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Power Smart:
Enabling IoT with Power-Line Communication

Group Number: 27

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Abstract

The demand for ability to control and monitor household and industrial appliances is continuing to grow. Many current communication schemes use Wi-Fi integrated systems for power management and control. However, Wi-Fi may not be available in every part of the system, and is not reliable at every point of large homes and industries. Another option is to use power-line communication as a resource for home automation. Power-line infrastructure is a resource available in every household but is not used for internal communication. The goal of this project is to design a platform for communication and management of any system that uses electrical power inside a home, using the existing power lines within it. Power Smart solution connects all appliances through the existing power-line infrastructure to a centralized controller hub. This solution consists of a module with integrated power-line protocol chips, a microcontroller, and a hub running an embedded Linux server. It requires the understanding of power electronic circuits, analog filters and embedded software. The main advantage of the Power Smart platform is that it will allow bidirectional communication within appliances and machines within houses and industries for controlling and energy monitoring purposes.

Acknowledgements

We would like to acknowledge two people for their help with our fourth year design project. Firstly, we’d like to thank Rasoul Keshavarzi-Valdani for his invaluable guidance as our project advisor. We would like to especially thank him for his help in validating our circuit board design, and the effort he made to meet with us on an almost weekly basis. The feedback he provided throughout the past two terms has helped us make this product a success.

We would also like to thank Trevor Smouter for his advice on safety. With his help, we ensured that our prototype was safe, and ensured that all hazardous risks that it posed were mitigated.

We hereby confirm that we have received no further help other than what is mentioned above in writing this report.

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1 High Level Description of Project

This project is the combination of power-line communication (PLC) systems and embedded software systems to facilitate smart home control and power monitoring applications.

1.1 Motivation

The motivation for creating a platform for a smart home through power line communication (PLC) came from the growth of the Internet of Things (IOT), and the need of a platform to centralize it. A recent article published by Business Insider predicts that the internet of things "...will be more than double the size of the smartphone, PC, tablet, connected car, and the wearable market combined." [1] For such a big upcoming market there must to be a platform to control these IOT devices to make communication through multiple systems seamless.

This platform operates over the power line as devices must be connected to a power source to operate in the first place. Therefore, there is no need for extra wireless modules to let devices communicate with one another. Also the infrastructure comes at no additional price as the power-line infrastructure we intend to user should already be built into every home. Power-line communication also comes with advantages over wireless systems, such as the ability to communicate reliably over long distances without having to worry about a building's structure.

Current PLC solutions include products that are available from Lumenpulse, which provides control over LEDs in homes or manufacturing plants with many different technology topologies to cover the user's needs [1]. Maxim integrated chips also provides a PLC chip to allow virtually any electronic device to use the power line as a data communications medium [2]. These solutions however do not include power management of the target device (i.e. it does not measure the power used by the appliance, or allow the user to access this information without intervention from a third party, such as a power supplier).

1.2 Project Objective

The purpose of this project is to provide a centralized communication and power monitoring platform for household appliances through already built power-line infrastructure.

1.3 Block Diagram

There are two major system blocks in this power-line communication platform over mains electricity power lines in houses: the Hub and the Node, as shown in Figure 1. The Hub is made up of two PCBs, the power-line communication PCB (PLC PCB) and the BeagleBone Black board [17]. The Node also consists of 2 PCBs - the first being the PLC PCB and second being the power monitoring (PM) PCB. Each block marked with (D) is to be designed, and blocks marked with (ND) are not designed as part of this project.

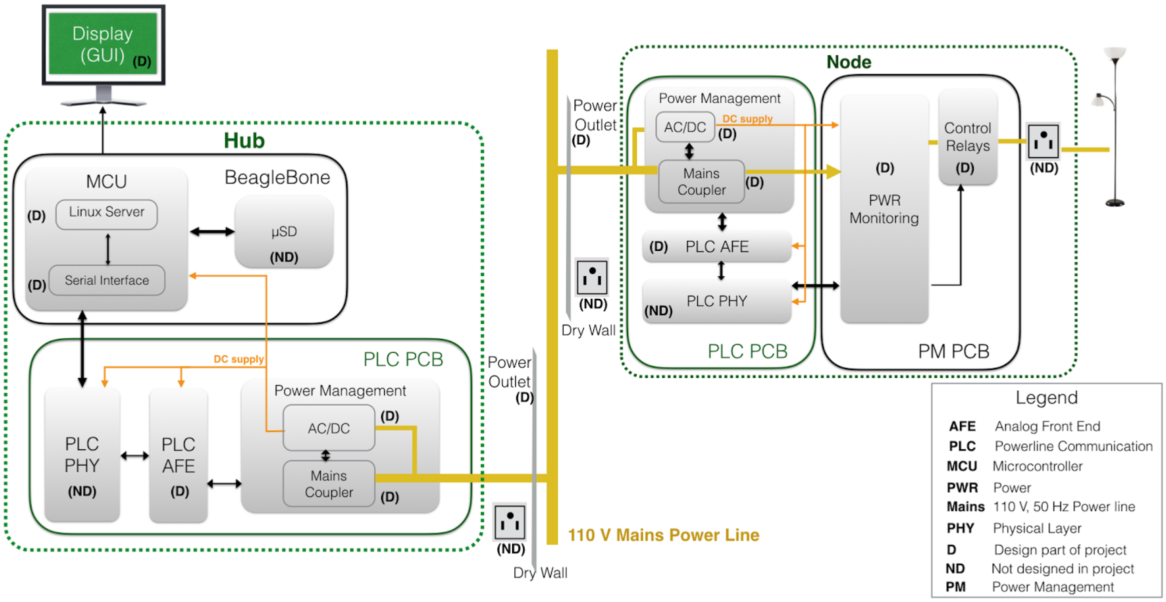

Figure 1. Power Smart block diagram

The block is made up of 3 main sections, user interface (GUI), the Hub, and the Node. The user interface is a stand alone system designed to make a GUI that gives access to controlling power sockets, as well as give power management readings, such as voltage, current, and power usage of a particular socket. As mentioned above, the Hub has 2 PCBs that make five subsystems, two of which are broken down into smaller subsystems. Similarly, the Node has six subsystems, two of which are smaller subsystems found in the power management subsystem and in the microcontroller. The PLC PCB is a common PCB designed to be programmed for any intended use, as the Hub or the Node.

The Hub is described to be the control center of the entire PLC system. This is where each power outlet is controlled and has their measurements managed using a database containing all information about a particular socket This includes power used by the socket and which socket is being used. The PLC PCB holds the CYPRESS chip [4], which is the chip that is used to facilitate power-line communication, and is made up of two subsystems. The AC/DC conversion and MAINS coupler, both designed in the scope of this project. Both are used as an interface to connect and help the Hub communicate through the 120 V mains power line that is found at home or in a factory. This subsystem then provides DC power to the microcontroller, the PLC physical layer (PHY) as well as the PLC analog front end (AFE). The microcontroller here is the BeagleBone Black [17] that is connected to the PLC PCB in a modular way. It uses a Linux server with a designed serial interface. The interface is then used to control transmission of control data to the PLC chip found in the Node, through the PLC PHY and PLC AFE. All data sent to the microcontroller is stored on a microSD card which the user can access through a web page. The PLC PHY and AFE is considered as gates through which any signals sent or received is converted to a form that is read by the transceiver as it is sent along the MAINS line. The PLC AFE is the analog circuit that is used to convert signals from the mains line to be used by the microcontroller, and vice versa.

The power outlet utilizes a drywall fixture intended hold the power-line infrastructure that is used to represent the entire power-line infrastructure of a house. The dry-wall holds the circuitry of the Controller Hub and the transceiver, and is connected to the mains of the house.

The Node, like the Hub, has a power management system on the PLC PCB that contains two subsystems: AC/DC conversion and MAINS coupler. This subsystem would have the same features as the one found on the Hub. However, unlike the Hub, a PM card is modularly connected to the PLC PCB. Demonstrating that, if programmed correctly, the PLC PCB can be used to either be the Hub or the Node depending what is needed, since it is the common board between the two systems. Currently, multiple Nodes can be connected to one Hub. The PM card is designed to record voltage and current readings used by the power socket in use. The control relays are chosen and controlled by microcontroller in the Hub that is used to turn on or off the chosen socket. In this case the microcontroller is the STMP001 [18]. The microcontroller gets control information from the mains through the PLC PHY and PLC AFE that converts the signals sent from the power management system. The microcontroller can also send information on the instantaneous status of the relays and power monitoring data to the Hub. It utilizes the PLC PHY and AFE as described above.

Finally, the power sockets are designed so that each one is connected to a relay to allow for basic on/off control of the socket. This is connected to the power monitoring system. Thus, this overall system is able to get power measurements of each power socket while allowing for basic control which is done through the 120 V mains power-line infrastructure that is already built into the house.

2 Project Specification

2.1 Functional Specification

2.1.1 Hardware Specification

Table 1. Hardware specifications of Energy Monitoring and Control over Power-line platform

#	Specification	Classification	Description
1	Communication capability over mains power line	Essential	The hub and node should be capable to communicate serially through the 50-60 Hz 120 V mains power line.
2	Power Monitoring	Essential	Node should be able to monitor the power, voltage, current, and power factor of two channels continuously with less than 2% error. It should be able to transfer monitored data back to the hub.
3	Appliance Control	Essential	Node should be able to receive control bits from the hub and decide [done by user] whether the connected appliance should be turned ON or Off.
4	Each power outlet should have an LED indicator	Non-essential	LED indicator on outlet socket allows customer to show that the socket is powered on and has control capability.
5	Not to dissipate excessive amount of heat	Essential	Power consumption of the hub and node should not go above 5 W (each).
6	Hub should support at least 2 nodes	Essential	At least 2 nodes should be able to be controlled by the hub. This can be later expanded.
7	Programmable PLC chip	Essential	PLC chip should be able to work on both the Hub and the Nodes, and should be programmed accordingly.
8	One centralized hub	Essential	One centralized hub that would have control of the nodes that are attached. Current system should only allow one central hub on the network.

2.1.2 Software Specification

Table 2. Software specifications of Energy Monitoring and Control over Power-line platform

#	Specification	Classification	Description
1	User Interface	Essential	Web GUI allows user to view and control connected devices through a web page that must be accessible from a web browser on the same local network. Web UI must provide controls to turn ON and OFF devices and provide real-time power analysis.
2	Device Awareness	Non-Essential	When a device is plugged into the wall it must automatically communicate with the hub and tell the hub what kind of device it is. Devices should be “plug and play”, and each device should have its own software space (database + controls app) on the hub.
3	Data Logging	Essential	Power Monitoring devices on the node must be able to transmit data to the hub and hub should be storing the monitored data associated with particular node to the SD card so that it can be viewed by a user at a later time
4	Control Scheduling	Essential	Must be able to schedule control operations a repeated points in time for automated control
5	Device uniqueness	Essential	Devices on the power-line network must be uniquely addressed so that they can be controlled and viewed individually
6	Real-time updates	Essential	User interface must be able to provide updates and alerts to users through the UI with a delay less than 10 s, including graphs showing new sensor readings and alerts when new devices are connected to the hub.
7	Device control groupings	Non-essential	User must have the ability to group common devices together so that a collection of devices can be control through a single control
8	Devices classification and Identification	Non-essential	Users must be able to upload floor plans and identify where their different devices are in reference to the floor plan.
9	Authentication	Non-essential	When a device is connected to the power line, if it is it's first time connecting the user must grant permission to this device through the hub

2.2 Non Functional Specifications

Table 3. Non-functional specifications of Energy Monitoring and Control over Power-line platform

#	Specification	Essential	Description
1	Power sockets should be North American standard	Yes	Socket should fit North American standard appliances
2	Cost for the hub should be at most $40	No	Cost of the hub should be affordable to the general public.
3	Cost for PLC interface should be at most $25	No	Cost should be minimized due to the large number of sockets needed to be purchased in a home
4	Password Protective GUI	Yes	PLC controller Hub GUI must be password protective.

3 Detailed Design

3.1 PLC Controller HUB Design

The PLC Hub Controller consists of PLC PCB capability and the BeagleBone [17] microcontroller board**.**

3.1.1 Hardware Design

The hardware design of the PLC controller contains the following subsystems: PLC PHY, PLC AFE and interface with the BeagleBone board.

3.1.1.1 PLC Analog-Front-End Filter, Amplifier and Coupling Circuit

To fulfill our prototype specification of the communication over the power line, we picked Cypress CY8CPLC20 PLC chip. This PLC chip has its dedicated PHY layer and a Frequency shift keying (FSK) modulator block which establishes its PLC capability.

See Figure 2 for the FSK modulation concept. The PLC Chip PHY layer serializes the digital data and feeds it to the FSK modulator. It uses 132.55 kHz as a carrier frequency and shifts the frequency depending on the logic level 0 or 1 around the carrier, shown in Figure 2. The FSK modulator has an internal Phase Locked loop (PLL) running at 23.986 MHz which multiplies or divides the local clock oscillator frequency (32.768 kHz) by a definite number to get the shift of 132.55 kHz + 1.75 kHz [4]. For logic 0 or 132.55 kHz + 1.75 kHz for logic 1, respectively [4]. These are the square wave frequencies that are forwarded to (in transmitter case) or received from (in receiver case) the power-line coupling circuitry to couple signal into or decouple from the power-line channel, respectively.

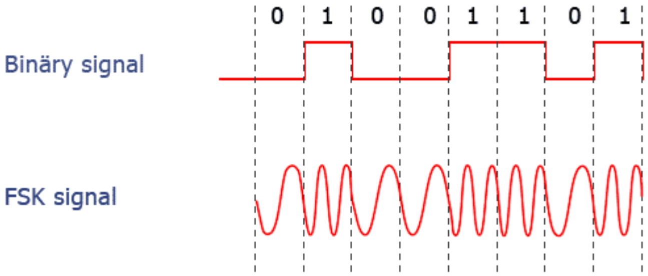

Figure 2. FSK (Frequency Shift Keying) Modulation Concept [15]

3.1.1.2 Transmitter Design

There are two key components to the Transmitter (TX) block of the AFE: Filter and the Power Amplifier as shown in Figure [3]

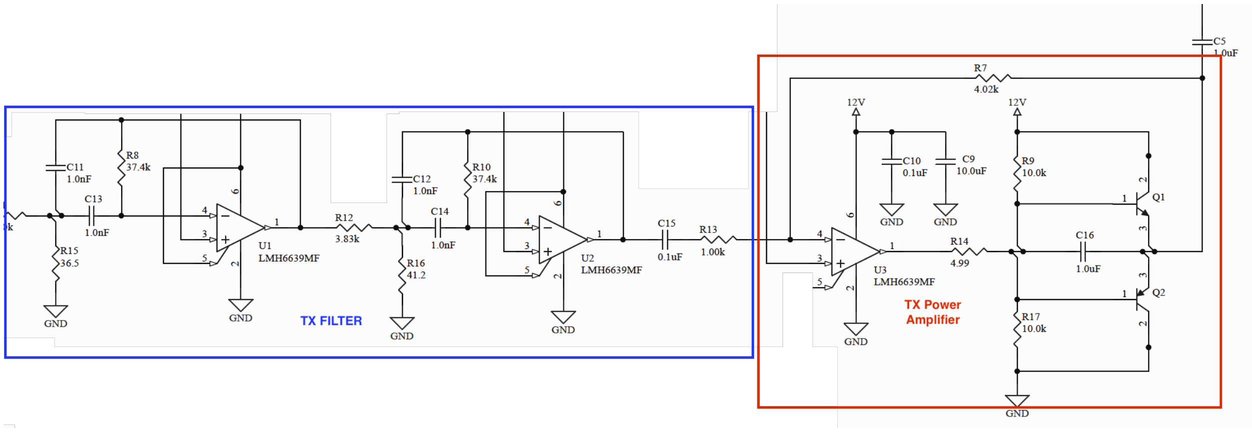

Figure 3. Transmitter AFE design with TX filter and power amplifier [3]

The Filter was designed according to the recommended active fourth order chebyshev filter in PLC chip datasheet [3] and also shown in the Figure 4**.** The chebyshev filter is a better choice because it has faster roll off but has a bandpass ripple. Since this PLC chip deals with FSK modulation, the frequency of the modulated data matters far more than the amplitude of the signal. The bandpass ripple in chebyshev having uneven amplitude of the transmitted signal isn't any important to the chip and thus we confirmed that chebyshev filter is the most appropriate filter to go for. The sharp-roll off at the -3dB frequencies are important to filter out any other noisy and just filter-in the carrier and the modulated signal.

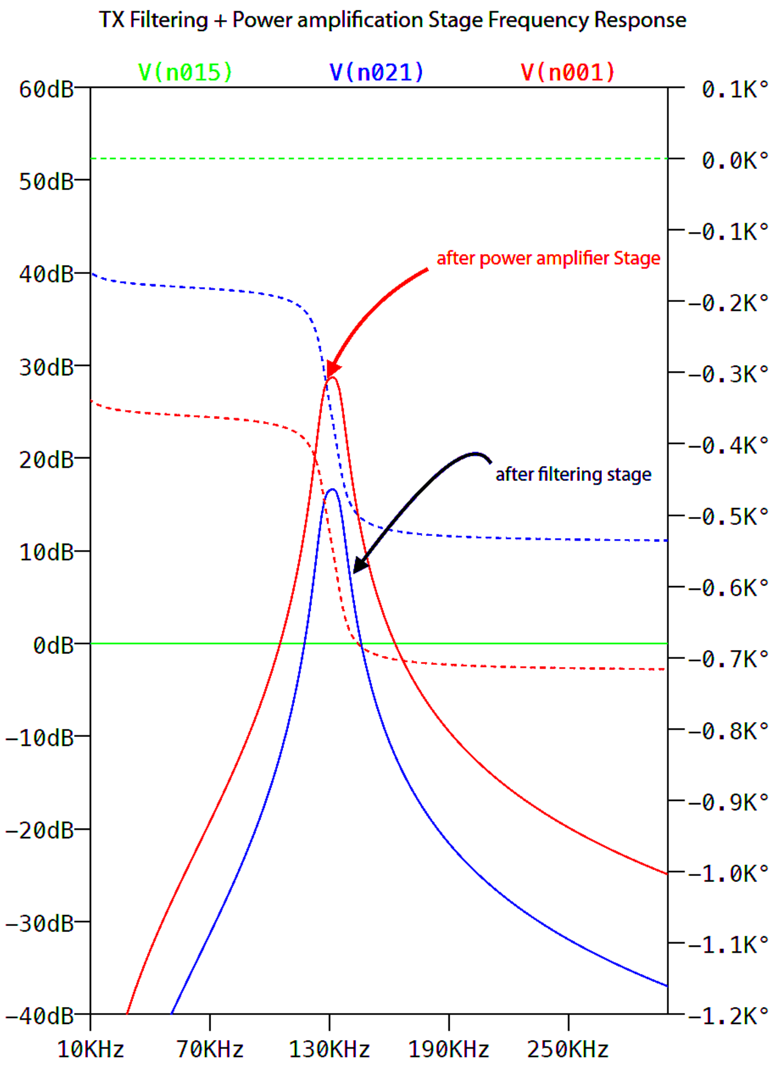

Figure 4. Transmitted signal from the PLC and the RX Filtering response of the LTSpice simulated AFE

The fourth order chebyshev is implemented by using LMH6639MF 190 MHz op-amp [16] and is defined by the first two stages of the circuit shown in in Figure 3**.** Since the center frequency for this PLC communication remains constant, the PLC manufacturer, Cypress, also recommended precise capacitor values and the resistors values for this chebyshev filter to comply with their chip. As this filter is one of the key component in our prototype, the simulation of the Figure 3 is shown in Figure 4 where precise amplifier and BJT spice model provided by manufacturer were used for simulation to give us more realistic data.

As shown in Figure 4, the filter stages gave around 17 dB of gain. Additionally, the third amplification stage was added using the same op-amp chip with simple inverting resistive feedback, and two complementary npn and pnp BJTs were used, which gave additional of 11 dB of gain.

3.1.1.3 Receiver Design

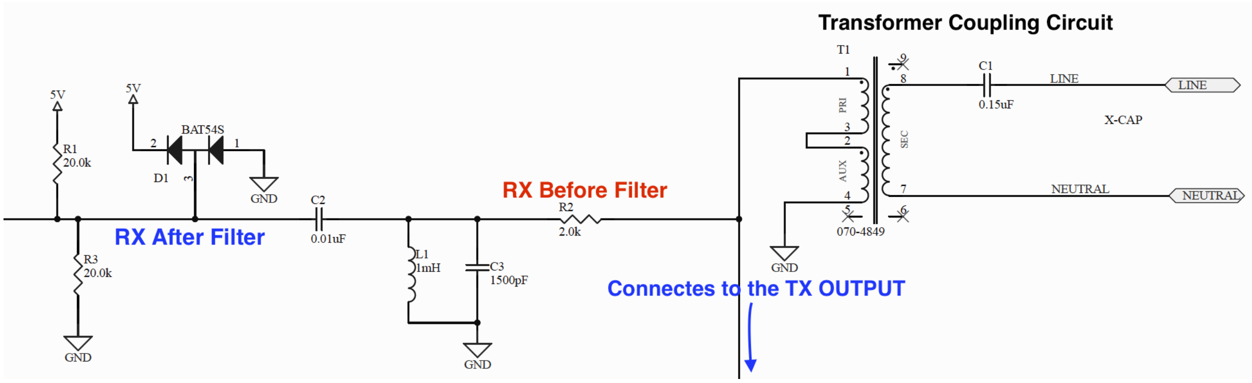

Figure 5. RX AFE and Transformer Coupling circuit

The transformer coupling circuit as shown in Figure 5 is used to couple in the transmitter signal into the power line or decouple the receiving signal from the power line. The C1 capacitor isolates the high voltage low frequency (60-1 kHz) signals from the low voltage circuits and allows only the high frequency, modulated PLC signals to pass through.

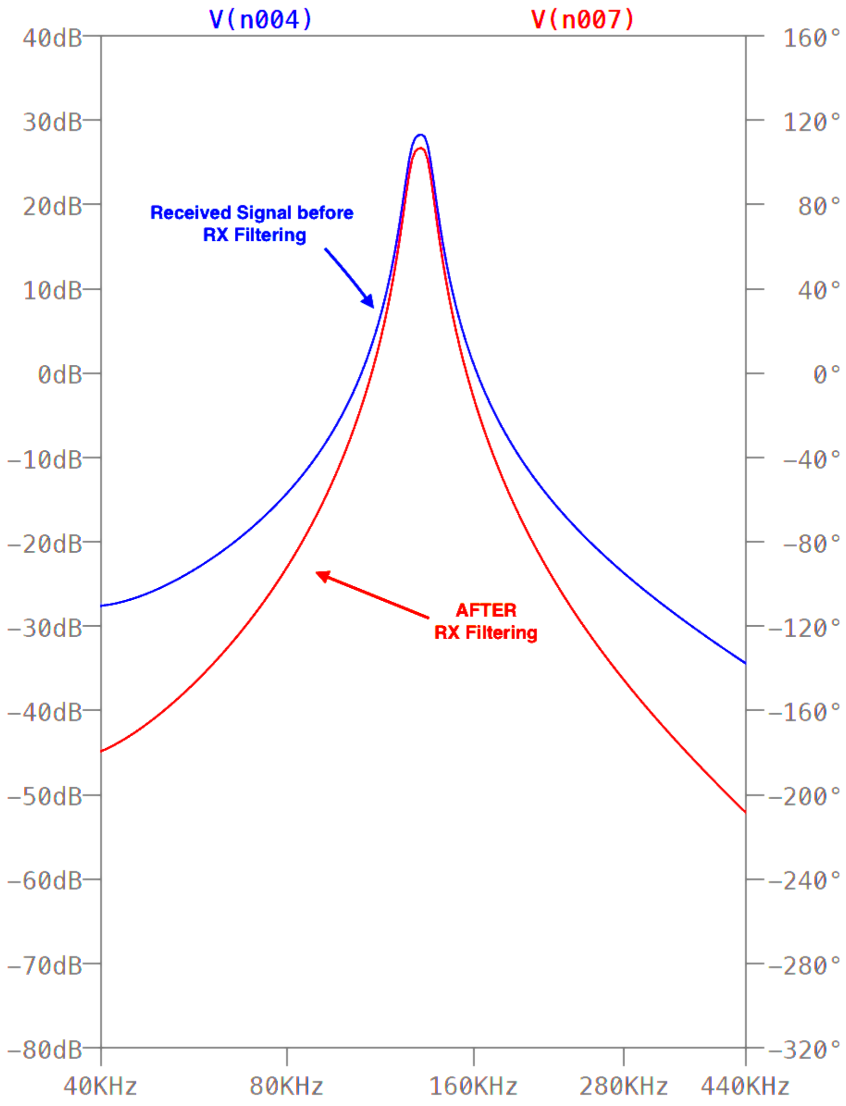

Figure 6. Received signal and the RX Filtering response of the LTSpice simulated AFE

For receiving the modulated signal, the RX passive band-pass filtering circuit filters 15 kHz bandwidth around the center frequency of 133.55kHz as shown in simulated RX circuit in Figure 6. This circuit helps feed the signal of desired spectrum from 125 kHz to 140 kHz to the PLC PHY chip. The PLC PHY chip performs the FSK demodulation to output the DC logic level 1 and 0 which are then passed through the low pass filter to support the 2400 bit rate. This data is then fed into the serial I/O buffer to be consumed by the microcontroller through a serial interface. Note: This baud rate refers to the actual data rate and doesn't include any protocol related overhead (i.e. header bits, error correction bits, address bits etc.) that are handled by the PLC chip.

3.1.2 Power Supply Design

3.1.2.1 Power budget and the Power supply selection:

Providing a power efficient solution is one of the strong criteria for an excellent communication platform. Our goal is to operate whole PLC controller Hub system under 5 W of power. 5W of power should be able to supply the PLC PCB as well as the connected BeagleBone board under full loading conditions. The BeagleBone Board power consumption under full loading condition is approximately 2 W [17]. Therefore, the rest of the PLC PCB must operate on 3 W of power.

Table 4. PLC chip power consumption calculation

PLC Chip	**VDD (V)**	**Current (mA)**
CPU Current	5	9.384
Digital Block Current	5	8.714
GPIO Clk	5	31.052
Analog Blocks	5	17.008
Total Current	5	97.692
Total Power	V x I = 5 x 97.692 = 512.8 mW	

From the help of the power consumption application note specified by the Cypress semiconductor for their PLC chip, the power consumption of the overall PLC chip under full loading condition was calculated as 512.8 mW as shown in Table 4 [18].

Table 5. Power budget for Hub controller under full loading condition

	Voltage (V)	**Current (mA)**	**Power (mW)**
PLC chip [3]	5	97.69	513
TX Amplifier	12 V	16	200
BeagleBone	5	400	2000
Total Requirement		566	2713
Conversion Loss from 12VDC to 5 VDC		1 - 5V/12V = 59% loss	2713*0.53 = 1437
Conversion Loss from 120 AC to 12 VDC		15% Loss **[11]**	(2713+1437)x0.15 = 622
Total Consumption		**272 mA ~ 300 mA**	**4808**

The PLC Hub controller requires 120V AC to be converted into 12 V and 5 V. However,
before making any decision on purchasing the power supply unit, we performed the power budget analysis for our Hub controller system shown in Table 4 and Table 5. Also, the power consumption calculation and the power supply selection was a simultaneous process as power budget must also include the power consumption due to the inefficiency of the power supply unit.

Power Supply Selection:
The switching power supply being one of the most efficient power supply was the prime choice for our power supply selection. After doing the Power Budget analysis of the minimum power supply requirement, our Hub controller system required total of about 4.8 W as shown in the Table 5; which is within our specification of 5 W. Finally, after considering the shipping delays, cost ($30), conversion efficiency and required board space, we ended up selecting the switching power TUHS-12 AC-DC converter from Cosel [11] which is C-UL and ROHS certified part. This selected power supply is able to supply up to 0.9 A at 12 V = 10.8 W of power which is well above our required power of 3.2 W specified in Table 5. We chose a 120 AC to 12 V DC power supply because 12 V is PLC PCB's highest voltage rail which is only used for the AFE. The rest of the PLC board operates on 5 V supply which can be converted from 12V regulated DC by a simple linear regulator LD1117 [12].

Since we are using 12 V to 5 V linear regulator which will have the efficiency of 5 V / 12 V = 41.67% So, there would be loss of 59% of the power during this conversion. It is not very effective but purchasing another switching power supply of 5V would cost us more money and more space on the board. Thus, using one AC-DC converter and one linear regulator was a good choice for achieving 12V and 5 V rail for the required loading conditions.

3.1.2.2 Power Supply Circuit and Electrical Safety Analysis

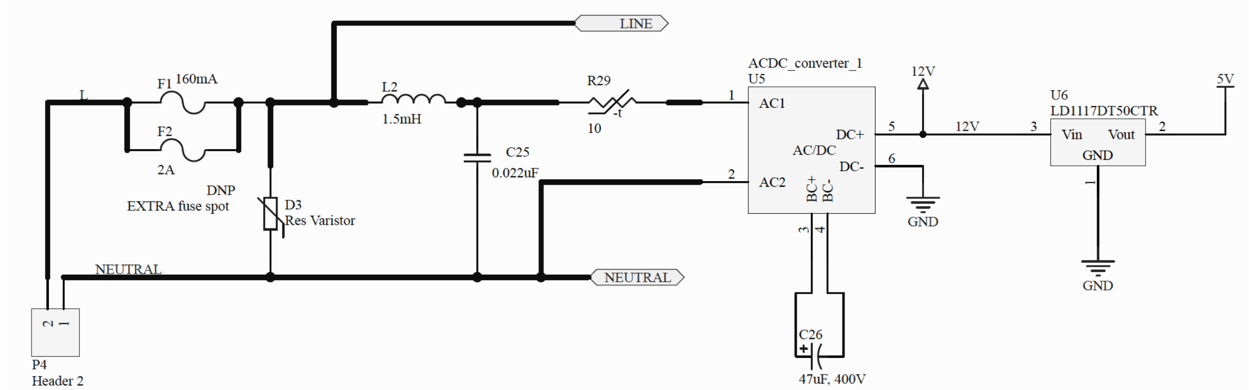

Figure 7. Power Supply (AC/DC) Circuit Design

The PLC PCB has the 120 V mains input terminals for the line and neutral wires to be connected to the board. However, before the line and neutral wires are connected to the AC/DC converter, there is significant attention given to the safety. First the appropriately rated fuse is required. Since our AC/DC converter only takes 100 mA at maximum according to the TUHS12 Datasheet, putting 160 mA rated fuse is a safe choice to go to. Also D3, a Varistor is used to suppress any high voltage spikes coming from the mains line and damaging the expensive circuit components. After the fuse, the Line could be directly connected to the coupling transformer [13] for the AFE as shown in the PLC AFE Figure 7. The L2 was required for two main reasons: To block the PLC signals from getting into the AC/DC converter and block harmonics from the AC/DC converter going into the power line, corrupting the PLC signals.

Also, due to the usage of large smoothing capacitors, there is a high chance of high inrush current coming into the AC/DC converter and therefore, the Negative Temperature Coefficient Resistor (NTC) designated as R29 in Figure 7 was used to block inrush current. In other words, when there is no current flowing through the NTC initially, it inhibits much higher resistance which helps block instantaneous inrush currents. Also, its resistance is low when there is a steady current flowing through it. The C26, 47 uF 400V rated capacitor was recommended by the Cosel for smoothing the output of the internal rectifier used in their AC/DC converter module.

3.1.3 Microcontroller to PLC PCB Communication

To communicate between the BeagleBone Black microcontroller and the selected Cypress PLC PHY chip the I2C bus interface is used which is available on each of the units. This interface is important as it is required to achieve the specification of sending and receiving data over the power line. Using this bus, we can transmit data at a rate of up to 400 kbits/s [3], which is much faster than the speed at which the PLC chip can send or receive data, which is 2.4 kbits/s, so this bus will not act as a bottleneck [4]. An additional wire was also used as an interrupt input to the microcontroller so that the PLC PHY chip could notify the controller when a new packet was received.

Level Shifting

One issue that arose when designing the correction between the microcontrollers and the Cypress PLC chip was that the PLC chip operated the bus at 5 V, whereas the two microcontrollers operated the bus at a 3 V. This means a logic level converter must be designed to bridge the two sides of the connection. The reference design in Figure 8 is adapted into the PCB design of the project to create this bridge using an N-Channel logic level enhancement mode field effect transistor.

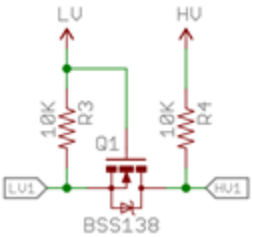

Figure 8. Design for I2C bridge between a 5 V and 3 V I2C bus [4]

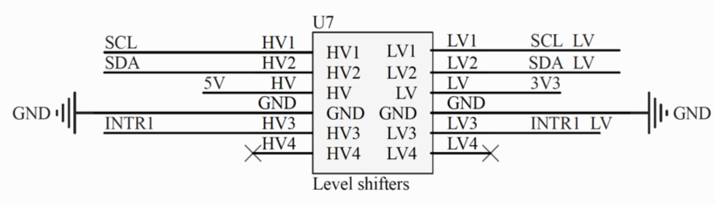

Figure 9. Design for I2C bridge between a 5 V and 3 V I2C bus [4]

The reference design in Figure 9 is adapted into the PCB design of the project to create this bridge using an N-Channel logic level enhancement mode field effect transistor.

3.1.4 PCB Layout

The PCB layout of low voltage digital signals (3V - 5V) and accurate analog signals with high voltage power signals on the same PCB requires conscious design strategies and component placement. The PCB was designed to meet the Institute for Printed Circuits (IPC) Design rule check standards [14]. The PCB layout was performed in Altium software and fabricated through Seeedstudio fab-house in china.

Figure 10 shows the 4-layer PCB layout of the PLC PCB, both front and back view. The PCB layout for the PLC PCB required a lot effort to do appropriate component placements to avoid unnecessary coupling, ground loops etc. The PLC PCB has first and last layer consist of signals whereas second and third layer consist of GND and VDD rails, respectively. The third layer has two VDD rails, 5V and 12 V. The GND layer has AGND and DGND for AFE and PLC chip, respectively to avoid digital harmonics getting coupled into the AFE analog signals. Electrically AGND and DGND are the same node but the there is a physical polygon slice between AGND and DGND to ensure that return path of the current from Analog circuitry and digital circuitry is routed without interfering into each other. Moreover, all the Signal, GND and VDD layers were isolated from the high-power circuit components to avoid electromagnetic interference noise coupling into low voltage sensitive circuits.

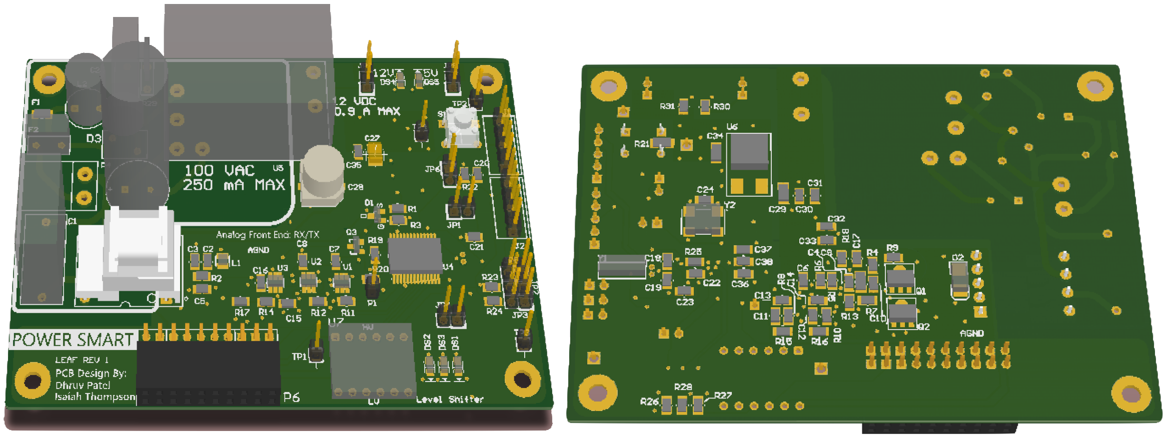

Figure 10. PLC PCB (10 cm x 7 cm x 2.5 cm)

3.1.5 Software Design

3.1.5.1 PLC PHY

This is the core of the system where it modulates and demodulates the power line communication signal. Most of the PHY functionality is provided by the selected Cypress CY8C20 PLC Chip [3]. The physical layer (PHY) is described as the physical coding sublayer where the chip encodes and decodes the data that is transmitted and received. The purpose of the encoding is to make it easier for the receiver to recover the signal. The physical layer has three main integrated sub-blocks: Transmit Filter, Transmit Amplifier and Receive Filter. The transmission signal from the chip is filtered and amplified through the integrated mixed-signal blocks inside the chip itself so that the signal is ready to be transmitted under the PLC protocol specifications defined by the PLC chip.

The selected PLC chip can send 2.4 kbps over the power-line channel. However, from the datasheet of the PLC chip, we know that for each data packet we send of size 0 to 31 bytes, there are 7 bytes of header and footer information that must be sent first [3]. Each power monitoring Node on the network will send data packets of size 3 bytes (1 byte for voltage reading, 1 byte for current reading, 1 byte for power factor) amounting to a total of 10 bytes sent every second. To ensure reliable transmission and delivery, acknowledgements are used which are sent in reply to every message and are a total of 7 bytes long. The total theoretical throughput of the system would then be:

$$(2400\ bits/s)/((10\ +\ 7)\ bytes/message\ *\ 8\ bits/byte) = 17\ messages/second$$

So the Hub could theoretically receive a total of 17 power measurements a second or receive updates from 17 different power monitoring devices every second on the network which is well in the range of our specifications.

After constructing the prototype of the system with the development boards, the throughput was recorded for varying packet lengths with returned acknowledgements as seen in Figure 12. It was found that after taking into account the delays of writing the data to buffers and the time it took for the Hub to pick up the data and return an acknowledgement, the throughput was significantly less than expected. However, given that the payload length for the power measurements as described above are only 3 bytes, the system is still able to send three power measurements per second which still fulfills the requirements of our system by providing real-time updates of power readings over the power line. From these results it was also found that increasing the payload length did not have a significant effect on the throughput so it is more efficient to fit as much information as possible within a single packet than to send many individual packets.

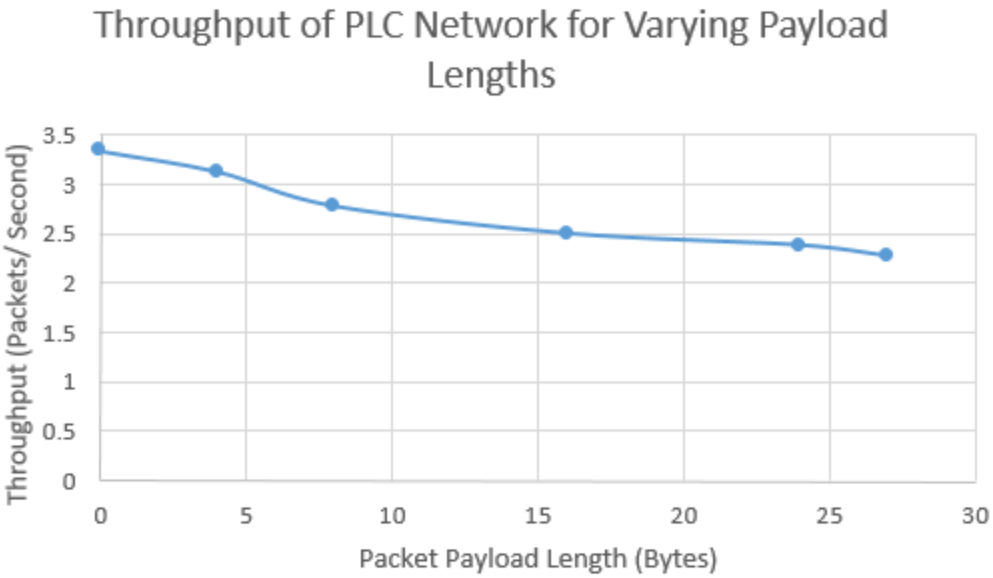

Figure 11. Actual Throughput of PLC Prototype for Varying Packet Payload Lengths with Acknowledgements

3.1.6 PLC Hub Software Architecture

There are three crucial features that the software architecture and design of the PLC controller Hub must have to satisfy our specifications:

1. A software driver to send and receive messages through the I2C interface with the Cypress PLC chip.
2. A central server which must receive process and route messages from both the PLC driver and the web GUI to controls.
3. A database which stores sensor data, user data and information about the devices connected to the Hub.

Figure 11 shows an overview of the different software components and technologies and how they are used to accomplish the required features. The software driver to send and receive messages through the I2C interface is a C++ application that runs on a separate thread on the server to asynchronously handle PLC messages. The second feature is accomplished using the Express.js framework for Node.js, and was chosen as the desired server framework to structure the Model View Controller (MVC) application and define the HTTP and WebSocket interfaces. To achieve the third feature, SQLite is chosen as the technology used to store and retrieve sensor and user data.

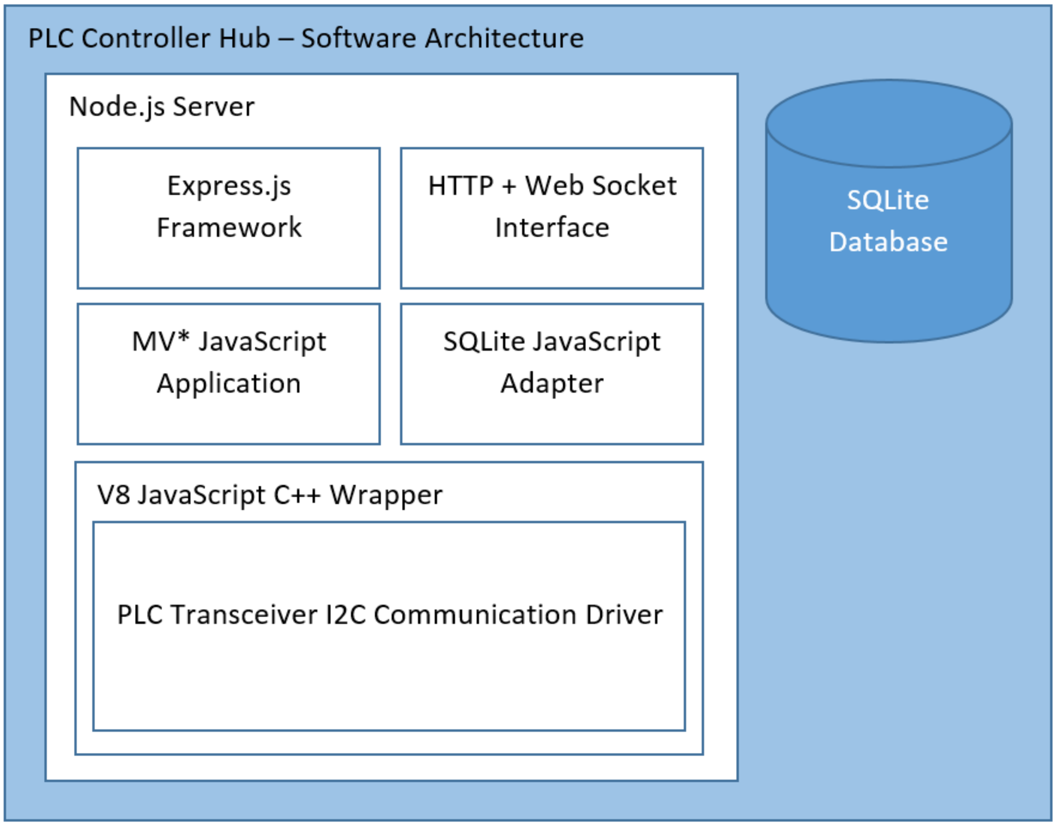

Figure 12. Software component architecture for the PLC Controller Hub

3.1.6.1 Application Server

Express.js is chosen as the Node.js server framework to build the PLC Controller Hub software application for a number of reasons. Many members of the team has had experience with using the framework in the past, it is one of the most contributed to, supported and tested frameworks for Node.js, and it will allow us to achieve all of the specifications for the project. This minimizes the risks associated with the building and designing the software for the hub.

The application will be able to satisfy the user interface specification since the Express.js framework allows the application to serve web pages and send live updates using WebSockets. In a browser a user can connect to the server running on the hub and the application will deliver a web page through HTTP request. The application will map different URLs specified by a user to different tools in the application allowing the user to view device data and issue control commands to those devices.

The application will also be able to accomplish real-time updates, device awareness and data logging requirements since the application server follows the “always on” paradigm. In the application, an interrupt service routine will be defined which will be called whenever the I2C Cypress chip driver receives a message on the power-line. This allows us to process and forward messages to connected web-pages through the use of WebSockets and call a procedure to store received data in the database to satisfy both of these specifications.

To satisfy the control scheduling specification two alternatives are considered to solve this problem. The first solution involves using a separate timer for each scheduled command by the user so that that command executes at a defined point in the future. The second solution involves using a single timer that periodically checks the database for a schedule command and issues the command if the current time matched the command's time. A weighted decision matrix that compares the two options can be seen in Table 7 with weights given in Table 8. Using a timer for each scheduled event is the best option. Although it requires additional processing power and more memory than the alternate solution, the expected number of schedule events for this project is low so that the impact will not be as high and a great deal of time is saved on development complexities.

Table 6. Weights for event scheduling process

Ease of Implementation	Processing Requirements	Memory Requirements
50%	25%	25%

Table 7. Weighted decision matrix for event scheduling process

Option	Performance	Comprehensiveness	Ease of Use	Total
Timer for each scheduled event	8	4	5	6.25
Single Timer and database of scheduled commands	3	5	8	4.75

3.1.6.2 Embedded data storage solution

The choice of SQLite as the chosen database technology for the hub is based on a number of performance factors as it has to run on a BeagleBone Black (BBB) development board which has a 1 GHz processor and 512MB of RAM. SQLite is able to operate without running its own server which decreases the amount of memory and processing requirements. It also supports the majority of SQL statements and features, increasing the ease of development required for storing, structuring and retrieving data.

3.1.6.3 Software driver for communication with the Cypress PLC chip

The hub application communicates with the Cypress PLC chip through an I2C interface. To orchestrate and schedule this communication, a C++ program is built with APIs to send, receive, and call an ISR when messages are sent and received over the power line. A separate C++ program is written instead of using the Node.js server to ensure performance, facilitate the interface between the application and the Linux I2C drivers, and to reduce development time by writing a portable driver that can be used on both the BBB and the Teensy microcontroller used in the end devices that connect to the hub. To interface between the Node.js application server, the C++ driver is wrapped in a V8 JavaScript engine C++ wrapper which allows the C++ application functions to be called from JavaScript. This allows user queries on the server to send messages over the power line. The C++ driver accepts function pointers to register interrupt service routines so that the Node.js server can be notified when a new message has been received by the driver. To ensure that messages are not missed and that they are received in a timely manner, the C++ driver runs as a separate thread within the server process so that it can process and send messages while the server is storing data and responding to user queries.

3.1.7 Communication Protocol Design

The design of the communication protocol was essential to this project as it would govern how the Hub which runs the web server and application is able to identify and communicate with different nodes on the power line network. The final design for the communication protocol can be seen in Figure 14. Whenever a new fruit node connects to the power line it will immediately contact the trunk to request to connect to the network. The Trunk will then respond to the Fruit, assigning it a logical address that it will use for all future requests. The assignment of logical addresses was done in place of using the unique= physical addresses of each Fruit, since it is a smaller address and will make the messages sent over the power line smaller, improving throughput and decreasing the probability of error. The protocol also allows for the hub to send control packets to the nodes after the connection setup has been completed, thereby fulfilling that required specification.

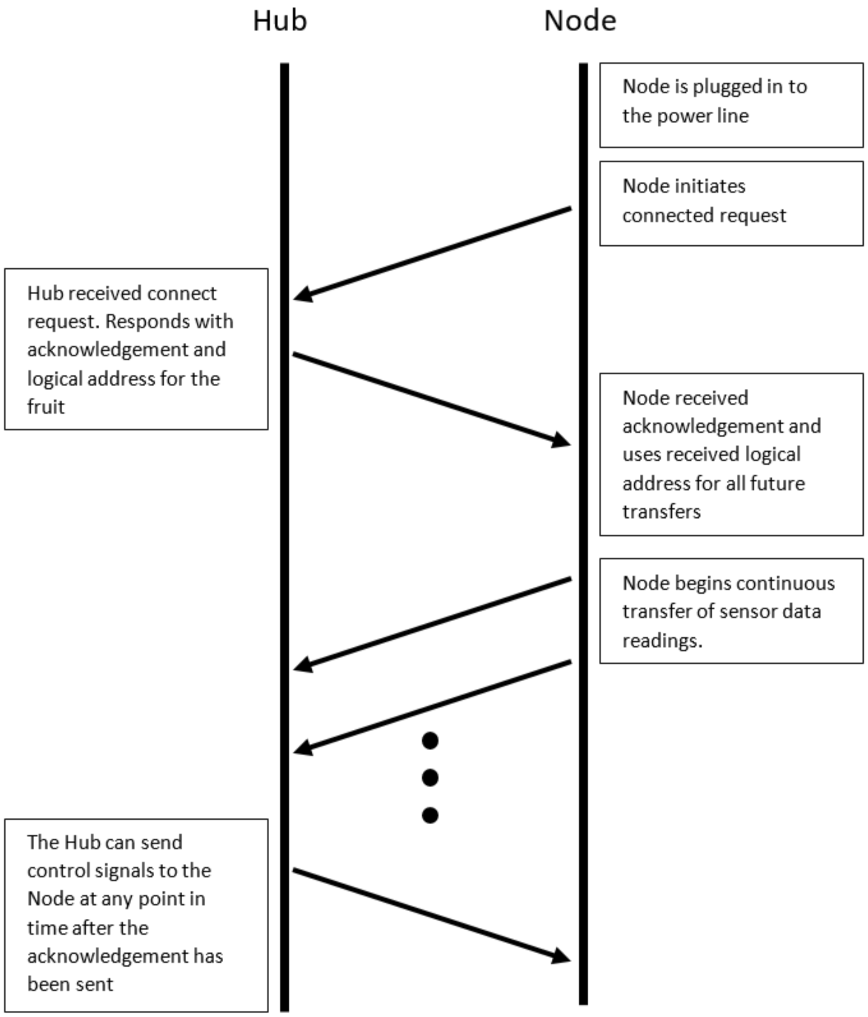

Figure 13. Fruit to trunk connection and communication protocol

3.2 PLC Node

3.2.1 Hardware Design of PLC NODE:

3.2.1.1 TX Filter:

Please refer it to section 3.1.1.2 above.

3.2.1.2 RX Filter:

Please refer it to section 3.1.1.3 above.

3.2.1.3 Power budget and the Power supply selection:

The power budget and power supply selection for the PLC PCB in NODE was performed similar to one the performed in the HUB controller design with few changes to it.

Table 8. Power budget for Hub controller under full loading condition

	Voltage (V)	**Current (mA)**	**Power (mW)**
PLC chip [3]	5	97.69	513
TX Amplifier	12 V	16	200
Power Monitoring Board	5	6	30
Relay Circuit	12	40	480 mW
Total Requirement		566	**2713 < Power requirement for Hub Requirement**

In addition to the Table 8 for PLC HUB power budget analysis, there are additional power consuming parts added for the PLC NODE. However, the PLC NODE does not include the BeagleBone. Since the Table 8 shows that the power requirement for the Node controller is less than the power requirement for the HUB controller, the same power supply chosen for the PLC HUB could work perfectly fine with the PLC PCB in Node. In fact, this allows us to have a common PLC PCB with same components as seen in the block diagram in Figure 1.

3.2.1.3.1 Power Monitoring and Control Design

One of the important subsystems in the Node is the Power Monitoring (PM) PCB. The PM PCB is responsible for controlling the power flow which allows user to control any appliances connected to the PM PCB through the outlet socket. Moreover, it is also responsible to measure current, voltage, power and the power factor of the power flowing through/consumed by the connected load shown in Figure 1.

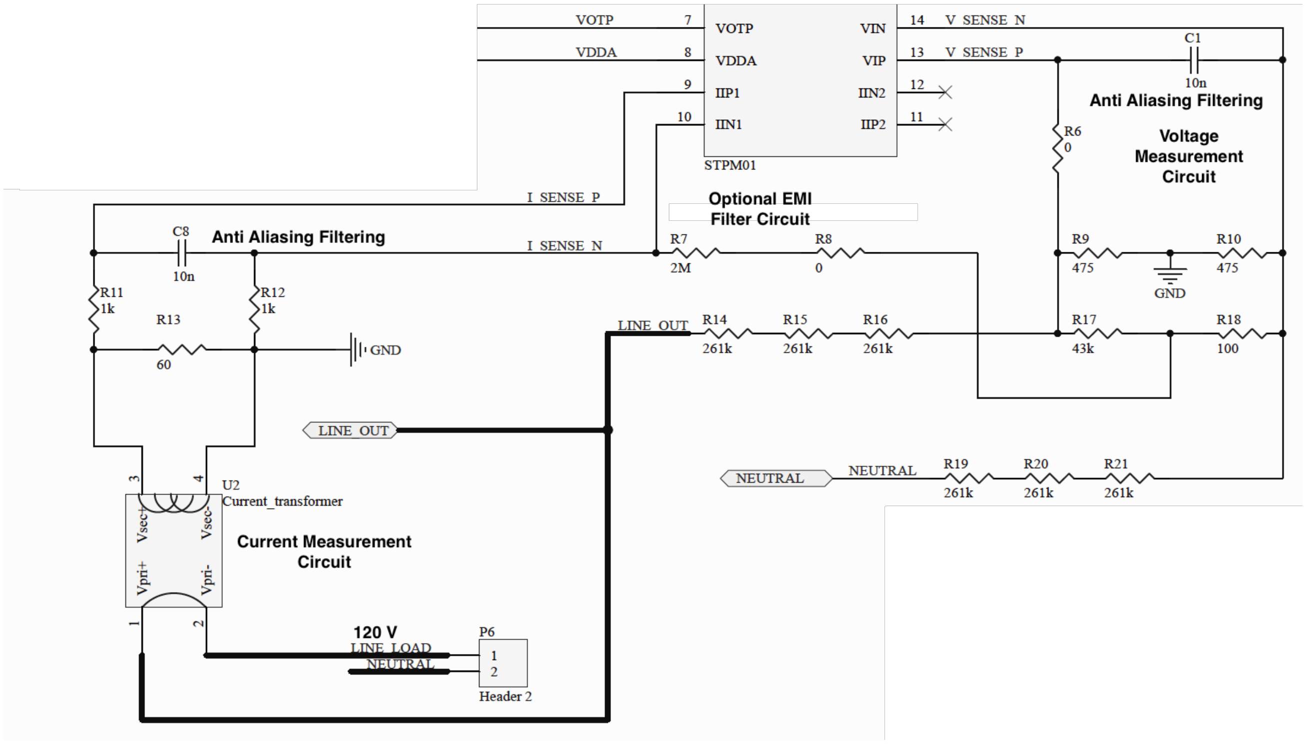

Figure 14. Current and Voltage Monitoring Circuit Design [5]

Power monitoring Chip Selection:

Our criteria for selecting the power monitoring chip was that it must have a at least 8-bit resolution, simple communication protocol capability such as SPI or I2C for ease of communication and should have inbuilt math functions for calculating current, voltage, power and power factor. Also, it should have its own flash memory for storing calibration offset correction parameters where the user can enter any current, voltage or phase offset introduced by the measurement circuit and needs to be corrected. In-built math functions allow users to program the chip with appropriate math formula and store it permanently in its flash memory. This lead to our decision on selecting of STMicroelectronics's STPM01 power monitoring chip which meets all of our requirement for power monitoring function [18].

Current Monitoring Circuit Selection:

There are two major techniques that are used for the high power current measuring techniques: 1) simply adding high power rated series resistor and measure the voltage across it. 2) Pass the hot wire through the coiled solenoid which induces current in the solenoid proportionate to the current flowing through the hot wire. The first technique is very risky as it is not electrically isolated from hot wire and not very accurate as it manipulates the hot wire circuit. The second option could be slightly costly but it is the most appropriate and widely adopted option for measuring high voltage current as it is electrically isolated from the hot wire. Therefore, this lead us to select the TRIAD CSE187L current transformer [9] which has primary to secondary coil ratio of 1:500 and maximum current before core saturation of 30 A. Thus this transformer has the following equation for current transfer ratio: $N1/N2 = I2/I1 = 1/500 = 0.002/1$. Meaning, every 1 A of flow through the primary side will induce the current of 2mA in the secondary side. In the current measurement circuit above, the recommended burden resistor of 60 ohm was used to suppress any high current surges and avoid the short across the transformer [9]. The induced current is then passed through this burden resistor generating the voltage across it and then this generated voltage is then sensed by the power monitoring chip.

I_find = 500*I_sense
I_find = 500*V_sense/60 ohm
I_find= 8.33(1/ohm)*V_sense

Therefore, we will have to incorporate the 8.33 factor in the Power monitoring chip to get the actual value of the measured current.

Voltage Monitoring Circuit Selection:

The voltage across the Line and Neutral was measured simply by introducing high resistive loads in Megaohm range (R14+R15+R16+R19+R20+R21 = 1.57 Mohm) to the power line and measuring the small voltage drop across a small resistor (R9 and R10) as shown in fig. The calculation for complete calculations are as follows.

V_to_find = (V_sense)/(R9+R10)*(R14+R15+R16+R19+R20+R21+R9+R10)
V_to_find = V_Sense*1.56695M/950
V_to_find = V_sense*1649.4

Therefore, we will have to incorporate the 1649.4 factor in the Power monitoring chip to get the actual value of the measured voltage.

The six series resistors (R14+R15+R16+R19+R20+R21) were used instead of just one big resistors for two main reasons: We will can get away with choosing resistors in cheaper price. Price of buying higher power rating resistors as compare to 6 resistors in lower power rating is cheaper, i.e. not more than 10 cents in total. The main reason to use multiple of them in series is to protect the circuit if one fails, the others resistors is still being in the series which can limits the current flowing through the board. Lower power resistors also come in smaller package reducing PCB area. These are all safety improvements to the design.

Relay Control Circuit:

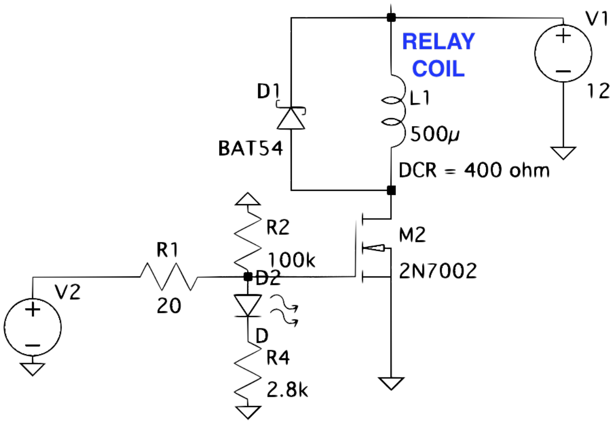

Figure 15. Relay Control Circuit

The relay control circuit is being controlled by the PLC PCB which is connected to the PM PCB. The control signal from PLC PCB to the PM PCB is passed through the connector shown the PCB layout Figure 15. The Relay control circuit consists of a relay [10], freewheeling diode [8] and a N-channel mosfet [7] meeting the current requirement of the coil to close the relay (30 mA) as shown in Figure 16 and Figure 17.

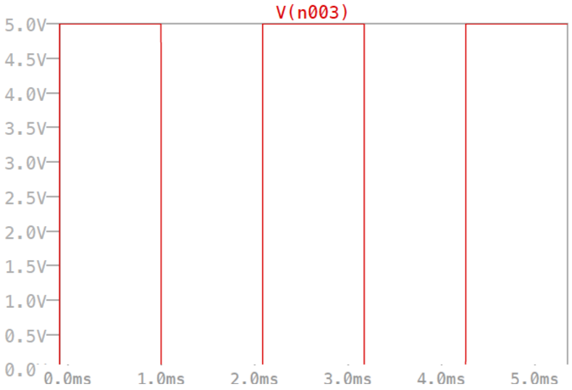

Figure 16. Input voltage

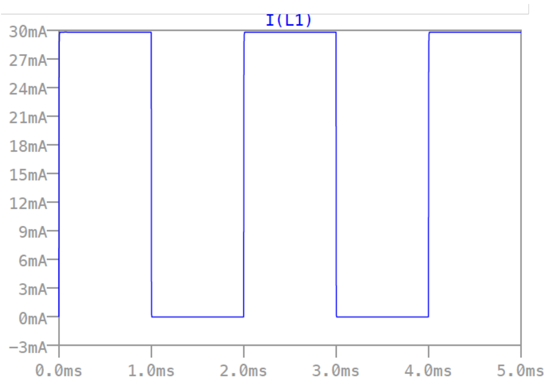

Figure 17. Relay coil current (30 mA max)

The maximum current flowing through the Relay circuit is 30 mA in the simulation and 28 mA from the actual power monitoring prototype; which are very close.

Calibration Offset Correction:

Due the the noisy nature of the power line, the unnecessary noise from the measurement sample must be filtered before the monitoring chip samples the data. Thus, we added the anti aliasing filter to filter unnecessary harmonics from the sample signals.

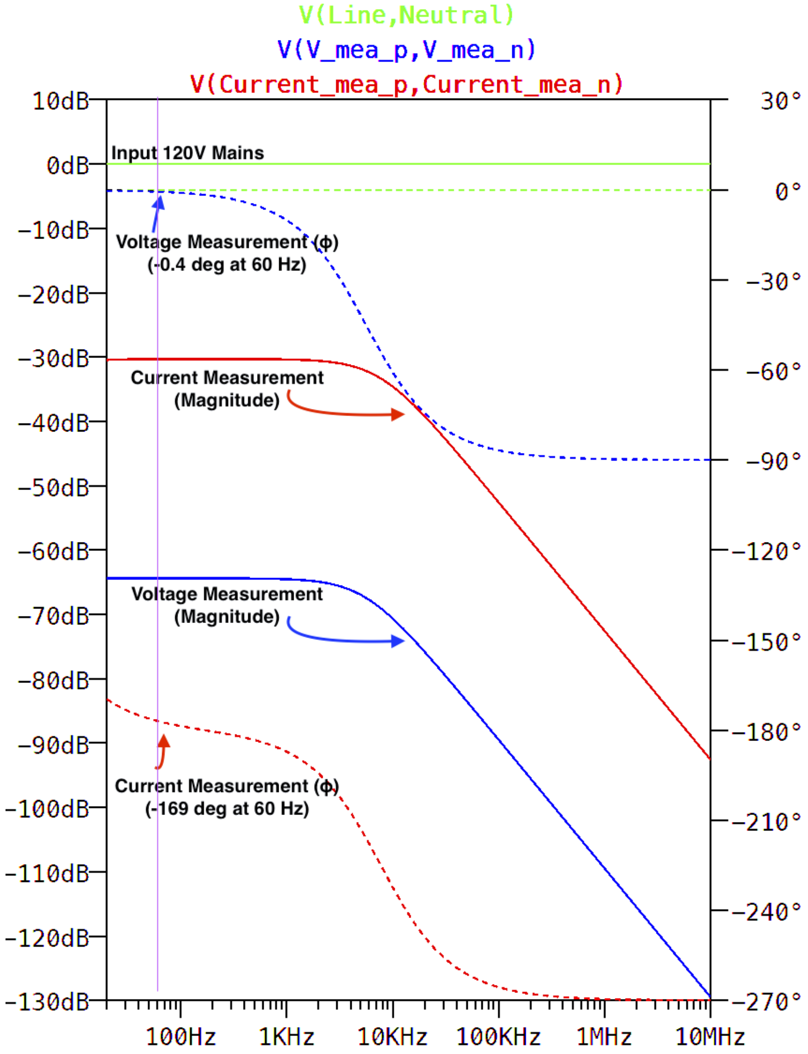

Figure 18. Current and Voltage measurement circuit frequency response for phase calibration

Our ADC inside the power monitoring chip has sampling frequency of $F_{sampling}$ = Fclk/4 = 4.196 MHz/4 = 1.049 MHz. The divided by 4 comes from the datasheet of the power monitoring chip as its their internal divisional factor. This leads us to say that Anti aliasing filter must have the GBWP of $F_{sampling}$ /2= 1.049 MHz/2 = 0.5254 MHz = 525.4 KHz according to the nyquist theorem. Since, passive RC filter, have has no gain (0dB), the BW = GBWP = 525.4 KHz = 525.4 KHz.

In our circuit we have R=2kΩ for current measuring, R=950 kΩ for voltage measuring circuit, C=10nF (C1 and C8) and thus BW = 1/(2πRC) 1/(2*pi*2e3*10e-9) = 7,957 = roughly around 8 kHz for both voltage and current measuring circuit, which is well below the nyquist sampling limit (525.4 KHz) calculated above. Thus, the anti-aliasing filtering is good for minimizing the distortion in the sampled signal but adding a pole in the circuit introduces a small phase shift that should be accounted as an offset for calculating the power factor of the circuit. Thus, this reactive components must be subtracted from the calculated power factor. The simulation of the correction phase for calibration is shown in Figure 18.

The above Figure 18 shows the simulation of the anti-aliasing filter as well as the phase offset correction required at 60 Hz for both current and voltage measuring circuits. The simulation was performed under pure resistive load to help us find any phase offsets. The simulation from Figure 18 indicates that the voltage phase needs to be corrected by -0.4 degree and current phase needs to be corrected by -169 degree and both will be incorporated as our calibration parameters. The current phase is much higher because of introducing the transformer in the current measuring circuit leading to much higher phase offset.

3.2.1.3.2 Decoupling circuit for Digital Supply stability.

Powering chips with certain voltage range is important but it is not the only thing that matters. The noise over the supply rails matters for the reliable operation of the chip.

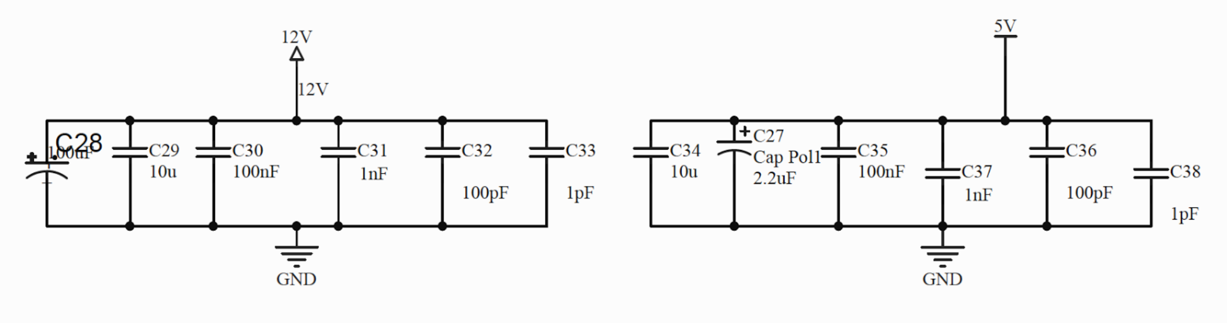

Figure 19. Decoupling capacitors for 12V and 5V rails

Especially, when you have high-voltage switching on the board inducing small emf across any electrically closed loops represented by tiny inductors and thus increases noise in power supply rails or signal traces. The digital decisions made by PLC and power monitoring chips are heavily affected by the power supply noise. Especially, it becomes more important when you have mixed-signal IC consisting of critical analog and digital components. One of most common way to achieve stable power supply voltage is to add parallel decoupling capacitors at the VDD rail to the ground rail. The key is to suppress the switching noise coming from the AC/DC converters as well as any noise from EMI up to the 10 GHZ range. To suppress these frequencies and to come over capacitors' self-resonating frequency, we added multiple capacitors in parallel declining its value by 100 times than the previous one as shown in the Figure 19 because smaller the capacitor, greater its self resonating frequency. Also, the smaller the capacitance, closer it was placed to the VDD pin of the chips. The decoupling capacitors are also implemented in the HUB design as well.

3.2.2 PCB Layout

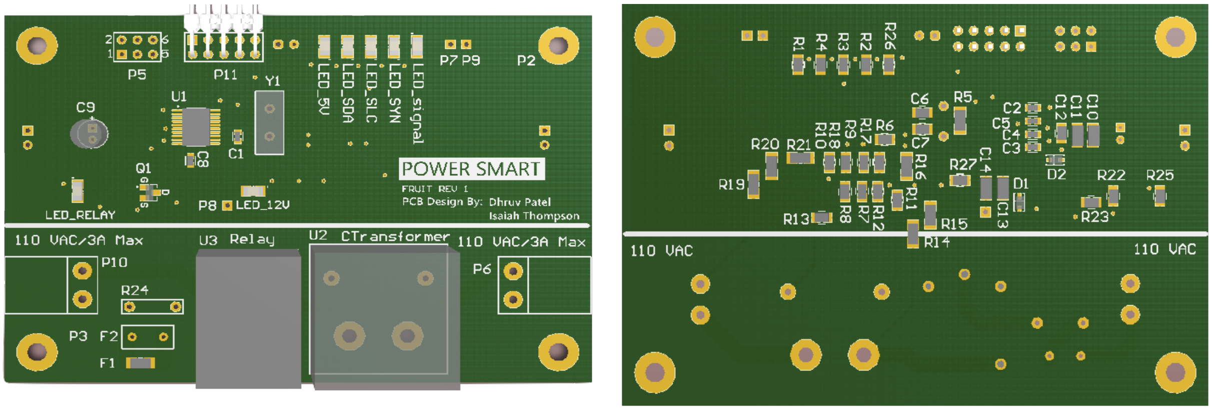

Figure 20. PM PCB (9.4 cm x 6.3 cm x 2.5 cm)

The Figure 20 shows the 2-layer PCB layout of the PM PCB, both front and back view. The top layer consists of signals and GND whereas bottom layer consists of VDD and signals. The most of the critical components that are connected to the high power circuit is placed at the back of the PCB so that we don't accidentally electrocute ourselves during testing. Also, the high power circuit is isolated at the bottom with the bright highlighted line; the top portion of the PCB contains all the low voltage digital circuitry. This PM PCB is capable of taking 3 A of current at maximum due to the limit given to us from the safety coordinator Trevor Smouter. The inlet AC terminals are fused with the 3 A and connected with inrush current limiter in series previously used in the PLC PCB lowering any chances of fire hazards.

3.2.3 Software Design for the PLC Node

There are two crucial features that the software architecture and design of the PLC transceiver must have to satisfy our specifications:

1. An application must be able to poll and read sensor data as well as control devices based on commands it receives.
2. The application must initiate a connection with the Hub over the power line and arbitrate the sending and receiving of control and sensor data.

To accomplish these two features for the transceiver a single software application was written in C and programmed to the Cypress chip. Upon startup this application will instruct the Cypress chip to send a data packet to the Hub's address so that it can request to connect to the power line network. Upon receiving the reply, it will use the logical address assigned to it by the Hub for all future communication. The application will then use the additional external GPIOs on the cypress chip to communicate and poll the sensor data from the power monitoring chip. For every sensor reading read, the data is then sent to the Hub over the power line and then the processes is repeated indefinitely.

3.3 Display (GUI)

The user interface provides the means for end users to re-view sensor data collected over the power line network and control any nodes on the network. The software framework of the web application makes up the underlying structure for the entire client-side user interface. AngularJS which uses the MV* (Model, View, Star) paradigm is an architectural pattern used to help developers manage their web applications [6]. It defines the “model”, which stores application data and business logic, and the “view”, which dictates what the user sees. A third component, typically called the “Controller”, acts as the bridge between the two. However, frameworks often implement their own version of the controller, which necessitates the use of the “*” as a catch-all.

Angular was chosen mainly due to the comprehensiveness of its library. In particular, it provides two-way data binding, allowing any changes to the model to be immediately reflected in the view, and vice-versa. This feature fulfills software requirement #6 which specifies that the user interface must be able to provide real-time updates and alerts to the user through the UI. In addition, Angular’s popularity in the web application development community made it an attractive framework to use in this project. It is well-documented and an typically seen as an easier framework to use than its counterparts.

In addition to AngularJS, Foundation.js was chosen as the HTML/CSS framework for this project [19]. Foundation provides a comprehensive library that will help develop an elegant and responsive client-side web GUI application that will fulfill software specification #1, which specifies that the GUI must allow users to control their hub through a web browser on not only their laptops and desktops, but also their phones and tablets. Foundation provides a structure called “Grid” which allows developers to define multi-device layouts that respond based on the size of the window of the device. It is also build on top of a CSS pre-processor named “SASS”, which is an extension to CSS that adds various features to improve the organization and usability of CSS.

To fulfil the real-time update requirements in the GUI, the AngularJS application will open a WebSocket connection with the web server running on the Hub so that it can receive real-time updates without requiring the use of polling. WebSockets act as a bi-directional communication channel between the server and the browser, which makes it a good tool to use for persistent connections. The client will use AJAX to issue requests and receive responses when it requires data to be fetched asynchronously from the server.

4 Discussion and Conclusion

4.1 Evaluation of Final Design

Our final design intends to meet all essential functional requirements for both the hardware and software aspects of the project. The components used for the PCBs were chosen based on their ability to meet these specifications. Most non-essential functional requirements are also met by the final design. Unfortunately, some functional requirements cannot be verified with certainty until the prototype has been fully built. However, those functional requirements are verified successfully by our circuit simulations. For example, it is impossible to determine if the Node is accurately monitoring power until the components are available to us. Should a hardware component not match the required specs, the best alternative is taken.

4.2 Use of Advanced Knowledge

Our project is rooted in concepts learned from multiple upper-year engineering courses across both computer and electrical engineering. The design and development of the Hub's software draws directly from experience gained in ECE 356. The creation of a web app and server, proper client-server interactions, and best practices for information storage, are concepts learned in this course. Relevant topics covered in ECE 358 include the message protocols that are used to send messages back and forth between the Node and the Hub. Link layer broadcast protocols, which can be used to easily register new devices, is similar to the address resolution protocols learned here. ECE 454 expanded on concepts that were taught in ECE 358. In particular, the ones related to this project include client-server communication, multi-threading, and fault tolerance. Embedded software concepts taught in ECE 455, such as interrupt scheduling, and working limited hardware resources, are also used in this project. ECE 363 and 463 provided insight into power circuits, filters for high power frequency, Fourier analysis, and power converters. Lastly, ECE 318 helped us understand communication protocols and signal modulation.

4.3 Creativity, Novelty, Elegance

Power-line infrastructure is a resource available in every building, but is often not taken advantage of for internal communication. Power Smart is an elegant solution that creates a platform for the management of subsystems, using a network that is already in place within every modern structure. Although there are other products that take advantage of power-line communication, Power Smart is a novel solution that aims to connects all appliances to a centralized Hub.

In terms of elegance, Power Smart is meant to replace wall sockets and light switches - it is meant to sit within the wall where those components would normally be installed. This means that the system should be elegantly hidden so that homeowners and business owners should be able to fluidly use our system without any compromise. Power Smart should work flawlessly and be invisible.

The web application itself should be intuitive for any regular user. Upon use, the Hub should automatically start sending data to be aggregated and displayed on the user's web browser. Sending control data back should also be easy and straightforward to do.

4.4 Quality of Risk Assessment

Table 9 is a list of the risks we determined at the end of ECE498A that would impact the final product. While some of these risks ended up being non-issues, several problems did arise. A discussion on how these risks were mitigated or solved will be made below.

Table 9. Risk Assessment made in ECE498A

#	Risk	Description	Impact	Probability
1	Unpredictability of power line	Technical risk resulting from unpredictable 110 mains power line could be noisy, which can affect the data reliability over the power line. In this particular case, the data could get dropped and may require huge overhead for error correction resulting in lower data rate. This can seriously affect the overall functionality of the system.	High	Low
2	PCB iterations	Only a few team members have an adequate knowledge and experience in PCB layout. Our team has great EE knowledge but none are extremely proficient at PCB layout. Therefore, PCB layout tasks could be time consuming. We are making two unique PCBs (Two PLC PCB and one PLC control Hub), so there is a good chance that mistakes will be made during the first PCB iteration. As a result, we might have to go through several PCB iterations, which could cause weeks of delays.	Moderate	Moderate
3	PCB re-assembling delays	Technical, knowledge/skill risk that can result after designing and fabricating our	Moderate	High

		PCBs, since we have to assemble and solder every single part. Mistakes could damage lot of components during testing and we may have to go through re-assembling parts on PCBs. This can also hurt our project schedule by good amount.		
4	Parts ordering and PCB fab out delays	It is highly possible that getting all the parts to be ordered and PCBs to fab out could take up to weeks. This will greatly delay our whole project.	High	High
5	Unpredictability and non-uniformity in Team members' Schedule	Getting all the team members to meet twice to three times per week for at least an hour could be challenging as all of us have different study schedule. This can have a slight impact on project schedule and team synchronization.	Low	Low

Unpredictability of power line

Power line noise is an important factor to consider in our project. A noisy signal could mean vastly different and incorrect values sent back to the Hub. In order to avoid as much noise as possible, an isolation transformer is used in the PCB. During simulation and testing, we found that using this component reduces a large percentage of the noise, alleviating most of the risk posed by power line noise.

PCB iterations

The PCB design was made with the help of Rasoul Keshavarzi-Valdani to validate correctness, and Trevor Smouter to validate safety. In addition, rigorous simulations were run to ensure that the board would meet the specifications we had set. As of Friday, February 12, the first board we have received works as expected. We are pending delivery on the second board, which, if malfunctions, we can expedite another order.

PCB re-assembling delays

To mitigate this risk, extra boards and extra components were ordered. In addition to re-assembly, this also ensures that if the PCB were to permanently malfunction during testing, we would not need to wait for new parts to be manufactured and delivered.

Parts ordering and PCB fab out delays

Parts were purchased well ahead of schedule to ensure that the time taken for the delivery of parts would not hinder the progress of our project. However, even after the precautions we took, the arrival of our fabricated PCB boards were still late. Luckily, this did not stall our development for too long. To ensure that we would not be delayed further, extra parts and boards were ordered.

Unpredictability and non-uniformity in Team members' Schedule

Although the majority of the team's schedules were different, this did not prove to be as big of a problem as we had initially determined. Four of the group members lived together and the last one lived across the street, so regular meetings could be held after class and on weekends. In addition, the responsibilities of each group member was clearly defined early into the project so that the group could work in parallel, with little dependencies from one person to the next until it was time to put together individual contributions.

4.5 Student Workload

Table # below shows an estimate of each group member's contribution to the project as of February 12, 2016.

Table 10. Estimate of percentage of overall workload achieved by each group member

Group Member	**Percentage of Workload**
Dhruv Patel	**35%**
William Mayo	**25%**
Isaiah Thompson	**15%**
Youngho Yoo	**15%**
Daniel Mak	**10%**

The uneven distribution of workload is caused by varying levels of expertise in different areas of our project. Dhruv Patel took on the largest percentage of the workload due to his expertise in hardware design and analysis. Dhruv and Isaiah Thompson did most of the work on the PCB designs, component selections and simulations. Will Mayo had previous experience working on embedded systems, as he was the one who did the majority of work on the BeagleBone server software, as well as architecturing the design of the web application, server and IC communication protocols. Youngho Yoo and Daniel Mak worked on the SQL database, node.js server, and AngularJS web application.

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Appendix A: Completed Prototype Hazard Disclosure Form

ECE498B: Prototype Hazard Disclosure Form Group number:__2016.27		
Instructions: **Answer all the following questions by putting an *X* in either the yes or no column. If unsure, answer yes. If you answer yes to any question, set up an appointment with the Lab Instructor to ensure your prototype is safe for the symposium. Include this completed form in your Final Report (Appendix A) even if you answer no to all questions.**		
Question: Does your prototype…	**yes**	**no**
1. include any circuitry that you designed or built by yourself?	**X**	
2. †include any circuitry that is not enclosed in an approved plastic or metal box?		**X**
3. †have a 120V AC power supply/adapter that is not approved by CSA, UL, ULC, or ESA?	**X**	
4. †involve any other 120V AC circuitry/device that is not approved by CSA, UL, ULC, or ESA?	**X**	
5. †involve circuitry that is not connected to its power supply with a fuse and a switch?		**X**
6. †use high-capacity or high-density (e.g., lithium-ion or lead-acid) batteries?		**X**
7. †have exposed moving parts that may pinch, hit, or crush a person?		**X**
8. †have parts that are top-heavy and risk falling over?		**X**
9. have exposed sharp edges or points?		**X**
10. use strobe lights or unprotected lasers of any class?		**X**
11. involve projectiles or any part that can fly?		**X**

12. use high-pressure gases or liquids?		X
13. emit dangerously loud sounds?		X
14. involve accessible components that reach temperatures above 40°C or below 0°C?	X	
15. emit non-trivial amounts of RF radiation?		X
16. involve irritating/dangerous chemicals, any biological materials, or any food/drink?		X
17. involve x-rays or radioactive materials?		X
18. eject gas, particles, or fluids into the environment?		X
19. involve any other hazard? Describe:		X
† *If you checked "yes" to any of these questions, you must contact the Lab Instructor by Feb 22 2016.*		

Lab Instructor Inspection Report (needed only if "yes" is checked to any question above)

Prototype is deemed to be <u>unsafe</u> in its current state and requires another inspection after changes are made.

Prototype is deemed to be <u>conditionally acceptable</u>† for the symposium, and another inspection is not required.

Prototype is deemed to be <u>safe</u> for the symposium in its current state.

†*State on the back of this form what minor changes are required for the prototype to be considered safe for the symposium.*

Lab Instructor Signature   Date

Project Consultant Inspection Report at Final Prototype Demonstration (needed for all projects)

yes no

The group appears to have accurately answered the above 19 questions.

The prototype presently appears to be safe for the public symposium.

Consultant Signature   Date

Appendix B: Completed Symposium Floor Plan Request Form

ECE498B: Symposium Floor Plan Request Form Group number: 27

Instructions: Answer all the following questions by putting an *X* in either the yes or no column. Provide additional information in the far right column as requested. Include the completed form in Appendix B of your Final Report, even if you answer no to all questions. Requests for equipment (e.g., an oscilloscope, a power supply, a large monitor, a computer, or a lab stool) should not be included on this form; instead, for such equipment requests use the on-line reservation system as described in the *Symposium Checklist and Schedule* document.

Question:	**yes**	**no**	**if you answered "yes"…**
1. Does your project require one or more hardwire internet connections at the symposium? **Note:** We provide Ethernet connections only, via a male RJ-45 connector. The connection comprises a static IP address in the uwaterloo.ca domain on a shared 100Mbps link. Do not count on the DC building wireless system being available for your project.	x		If yes, state how many connections you require: 1
2. Do you desire to use your own wireless router at the symposium? If yes, you will need to work with the university Information Systems & Technology (IST) people to get your setup approved well before the symposium date. Unapproved routers are strictly prohibited.		x	If yes, the course coordinator will contact you with information on what you need to do to get approval.
3. Each booth has a 7.5-amp 6-outlet power bar. Does your project require more than 7.5 amps of mains (120 V AC) power?		x	If yes, state how many amps you require in total:
4. Each booth has a 7.5-amp 6-outlet power bar. Does your project require more than 6 outlets?		X	If yes, we will supply your booth with two power bars.
5. Do you intend to put any electronics/computers on the floor under your booth?		X	If yes, we will ensure you can do this safely.
6. Does your project involve projectiles or flying parts? (We have a large "cage" at the symposium for projects that involve projectiles or flying parts.)		X	If yes, state the nature of the projectile or flying part:
7. Does your project require special lighting conditions (e.g., dim light, bright light)? We will do our best to accommodate lighting requests, but no guarantees are		X	If yes, state the nature of the desired lighting conditions:

made.			
8. The default booth consists of a 5' wide by 2.5' deep table. The table is 2.54' tall. Does your project require extra table space (giving you a total table area of 7.5' wide by 2.5' deep)? We will do our best to accommodate space requests, subject to the urgency of the request and overall space and safety constraints.		X	If yes, explain specifically why you are requesting the extra table space:
9. The default floor space, including the table and area for you/visitors to stand, is around 6' by 6'. Does your project require extra floor space? We will do our best to accommodate space requests, subject to the urgency of the request and overall space and safety constraints.		X	If yes, explain why you need the extra floor space: State how much extra space you are requesting:
10. Do you have any other special floor plan requests? Note: If you want an oscilloscope, a power supply, a large monitor, a computer, or a lab stool, read the instructions at the top of this form.		x	State your request: