command back for a clear-to-send flow control and also transmit the data out to the microprocessor. In this case, the data out will be for the power on/off capabilities of the project.



3.3.4 Figure 1: Flow chart on how data is sent between the microcontroller and the XBee module Awaiting permission from Digi International

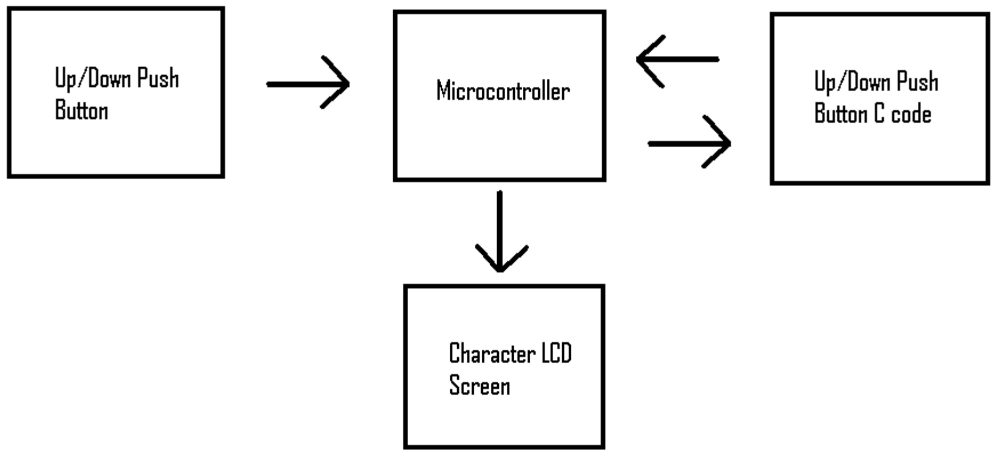
The figure below, 3.3.4 figure 2, shows how the chip is a transceiver. When information comes in from either another XBee chip or from the power sensor, it goes through pin 3 (DI) and when the information is processed, and needs to be sent out to either another XBee chip or from the power sensor, it will go through pin 2 (DO). When information is sent in through pin 3, the data is stored in the RF TX Buffer, which is the box to the left of the DI Buffer. Once the data is processed, it goes though the transmitter and flows down the diagram with the switch going from the top to the bottom, eventually sending out the information to whichever device it is supposed to be sent to.



3.3.4 Figure 2: Flow chart on how data in sent in and how it goes out of the XBee Awaiting permission from Digi International

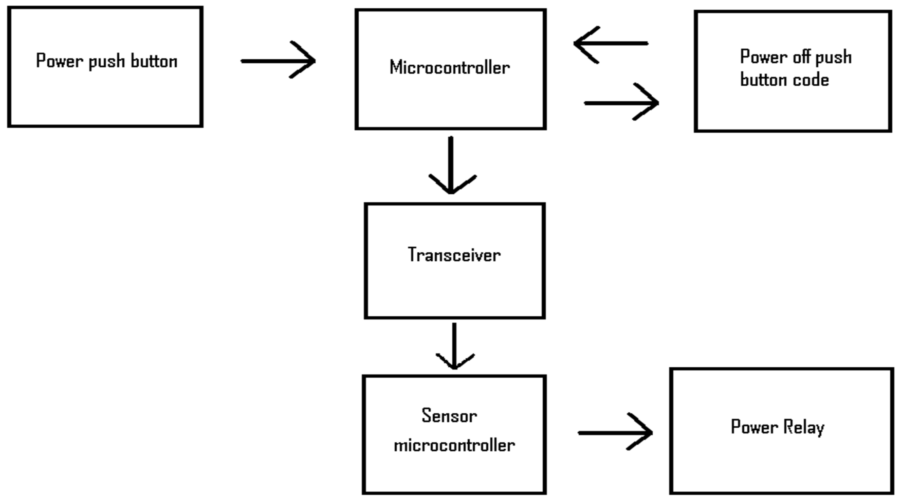
3.3.5 Push button / switch block diagrams

The image within 3.3.5 Figure 1 is the block diagram of the up and down arrow pushbuttons that are used to traverse through the character LCD display screen. What this block diagram shows is that when the user pushes the up or down arrow button, a switch is pulled sending a pin high within the microcontroller. This high pin then gets sent through the "C" code within the microcontroller which produces a change within the data so that the microcontroller can continue its course of changing the listed devices being measured. This change in the data to be displayed gets sent through the microcontroller to the character LCD screen in the form of a different listing of devices.



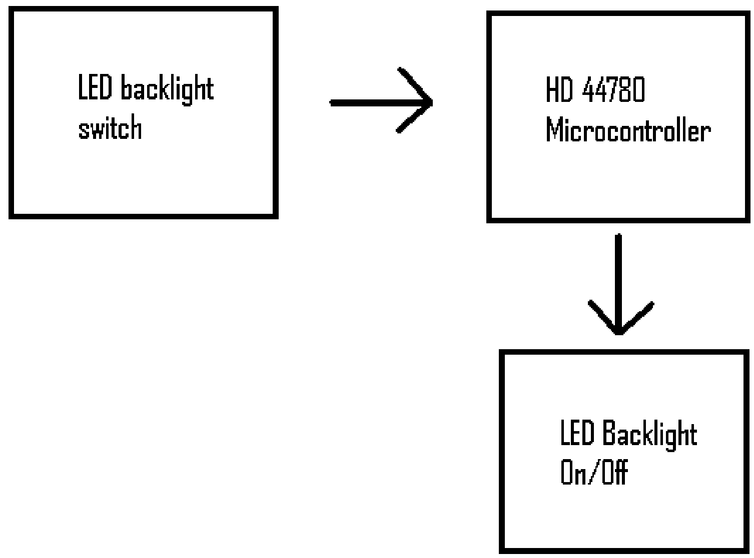
3.3.5 Figure 1: Up/Down pushbutton block diagram.

The next image is 3.3.5 Figure 2 which is the block diagram of the power on/off switch on the main receiving unit. This button is used to turn off the power supplied to the appliance that is being measure by the selected device from the list. As displayed below, when the user pushes the button similar to what was discussed before, a switch is pulled sending a voltage through the connected pin of the microcontroller. The microcontroller then sends this data through the "C" code of the power off push button, which instructs the microcontroller to either turn on or off the supplied power of the selected device. It does this by sending the data through the transceiver into the specific sensor which must turn off the power supply. The power supply will then flip the relay, removing supplied power from the device being monitored.



3.3.5 Figure 2: Power On/Off pushbutton block diagram.

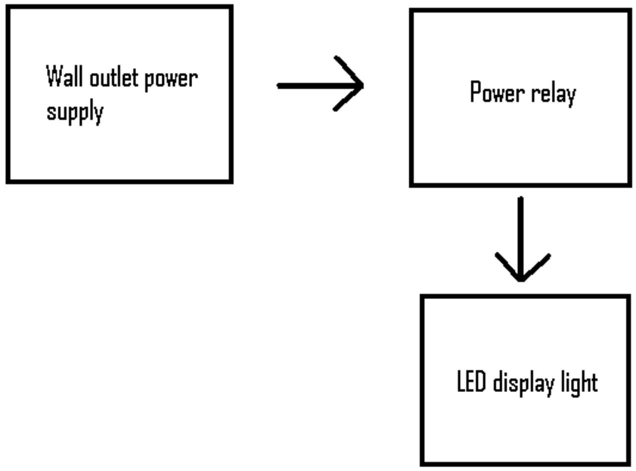
Lastly in the realm of a switch is the block diagram for the LED backlight of the LCD device that is described in 3.3.5 Figure 3. This is a simple block diagram which shows how the device works to turn on or off the LED backlight of the character LCD screen. When the switch is flipped from non-conducting to conducting, a voltage is applied to the pin of the HD44780 style microcontroller that turns on the LED backlight. However, when the switch is flipped from conducting to non-conducting, the voltage that was on the pin of the HD44780 style microcontroller is removed, turning the backlight off.



3.3.5 Figure 3: LED backlight block diagram.

3.3.6 LED power indicator light block diagram

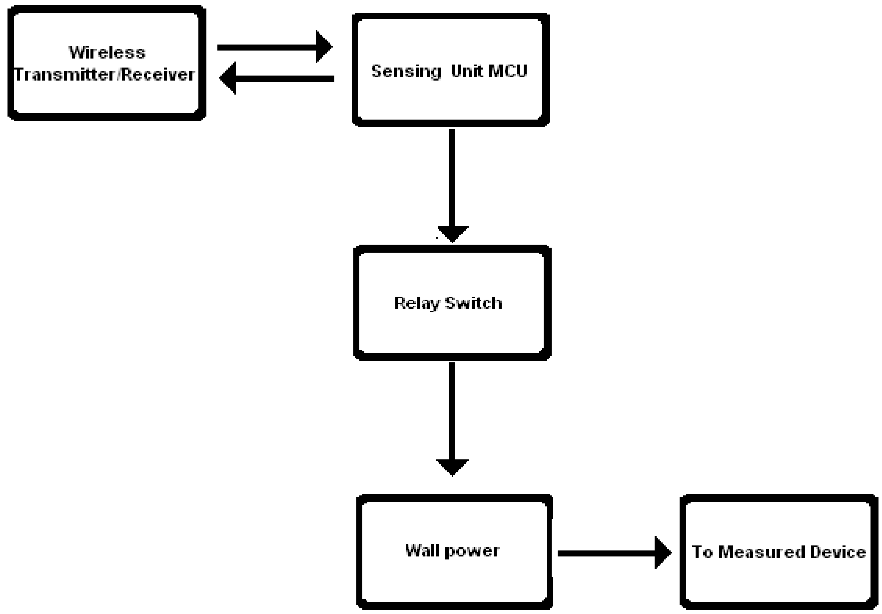
This project will also need a LED indicator light to turn on or off based of the supplied power going into the device. 3.3.6 Figure 1 below describes how the LED indicator light will work. The LED light will work with the use of a simple voltage divider circuit which draws power from the supplied power to the appliance. As described below, the supplied power from the wall outlet flows through the power relay when the device is on, and the power supplied is then used to turn on the LED indicator light. However when power is cut from the device, the LED also will have its power cut and the unlit light is the result. This is done to ensure that absolutely all power has been cut from the appliance being monitored.



3.3.6 Figure 1: LED indicator display light block diagram.

3.3.7 Relay/Switch block diagram

The design will need a relay switch to turn off and on power to any desired measured device. 3.3.7 Figure 1 shows the basic block diagram of how the relay switch will be implemented. The wireless receiver will wait until it receives a signal from the main unit’s wireless transmitter to turn off a specific device. Once that signal has been received by the sensing unit’s microcontroller, it will change a digital logic output pin. The voltage change will cause the relay switch to disengage the connection between the wall’s voltage supply and the measured device. This relay, and circuit, will remain like this until the sensing unit’s wireless receiver gets another signal from the main unit’s wireless transmitter. Once the sensing unit’s microcontroller detects another signal, it will trigger the output pin that controls the relay switch and reengage the voltage supply to the device to be measured.



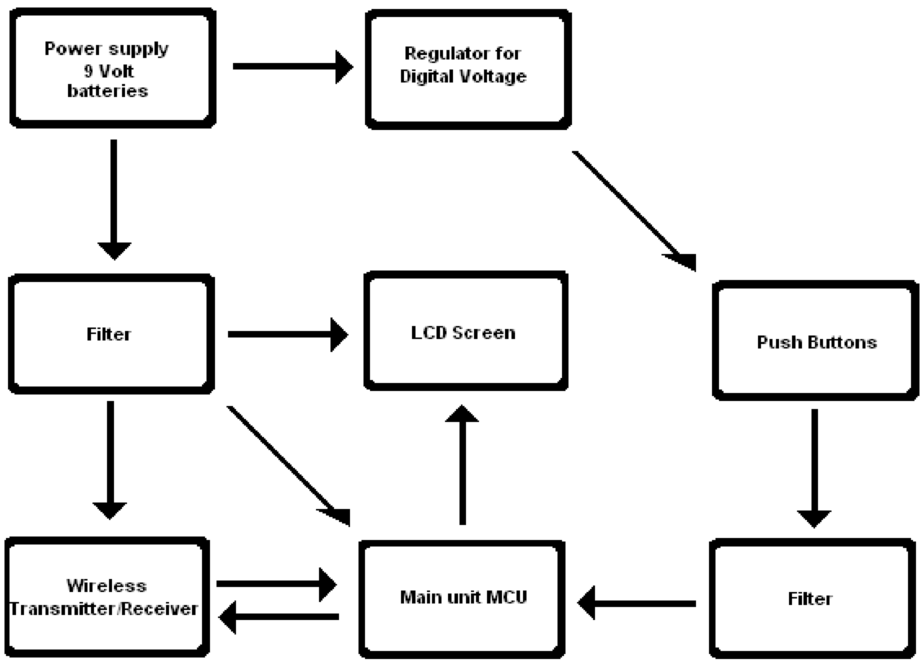
3.3.6 Figure 1: Relay/switch block diagram

3.3.8 PCB Design block diagram

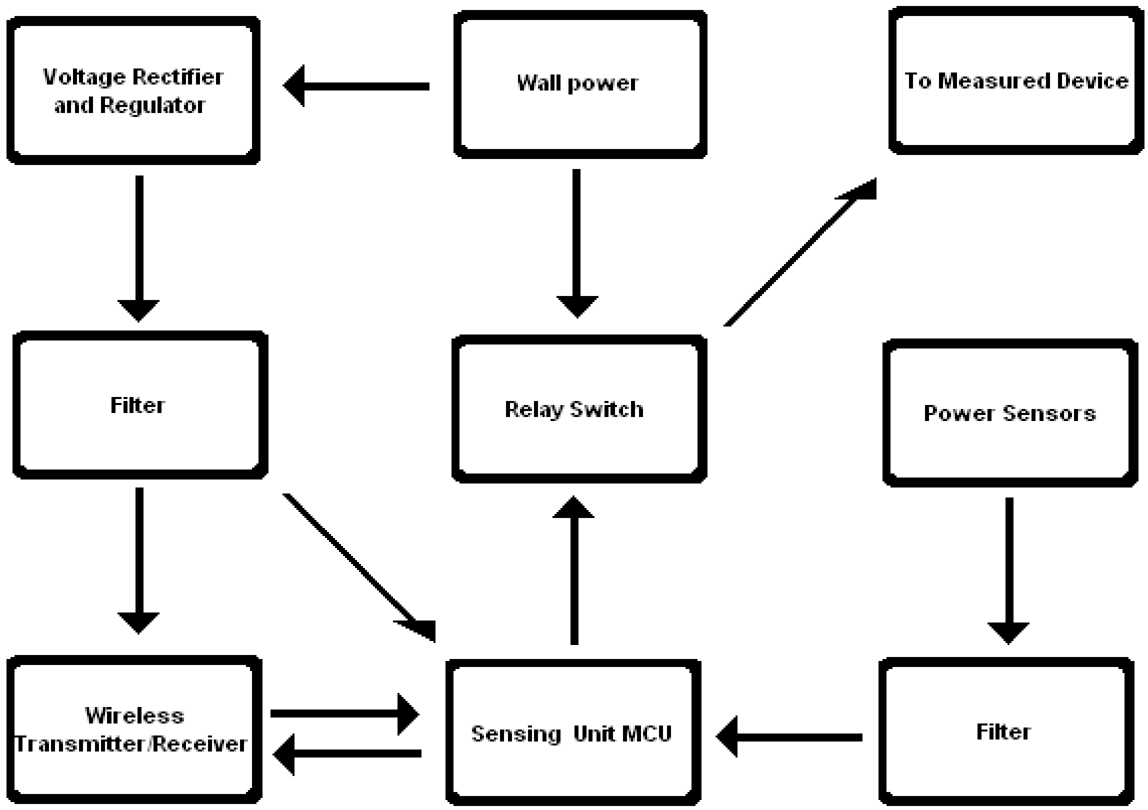
The main unit's printed circuit board will have a single are associated with the power supplying batteries. These will then pass through a single low pass filter to prevent any random power spikes, such as turning the entire unit on or replacing a battery. The power will then travel through the printed circuit board into the LCD screen, all the wireless components, and the main unit's microcontroller. The power supplying batteries will also be passed through a regulator to drop it to a digital voltage level. This voltage will then pass through the push buttons, when depressed, a filter, and then into the main unit's microcontroller. The main unit's microcontroller will also need to have connections between both the LCD screen, to communication information to be displayed, and to the wireless components, to transmit to and receive information from the sensing unit's microcontrollers. The basic layout of this board can be seen in 3.3.8 figure 1 in block diagram form.

The sensing units' printed circuit boards will share a similar architecture as the main unit's printed circuit board. The power for the entire circuit board will come from the wall, instead a batter, and will pass through rectifiers and regulators to get the voltage down to a usable voltage. The voltage will then pass through a low pass filter and will be used to power both the wireless devices and the sensing unit's microcontroller. The power sensor will send its signals through a filter to provide a more accurate and stable reading and have a connection to the microcontroller. The microcontroller will also need a connection to the relay switch, which will have a direct connection to the supply voltage to the measured device. This printed circuit board layout can be seen in a block diagram form in 3.3.8 figure 2.

On both the main unit and the sensing units' printed circuit boards, the microcontrollers and wireless components will all be on preassembled printed circuit boards. Because of this, the circuit board will need to be designed in one of two ways. These components can be set on "plugs" to allow a slight clearance over the rest of the printed circuit board and potentially avoid any difficult spacing or these components can strategically placed to avoid any spacing issues that may be caused from other components on the printed circuit board.



3.3.8 Figure 1: Main unit PCB block diagram



3.3.8 Figure 2: Sensing unit's PCB block diagram

3.4 Estimated Costs & Funding

Each sensing unit will house a single microcontroller. As well, it will house a Arduino XBee shield, a LED indicator light, and a relay switch. Each individual Arduino costs roughly $18.50. The Arduino XBee shield is roughly $73, while the relay can cost roughly $8.50 and a single LED can potentially cost $1. This brings the total for the sensing devices to roughly $101, excluding any project enclosures, printed circuit boards, or basic components. As a total of 4 of these devices will be required for this design, a total of $404 will be spent on these devices. Because of the pricing of printed circuit boards, the total price for these will be roughly $500. This new price includes 2 layer printed circuit boards along with project enclosures and basic circuit components.

A single, different microcontroller will be used for the central unit. This unit will also house another Arduino XBee shield, an LCD display, and push buttons to be used by the user. This specific Arduino will cost roughly $49.50. The Arduino XBee shield is roughly $73, the LCD display will be $23.50. The push buttons can be roughly $3 for a package of 2 buttons. This will bring the total for the central unit to roughly $152 without the printed circuit board, project enclosure, or basic components. With an included circuit board, battery capabilities, and basic circuit components, including the creation of the filters, will cost roughly $175 to $200.

As no sponsor for the designed project has been found, all funding will come from the designers.

3.5 Explicit Design Summary

The project designed relies on two different types of units. One of which has the initial purpose of measuring power and transmitting a measured value of power to another unit. It also has a secondary purpose of being able to connect or disconnect the measured device without manually disconnecting the device. The other device is designed to serve as a hub for all other measurement devices. This main, or central, unit will communicate with all sensing devices through wireless communications. This central device will display, in an organized fashion, the power being consumed throughout all the sensing devices currently being utilized. These will then be able to be scrolled through, if more than can be displayed at once are being utilized. The central unit will also be able to send out a signal to a specific sensing device, when the user prompts it, and have the power disconnect from the measured device. These must also be able to be reconnected to their power source by the same means. The central unit must also have a means to have certain parameters be reprogrammed while still in use to change the outcome of the displayed information.

3.5.1 Main Unit Design Summary

The main unit will be using an Arduino Mega microcontroller due to its pin availability, programming schemes, versatility, and ability to interface with wireless communications easily. This microcontroller will handle all information inputted by both the sensors and the user. The user will be using push buttons to enter any variable changes. These push buttons will also be implemented to scroll through all currently connected and transmitting sensing devices. As well, the push buttons will be utilized to engaged and disengage power to the currently measured device of any of the transmitting sensing devices. In order to prevent potential false readings of push buttons, both software and hardware debouncing will be implemented on the push buttons through delays, interrupts, and analog circuit filters. The wireless communications will be done with XBee modules. These modules will be with Arduino XBee shields to assist with interfacing between the two devices. The XBees were chosen because of their peer-to-peer and transceiver capabilities. The design will also utilize a 40 character by 4 line LCD screen provided by New Haven International. This LCD display will adequately show enough information to both show information gathered by the sensors, as well as show multiple, live sensors, rather than a single sensor at a time. All devices within the main unit will run strictly off battery power. This is done to prevent substantial power consumption added to a home from the design itself.

3.5.2 Sensor Unit Design Summary

The sensing units will be using Arduino Pro Mini microcontrollers. This choice is due to its adequate pin count, ability to interface with the wireless communications, and programming scheme. The Pro Mini microcontrollers will handle all incoming values from the sensing devices. These devices will consist of both voltage and current sensors to give an accurate power consumed from each measured device. These readings will then pass through a low pass filter to prevent any random spikes in values to affect the overall outcome of the sensors. All wireless communications will be handled with the XBee transceivers. These transceivers will also have the Arduino Xbee shields attached for easier interfacing between the two devices. The Pro Mini microcontroller will have control over a relay switch which it will turn off and on as it receives the appropriate signal from the main unit's microcontroller. An externally visible LED will also be attached to the sensing units to easily display whether a measured device is currently having power transmitted to it or if it the circuit has been temporarily opened. The LED will act as a visible connectivity, it will be on when the circuit is closed and the measured device has power and it will be off when the circuit is disengaged. The sensing units will run on wall power, as they will already be attached to the power supply and should not consume a substantial amount of power. As well, the power consumed by the sensing units should be known. This is to aid in power consumed calculations in the central unit's logic and to be displayed on the LCD screen.

4 Prototype

4.1 Build and implementation strategy

4.1.1 Design planning

With so many parts to this project the group had to find ways to mesh all their portions into one working project with multiple devices scattered throughout a home. The LCD screen will solely be placed on the central unit and will work hand-in-hand with the microprocessor. A microprocessor and a wireless telecommunication chip will be the sole similarity between the units. Each of the scattered power units will have a power sensor attached to the microprocessor, which will feed the information gathered to the wireless telecommunication chip. This chip will transmit the information received to the telecom chip found in the central unit. The central unit telecom chip will receive this data from all the scattered power-sensing units. The only thing the central telecom chip will send out is whether to turn on or turn off the scattered power units.

4.1.2 Personnel distribution

Having four members in the group made this project very to distribute assignments. Amir Shahnami will be working on the wireless telecommunications between the central unit and power units spread out a house. Alex Demos will be working on the microcontrollers to ensure the data runs smoothly from the sensors and then to the central unit, also making sure the information sent in from the wireless chip make it to out properly. Manuel Rodriguez is assigned to work the power sensors at each of the power units, this will ensure accurate data is being read and displayed. Frank Ladolcetta is working on the LCD screen to display all the information received from the power sensing.

4.2 Parts acquisition

Many parts are required to create the designed project. As most of the components are to be purchased online, the table below, 4.2 table 1, lists where each part will be purchased from. Each supplier will carry one or more of the components needed for the design, and is listed showing which part will be purchased from each.

As Arduino does not explicitly sell any of their own boards directly, all microcontroller boards discussed must be purchased through another vendor. However, since the group wanted to expand our knowledge of microprocessors and their development, the group has opted to build our own device using a microcontroller chip and other parts necessary to get our device working. The group decided that the use of a board would not appear as impressive of a design as that of a homemade microcontroller method. This microcontroller will be built with a similar design as to that of the microcontroller designed in our project, but will have a much simpler design.

Supplier	Part
Amazon	Arduino Mega
Sparkfun	Arduino Pro Minis
FunGizmos	Arduino XBee shield
New Haven Displays	LCD Screen
SemiconductorStore	Power Sensors
Express PCB	Printed Circuit Board
RadioShack	LED Resistors Capacitors Push Buttons Relays Switches

4.2 Table 1: Table of potential vendors and corresponding parts

4.3 Coding

4.3.1 Sensor Microprocessor coding

The sensing unit's microprocessors coding will have three main functions. The first, and most important, of these functions is the sensing blocks. The next is the wireless communication section. Finally, the last function acts as the power connection function.

The first function block is the block for power sensing. This function will need to take in the measured power and store it into a dynamic variable. The sensing function will need to be called more than any other of the functions as this function alone results in the accuracy of other functions and, ultimately, the output seen by the user.

The next block is the wireless function. The first purpose of this function is to transfer the measured power that is passed from the previous function from the sensor's microprocessor to the main unit's microprocessor. This function will mostly prepare the data in such a way the measured power can be transmitted to the main unit's wireless receiver with ease. As well, the second purpose of this function is to handle all incoming data from the main unit's wireless transmitter.

This data, which will only act as a simple on or off signal for the power, will need to be passed into the connection function.

The wireless function can also be used to conserve some power on the sensing unit’s end. Once the microprocessor has received the signal from the main unit’s wireless transmitter to disconnect power for the device being measured, the microprocessor can rapidly enter, and exit after a small amount of time, a lower power consuming sleep state. By constantly entering and exiting a timed sleep state, the microprocessor consumes less power than it would if it were constantly running, while still checking at an adequate rate for a signal from the main unit’s wireless transmitter to reengage power to the measured device. Another approach is to allow the sensing unit’s microcontroller to enter a sleep state and use an external interrupt associated with receiving a “reengage” signal on through wireless communication to force the microcontroller to exit the sleep. This second approach would also require the program to disable interrupts throughout the majority of the program and only enable interrupts shortly before entering a sleep state.

The last main function to be done in the sensor’s microprocessor is the connection block. This function will only be called once a signal from the main unit’s wireless transmitter has been sent to the sensor’s receiver to disengage power to the measured device. The connection block of the programming will change a single bit stored within the microprocessor. This bit will be sent directly from the microprocessor to a relay switch to engage, or disengage, the power supply to the measured device while still allowing power for the entire sensing unit. This connection function will also be called one more to reengage power to the measured device. This will be done in the same approach for disconnecting power.

4.3.2 Main Unit Microprocessor coding

The main unit’s microprocessor’s coding will consist of four main functions. The first of the functions will be to handle all user button interactions. The second function will be to for wireless communications. The next function serves to handle all information transmitted to the main unit’s microprocessor from individual sensing unit being utilized. The final main function dealt with in the main unit’s microprocessor is for printing to the LCD.

The first function of the main unit’s microprocessor is to handle all user button interactions, which can be broken down into three major parts. The first part of this function is to alter variables stored within the microprocessor that are used for calculating the costs. This will be done by requiring either a combination of buttons to be pressed or a single button to be pressed which will trigger an ‘interrupt’ state. Once in this state, it will reutilize the push buttons to change the values already stored in the microprocessor and be able to exit with the same means it entered.

The second part of the user controller button function is to cycle through the sensing unit's outputs on the LCD screen. This portion of the function will simply "highlight" any given line as well as change the range of displayed sensors, such as from mapped sensors one to three, to two to four. The final part of this function is to send the signal to disable, and enable, a sensing unit's device. This will be done by allowing the user to "select" an individual highlighted output. Once this has been done, it will prompt to disable, or enable, the device, or leave it alone.

The next function is to handle the wireless communications. The biggest requirement of this function will be to constantly receiving information from the sensing units' wireless transmitters. Because this will need to be constantly receiving information, this function will be called the most, and be the more important portion of the microprocessor. As well, this function will also need to receive both that a unit's measured device should be connected or disconnected, as well as the specific unit to connect or disconnect, from the push button function. Once this has been received, it will need to send a single bit to tell the sensing unit's microprocessor to disengage or engage power to the measured device.

The third main function in the main unit's microprocessor is to handle all information given to it and manipulate it. In this section, it will use all values entered by the user from the push button functions. It then will take in all values received from the sensing unit's microprocessors through the wireless devices. This then will perform simple mathematical operations on them and store the result into other variables with a fairly high accuracy. These variables will constantly be updated as any new information is received. Finally, before they are displayed on the LCD screen, the values will be rounded and stored in a temporary variable which will be overwritten each time the value changes for ease of viewing on the LCD screen.

The final main function in the microprocessor is that to display information to the LCD screen. Most of this LCD screen programming is explained in section 4.3.4. One main advantage of this function how frequently the LCD screen must be updated. Because most of the information displayed on the LCD screen will be relatively constant, it does not need to be updated unless one or more values have been changed. As well, the microcontroller could have an "idle" state, which has been triggered when a button hasn't been touched after a set amount of time, and only update when it is not in this idle state.

4.3.3 Wireless coding/decoding

Please refer to section 3.1.4.4 for all commands used for the wireless telecommunications portion of the project. In this project, the coding for the XBee chip is based on the combination of commands and parameters set to specified commands. There are two ways to implement the commands but, for the duration of the project, the group will be using AT commands.

4.3.4 LCD Display Screen Coding

Since the device will utilize the Arduino microcontroller, the group will be able to utilize the “C” programming language to code the LCD display screen’s operations. This is a positive factor of the Arduino microcontroller in that each member of the group is quite adequate at programming in “C” code. This is also a success in the LCD display screen side of things, in that there are many websites and resources which have the entire programming for the HD44780 scheme of displaying characters all completely done in “C” code for free use. In addition, the LCD display screen’s manufacturers already have in stock copies of an example code for use with this exact display screen, which the programmers know works. More than likely however the group plans on using these resources as references to better understand the inner workings of the HD44780 compatible microcontroller design.

First off, the device will need to have a library to draw from which describes each pin of the Arduino microcontroller in terms of a “C” variable. This library will be described in detail within the Microcontroller coding section of this device documentation sheet. The group will also need a separate code, described in the same microcontroller coding section, which will call the LCD coding to instruct the LCD screen when to operate and display specific characters. The main Arduino coding will constantly run, gathering power generation data for each device, storing them in specific locations. When it comes time for the device to begin outputting data it will need to run a LCD device initialization code to begin the program for use. The code will operate all the commands within the initialization setup from the LCD interfacing section, listed within 2.2.4 of this documentation. Each command will set certain pins high or low within the “C” code and send out the command onto the pins from the Arduino microcontroller’s code. When a command is done, the initialization code will continue until each command from the code is sent out to the LCD microcontroller. This code will allow the LCD display device to begin its output of characters for the user to read.

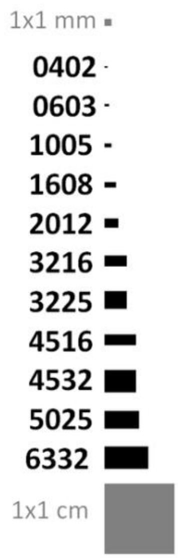
When initialization is complete, the main receiver’s microcontroller will then continue collecting wireless power consumption data. If this is the first time the device has been run since the battery was removed there would be no prior data stored, so the device would display zeros for all values of each device. The user would be required to enter in the date, the bill due date, and the cost of the device as explained in 2.2.4 of the documentation, where instructions and numbers would be displayed within the LCD screen as per the coding of that section. Described in detail within the microcontroller section, when the correct button combination is touched, the code would then be programmed to accept in data for these values and return them to the main microcontroller for power consumption use. After 60 seconds of recording, the device now has information that needs to be displayed. This is done via a separate code for data output. This code will take in the values for each device number and will display all four horizontal lines of code at once, including the heading of the device. The way this works is detailed in the LCD interfacing section in 2.2.4. After completion of its character output, the code returns a null value and begins to wait 60 more seconds for the next output display. This procedure will repeat every 60 seconds for as long as the device is in operation to allow the user to see continuously updated details of their total power consumption. If possible, a set of embedded microcontroller LCD display codes will be used to make LCD programming more efficient.

4.4 Surface mounting of Parts

As discussed in section 2.2.6, the group is planning on using parts that require the use of surface mount technology in order to apply them to the printed circuit boards. Currently, no member of the group has the necessary skills to apply surface mounted devices to the PCB of the devices, which could be a problem. Although most of the group has some experience soldering or using through-hole technology to apply parts to a PCB, no one has attempted to solder surface mount technology devices. For now, the group has two options as to where and how to go forward with surface mounting their devices to the PCB. The two options that will be looked into will be that the group will either call upon someone who has more experience with surface mounted devices to do the work for a fee, such as a member of the radio club. If this is not possible, the members of the group will painstakingly learn how to apply these parts to their PCB by themselves. Anyone can go to Google to search for surface mounting tips and they will find a vast array of websites based on teaching visitors how to do surface mounting. There are many videos, how-to’s and literature to learn more on the subject, however to master the method a user must go through hours of practicing patiently, hopefully not ruining the expensive surface mounted devices in the process.

As talked about earlier, the main difficulty with surface mounting parts to a PCB is the incredibly small size that each pin can potentially be on a surface mounted device. For example, the smallest leads on a surface mount technology device could be as small as .4 mm by .2 mm, which is incredibly small, and difficult to work with, even with a magnifying glass. Applying these devices to a PCB is normally very easy when you have the proper equipment; however it is very hard to do by hand, especially if you do not have the experience. Since the group does not have a wave soldering machine, or a circuit plan for use in a pick and place machine; the only method left is hand soldering. As displayed below in 4.4 Figure 1, the reader can see the relative sizes of each of the pieces to be able to grasp the minuscule proportions of each of the leads of a surface mount technology device. This figure is displayed in the actual width and height of the lead sizes that they represent. The numbering system below describes the width and height in increments of .1 mm. For example, the device at the bottom labeled

6332 is 6.3 mm long by 3.2 mm wide. This numbering scheme makes it easier to pick out the proper wire size and space between wires in order to connect the PCB to the leads.



4.4 Figure 1: Relative Surface Mount Technology Lead Sizes (Actual Sizes): Provided under the creative commons license

The group will need someone who is in charge of surface mounting the parts to the PCB, whether this is one person, or the entire group. Each member who is surface mounting the device will be required to read the literature, and watch the how-to videos to ensure that they know what they are doing when they are soldering. Also, anyone working on surface mounted devices will be required to have at least a medium amount of practice on cheap parts to gain experience before they will be allowed to surface mount expensive parts to the board. This is because if the person is inexperienced with surface mounting, they have a chance to miss-solder, break a lead, discharge static electricity, or ruin the printed circuit board. If this does happen, these devices will be useless to the design that will lead to unwanted expenditures. However if the person gets their practice out on inexpensive parts, the chance of making a mistake on a part that will cost a significant amount decreases in probability.

Although the aesthetic look of the circuit is not important to the group since it would be hidden away from user view, the group would like the soldering to be done professionally, so that troubleshooting the device becomes a much easier task to do. While prototyping is being done, each part will be tested individually once placed onto the board to ensure that the connections are made and the device is still in working order after soldering. Each part will be slowly and meticulously added to the PCB for the main console and this will be tested for complete and successful work. Then, the devices will be soldered onto the PCB for the sensor devices and will be repeated for each sensor device to ensure that nothing is changed in the design of each sensor and to ensure that everything is perfectly soldered. Then the devices will be tested to ensure that all four of the devices are in working order before the protective outer covering will be applied to each device for outer aesthetics. If possible, the device would have fewer surface mounted parts to improve the overall ease and solder quality of the device. With through-hole technology, the parts are similar and the insertion of pins is a much simpler task.

4.5 Design Changes

During the creation of our prototype, the group had to make a lot of design changes as well as testing of different designs to see which would give us greater accuracy and a better quality project. At the end however, there were very few major changes to the device; most changes were minor.

One important design change that the group tested and changed was that of the sensor itself. The first design that was tested was the accuracy of the sensors with the opto-isolators. The group tried for days to understand how the devices worked, as well as improve the accuracy of the device. When the device failed to improve, the design team decided to test another method of measurement of current and voltage using a set of specific Op-Amps design for AC use. However after several days, and several mishaps the design team returned to the original opto-isolator design and improved the accuracy to a proper level with the help of the makers of the optoisolator devices; Avago. We then experimented with various ways to reduce noise through the use of high frequency filters as recommended by the Avago personnel. We also decreased the current sensing resistor from .2 Ohms to .025 Ohms to increase the maximum current measurement, and also increased the 1 MOhm resistor to 2.2MOhm to help improve the accuracy.

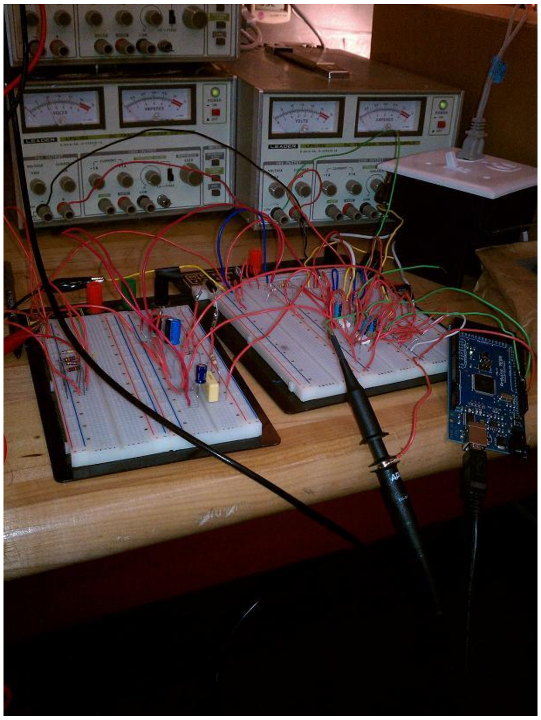
Due to such low resistances on the device any wire additions cause an increase in resistance measured, requiring the group to calibrate the devices individually in order for it work properly, this is due to PCB errors and additional wires added.

The group also needed to understand the way to power the device keeping in mind our goals of cost, size, and risk of danger. The group experimented with several different methods of power supply. This included a single power supply from the main wall plug. This was a simpler method, however it was also a more risky method which would remove the safety requirement of the project. We also tried 2 transformer-less power supplies per device in order to decrease overall size and cost of the project. This method would have worked had the opto-isolators not required isolation from both the left and the right sides of the IC. The end result was that we used two separate 120V to 12.6 volt transformers along with a bridge rectifier and a 5V power regulator. This solved the power supply problem, but came at a price of increase size and cost. The new design worked great but caused issues with a higher voltage than necessary entering into the

5V regulator, which caused heating problems with that device. This was remedied through the use of a heatsink being attached to the 5V regulators as well as the power relay for better heat dissipation.

The coding that the group used for the character LCD was the coding scheme provided by the Arduino microcontroller, which simplified the coding design tenfold. An additional button for a menu was also added to simplify the coding and reduce debouncing caused by the depressing of two buttons simultaneously.

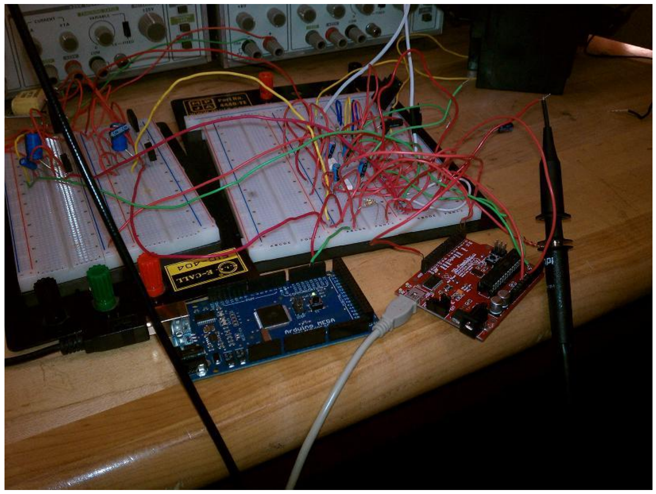
The microcontroller was changed from the original design in order to increase the complexity of the project as well as allow the group to explore new interesting subjects within the electrical engineering field. The group originally planned to use premade microcontroller boards, but decided to use a design based off of that design to experienced a more in depth knowledge of the device. This was also done to reduce the complexity of the design.



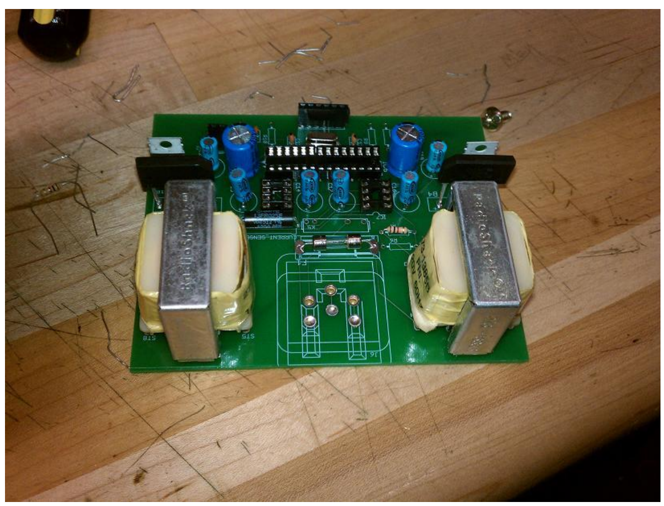
4.5.2 Breadboard Device Testing

The schematic that was used to design the PCB layout that was ordered from www.4PCB.com changed significantly in order to ensure that our device works as expected. The changes were mostly dependent on the positioning of wires for increased safety due to the high power coursing through the device.

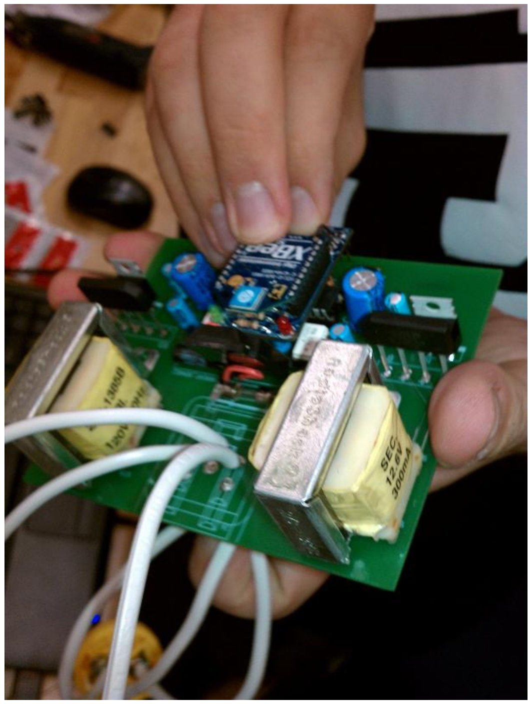
Lastly, the Arduiono XBee shield was changed to an XBee adapter kit. This XBee adapter kit utilizes the 10 most important pins. However, the only four pins used were the RX, TX, VCC and Ground pins. This kit was substantially cheaper when taking into consideration that four kits are needed. This kit also needs to come with a cord that connects the pins to the computer. Using the X-CTU program, the XBees were programmed so they could work in an Association network. This network is like a peer-to-peer but with a head XBee.



4.5.3 Wired Communication



4.5.4 Initial PCB Setup and Soldering



4.5.5 Wireless installation

4.5.6 Successful Operation of device

4.5.7 Device in case

4.5.8 Transmission Testing

5 Testing

Once the design is built and complete, there's a need to make sure it is actually measuring what it is supposed to measure. There are a few ways to make sure the system is working with the expected accuracy. The first method is to compare the results obtained with similar products already on the market. There are readily available consumer friendly power sensors such as the "Kill a Watt" device and other similar devices that will measure power in watts for home appliances. A very simple way to test the sensor is to take a reading with the sensor and compare to a reading from one of the available power meters on the market. This would give us a sense of how accurate the design is compared to what the public can purchase today. These readily available sensors claim from .02% accuracy such as the “Kill a Watt” to 1% such as “The Meter Reader EM-2500” all the way up to 8% accuracy such as the “What’s up?” power meter. The goal is to make a competitive system that will give an accuracy similar or better as these available products.

The real test of the design is to compare it’s readings to the actual current and voltage being used by the load. In order to do this it would be needed to measure the voltage at the outlet and the current going into the device. This could be accomplished by using a multimeter. To make sure the measurements are correct at least two different multimeters could be used to make sure that the measurements are correct.

An even simpler way to measure the accuracy of the design it to create a circuit that includes a load, measure the voltage and current consumed by the load using either a multimeter or an oscilloscope and then using the power sensor to corroborate the measurements. This design is will also calculate daily, monthly, and yearly power usage. These calculated values will be integrated in the display software. In order to make sure that the calculated values are correct, a simple calculator can be used to compute the predictions of usage as displayed by the design.

The power measurements will obviously depend on the load. A light bulb will not pull as much amperage as a clothes drier. Different appliances will be tested to ensure that the design can measure a variety of loads. Certain energy meters on the market are only able to measure a particular range of the power load. This design should be able to measure power from a light bulb up to a clothes drier. Therefore, after comparing the design for accuracy as described above, measurements of the most common home appliances will be taken simply to corroborate that the design is able to sense the power of these appliances. Of interest would be the following: toaster, coffee maker, clothes drier, TV, radio, computer A/C system and refrigerator. Not only will these appliances be tested when running, they will also be tested when not in used but plugged in to a wall. The design should be sensitive enough to measure the power being used by an appliance when not in use.

The sensor circuit will also be tested in a virtual manner. For example there are various calculations to be made to decrease the voltage seen by the digital portion of the system compared to the voltage on the analog side. Once the calculations are done for the resistors needed, a program like Multisim or Pspice will be very handy to test the design. It’s much less time consuming and costly to test the design in a virtual manner than in a live circuit. If a mistake is made in the calculations and there’s too much current seen by the digital side, it’s only a matter of making some better calculations and trying the design again. If, on the other hand, the circuit is wired and goes live with the wrong components, there could be some burnt parts as a result. Another good thing about using a program to mock the circuit and test it is that it can easily be tested in sections so that in the end it is easier to put everything together once every section has been tested and fine-tuned. Since the system is virtual in one of these programs, it’s easy to test the limits of it without damaging anything. The voltage and current can be increased somewhere above the limits of what would be seen in the real life circuit and any safety features built in the circuit can be tested for proper functioning. Definitely, virtual testing will be an integral part of the system design.

5.1 Testing Chart

Light Bulbs	Reader	KillAWatt	Percent Error
0	7.5	7.9	5.063291139
40	44	46.9	6.18336887
80	85	84.6	-0.472813239
120	124	130	4.615384615
160	165	171	3.50877193
200	207.7	215	3.395348837
240	249.5	255	2.156862745
280	286	294	2.721088435
300	309	316	2.215189873
340	350	354	1.129943503
360	372	374	0.534759358
400	417	418	0.23923445

Figure 5.1.1: Chart of Percent Error in Reader Vs. KillAWatt

As displayed in figure 5.1.1 above, the accuracy of the device improves as the power consumption increases. This is due to the fact that the device is optimized towards higher power consumption devices. This is because low power consuming devices typically will not be measured for power consumption due to the minute amount of power consumed. The average error measure in our test was 2.686%, which falls far below the 10% accuracy requirement.

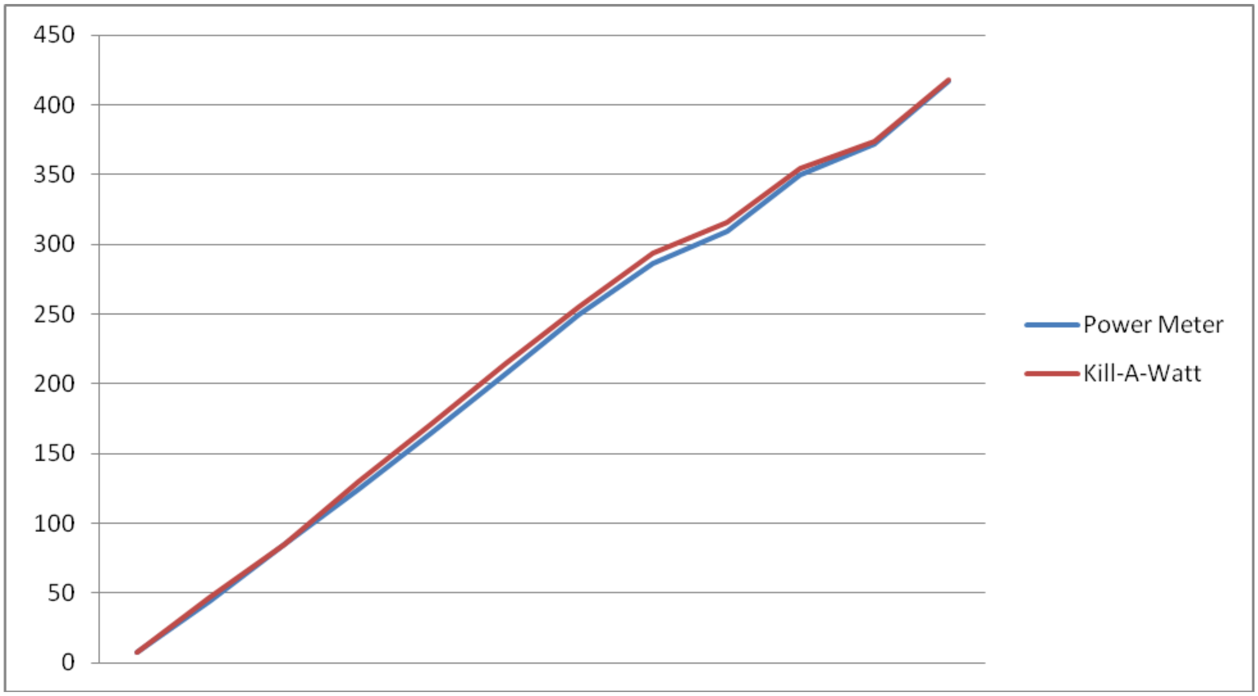


Figure 5.1.2: Test of Accuracy

5.2 User Manuel

1. **Plug in main unit.**
2. **When requested, enter the cost in Cents/ kWh using power button to increment, Up button to go to a left digit, Down button to go to a right digit.**
3. **When correct cost is entered, press the menu button to advance.**
4. **Begin by plugging in a sensor unit.**
5. **Shortly the device will begin to turn on, and within 15 seconds the device will appear on the device.**
6. **Pressing power will turn on the device selected in the top left corner.**
7. **You can then plug in as many devices as needed.**
8. **Using the up/down arrows the user can then see the information for each of the devices.**
9. **Each device will update every 15 seconds to ensure accurate representation of power.**

6. Reflections

6.1 Features left out

For the most part, the design incorporates just about every feature needed on a home energy measurement system. The main feature is for it to measure energy consumed and to relay that information in a manner that is easy to comprehend. This design does that by measuring the energy consumed by home appliances and showing the amount of that consumption in an easy to understand unit of measurement; dollars and cents. But of course, other than the very basic and most important feature, there are other features that could have been implemented that would make the meter an even more valuable energy measurement tool.

The biggest feature left out of the design that could be of the biggest asset to a consumer is the ability to read the energy consumed by the A/C unit. Leaving out this feature had to come to a vote of the team. It was that important. In the end, it was left out due to the complications that it would bring to the design. The design as it is will measure the power of any appliance that is connected thorough a socket to the main household wires. This includes appliances that consume 120 volts or 240 volts. The A/C units, as they are mostly wired today, do not connect to the household wiring through a socket. They basically do not have an electrical plug; Instead they are wired directly to the main wiring. Basically the A/C compressor has its wires connected to the home wiring using a semi permanent connection. In the case of most modern compressors, which is the main component of the A/C system, the wires are fed into the wall using a metal sheath to protect them. The only way for a consumer to “disconnect” the A/C compressor would be to turn off the circuit at the main electrical panel. Due to the form of connection used for the compressor, a hall effect sensor would be needed to measure the current. It was decided to use a shunt for the design which is a much simpler and inexpensive way of measuring current. With a shunt, every single device can have its current measured other than the A/C compressor. Therefore simplicity and cost won over completeness of design.

A way to implement this in the design would have been to add an adapter to the power sensor that had the ability to handle a hall effect sensor connection so that the consumer could choose which method to use to measure the current. A simple switch could be used that would let the consumer make the switch. This would obviously add much more complexity to not only the printed circuit board but to the outer shell of the meter sensor where a switch and an extra connection to the hall effect sensor would have to be added. It would also add to the cost of the system, as a hall effect sensor is a much more expensive than a shunt design. Since literally, 99.9% of the appliances can have their power measured with the design, it was deemed not a good idea to implement such a complex addition to the design simply to add the ability to measure the power of an single appliance. The biggest drawback of not having the ability to measure the power of the A/C compressor is that the ability to measure the power to one of the most power hungry appliances in a home is lost. The A/C system in a typical house, draws the most power of any home appliance and knowing how much energy that is in terms of dollars and cents is crucial in the power management of the house. By changing the thermostat settings that control the amount of time the A/C compressor runs on a typical Florida day the consumer could save a large amount of money and saving money is the main reason for having a power measuring system.

Another feature not included in this design is a phone or internet interface to display the measurements and control the turning off and on of the appliances. This feature was included in the initial plans of the design but due to its complexity was deemed unnecessary. This feature would be mostly programming intensive and, especially trying to implement it using a phone, would add a whole new dimension of design to the system. Many people these days use smart phones which are basically very small computer that happen to have the capability to be used to make phone calls to people. These phones, in particular the Iphone, have the capability to run various programs that the consumer can use for either work or entertainment purposes. Of the consumer available power measuring systems in the market, at least a couple of them have phone applications. These applications have the ability to display the power consumed in the house as a whole or of particular appliances. They also have the ability to turn on and off said appliances. And some of them have the capability to display these measurements on a web based form so that the consumer can remotely monitor the energy consumption of the home and turn appliances off and on. This feature adds a dimension of control to the system that makes it more complete but It's not vital to its use.

6.2 Future improvements

The biggest improvements to the system would be to add the ability to measure the power of the A/C system. This would help the consumer have a more complete manner of controlling home energy expenditures. Another improvement would be to add a different manner of displaying the measurements. As mentioned in the previous section, this could be implemented using a smart phone or a web based design.

The biggest improvement by far would be to increase the accuracy of the system to a level where what is read by the meter is almost the same as that read by the power company. This would allow the consumer to know with much more accuracy how much exactly will be the energy bill for the month. This also help the consumer make comparisons to the point where if the two measured amounts are off by a large amount, the consumer could dispute the difference with the power company. In order to make this accuracy level higher parts with tighter tolerances would be needed and most likely an even more complex programming scheme would be needed.

Another improvement to the system would be to make it a “smart system”. Basically this would mean that the system could be programmed to control the energy consumed by turning on and off certain appliances. The consumer could set certain consumption parameters and the systems would in turn control which appliances are allowed to run and which are not. This improvement would be much more programming intensive to implement but it is a nice goal to keep in mind for future iterations of the design.

7 Conclusion

The more aware people become of the importance of saving energy, the more common this type of power meter will become. Power meters might become the PC of the future. Every home will have one. Just as there are fuel gauges in a car, there could be this type of fuel “gauge” for the house. As more people realize the type of savings that they can accomplish individually and as a whole, the more common this type of device will become. The power bill of the future will not be a monthly surprise as it is now. Power meters will be used to budget power consumption. More and more of these devices are showing up in the tech news of news mediums. Like anything else, the more are designed, the more features they’ll have and the more efficiently and accurately they will be able to measure power consumed. Cars are sold with a miles per gallon indicator and maybe in the near future people will buy home appliances based on energy consumption. It might become very common to know how much a certain appliance will cost per month to operate. That would include every home electric home appliance, from TV’s to refrigerator.

This project was designed with the thought of helping people be able to measure the power usage of their home electrical appliances. Many meters in the market are able to measure and are designed specifically to measure the energy consumption of the house as a whole. But what good is that if you can’t pinpoint exactly what appliances are using the most power? Using this power meter, the consumer can know exactly how much it is costing them to use whatever appliance. This is definitely a more educated measurement as not only it is in a unit well known to everyone (dollars and cents) but is also specific to each device. The more clear and specific the information, the more useful it is and this is one of the goals of this project. To offer a means of giving energy consumption information to the common person in a matter they can easily understand and in a manner they can use to make changes in order to use less energy.

There is certainly room for improvement in this design. But it is surely a device that will be used in generations to come. In this era the world is awakening to the fact that energy is an incredibly valuable resource that needs to be spent wisely. The economic turn down and the increase in gas prices has made everyone aware that keeping track of their energy expenditure is of prime importance. Most likely the device here designed can be made smaller, more accurate and even easier to use. But it is a start. And it was designed in the hope to make energy consumption awareness a priority. Not only to save energy in the here and now but to also help keep these resources available to those that will be part of this world in the future.

APPENDICES

I. Permission to use materials

2.1.4 Figure 1 – Character charts of HD44780 compatible controller- provided by Newhaven Display International

Saurabh Bhatia to me, clagerstam, Gary

Hi Frank,
Feel free to use our images or contents of our datasheets for your senior design project.

Regards,
Saurabh Bhatia
Applications Engineer
Newhaven Display International, INC
www.newhavendisplay.com
2511 Technology Drive., Suite 101
Elgin, IL 60124
Phone: 847-844-8795

-----Original Message-----
From: Frank Ladolcetta [mailto:customerservice@newhavendisplay.com]
Sent: Monday, April 05, 2010 8:30 PM
To: nhtech@newhavendisplay.com
Subject: Message from Newhaven Display International, Inc.

From: Frank Ladolcetta
Email: sirjimboiii@gmail.com

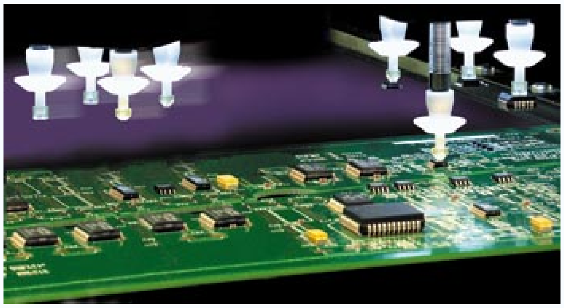
We are planning on using your NHD-0440AZ-FL-YBW 40x4 character LCD in our senior design project. I would like permission to use charts from the data sheets found in the PDF that is display on this site to show the quality characteristics of your device. In addition I would like to use the image of your device in this same Senior Design documentation paper for school and am seeking your approval to do so.

2.1.4 Figure 2 – Continued character charts of HD44780 compatible controller - provided by Newhaven Display International

2.1.4 Figure 3 – Address values of the HD44780 compatible controller – provided by Newhaven Display International

2.1.4 Figure 4 – Pin layouts of the HD44780 compatible controller – provided by Newhaven Display International

2.1.6 figure 1: Pick and Place diagram - printed with permission of John Pompea, Contact Systems under the creative commons license



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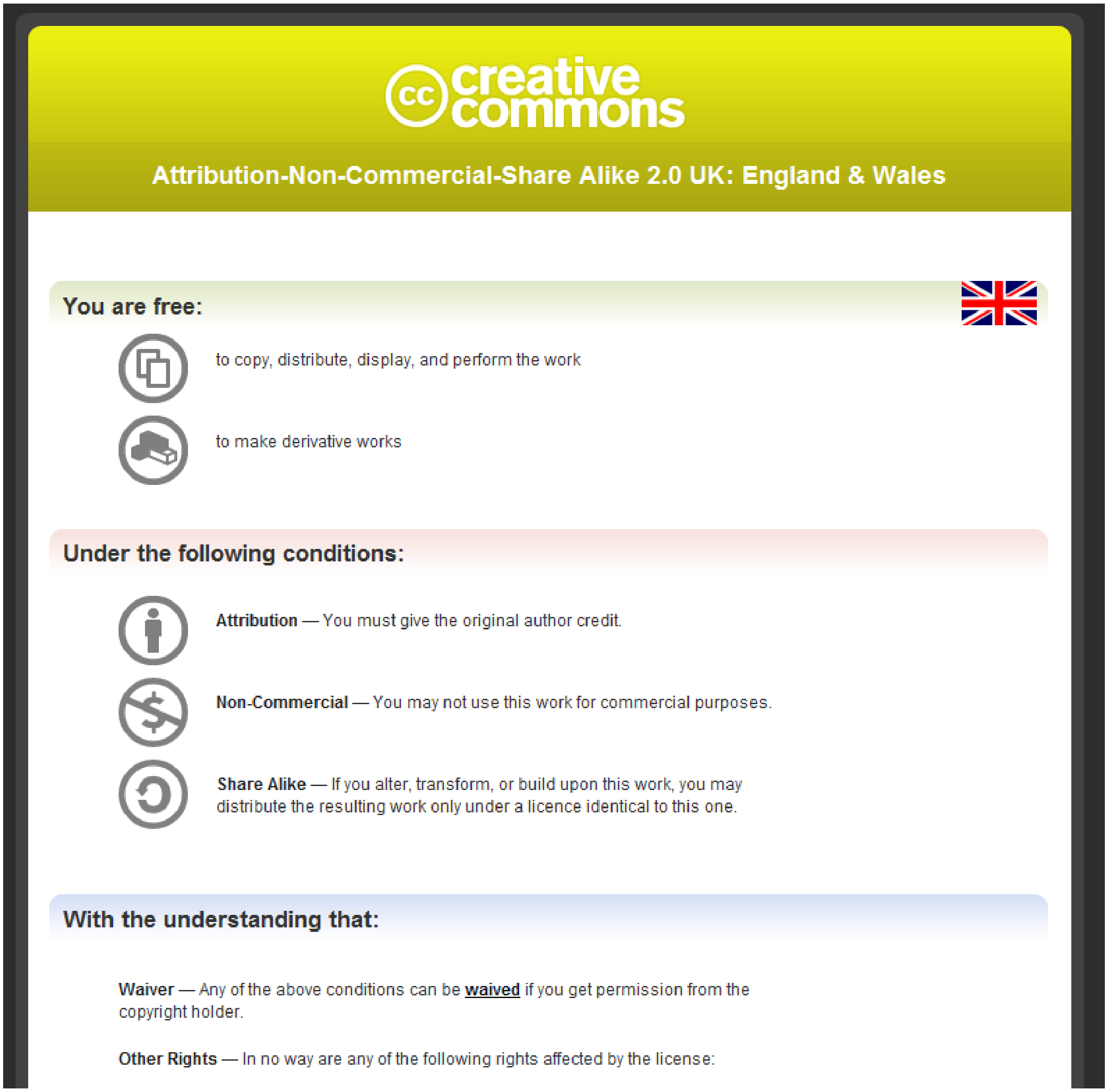
2.1.6 figure 2: Wave Soldering Diagram - printed with permission Martin Tarr, University of Bolton under the creative commons license



2.2.1 Figure 1: Example of off/on characteristics of TN LCD – printed with permission of GNU Free Documentation License, under the creative commons license

2.2.1 Figure 2: Example of 4 x 20 Character LCD - printed with permission of David Cook, Robot Room

David Cook
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3.1.1 Figure 1: Electrical Characteristics of NHD-0440AZ-FL-YBW – Printed with permission of Newhaven Display International.
3.1.1 Figure 2: Optical Characteristics of NHD-0440AZ-FL-YBW – Printed with permission of Newhaven Display International.
3.1.1 Figure 3: Timing Characteristics of NHD-0440AZ-FL-YBW – Printed with permission of Newhaven Display International.
3.3.1 Figure 1: LCD block diagram. – Handmade
3.3.5 Figure 1: Up/Down pushbutton block diagram. – Handmade
3.3.5 Figure 2: Power On/Off pushbutton block diagram. – Handmade
3.3.5 Figure 3: LED backlight block diagram. – Handmade
3.3.6 Figure 1: LED indicator display light block diagram. – Handmade
4.4 Figure 1: Relative Surface Mount technology lead sizes: Provided under the creative commons license

Permission emails:

Hello Manuel,

Sounds like a fun project. By all means feel free to use the image. Here's a couple others if needed.

Good luck on the project! Go Knights!

Jason

Jason Swanson
Director of Communications
TTI NA Power Tools Division
1428 Pearman Dairy Rd, Anderson, SC 29625
P 864.964.3363
jason.swanson@ttigroupna.com

From: noreply@ryobitools.com [mailto:noreply@ryobitools.com]
Sent: Thursday, April 15, 2010 9:50 AM
To: Swanson, Jason
Subject: Ryobi Media Contacts Message

Message from the Ryobi Media Contacts Form: Name: Manuel Rodriguez Email: mranziani@knights.ucf.edu Message: I am an electrical engineering student at the University of Central Florida. I am doing a senior design project which consists of building a power meter. I would like to ask for permission to use the image of the power usage meter found on your website for the written report. Thanks for your help, Manuel Rodriguez

2) Manuel,

Thank you for contacting ExpressPCB.

Please feel free to use materials from our website, as long as they will only be used for a student report.

Good luck with your project,

- Stan -

At 04:43 PM 4/12/2010, you wrote:
I am an electrical engineering student at the University of Central Florida. I am doing a senior design project which consists of building a power meter. I would like to ask for permission to use some of the information and images found on your website for the written report. Thanks for your help,

Manuel Rodriguez

Thank you for your interest in Honeywell Sensing & Control products.
Any item on our website can be copied or reproduced.
If you have any further questions, or need any other assistance, do not hesitate to contact us.

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FAX: 815-235-6545

E-Mail: info.sc@honeywell.com
Website: www.honeywell.com/sensing/

From: mranziani@knights.ucf.edu [mailto:mranziani@knights.ucf.edu]
Sent: Saturday, April 03, 2010 8:55 PM
To: Sc, Info
Subject: Inquiry to use images on website

I am an electrical engineering student at the University of Central Florida. I am doing a senior design project which consists of building a power meter. I would like to ask for permission to use the image of the Hall Effect Sensor (Micro Switch) found on your website for the written report. Thanks for your help,

Manuel Rodriguez

Thanks for asking.
You are welcome to use the information, as long as you acknowledge our student's work.

<=====================================>
Bruce R. Land, Sr. Lecturer, ECE
(607)254-4346; FAX:-4308; bruce.land@cornell.edu
W246 Mudd Hall, Cornell Univ, Ithaca, NY 14853
http://www.nbb.cornell.edu/neurobio/land/
<=====================================>

From: mranziani@knights.ucf.edu [mranziani@knights.ucf.edu]
Sent: Tuesday, March 30, 2010 10:28 PM
To: Bruce Land; Bruce Land
Subject: Request to use website information

Mr Land,

I'm an electrical engineering student at the University of Central Florida. I'm working on a senior design project and would like to ask for permission to use some of the information contained in the following document:

http://instruct1.cit.cornell.edu/courses/ee476/FinalProjects/s2008/cj72_xg37/cj72_xg37/index.html

We are also building a power meter and we could use that project as reference. Thanks for your help,

Manuel Rodriguez

Hi, Manuel,
You can use anything from HyperPhysics for a student project. Best wishes with the project.

Regards,
Rod Nave RodNave@gsu.edu
Department of Physics and Astronomy
Georgia State University
Atlanta, GA 30302-4106

On Mar 20, 2010, at 7:15 PM, <mranziani@knights.ucf.edu> <mranziani@knights.ucf.edu> wrote:

Mr Nave,

I'm an Electrical Engineering student at the university of Central Florida. I would like to request your permission to use images and information from the HyperPhysics website. Me and three other classmates are doing a senior design project on making a power measuring system for home use. In order to explain some of the concepts involved we are going to need some diagrams and after browsing your website we have come across a few diagrams and general information that we could use on our report. We would be very grateful if you let us the information on your website. Thanks for your consideration,

Manuel Rodriguez

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Massimo Banzi to me, team show details Apr 18

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> http://arduino.cc/mailman/listinfo/team_arduino.cc
>

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