PREPAID ENERGY SYSTEM

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1.0 Executive Summary

Texas Instruments is an American company that designs a plethora of electronics and mass produces semiconductors. They were first founded in 1951 with their primary focus on defense electronics. They designed the first commercial silicon transistor. TI is now involved in selling electronic components and design schematics all over the world. This company is the third largest semiconductor production company in the world, and second largest in supplying chips for cellular applications. From analog semiconductor devices, to digital signal processing chips, to calculators, Texas Instruments is involved in a vast variety of segmentations that make up the field of electronics.

The project team and I have all been exposed to Texas Instruments products from an early age. All of us have been using Texas Instrument's graphing and scientific calculators in our college careers. Along with using their calculators, we have been performing experiments in the labs with their line of microcontrollers. In a course offered in the University of Central Florida, called Embedded Systems requires students to program microcontrollers in high level and assembly language.

The University of Central Florida has a whole lab that was funded by Texas Instruments this lab includes several oscilloscopes, multi-meters, 3D printer, and other tools to aid students on hands on projects. Many microcontrollers are available for students to work on. The MSP430 seems to be the microcontroller that many professors recommend when learning about applications of microcontrollers.

Texas Instruments offered a few projects to the University of Central Florida. Those projects were then ran through by Dr. Richie, who passed them to Dr. Chan, who eventually choose the four of us to work on this project. It is an honor to have Dr. Chan give us this opportunity to deliver Texas Instrument their project.

2.0 Project Description

The prepaid energy system is a pre-payment solution that will allow consumers to pay their electric utility bill as they go. It will utilize RFID technology so that users can add credit to the system just by using their smart phones and an app like Android Pay. The system will also be connected to the internet to send real-time data and alerts directly to the users' smart phones. The user will have an extensive amount of data and statistics regarding their usage right in the palm of their hands.

2.1 Project Motivation

The inspiration behind this project comes from the issue of consumers defaulting on utility payments. Utility companies provide their services to the customer and at the end of the month the customer does not pay be it due to financial crisis or irresponsibility. This results in a waste of energy and a loss of revenue. A scenario of this would be in a college town where many homeowners rent out their rooms for college students. As we know, college students are notorious for being broke, but with the pre-paid system, paying the utility bills becomes less of a burden. Residents would have the option of monitoring their energy usage and determine how much energy they are actually using on an hourly or daily basis. In addition, the prepaid system would allow them to budget their energy costs by paying in advance, or by paying in increments, similar to financing. With the phone app, they can monitor their usage and receive low balance alerts from within their home. By helping the residents, the prepaid system makes it easier for the property owners and cause fewer complications between them and the power companies. This will be very beneficial to the power industry and will allow them to obtain their profits on time.

If residents fail to replenish their energy meter balance, the power will automatically be cut-off. If this happens, the prepaid system will still be operable so that the residents can add money to their accounts and instantly turn the power back on. By having a system that automatically regulates the power, we eliminate the need for the power companies to send a technician out, and we save them the resources and labor.

This is also useful for residents that stay at their home temporarily throughout the year. If a resident decides to leave their house due to work, and in advance knows that he will only be staying in the house for a miniscule margin of time, they can decide to purchase less power for the following days.
Other times that this can come in handy is for people with vacation homes. Year around they are not always living in their house. If the house is used for two weeks out of the whole year, it is redundant to bill the people for the remaining fifty weeks when the person is simply not using the house.

The prepaid system will utilize Radio Frequency Identification (RFID) technology for its method of payment. RFID is an identification scheme that transfers data wirelessly using electromagnetic fields. The data that is transferred is similar to the data found in barcodes when scanned. However, unlike barcodes, RFID does not need to have the scanner and tag within line of sight of each other.

A specific branch of RFID that we are using is NFC, Near-Field Communication. It consists of high frequencies and is compatible with most cell phones. As seen from the name, this type of communication is short-range communication, where the devices must be within a few centimeters of each other. A cell phone will be used as the tag for communication with the reader on the prepaid system. The cell phone will transmit to the reader a unique “password” for authentication. This prevents unauthorized users from accessing the system. For user interface, an app will be designed so that the user can replenish their balance as needed. The system will also be capable of sending alerts to user, which will be sent out using a method of mid-range wireless communication.

The system will be designed to measure and regulate three phase power systems. However, it can easily be scaled down for a one-phase power system, which is what is used for most residential houses. This flexibility allows both commercial and residential areas to make use of the prepaid system.

2.2 Goals and Objectives

Our objective is to design an easy to use prepaid system that can be installed in any home or facility, and can provide an efficient and reliable method for monitoring and regulating energy usage. We hope to give the user more control and insight of their energy usage with the customizable phone app and other features.

Another objective of ours is to design a system that relieves the burden of regulating power from the utility companies. By design a user-controlled, automated prepaid system, we hope to free up some of their resources that can be used for other, more important matters.

Overall, our goal is to develop a product that can be of benefit to both sides; the energy providers can save money and resources, and the consumers can have more control and insight of their usage.

2.3 Requirements Specifications

The prepaid system has the following requirements specifications:

- The system should validate the user through RFID within a range of 3 cm.
- The system should accept any payment greater than 0 US dollars.
- The system should replenish and display the user's balance within 1 second of activation.
- The system should have the ability turn power ON/OFF through a utility meter when the balance drops above/below $00.00.
- The system should collect kWh data every 15 minutes.
- The system should fit inside a standard 15x11 utility box
- The system should operate in any weather condition, up to 100 degrees Celsius and down to -40 degrees Celsius.

2.4 Project Functionality

The system will initialize once it receives payment. This will be accomplished via NFC with a smartphone and an RFID transceiver. The user will purchase credit through an app and bring the phone within a few centimeters of the transceiver in order to send the payment to the system. Once the system processes the payment, it will automatically turn the power on to the load. The system will continuously monitor kWh usage and send statistics and alerts to the smartphone via the internet. The system will be always be ready to receive payment, and display information on the LCD at the user's request. If the user's balance drops to zero, the system will automatically turn the power off.

3.0 Project Background

The project background includes related products and projects that have already been designed, project constraints, and relevant standards. These topics will be discussed in further detail in their respective sections.

3.1 Related Products and Projects

Like most ideas that are thought to be original and unique, the prepaid utility system had already been implemented. As it turns out this project has already been worked on and implemented in multiple countries.

3.1.1 Conlog

Conlog Solutions for utilities found in South Africa is also implementing the prepaid power method. The user will be able to purchase electricity on the internet or at a shop with a scratch-card method. This will give the consumer the freedom of purchasing electricity 24 hours a day. They will then install the prepaid electricity meter, which may be a split meter, or a combo meter. The split meter will have a user interface unit within the home, and a meter in the box to measure power consumed.

The combo meter will have both units in one solution that will be found in the box outside the house. Their final step would be to train the consumers on how to use this new technology. Freescale Semiconductor is a company that has already designed and built a prepaid electricity meter. Their device consists of an LCD to display metering values, NFC for user to be able to upload energy credits using smart card technology or a phone that contains an NFC feature.

3.1.2 INSIDE Secure

A secure element from INSIDE Secure is being used in the device to implement a stronger security while using the device. Security is a key feature for this device and important since the customers are directly involved and in control of their energy payment. Moreover, the heavier a device is with technology the more security becomes a priority for both the consumers and the company selling the energy credit since systems can be hacked or tampered with.

3.1.3 OUC Power Pass

One of the companies in the US that has applied this method is the Orlando Utilities Commission. Orlando Utilities Commission (OUC) offers an alternative to the standard month-to-month billing option. It is known as OUC Power Pass, and it is a pay as you go system that allows the resident of a home to check the electric or water usage every day. It also allows for on the spot payment options. The change this method has on the previous is that all analog meters are switched with digital meters, which show the exact power consumption used. This allows less cost on employees to check on the meters. It boasts the following benefits:

- No Security Deposits
- No Reconnect or Late Fees
- Consumption is calculated daily
- Web-based access to review consumption

OUC has upgraded their entire service area to be using digital electric meters with LCDs, similar to the smart meter found in our system. According to their website, it utilizes a low power “mesh network” where the meter communicates with the next meter until it reaches the main hub. One of the shortcomings of this system is that it collects data daily, as opposed to our system that collects it hourly. Such a large gap in collection can lead to overages and unexpected power shut offs. It also requires a fifty-dollar deposit and forty dollar connection fee.

3.1.4 Powerhouse Prepaid Energy

Another company in the US that has implemented the prepay method for utilities is Powerhouse Prepaid Energy, a utility company located in Texas. They boast the similar benefits to other companies, such as no reconnection fees, no late fees, no credit check, etc. Their smart meter collects data in fifteen-minute intervals, much faster and more accurate than our system and other companies. One of the shortcomings of this product is that users must purchase prepaid cards from stores and vendors, which makes the billing payment method more convenient.

3.1.5 TI’s Smart Plug

Texas Instrument’s Smart Plug is a reference design that implements single-phase energy measurements from an outlet with remote disconnect/reconnect and Wi-Fi connectivity.

Figure 1 Texas Instruments Smart Plug

Courtesy of Texas Instruments

This product implements many of the same features as our system, such as the power connect/disconnect and Wi-Fi connectivity. It is capable of connecting and disconnecting the power remotely from a smartphone, and can send energy usage information over the internet to the user's smartphone.

3.2 Project Constraints

The project utilizes software and hardware thus having constraints in both, where some of the software constraints also affect the hardware. The app that is going to be developed for the project is an example of that type of constraint since we are only going to develop an app that works for android phones. Therefore, the constraint will be limiting phone use for alerts and a long-range wireless communication to android users only and not IPhone users. Since the device will be using NFC and wireless communication there will be a range constraint for payments and connectivity to the device.

Furthermore, there are physical restraints that must be met, such as the dimensions of the system. The entire system should be able to fit inside a standard utility box with dimensions of about a foot and a half long and nine inches wide.

3.2.1 Environmental

Environmental constraints are based on the surrounding of what is being built. Examples of this would be if the project would contribute to pollutants in the air or release carbon emissions that can harm the environment. Other forms of environmental constraints would be if this would cause pollution to water around it such as rivers. Noise is also a constraint that can limit certain projects development. Fortunately, our project does not contain any portions that would hinder nature in a negative way.

Since the project we are developing is intended to work in conjunction with the power lines that are already installed for many houses and building that uses electricity, there are not many environmental constraints. The idea behind this project is a simple alternative to billing customers and monitoring their power consumption, with minimal amount of installations.

Along with the project having an effect on its surroundings, the environment can also affect the device we are building as well. The device we are building needs to be able work under all weather conditions since it is not going to be moved once it is installed. This means that it has to fully function in rain, snow, heat and other weather condition. As far as moisture goes, there will be a protective box around the PCB components, sealing it away from getting wet.

Electrostatic distortion is another concern when dealing with circuit boards. This occurs when two different materials rub together, and become positively and negatively charged. The stored charge then encounters a component in the electronics and creates a sudden voltage spike throughout one of the circuits; this sudden voltage spike can cause permanent damage to the circuit if the proper components are not added as a prevention to these events. In some cases, a diode in reverse bias can be applied to the circuit to create an open in these cases. Many times ICs that are purchases come with this in mind.

The temperature is also an environmental constraint that will be taken care of. The device must be able to withstand the hottest days in Florida along with being able to function during frosty nights in New York. This issue can be resolved with the proper insulation that corresponds to the location of installation.

3.2.2 Size

This project’s constraints when dealing with its physical dimensions is an important factor. The finish product should be able to fit in a concealed box with all the PCB components. Along with functionality of the product, aesthetics is also prioritized. Since the product that is being developed is designed for the use of many home owners and not just industrial buildings its appearance matters. A bulky contraption with wires contorted around it is not what we have in mind.

3.2.3 Health and Safety

When dealing with high voltages there are some precautions that have to be taken into consideration. When designing this project we first had to do everything on paper and on computer simulations before going into the lab and running test with the three-phase power that comes out of the wall. A prerequisite before working with high voltage is having the fundamental concept of circuit theory. Knowing about voltages, currents, capacitance, inductance, and resistance.

The first thing in the lab before going in and working is a list of safety precautions and regulations. One of the ones that stood out the most was not to be in the lab alone. Understand the consequences of working with 120 volts.

When dealing with electricity high voltage is usually considered working with voltages that are over 1000 volts RMS or 1000 volts DC with a current of 2mA AC or 3 DC. For our project, we are dealing mainly with 120 volts with currents of 2mA to 3mA, which falls in the range considered moderate voltage.

Conductors such as wires or mainly metals are important when working with safety precautions in mind. Bare conductors, wires that are not covered or lacking electrical insulations is something to look out for. Covered Conductors are conductors that are enclosed within a material of composition or thickness this is not defined as electrical insulation. An insulated conductor on the other hand is, these are conductors that are encased within matter of composition and thickness defined as electrical insulation.

Besides following safety, protocols when testing out the project in the schools labs. The finish product must be built so that it is safe to install any given place such as a residential house.

3.2.4 Sustainability

An apparatus with minimal amount of maintenance would be ideal. With this in mind, the project team and I are trying to develop the most user-friendly product. The meter will run on the main line as the power source. Since Texas Instruments makes high quality parts, the components in the device should have a long life span.

3.2.5 Ethics

One way that this project might have an effect that is considered ethical is that it might take away some jobs from the technicians that visit homes and or any sort of area each month and check the power consumed on the meter. However if this idea ever gets implement there will be jobs on installing them places as well as maintenance and technical support of the meter since it will be more technologically advanced. On the other hand, since the power companies are getting the money in advance they might be more inclined to reduce the cost of energy purchases, and users can be more efficient and alert with their power consumption which in return will have them save money.

3.2.6 Political

The design or operation of this project is not affected by political constraints.

3.2.7 Social

The design or operation of this project is not affected by social constraints.

3.2.8 Economic

This project must be designed within the budget of the team. The product must also be within the price of similar products and economically viable for companies to purchase.

3.2.9 Manufacturability

The design or operation of this project is not affected by manufacturability constraints.

3.3 Relevant Standards

This project must meet necessary industry standards in order to become a viable product in the industry. It will follow standards such as the NFC standards ISO 14443A (NFC-A), ISO 14443B (NFC-B), ISO 15693, ISO 18000-3, and JIS: X 6319-4 (NFC-F), the Wi-Fi set of standards IEEE 802.11, and the IEC power standards.[3]

3.3.1 Wi-Fi

Wi-Fi is the commonly referred to name when referring to the set of standards that consist of the IEEE 802.11. The most common ones are 802.11a, which operates at a frequency of 5GHz and a rate of 54 Mbit/s, 802.11b which operates at a frequency 2.4GHz and a rate of 11 Mbit/s, and 802.11g which also operates at 2.4GHz but at a rate of 54 Mbit/s. There is also 802.11n, which operates between 2.4GHz and 5GHz and a rate of 450 Mbit/s, and 802.11ac, which operates at 5GHz and a rate of 1.3 Gbit/s. The distances between devices communicating over Wi-Fi can reach ranges up to three hundred feet.

3.3.1.1 WPA2 (IEEE 802.11i)

Wi-Fi Protected Access (WPA) is a security protocol and security certification program developed by the Wi-Fi alliance in 2004 for securing wireless networks. The WPA protocol implements much of the IEEE 802.111i standard and has replaced the old WEP protocol. WPA uses 128-bit encryption and was able to fix the security vulnerabilities of WEP. WPA2 replaced WPA and implements all the mandatory elements of IEEE 802.11i. The most significant addition is the use of Advanced Encryption Standard (AES) for encryption.

3.3.2 NFC

NFC is an open-platform technology that is being standardized in the NFC Forum. NFC was first derived from the communication technology specified by ISO/IEC 18092 (NFCIP-1). NFC known as near field communication is a subset of RFID. Since it is a subset they are both wireless communication schemes. RFID has multiple frequency bands and the different frequency bands can work up to a certain distance. The different frequencies allows for different distances of operation from the transponder tag to the RF reader. NFC works up to mainly the high frequency band of RFID which is at 13.56 MHz. This allows the devices that are in communication with one another to operate at a maximum of 1 meter apart.

The reason NFC was chosen rather than a more distant RFID communication is because it can increase the security of the system. The security increases since the user that will be using this communication scheme must be within a meter but this number is usually closer to the centimeter range within the system. Therefore, it will be harder for another user to intercept the data between the two devices that are in communication with one another. The father the devices communicate the easier it is for another device to intercept this communication and tamper with it. RFID is usually a one-way communication but NFC can also work two ways in card emulation mode as well as peer-to-peer mode. On the other hand, RFID can scan multiple tags at the same time while NFC is just limited to one tag at a time. This feature is there to additionally increase the security of the complete system between the tag and the reader. It will also make sure that the device is communicating with only one device and therefore the data that is being sent is not confused with other tags around which will be less of a problem when it comes to sorting the data that is being sent. This is important because NFC is being implemented in many applications, mainly in payments [2], [4].

3.3.2.1 ISO 14443A/B

Cards that use the standards of ISO 14443 are proximity cards that use a frequency of 13.56 MHz. This standard contains both types A and B because of two companies that could not decide on the modulation schema. Type F cards came later and was introduced by Sony in Japan. Both Type A and B standards use the same communication speed of 106 kbps the only difference is their modulation coding. Type A uses 100 % Manchester Encoding, while Type B uses 10 % Non-Return Zero Encoding.

The above figure shows the difference between Manchester and NRZ encoding and modulation technique, as users of NFC and even developers we do not need to worry about implementing these since they are already done on the NFC chip itself, but it would help give us a better understanding of how data is transferred in different types of tags. Active devices usually support all if not most of these standards. Within Types A and B standards there are four different tag types going from type 1 to type 4. Type 1 tag and Type 2 tag are similar in the fact that they are based by the 14443A standards and both tags can be read/write or configured to read only.

Type 1 tag contains 96 bytes of memory within it while as Type 2 tag only contains 48 bytes of memory, but both tag types can expand their memory up to 2 kilo bytes. A major difference between type 2 tag and type 1 tag would be the amount of bytes that is read from the tag. The reason why type 2 tags have a lower memory is because they have anti-collision support, while type 1 tags do not have that function or algorithm. Anti-collision support is a function found within the tag that is used to avoid interference when there are more than one card happens to be within the reader’s magnetic field.

While both tags work at a communication speed of 106 kbps type 2 tag uses a block memory format where each block contains four bytes of data and thus is read 4 blocks at a time while type 1 tag is only read 1 byte at a time. This makes the type 2 tag a more famous tag and is widely used in most applications. Type 4 tags are the more advanced of both types 1 and 2 since they are compatible with both standards 14443A and 14443B making it a more versatile tag. The only downside is that those tags must be pre-configured at the manufacturers to either be read only or read and write and to determine which standard compliant if either A or B. The memory space within the tag is variable and up to 32 Kbytes. Type 4 tags can communicate at a speed of 106 kbps, 212 kbps, 424 kbps, and 848 kbps. The memory format of a type 4 tag is object oriented using files and not blocks [2], [3].

3.3.2.2 ISO 15693

Cards that use the standard of ISO 15693 are vicinity cards that operate at 13.56 MHz. Even though they are part of the RFID communication, vicinity cards can communicate at a much farther distance than proximity cards and therefore the standardization body does not consider them for NFC. This standard has four distinct parts, each part describing a separate feature of the card. Part 1 describes the physical characteristics of the card, part 2 describes the air interface and initialization between the tag and the reader, part 3 describes the transmission protocol, and part four describes an extended command set as well as security feature [2], [3].

3.3.2.3 ISO/IEC 18092

ISO/IEC 18092 defines communication modes for Near Field Communication Interface and Protocol (NFCIP 1) using inductive coupled devices operating at the frequency of 13.56 MHz. It also defines both the Active and the Passive communication modes of Near Field Communication Interface and Protocol (NFCIP-1) to realize a communication network using Near Field Communication devices for networked products and for consumer equipment. ISO/IEC 18092 specifies, in particular, modulation schemes, coding, transfer speeds, and frame format of the RF interface, as well as initialization schemes and conditions required for data collision control during initialization.

Peer-to-Peer mode is one of the three NFC modes that is standardized on the ISO/IEC 18092. Type 3 tags generally use ISO 18092 standard and can communicate at a speed of 212 kbps, and 424 kbps [2], [3].

3.3.3 Power Metering

The project's power supply and power metering system will meet the following sets of standards:

IEC 60038 – Set of standard voltages for use in low and high voltage AC electricity supply systems.

IEC 60083 – Set of standards for plug and socket outlets for domestic use.

IEC 62041 – Standards for electromagnetic compatibility for emission and immunity in the range of 0 – 400 GHz.

EN 55022B – Standards for equipment and devices that are in a domestic environment to control electromagnetic interference (EMI).

4.0 Research

Research must be done on the various technologies that are relevant to our project so that we can fully understand how they work before working with them. Research must also be done on the possible hardware choices so that we can determine the best pieces for our project.

4.1 Communication Protocols

The communication scheme being utilized in our system is serial communication, which is the process of sending one bit of data at a time. There are many protocols that can be used; however, the most common of them are UART, SPI, and I2C. These are the three that will be discussed in further detail.

4.1.1 UART

Universal Asynchronous Receiver Transmitter (UART) is hardware circuitry that converts parallel data to serial data and is one of the oldest of serial communication protocols. Looking at Figure 2, the UART takes in parallel lines of data and converts it to single serial transmit and receive lines. The biggest benefits is that it only requires two pins and is easy to setup. One of the biggest drawbacks of UART is that it is asynchronous, meaning it does not have a clock, so both devices must agree on transmission speed before communicating. It is also the slowest amongst when compared to SPI and I2C.

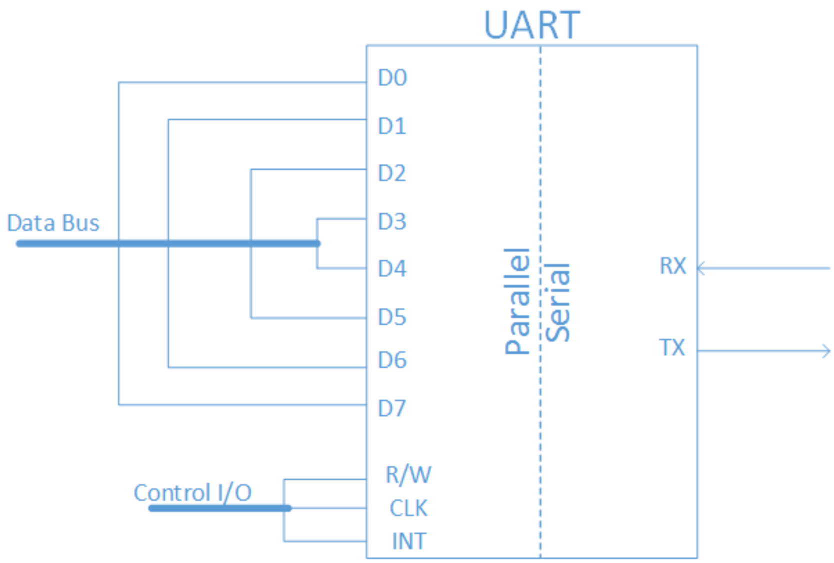


Figure 2 UART Interface

4.1.2 SPI

Serial Peripheral Interface (SPI) is another serial communication protocol. It consists of four wires: Master In Slave Out (MISO), Master Out Slave In (MOSI), Clock (SCK), and Slave Select (SS). It works by sending a clock signal, and sending one bit out to the slave device, and one bit into the slave device. By using the SS line, master devices can connect to multiple devices. SPI has a fast data rate, supported clock rates up to 10 MHz, making it faster than both UART and I2C. It only needs shift registers at each end, which makes the programming much simpler. The biggest drawback of SPI is the number of pins required. At four pins, it requires more than both UART and I2C, and with multiple devices connected to a single master, the pin connections can become complicated, especially in tight PCB layouts [27].

4.1.3 I2C

Inter-Integrated Circuit (I2C) is one of the latest serial communication protocols. It consists of only two wires, one for the clock (SCK) and one for the data (SDA), making it very simple at the hardware level. It allows for multiple-slave and multiple-master systems, by using device addressing. It can reach speeds of up to 400 KHz, making it faster than UART, but slower than SPI. Communication via I2C is much more complex and requires more implementation on the software level.

To reiterate the differences between each communication protocol, a table has been compiled for easy comparison:

	UART	**SPI**	**I2C**
Number of Wires	2	4	2
Speed	115KHz	10 MHz	400 KHz
Software Implementation Difficulty	Moderate	Easy	Difficult

Table 1 I2C vs. SPI vs. UART

4.2 RFID

For the communication and payment portion of the project, we decided to go with radio frequency identification or RFID. RFID chips work in many different frequency bands, the frequency band that we will work with would be the Industrial Scientific and Medical frequency band. The ISM band itself has many different operational frequencies, and Common applications of radio frequency is the automated toll systems that are utilized on today's highways.

An advantage of using RF for this is that there is no need to have a scanner to individually scan each car. Instead, the electromagnetic wave reacts with the passive tags and send back bits unique to each driver. Another great characteristic about using radio frequency is that multiple cars can be scanned at once. Since the reader is main, purpose is to receive the bits form the transponders it allows the computer that the reader is connected to, to do the data processing with it. The idea behind RFID is quite simple, there is a signal that is sent and a transponder is used to identify.

Transponders fall in two categories active and passive. A passive transponder has no independent power supply to act as a source for the circuit inside the tag. Inside most transponders is a circuit with an inductor that responds to an electromagnetic field emitted from the reader. The inductor then generates due to induction from the field, this is then used to power the circuit. The circuit is then able to communicate back to the reader though an antenna that transmits a unique set of bits to the reader. These bits are the identification portion of the whole idea behind RFID [25], [26].

4.2.1 NFC

A form of communication is Near Field Communication or NFC. This is going to be implemented in the project as the bridge between the microcontroller and the mobile phone. Android has developed a feature called Peer-to-Peer communication (P2P). The most common application of this method of communication is media transfer between phones. The project team and I figured if this method can transfer images from electronic device to device, that it can be implemented for simpler data transfer such as a set of bits. This feature is important because it will be the method of transferring data, the phone will emulate a card, and simulate having a passive tag for the chip to read. With regular passive tags, the only have one function and only store one set of fixed bits. The project is going to need a tag that changes every time a purchase is made so the set of bits cannot be fixed [2], [4].

4.2.2 TRF7970A

In our initial design the RFID transceiver IC we were going to use was between the TRF7960A, and the TRF7964A. Both of these transceivers support the exact same standards but the TRF7964A is better since it has a 127-byte FIFO buffer inside of it while as the TRF7960A has a 12-byte FIFO. This buffer will allow us to store more data within the transceiver before sending it to the MCU using SPI. After more research, we found that TI had an even better transceiver being the TRF7970A. This new transceiver supported an additional standard being ISO 18092 and contained the same amount of buffer within it being 127 bytes. The 127-byte FIFO buffer is used after the framing engine in the transceiver performs parity checking removes the end of frame and start of frame settings and then organizes the data in bytes for the specified protocol, which is then ready to be delivered to the MCU through SPI. ISO 18092 is the standard for peer-to-peer mode, which will be discussed in section 4.2.2.3.

Figure 3 TRF7970A Block Diagram

The figure above is the general application block diagram of the TRF7970A. This will be the method the TRF7970A is used in any application. As seen on the right hand side of the block diagram it communicates with the MCU through parallel or SPI, and on the left hand side the communication scheme with the tag is shown through antenna matching and a crystal oscillator of 13.56 MHz is used for the NFC applications.

The table below shows the modes of operation that this transceiver can operate in.

Reader/Writer		Card Emulation		P2P Target	
Technology	Bit rate (kbps)	Technology	Bit rate (kbps)	Technology	Bit rate (kbps)
NFC-A/B (ISO14443A/B)	106, 212, 424, 848	NFC-A/B	106	NFC-A	106
NFC-F (JIS: X6319-4)	212 , 424	N/A	N/A	NFC-F	212, 424

Table 2 NFC Modes of Operation

Additional Features of the TRF7970A:

- Integrated Encoders, Decoders, and Data Framing for NFC Initiator, Active and Passive Target Operation for All Three Bit Rates (106 kbps, 212 kbps, 424 kbps) and Card Emulation
- RF field detector with programmable wake-up levels for NFC Passive Transponder Emulation Operation
- RF field detector for NFC Physical Collision Avoidance.
- Integrated State Machine for ISO14443A Anti-collision Operation (Transponder Emulation or NFC Passive Target)
- Programmable Output Power: +20 dBm (100 mW), +23 dBm (200 mW)
- Programmable I/O Voltage Levels from 1.8 VDC to 5.5 VDC
- Programmable System Clock Frequency Output (RF, RF/2, RF/4) from 13.56 MHz or 27.12 MHz Crystal or Oscillator
- Integrated Voltage Regulator Output for Other System Components (MCU, Peripherals, Indicators), 20 mA (Max)
- Programmable Modulation Depth
- Dual Receiver Architecture with RSSI for Elimination of "Read Holes" and Adjacent Reader System or Ambient In-Band Noise Detection
- Programmable Power Modes for Ultra Low-Power System Design (Power Down <1 μA)

Comparison between the parametric and features the different RFID transceivers at 13.56 MHz Texas Instruments has to offer will be summarized in the table below [9].

	TRF7960A	TRF7962A	TRF7963A	TRF7964A	TRF7970A
Standard	ISO 14443A ISO 14443B JIS X 6319-4 ISO 15693 ISO 18000-3	ISO 15693 ISO 18000-3	ISO 14443A ISO 14443B JIS X 6319-4	ISO 14443A ISO 14443B JIS X 6319-4 ISO 15693 ISO 18000-3	ISO 14443A ISO 14443B JIS X 6319-4 ISO 15693 ISO 18000-3 ISO 18092
FIFOs (bytes)	12	121	12	127	127
Operating Temperature Range (C)	-40 to 110	-20 to 85	-20 to 85	-40 to 110	-40 to 110
Output Power(mW)	100 200	100 200	100 200	100 200	100 200
Supply Voltage (V)	2.7 - 5.5	2.7 - 5.5	2.7 - 5.5	2.7 - 5.5	2.7 - 5.5
Power Down (uA)	0.5	0.5	0.5	0.5	0.5
Stand by (mA)	2	2	2	2	2
RX Current (Lowest)	10	10	10	10	10
TX - half power (mA)	70	70	70	70	70
TX - full power (mA)	130	130	130	130	130

Table 3 RFID Parametric Comparison

4.2.2.1 Reader/Writer Mode

In the Reader/Writer mode, one device will be the target and the other device the initiator. The target is also known as a tag and is a passive device, while the initiator will be the active device that will direct the communication between both. In this mode since either, our tag being the phone or RFID transceiver can play both roles.

In this mode the TRF7970A can be configured to read and write Type 2, Type 3, Type 4 A/B, and Type 5 tag platforms.

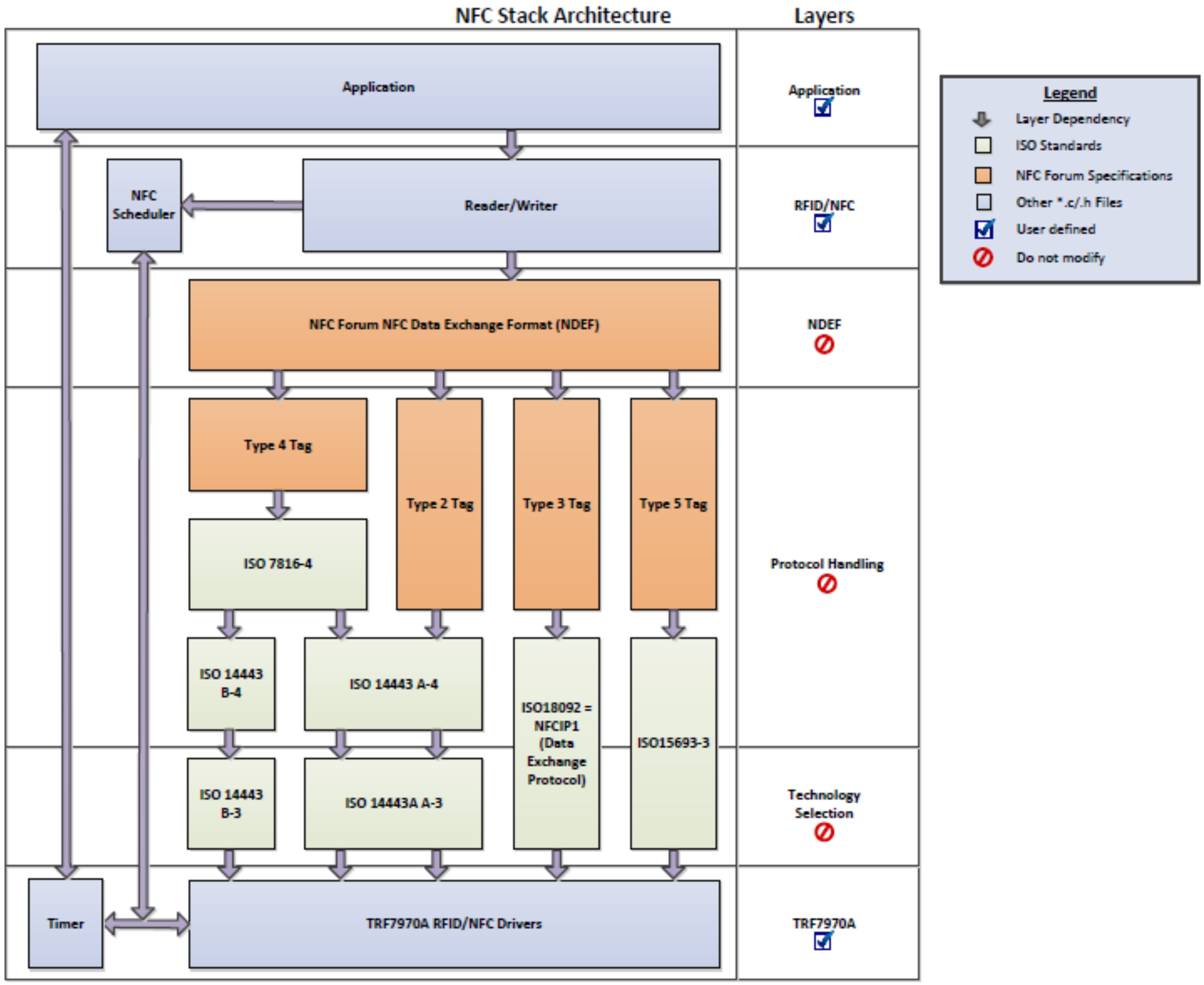


Figure 4 NFC Stack Architecture

Courtesy of Texas Instruments

The figure above displays the complete reader/writer NFC stack architecture, that explains the whole process as to how the software will handle everything in this mode such as tag type, Data exchange format, and standard selection. As seen from the figure there are sections that should not be modified by the developer such as NFC Data Exchange Format (NDEF), Protocol handling as well as technology selection. The stack architecture starts off by having the user decide what mode of NFC to go with, then it is also up to the developer to define Reader/Writer mode as well as ISO standards which will then automatically be handled by the firmware all the way down to the NFC Drivers where the user can modify to their desires as well as the timer and NFC scheduler [9].

4.2.2.2 Peer to Peer Mode

Peer-to-peer mode is one of the three modes of NFC, this mode is only operable in NFC-A or NFC-F. NFC-A follows ISO 14443A and will communicate at 106 kbps, while NFC-F follows IS0 18092 and can communicate at faster speeds such as 212 kbps or 424 kbps. Peer-to-peer mode can work in both active and passive communication. In passive communication it works very similar to reader/writer mode where the initiator generates the RF field while the target will then load modulates that RF field. In active communication, both the initiator and the target generate their own RF fields [9].

4.2.2.3 Card Emulation Mode

Card Emulation mode is the last of the three modes of NFC. In this mode, one of the two active NFC devices will enter a stage where it will emulate an RFID tag. This mode will enable us to use either the TRF7970A as a tag and the phone as the reader or vice versa [9].

4.2.3 Tags

In the NFC world, there are multiple types of tags and the majority of times the tags work on different standards from one another and therefore have different specifications from one another when it comes to memory space, communication speed, card configuration, and extra features such as data collision protection. There are four different tag types that will be summarized in the following paragraphs using bullet points below.

Tag 1 Type:

- ISO-14443A Standard
- Read and re-write capability
- Can be configured to be read only
- 96 Bytes of memory, can be expanded to 2KB
- 106 Kbps Communication speed
- No data collision protection
- Cost effective

Tag 2 Type:

- Similar to Tag 1 Type, but are derived from NXP/Phillips MIFARE Ultralight tag
- ISO-14443A Standard
- Read and re-writable capability
- Can be configured to be read only
- 96 Bytes of memory, can be expanded to 2KB

- 106 Kbps Communication speed
- Data Anti-collision support

Tag 3 Type:

- Derived from Sony FeliCa tags
- More expensive than Type 1 and 2 tags
- Japanese Industrial Standard (JIS) X 6319-4
- Pre-configured at manufacture to be either read and re-writable or read-only
- Variable memory up to 1MB
- Communication speeds of 212 or 424 Kbps
- Data Anti-collision support

Tag 4 Type

- Similar to Type 1 tags and derived from NXP DesFire tag
- ISO-14443A standard
- Pre-configured at manufacture to be either read and re-writable or read-only
- Variable memory up to 32 KB
- Communication speeds of 106, 212 or 424 Kbps
- Data Anti-collision support

In the early stages of research, we were simply going to use, passive tags such as smart cards for tags that we would be able to preprogram with a set amount of money and transfer that money through RFID. This would mean that the user will not have the desired flexibility on their payments, since the cards that will be in the market will have a set price. This would also create more problems for the user because they would have to either keep on buying cards or use several card in order to insert a specific amount of money.

One of our goals is to have a user-friendly system that will decrease the users' problems, thus after more research we saw that Android phones have been using NFC which is RFID technology since 2010. This gave us the idea to switch the passive tag with an active tag being the smartphone. Now that we are going to work with a phone, which is an apparatus that even kids have these days have; the user will not be obliged to buy extra things for this service. Having a smartphone being a tag gives us more freedom for the design of the system as to how the communication will occur; since both the smartphone and the RFID reader use all three types of NFC being reader/writer mode, card emulation, and peer-to-peer mode.

Since we are now going to use a smartphone we also decided to create an app for the user. This app will allow the user to receive notifications and alerts on their power consumption as well as their balance. Moreover, the app will allow the user to decide on the exact amount they would want to pay since we will also link the app to android pay or the user's credit card. Using a smartphone also gives us more memory space for the encryption and authentication code that we will add to the system to make it more secure and tamper protective even on the software level. This whole change in process will surely achieve our goal in making the whole service very user-friendly and give the user the utmost flexibility in payment method as well as pay amount [2], [4].

4.2.4 Authentication

Authentication is an important yet unseen feature in most applications nowadays. For that reason, we have decided to add it to our system, and it plays a key role. Authentication will be used for software security and tampering reasons, since we would not want anyone but the household owner or person in charge to be able to communicate with their own system.

4.2.4.1 Single Data Encryption Standard (DES)

DES is a symmetric cipher, which means that the same key is used for encryption and decryption that encrypts data 64 bits at a time, which uses 56 bits for the key and 8 bits for parity checking. DES is based on Feistel block cipher, which consists of multiple rounds where the bits are shuffled, substituted non-linearly, and XORed.

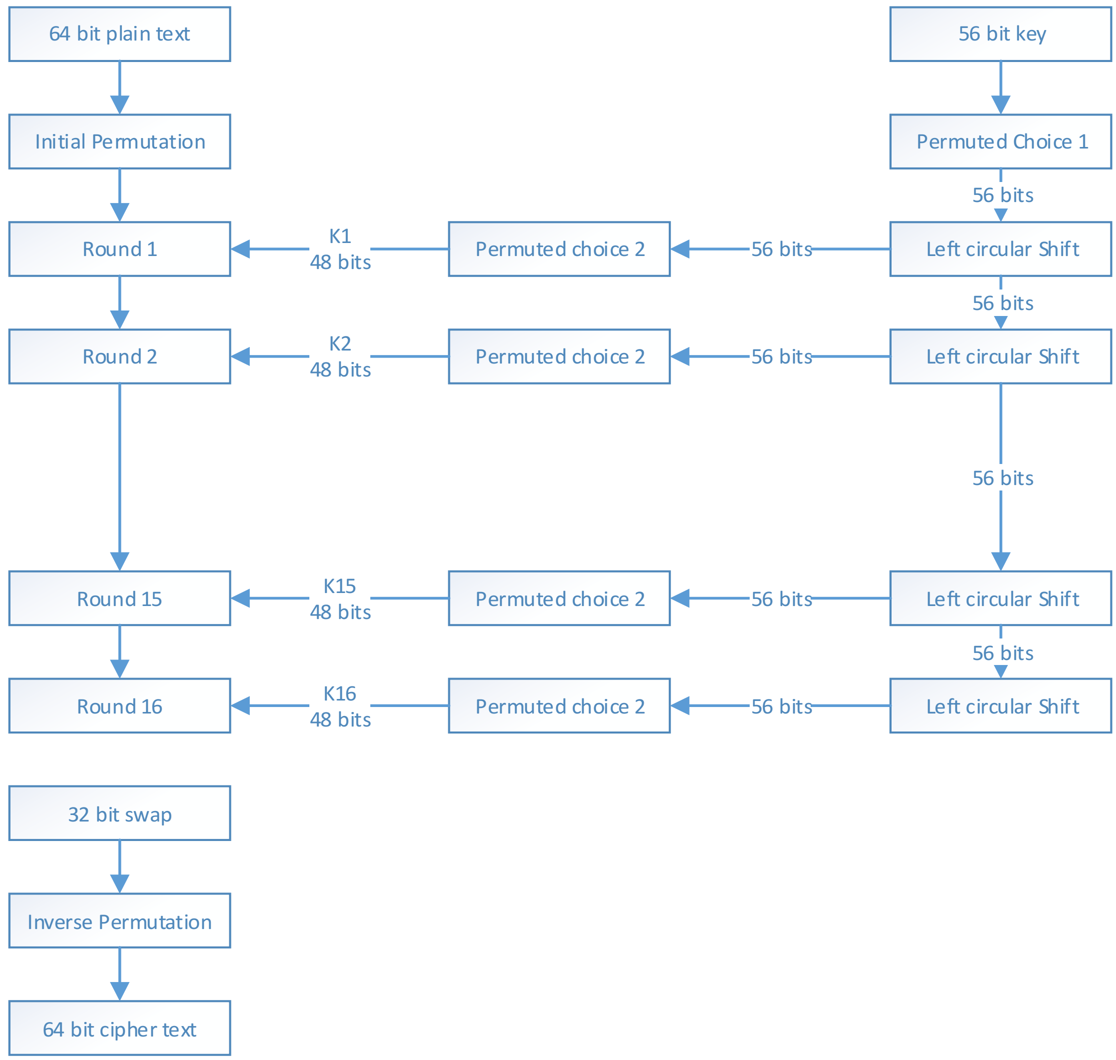


Figure 5DES Flowchart

4.2.4.2 Triple Data Encryption Standard (3DES)

Triple Data Encryption Standard also known as 3DES is an encryption algorithm that is based on DES, which applies the DES cipher algorithm three times to each data block. This standard uses three different options in which three different keys are used. The first option is where all three keys are independent of one another where each key is 56 bits and therefore the whole key bundle is comprised of 168 independent key bits. The second option may be known as double des where 2 keys are independent of one another and the third one is dependent on one of the 2 and therefore there will be a total of 112 key bits.

While the last option is like DES, where all three keys are equal to each other and therefore the total key bits is 56. 3DES and AES in terms of security are about the same but the key difference is running 3DES in software is very slow and therefore a hardware implementation must be made which in return will cost more. The figure below will show the major differences between DES, 3DES, and AES.

Factors	AES	3DES	DES
Key Length	128,192 or 256 bits	K1,K2,K3 are different: 168 bits K1=K2: 112 bits	56 bits
Cipher Type	Symmetric block cipher	Symmetric block cipher	Symmetric block cipher
Block Size	128,192, or 256 bits	64 bits	64 bits
Developed	2000	1978	1977
Security	Considered Secure	Secure only if operable where the keys are different	Unsecure
Possible Keys	2128 , 2192, 2256	2168, 2112	256
Possible ASCII printable character keys	9516, 9524, 9532	9514, 9521	957
Time required to check all possible keys at 50 billion keys per second	For a 128 bit key size: 5E23 years	For a 112 key size: 800 days	400 days

Table 4 AES vs. 3DES vs. DES

4.2.4.3 Advanced Encryption Standard (AES)

AES is the encryption that we will use in this project for network security. It is a block cipher just like DES but can use key lengths of 128,192, or 256 bits. The key length that we will use is 128 bits since it will be sufficient our system's cybersecurity. The encryption for processing the 128-bit key consists of 10 processing rounds where each round consists of four steps being a single byte substitution step, a row-wise permutation step, a column-wise mixing step and the addition of the round key. Even though 3DES contains a higher key number then

DES the downfall of 3DES is that it is very slow to run on software and therefore is not so reliable, if needed to have it on an application one must have to implement it through hardware. Another main factor that makes AES better than DES is that the decryption algorithm is different from the encryption even though they use the same amount of rounds and steps in each round. The following picture is an example of the cipher, which is the four steps or transformations that occur in each round of the AES algorithm. The transformations use: Sub Bytes, Shift Rows, Mix Columns, Add Round Key an example of how they are used in each round will be shown in the following figure [1], [6].

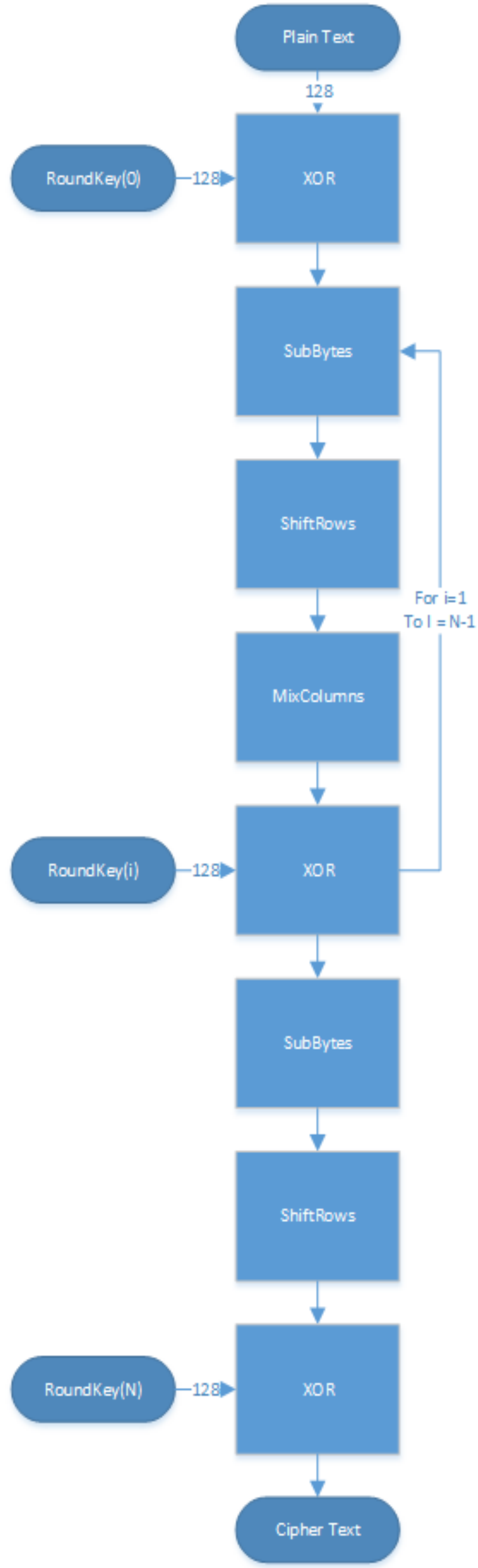


Figure 6 AES Flowchart

4.2.4.3.1 Hardware Implementation

AES hardware implementation may not be common but has multiple benefits over software implementation:

- Ultimate secrecy of the encryption key
- Faster Speed
- More efficient through higher levels of parallelism
- Lack of word size mismatch on different operating systems

The most crucial disadvantage of it is the cost, due to the extra hardware that will be associated within the system. Therefore, this implementation would only be used on very specific applications that have no worries about cost and care for the maximum security with maximum efficiency and speed [1], [6].

4.2.4.3.2 Software Implementation

AES software implementation is an algorithm that can be used in almost any programming language and environment depending on the application that will be running this algorithm. It is an already built algorithm and considered extremely secure.

Drawbacks:

- Word size mismatch within different programming environments, and languages
- No parallelism
- Lack of CPU instructions operating on large operands

Just like hardware implementation, it comes down to the cost, and that is the greatest benefit of implementing the algorithm using software since it can be implemented with no cost at all. Since most applications are trying to reduce cost and increase efficiency this implementation is more commonly used and we will be using it within our project for the lower cost associated with it [6].

4.2.5 Antenna Matching

Our system consists of two forms of wireless communication, Wi-Fi and RFID. Both of these forms of wireless communication fall within the RF frequency range. Since each of these communication protocols works at different frequencies, their circuit design for each antenna will be different.

The RFID transceiver will operate at 13.56 MHz and the antenna design must match a 50-Ohm impedance. The figure below is a schematic of a typical RFID antenna circuit and the impedance of the antenna as well as the Q factor will both be determined by the trace spacing together with the trace width. This design shows a trace width of 0.05 inches and trace spacing of 0.02 inches. The diagonal measurement is a rule of thumb in antenna design that the read range is usually two times the diameter length, therefore in our case the read range will be approximately 4 inches since the diameter is 2 inches. Although antennas can be fabricated on both the top and bottom side of a PCB, in our design we will fabricate it on the top side and have the ground plane away from the antenna traces and elements.

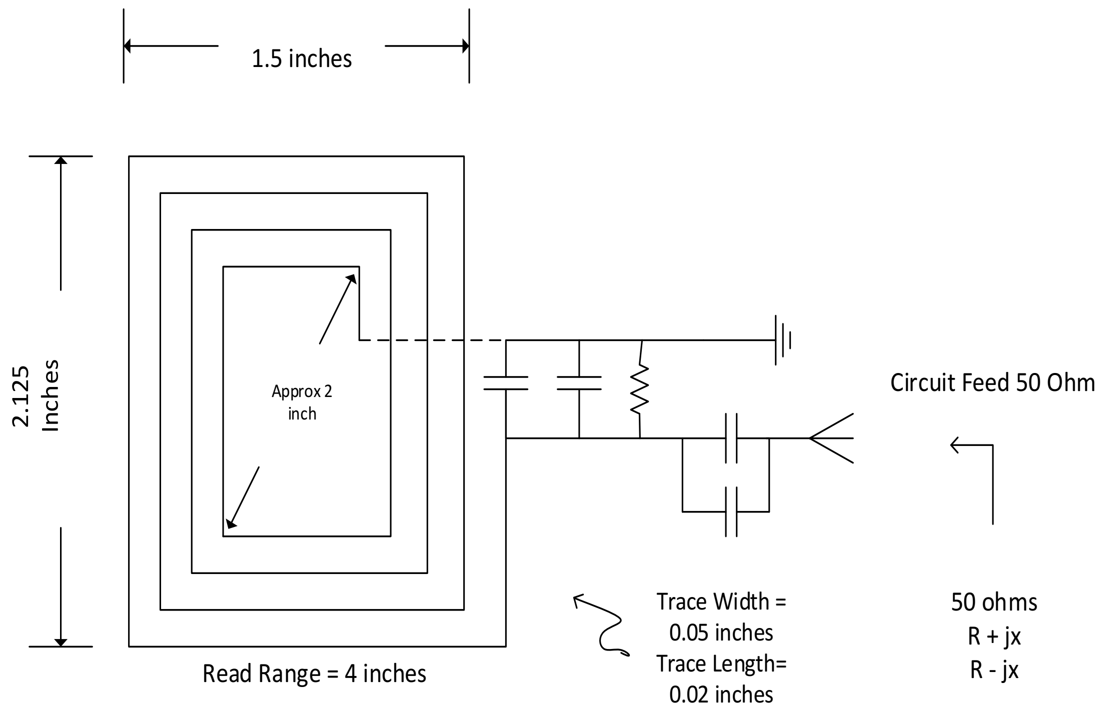


Figure 7 Typical RF Antenna Design

The method used for matching the antenna is derived from a TI antenna matching design for specifically for the TRF7960, which is the exact antenna that can be used on our TRF7970A. We will be impedance matching by using a 3-element match, which will give us the advantage of allowing the circuit Q to be a value of our choice.

The formula for calculating the Q value knowing the operating bandwidth and frequency is shown below

$$Q = \frac{F_0}{BW}$$

Where the bandwidth BW= 2 MHz, this specific bandwidth is chosen to accommodate the upper and lower RFID sidebands for the various data rates given in ISO15693 and ISO14443A/B .The operating frequency F_0= 13 MHz is chosen since the TRF7970A, RFID transceiver of choice, operates at this specific frequency.

This will give us a value of Q=6.78

This will then lead us to begin the process of impedance matching by calibrating the network analyzer. The calibration will consist of three different cases, the first case will be connecting the RF test connector on a circuit board with a 50-ohm load, the second with a short and the third with an open.

We start by connecting the antenna trace of a short to the test connector and measure the values using a smith chart.

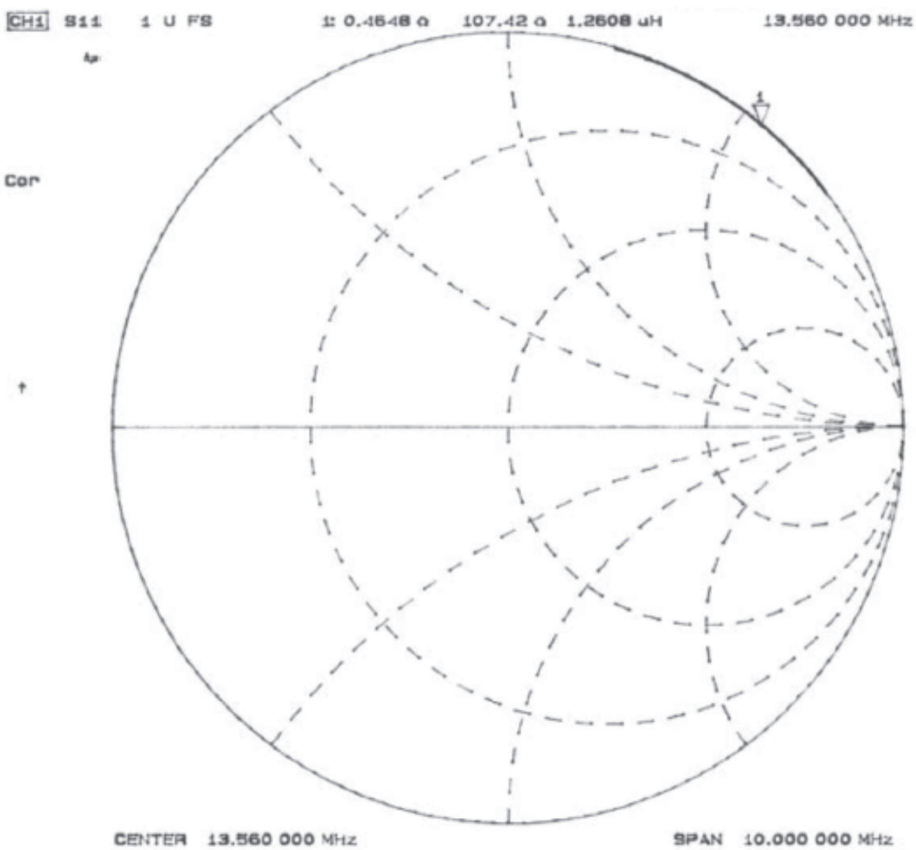


Figure 8 Initial Smith Chart

Courtesy of Texas Instruments

As seen from the smith chart the measured impedance is 0.4648+j107.42. The values from the smith chart as well as the already known value of Q will help determine the value needed for our resistor using the following equation,

$Q = \frac{R}{XL}$.

The impedance measured at a short will be our reference impedance, which we will use to add more matching elements to receive the desired match and in the figure will be shown as Imp1. The next figure will show how the added elements will move the impedance of the circuit by adding certain elements to achieve our goal.

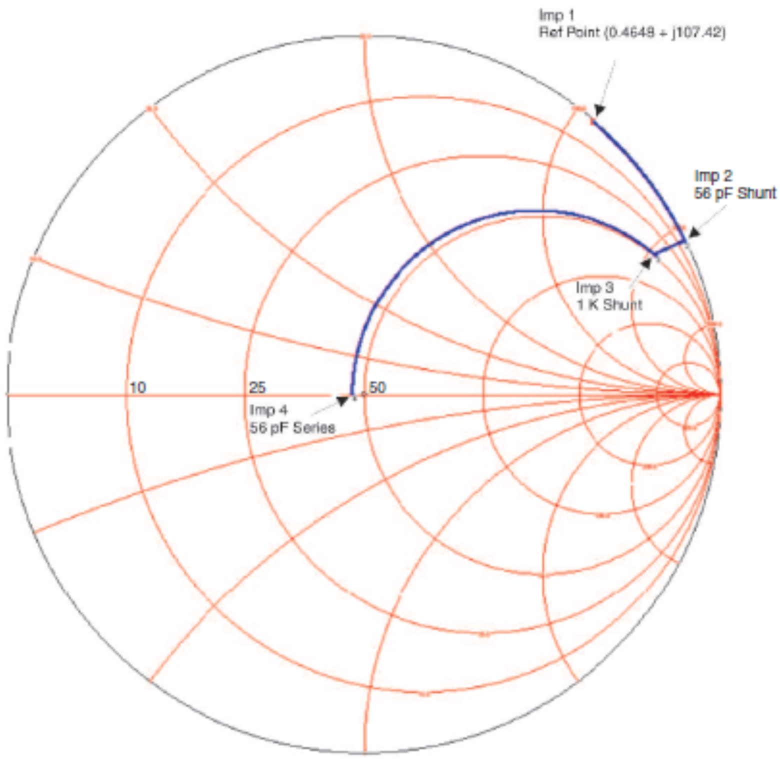


Figure 9 Final Smith Chart

Courtesy of Texas Instruments

We will then add a 56 pF shunt capacitor as suggested by the TI document which will rotate the impedance to Imp2, which will then lead us to adding another element which is a 1 kilo ohm resistor that will then rotate the impedance from Imp2 to Imp3, this is crucial since it moves the impedance to the 50-Ω circle on the smith chart. This added resistor will be the same resistor that is calculated in the previous step, will be rounded up to 1 kilo ohm to be able to use standard capacitor values for the match.

The last matching element will be another 56-pF capacitor, which will keep the impedance at the 50-Ω circle but rotate it from Imp 3 to Imp 4 where the impedance is 46.6 + j0.3. This final capacitor element will be split into two separate parallel capacitors, a 47 pF and a 10 pF, to allow fine tuning of the antenna frequency as well as to reduce the parasitic from the components.
This whole design will yield the final values for the antenna's circuit's components which will be shown below [9].

C1 = 56 pF

C2 DNP
R1 = 1 kΩ
C3 = 47 pF
C4 = 10 pF

4.3 Power Connect/Disconnect

The power switch in our system will connect/disconnect the power to the load. Since we are using three-phase power, it must be able to connect and disconnect all three phases simultaneously, and handle voltage up to 120V and current up to 20A. It must be able to receive a signal from the microcontroller so that it knows when to turn on and off.

4.3.1 Solid-state Relay

Solid State Relays are used in various electronics load-switching circuit including Cooking equipment, Plastic machinery, Lighting system, laboratory equipment. There are many different types of solid-state relays. The vast majority of application Solid State Relays used and such as heating and motion control, lighting and electric power distribution. Majority of application solid-state relays has been used to control three-phase load. In this project, the purpose of the solid state relays to control power distribution.

Solid State Relays function similar to electromechanical relays but no moveable contact and use semiconductor to perform switching between on and off state. They are not emitting noise since there are no mechanical parts. A typical solid state relays has optical semiconductor such as photo coupler that isolates the input signal by converting electrical signal into optical signal. A circuit is activated when voltage is higher than the relays specified pickup voltages that applied and deactivate when voltage is less than the minimum dropout voltage. A control circuit function as the coupling between input and output circuit.

Any voltage above 3 or 4 volts that produce enough current through the LED that will generate lights (photons). The photon travel a short distance and hit the photodiode or any other optical to electrical conversion device and the output switch will be triggered by current that produced by photodiode. For a DC SSR a FET is used and for an AC SSR a TRIAC (Triode Alternating Current Switch) used. The TRIAC is two silicon-controlled rectifier connected back to back.
Selecting SSR for the three-phase system:

Three-phase application have 3 ac lines so the output needs 3 solid state switches to control the load. We can either use three single channel SSRs or one three phase SSR. In every cases, the control signal or the input connect together so that we can activate these switch at the same time.

Teledyne relays are very good solid state relays that we can use for this project. They have a series of AC or DC solid state relays for one phase or multiple phases. The E3P series is for three phase SSR and it can control up to 75 A and 600 Vac three phase SSR. There are some of the benefit of using this SSR. It can provide three phase output, internal output protection, excellent thermal performance and high immunity to surges. This series of relay are designed to all types of load. It has a thyristor output and standard control LED for status [23].
Here is the comparison between some the SSR relays:

Part number	**Description**
E3P48R50-16	50 A, 520 Vac
E3P48D50-16	50 A, 520 Vac
E3P48D75-16	75 A, 520 Vac
E3P48D12	12 A, 600 Vac
E3P48D25	25 A, 600 Vac
E3P48D50	50 A, 600 Vac
E3P48A50	50 A, 600 Vac
E3P48D75	75 A, 600 Vac
E3P48A75	75 A, 600 Vac

Table 5 Different types of E3P series relays

The figure below shows E3P relay's dimensions. It also included the weight of the Solid State Relay (SSR), the relay comes in at a weight of 13.05 oz or 370 grams.

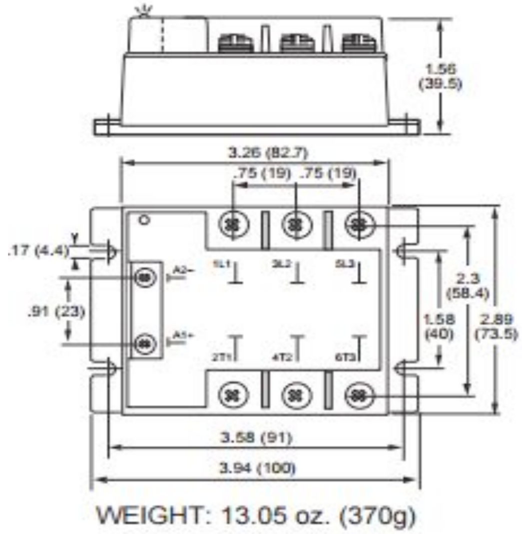


Figure 10 EP3P relays dimension in inches weight 370 g

Courtesy of Teledyne relays

This three phase relay is very easy to use and light weight according to the picture. The weight is 370 g which is very good for our project.

Input control specification for EP3P series:

Block diagram for different types of E3P model:

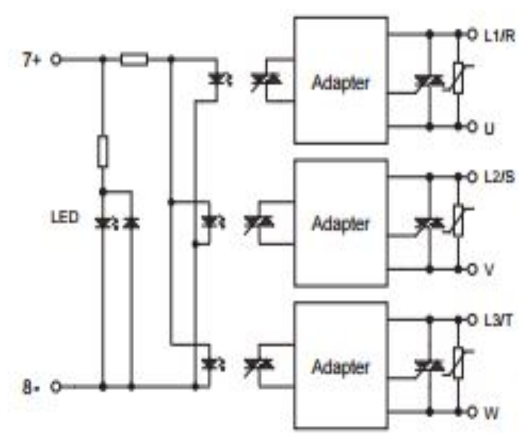


Figure 11 E3P48R50-16

Courtesy of Teledyne relays

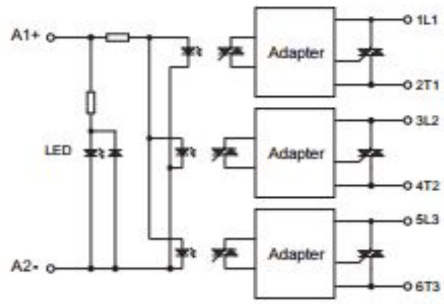


Figure 12 E3P48Drelay

Courtesy of Teledyne relays

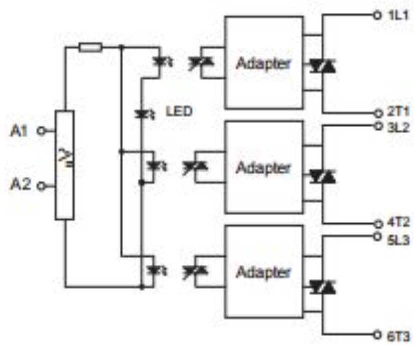


Figure 13 E3P48A50 and E3P48A75

Courtesy of Teledyne relays

Above all of this block diagram, three different model can handle different load currents. E3P48A75 relays can handle maximum 75A which is more than enough for our project. To be safe, we need to chose the relays with maximum load current since we don't know exactly how much current will be drawn from the load. 75 A seems like very reasonable number for the purpose of our project.

Control characteristics: Here is control characteristics E3P for input current as a function of voltage.

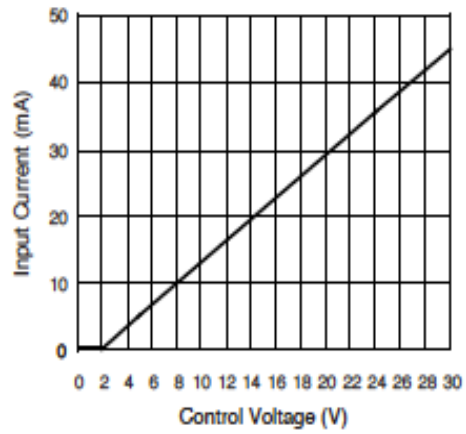


Figure All E3P relays except E3P48A50 and E3P48A75

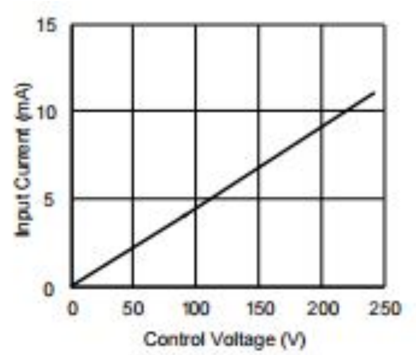


Figure E3P48A50 and E3P48A75

Courtesy of Teledyne relays

In next few table it will show how output load specification for different types of E3p series solid state circuit breaker[23].

	Min	Max	Units
E3P48XX-16	24	520	Vrms
E3P48	24	600	Vrms

Table 6 E3P series dimension in inches

All relays		1200	Vpeak

Table 7 Peak voltage:

12 A Output current	.005	12	Arms
25 A output current	.005	25	Arms
50 A output current	.005	50	Arms
75 A output current	.005	75	Arms

Table 8 Load current range:

E3P with-16 option 50 A output		12	Arms
E3P with-16 option 75 A output		16	Arms

Table 9 Inductive load current

12 A output		120	A
25 A output		230	A
50 A output		550	A
75 A output		1000	A

Table 10 Maximum surge current rating

All relays output current		1.4	V

Table 11 On state voltage drop

E3P48D50	10	680	Hz
All other relays	10	440	Hz

Table 12 On state voltage drop

12 A output		72	A^2 S
25 A output		265	A^2 S
50 A output		1500	A^2 S
75 A output		5000	A^2 S

Table 13 I^2t for match fusing (<8.3ms)

Environmental Specification:

E3P48D50	-55	100	C
All other relays	-40	100	C

Table 14 Operating temperature

E3P48D50	-55	100	C
All other relays	-40	100	C
Input-output case isolation	4000		Vrms
Output case isolation			
E3P48D50	2500		Vrms
All other relays	3300		Vrms

Table 15 Storage temperature

4.3.3 Electromechanical Relay

Electromechanical relays consist of a coil, an armature mechanism, and electrical contacts. Current charges up the coil and generates a magnetic field that controls the armature mechanism and opens or closes the switch. They are most commonly used relays and are found in escalators, automotive, HVAC equipment, and other industrial equipment.

4.3.4 Insulated Gate Bipolar Transistor (IGBT)

The Insulated Gate Bipolar Transistor is a power switch well suited for high-speed applications such as motor control, solar inverters and induction heating. Here is one of the IGBT that can be used as a switch[10].

The Datasheet of IGBT of NGTB25N120IHWT4G is given in the table below:

Rating	Symbol	Value	Unit
Collector-emitter voltage	V(CES)	600	V
Collector current @Tc=25 C @Tc=100 C	Ic	 30 15	A
Pulsed collector current, Tpulse limited by Tjmax	Icm	60	A
Diode forward current @Tc=25 C @Tc=100 C	IF	 30 15	A
Rating	Symbol	Value	Unit
Pulsed collector current, Tpulse limited by Tjmax	IFM	60	A
Gate emitter voltage	VGE	+-20	V
Power dissipation @Tc=25 C @Tc=100 C	PD	 130 55	W
Short circuit withstand time VGE=15, VCE=400 V, TJ<= 150 C	tsc	10	Micro s
Operating junction temperature range	Tj	-55 to 150	C
Storage temperature range	Tstg	-55 to 150	C
Lead temperature for soldering, 1/8 inch from case for 5 seconds	Tsld	20	C

Table 16 Datasheet of IGBT of NGTB25N120IHWT4G

4.4 Microcontroller Unit (MCU)

The microcontroller unit for our system is at the center of our entire design. It must be able to interface with all of the other devices, including the RFID transceiver, power meter, power relay, Wi-Fi processor, and LCD. It will receive payment information from the RFID chip and add it to the user's balance. It will also receive power measurements from the power meter and deduct from the balance. It will communicate with the Wi-Fi processor and send the user's balance, current energy usage, time remaining, and payment confirmation so that this information can be sent over the internet to the user's smartphone. It will also notify the Wi-Fi processor when alerts need to be sent. It will also send this information to the LCD to be displayed.

If the balance drops below a specified threshold, it will send a DC voltage signal to the power relay to tell it to cut off the power. Therefore, the microcontroller we use needs a sufficient amount of communication ports to interface with all of the devices and enough memory to run all the calculations. From Figure, we can see that we will need four ports for communication and one port for a DC voltage. It will also need to run various application processes; therefore it will need a large amount of RAM to accommodate this. In addition, it needs to be low power, and support various low power modes. Texas Instruments offers many microcontrollers that are capable of accomplishing these tasks so choosing the best one can seem daunting. With that being said, in order to reiterate our microcontroller requirements, a list has been compiled to highlight the major needs:

- Low power
- Four communication ports
- Enough analog I/O pins
- Very high memory
- Fast processor speed
- Easy to program
- Convenient software and libraries

As previously mentioned, Texas Instruments offers many microcontrollers that meet these requirements; however, we have narrowed it down to the CC3200 Single-Chip Wireless MCU, the MSP432P401 Mixed-Signal MCU, and the MSP430FR6989 Ultra-Low Power FRAM MCU. These microcontrollers both have their pros and cons, which will be discussed in further detail.

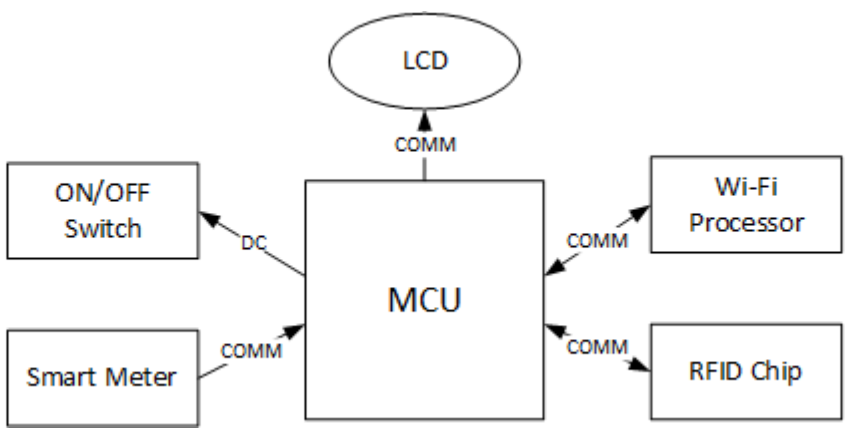


Figure 14 MCU Block Diagram

4.4.1 CC3200

Texas Instruments offers the industry's first Wi-Fi certified single-chip wireless MCU, the CC3200. The CC3200 is the first standalone MCU with integrated Wi-Fi connectivity. The MCU consists of three subsystems, the applications subsystem, the network processor subsystem, and the power-management subsystem. To iterate, the applications subsystem features an ARM Cortex-M4 CPU running at an impressive rate of 80 MHz that is solely for application processes, and 256KB of SRAM. The applications subsystem also contains many different peripherals, including SPI, I2C, UART, 8-bit parallel camera interface, SD/MMC, Analog-to-Digital Converters (ADCs), and multiple General Purpose Input Output (GPIO) pins. The CC3200's network processor is dedicated solely to internet connectivity and has its own ARM MCU that completely offloads the applications MCU.

The subsystem features a Wi-Fi Driver, 802.11bgn baseband, radio, and MAC, and 256-bit encryption. It has completely integrated TCP/IP and TLS/SSL stacks, HTTP server, and internet protocols. The power-management subsystem features DC-DC converters that allows for a wide range of supply voltages, and various low power modes [9]. The SimpleLink setup makes connecting to the internet very simple and does not require any previous Wi-Fi experience. As mentioned earlier, our system requires four communication ports; however, since this MCU has a built-in network processor, this eliminates the need for one communication port, so our system would only require three communication ports. This MCU has two UART ports, one SPI port, and one I2C port so it would be able to interface with all devices in our system, however it would require different protocols.

4.4.2 MSP432P401

The MSP432P401 is the latest addition to TI's portfolio of ultra-low power, mixed signal microcontrollers. It features an ARM 32-Bit Cortex-M4F CPU that can reach rates up to 48 MHz, 256KB of Flash RAM, 64KB of SRAM, and 32KB of ROM. It includes a plethora of peripherals including four I2C ports, eight SPI ports, four UARTs, two comparators, 24-channel ADCs, 8 channel DMA, and 84 GPIOs. It allows for a wide range of supply voltage, from 1.62V to 3.7V and supports multiple ultra-low power modes. This MSP432 combines the ultra-low power of the MSP430 with the speed of the Cortex-M4F processor. It has a fast CPU speed and the most memory out of all the microcontrollers we have looked at. It has more than enough communication ports with four I2C ports, eight SPI ports, and four UART interfaces. The biggest drawback of this microcontroller is that it is still not out for production, and after viewing its errata, it appears to have a significant amount of bugs that still need to be fixed. In addition, as it is a new platform, we would be required to port over sample codes from the MSP430 platform to the MSP432 platform [9].

4.4.3 MSP430FR6989

Texas Instruments offers the MSP430FR6989 Ultra-Low Power FRAM microcontroller. FRAM combines the speed and endurance of SRAM with the reliability of Flash. FRAM stands for Ferroelectric Random Access Memory and according to TI's website stores data as a polarization of a ferroelectric material. They explain that this structure, displayed in Figure 16, has the following advantages:

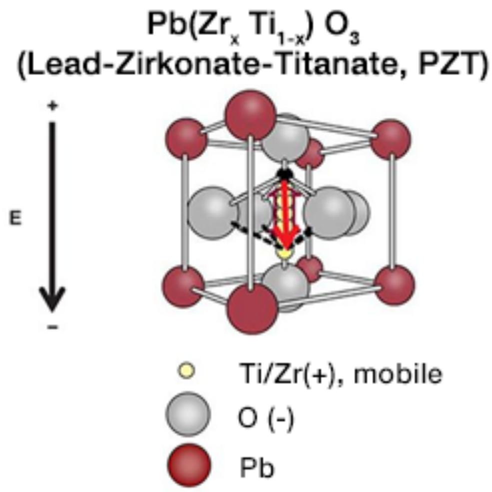


Figure 15 Structure of Lead-Zirconate-Titanate

Courtesy of Texas Instruments

- Non-volatility. It retains its contents during loss of power.
- Fast writes. Typical write speeds exceed 2 MBps, compared to 14 KBps with Flash
- Low power. FRAM write accesses are extremely low power because they do not require a charge pump.
- High endurance. Read and write operations on the order of 10^15 write or erase cycles.
- Resistance to electromagnetic fields, alpha particles, and other radiation, means data is more secure.
- Unmatched flexibility with code and data partitioning. Capable of changing these boundaries during runtime or compile-time.
- Data security. No charge pump needed, resistance to external fields, and state retention during power loss.

To reiterate, FRAM has many advantages when compared to SRAM and Flash. The MSP430FR6989 microcontroller itself features a 16-bit RISC CPU with a speed of 16 MHz, and 128KB of FRAM and 2KB of SRAM. It has an array of other features like a Real-time Clock, Watchdog, Scan Interface, Temperature Sensor, Brown Out Reset, IrDA, and IP Protection. For its peripherals, it includes a 16-input comparator, 3-channel DMA, two I2C ports, four SPI ports, and 2 UARTs. In addition, this microcontroller has an integrated LCD controller, so this eliminates the need for one communication port, so we would only need three communication ports if we were to use this microcontroller [9].

Overall, the MSP430FR6989 has the second most memory out of the microcontrollers we have looked at, and FRAM definitely has its advantages over the other types of memory. It has enough communication ports as well, and the integrated LCD controller frees up one port and eliminates the need for an external LCD driver.

Each microcontroller has its advantages and disadvantages. To reiterate them and get a better overview of each one, a table has been compiled listing the specifications of each device:

MCU	**CC3200**	**MSP432P401R**	**MSP430FR6989**
CPU	ARM Cortex-M4	ARM Cortex-M4F	16-Bit RISC
Frequency (MHz)	80	48	16
Memory Type	SRAM	Flash and SRAM	FRAM and SRAM
Memory Size (KB)	256	256KB and 64KB	128KB and 2KB
GPIO	27	84	83
I2C	1	4	2
SPI	1	8	4
UART	2	4	2
Min VCC	2.1	1.62	1.8
Max VCC	3.6	3.7	3.6
Standby Power (uA)	4	0.85	0.9
Dimensions (WxL)(mm^2)	9x9: 81 mm^2	14x14: 256 mm^2	14x14: 256 mm^2
Price	7.99 | 1ku	3.58 | 1ku	4.50 | 1ku

Table 17 Microcontroller Parametric

4.4.4 Coding language

The programming languages we will be using are C, Assembly, and java since they are the languages we are most familiar with, and because we will most likely be using TI's MSP430 microcontrollers, CC family, and TRF7970A which all support both C and Assembly. Java will be used in android studio since we will be using it to create an app for the android.

4.4.4.1 C

C is a general purpose; high-level language that can be used in many IDE’s to program various microcontrollers and IC’s. When compared to assembly, it is easier to read, write, and debug. However, it usually requires more memory than assembly, and takes longer to compile. Since it is easier to write it will be the primary language we program in, unless memory constraints require us to write certain blocks in assembly.

4.4.4.2 Assembly

Assembly language is a low-level language that can be used to program specific microcontrollers and IC’s. Most code that is written in lower level languages tend to be longer than those in C and Java. When compared to C, it is harder to read, write, and debug. Since it is closer to the machine language, it usually takes less time to compile and requires less memory. Most compilers today are very efficient at optimizing high-level code, so writing in assembly is not as necessary. Another reason that we most likely will not need to code in assembly is the fact that memory is not an issue with today's microcontrollers. Assembly used to be the preferred option when having more memory was a luxury; however, technology has made it readily available to the point that the tradeoff is so low it is not worth taking less space to code in lower level languages anymore.

4.5 Three-Phase Power Meter

The three-phase power meter we will be using features TI's MSP430F6779, which is a 16-bit microcontroller specifically designed to provide solutions for poly-phase metrology. The MSP430F6779 has a 25 MHz CPU, 512 KB of flash, and seven 24-bit sigma delta analog to digital converters (ADCs). These ADCs can be grouped together for simultaneous sampling of voltage and current. The microcontroller also features a 32-bit hardware multiplier to speed up math calculations. The ultra-low power nature of this microcontroller allows for low power consumption and the capability of running on battery backup in case of a mains power failure.

A typical connection of a one phase electric meter can be found in Figure 17 below:

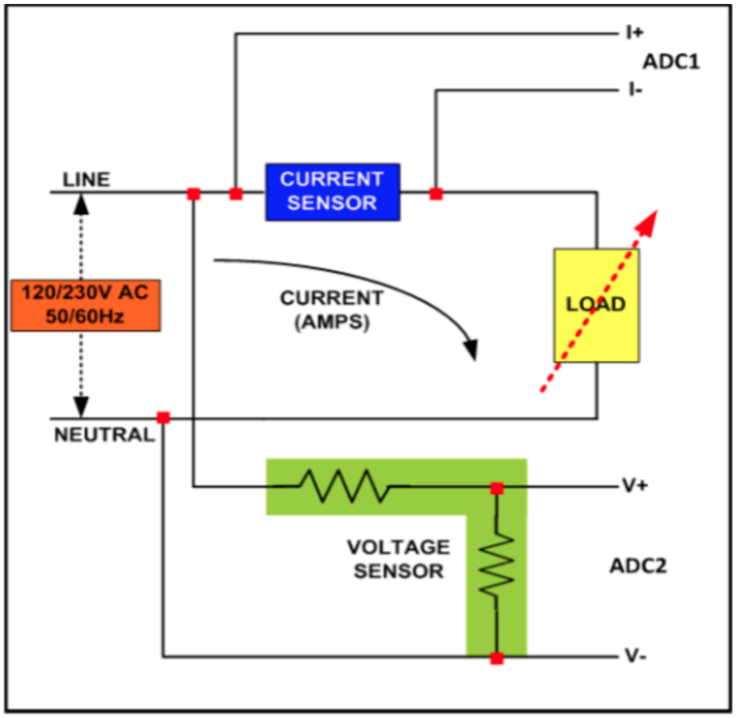


Figure 16 Typical Single-Phase Connection in a Power Meter

Image Courtesy of Texas Instruments

The standard ac voltages is 120 V/230 and frequency 50/60 Hz. This will eventually be needed to be stepped down to about half a volt for the input voltage.

The next figure shows a three-phase energy meter using the MSP430F677x. A three-phase four-wire star connection used and current sensor are connected to the each of the current channels and simple voltage divider connected to each of the voltage. The CT has an associated burden resistor that must be connected at all times to protect the measuring device. The LED's are used to transmit active and reactive energy pulses and used for calibration. In addition, pulses are used to transmit active power for the individual phases[9].

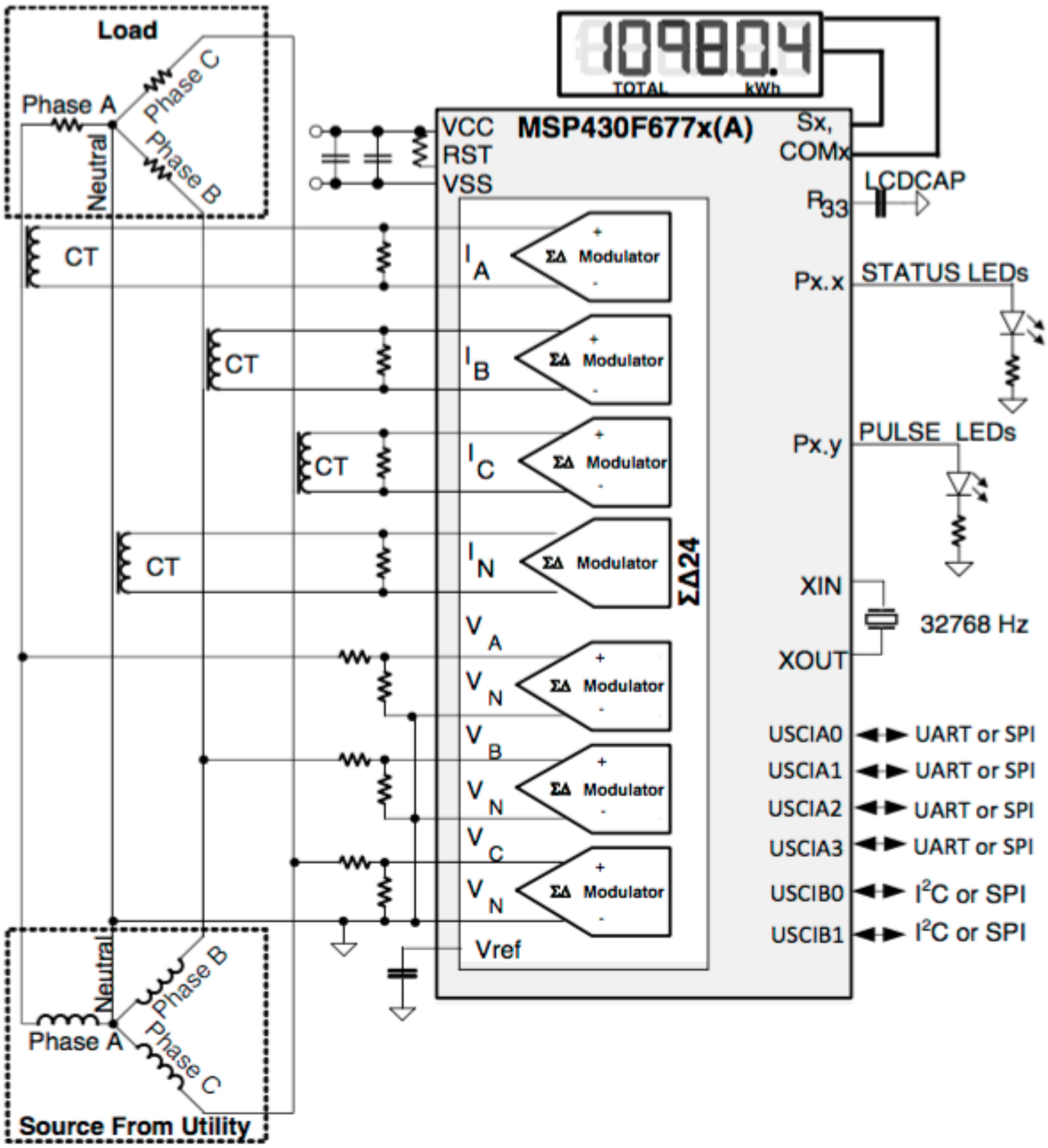


Figure 17 Three Phase Wire Star Connection Using MSP430F677x

Image Courtesy of Texas Instruments

For our project we decided to go with Texas Instruments Three- Phase Electronic Watt hour Meter, as seen in the figure below. The project description obtained from Texas Instruments required us to use this model of their line of Power Management Products. This specific model comes integrated with an LCD screen which will later be programed to output data obtained from the microcontroller.

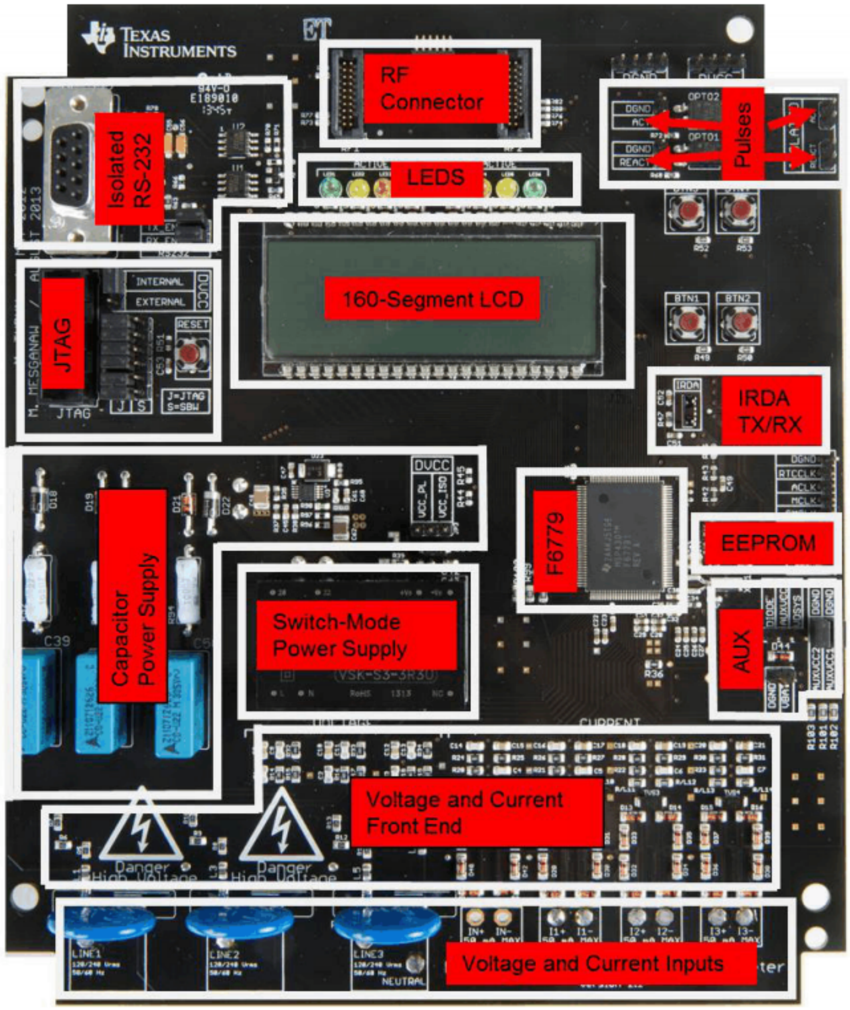


Figure 18 Top View EVM

Image Courtesy of Texas Instruments

The picture found in TI's datasheet shows the complete overview of the electrical power meter. It consists of voltage and current inputs, a switch mode power supply, 160 segment LCD, JTAG, RF connector, IRDA TX and RX, F6779, EEPROM, and capacitor power supply.

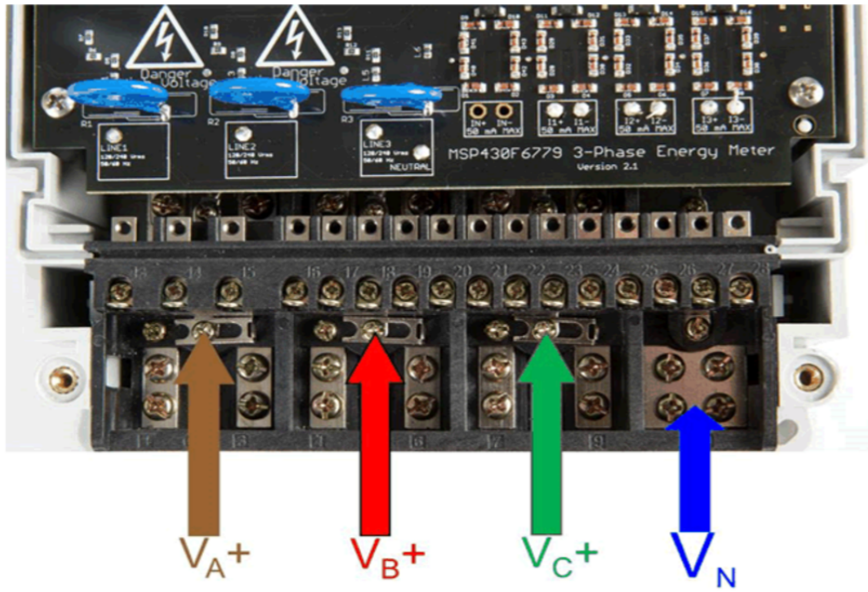


Figure 19 Top View of EVM with Test Setup Connections

Image Courtesy of Texas Instruments

This above picture shows physical connection of the three individual phases.

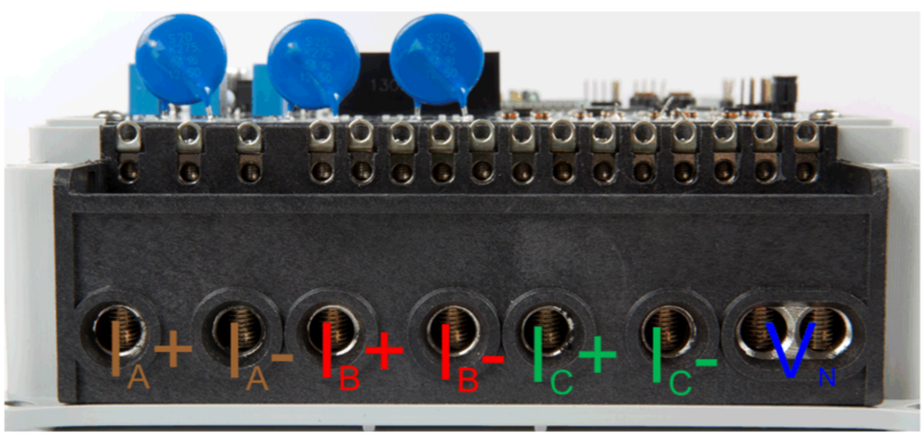


Figure 20 View of EVM with Test Setup Connections

4.5.1 Power Supply

The three-phase power meter can be directly powered from the three-phase line voltage. The low power nature of this device allows the power supply to be simple and inexpensive. There are various power supply designs for the meter that we are considering.

4.5.1.1 Resistor Capacitor Power Supply

The resistor capacitor power supply takes in voltage directly from the mains and uses an RC circuit to provide a single DC output of 3.3 V. Figure 22 shows the schematic of this power supply design.

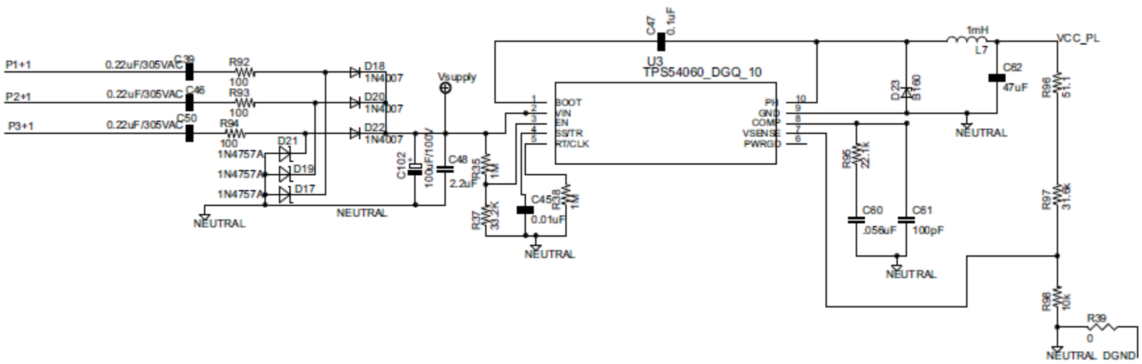


Figure 21 Resistor Capacitor Power Supply Schematic

Image Courtesy of Texas Instruments

The RC circuit takes in AC voltage is 120V at a frequency of 60 Hz, converts it, and steps it down to a DC voltage of 3.3V. This is what is required to power the MSP430F6779 at full power. In this configuration of the three phase, contribute to the output current drive. If we need a higher output drive then NPN output buffer can be used in the same circuit[9].

4.5.1.2 Switching Power Supply

Figure 23 shows the switching power supply design that takes in 120V AC directly from the mains and provides a DC output voltage of 3.3V for the microcontroller to run at full power.

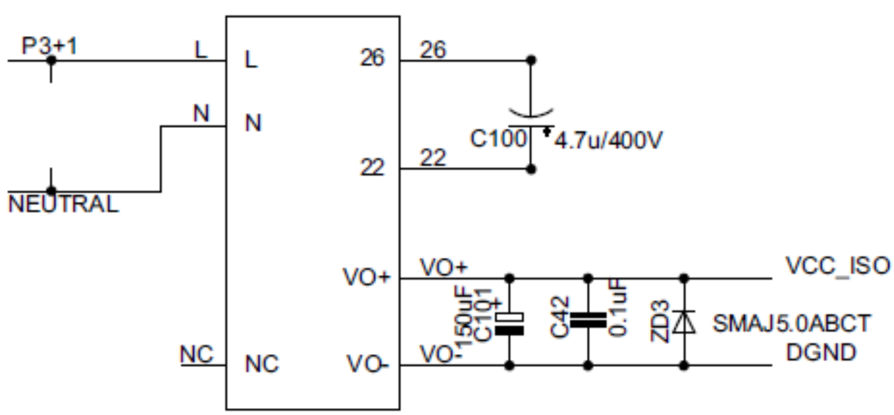


Figure 22 Switching Power Supply

Image Courtesy of Texas Instruments

The switching-based power supply powers the meters as long as there is voltage across the Phase C line on the three-phase main lines. [9].

4.5.1 Analog to Digital Conversion

The MSP430F6779 features 7 24-bit Sigma Delta analog to digital converters. They are fully differential and require the input voltages do not exceed +/- 930 mV (gain of 1). In order to meet these requirements, the voltage and current inputs must be stepped down. We will discuss the possible analog front ends of this device for voltage and current.

Voltage Input

The sigma delta converter has fully differential inputs that are designed to take inputs from the 120V AC main lines. The 120V must be brought down to 930 mV before being fed to the input of the microcontroller. The analog front end consists of varistors that protect against voltage spikes, a voltage divider to step it down, and an RC low pass filter for anti-aliasing. Figure 24 shows the front end for a mains voltage of 230V, which is brought down to 779 mV. It provides a safety margin for safe operation even during voltage spikes[9].

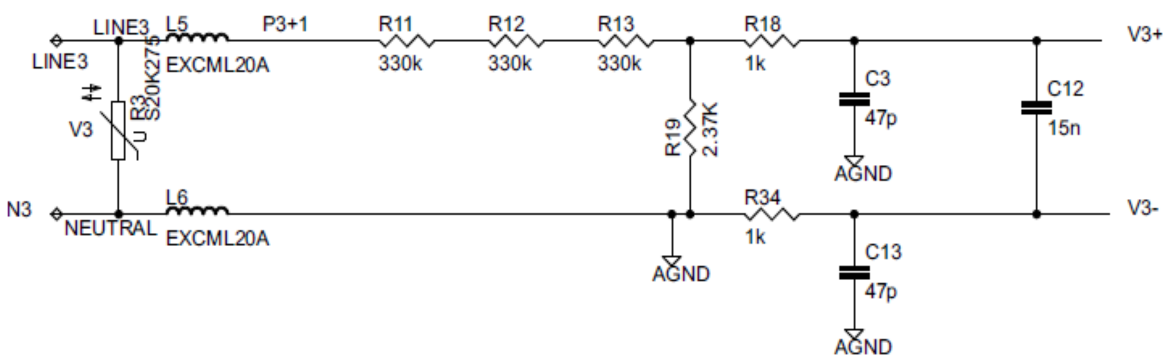


Figure 23 Voltage Front End

Image Courtesy of Texas Instruments

Current Input

The analog front end for the current inputs is displayed in Figure 25. The resistor R104 acts as a burden resistor on the current transformer and converts the current to a limited voltage. Following this resistor is the anti-aliasing filter, which consists of the resistors and capacitors.

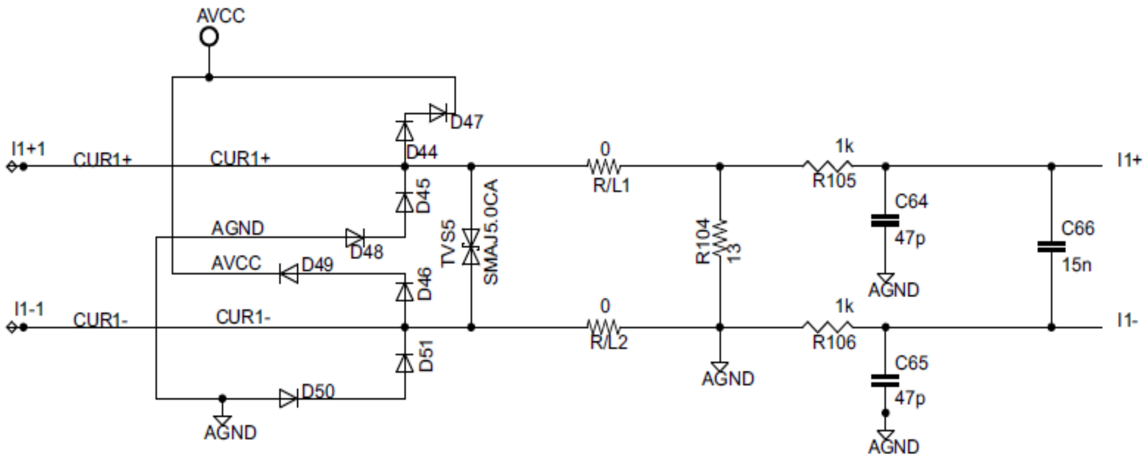


Figure 24 Current Front End

Image Courtesy of Texas Instruments

Voltage and Current Sigma

The MSP430F6779 has seven sigma delta data converters. Since our meter must measure three-phase power, we require at least six sigma deltas, three for voltage and three for current[9].

4.5.1 Tamper detection

Tamper detection is a large factor in this project. Since this device is in charge of completing purchases the tamper detection also important for the user. The power companies that are providing the energy are trusting that this product is accurate in measuring the customers use it installed. The tamper detection features will be implemented on the software portion of this device. One of the ways that we can make the project Robust to being tampered is to add a password and username. The login will have a finite amount of tries. If an intruder attempts to input the wrong password then the system will not proceed and notify the user.

4.5.3 Software implementation

Along with the hardware, design portion of this project comes the software integration that plays a big role. Since the meter is only in charge of collecting data from the three-phase source, there has to be a system that transfers it into a set of equations that convert it into the currency required to purchase it and a display that shows the consumption of the user at any given moment. The software has two main processes that it is realized in. The foreground process and the background process.

Prior to incorporating any code into the software portion of this project, some peripherals must be taken into account. These profiles include the 24-bit sigma delta (SD24_B) ADC, clock system, timer, LCD, and watchdog timer. For three phase at least six-sigma delta are necessary, they are all needed because with three phase there are 3 independent voltages and currents that require measurements.

The clock that this meter has runs at 16MHz. The sampling frequency is fs = fm/ OSR, the OSR is chosen to be 256 and the modulation frequency fm is chose as 1.048576 MHz. This results in a sampling frequency of 4,096 ksps. As far as the Real time clock interrupts go, they will occur at one-second intervals. At these intervals, the software is supposed to update the current time and data.

Since the meter comes with an integrated LCD on it, there will software needed to operate the LCD with the data containing the energy consumptions. This LCD can support up to 8 mux displays and has 320 segments and can also work in a 4 mux mode with 160 segments that will refresh[9].

Foreground Process

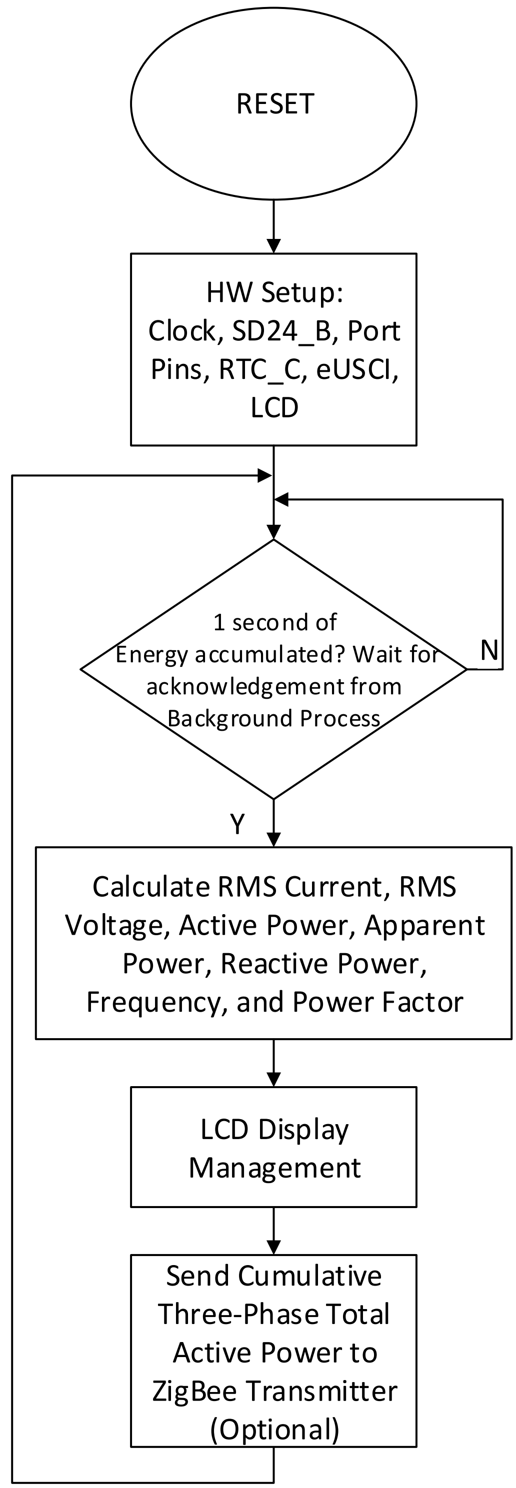


Figure 25 Foreground Process

For the foreground processes, the setup includes the analog to digital converter, the clock system, general-purpose input and output pins (GPIOs), RTC module for the clock functionality, LCD and a few more.

Formulas

To convert the raw data collected from the power meter the following formulas will be useful when incorporating the code portion of the project. The sampling rate at which these calculations are done is 4096 cycle per second. All of the sample that are take in 1 second are then needed for the calculations of the RMS values of the voltage and the current for each phase. Texas Instruments provided the formulas needed in the equations below.

$$V_{RMS,ph} = K_{v,ph} * \sqrt{\frac{\sum_{n=1}^{\text{Sample count}} v_{ph}(n) * v_{ph}(n)}{\text{Sample count}}}$$

$$I_{RMS,ph} = K_{i,ph} * \sqrt{\frac{\sum_{n=1}^{\text{Sample count}} i_{ph}(n) * i_{ph}(n)}{\text{Sample count}}}$$

Where,
ph = Phase whose parameters are being calculated
$v_{ph}(n)$ = Voltage sample at a sample instant *n*
$i_{ph}(n)$ = Each current sample at a sample instant *n*
Sample count = Number of samples in one second
$K_{v,ph}$ = Scaling factor for voltage
$K_{i,ph}$ = Scaling factor for each current

The power and energy calculations come from one frame of active and reactive energy samples. The samples are passed to the foreground process, the following equations are used to obtain reactive and active power. Two things are useful to keep in mind when dealing with these calculations, for reactive power the 90° phase shift approach is used for accurate measurements of the reactive power for very small currents, and it conforms to the international specified measurement method.

$$P_{ACT,ph} = K_{ACT,ph} * \frac{\sum_{n=1}^{\text{Sample count}} v(n) * i_{ph}(n)}{\text{Sample count}}$$

$$P_{REACT,ph} = K_{REACT,ph} * \frac{\sum_{n=1}^{\text{Sample count}} v_{90}(n) * i_{ph}(n)}{\text{Sample count}}$$

Where,
$V_{90,ph}(n)$ = Voltage sample at a sample instant *n* shifted by 90 degrees
$K_{ACT,\ ph}$ = Scaling factor for active power
$K_{REACT,\ ph}$ = Scaling factor for reactive power

Active energy is calculated from the active power,
$E_{ACT, ph} = P_{ACT, ph} * SampleCount$
$E_{REACT, ph} = P_{REACT, ph} * Sample Count$

When calculating the power consumption since the frequency always varies, it is important to measure the main frequency accurately to the phase shift the voltage sample accordingly. To get an exact 90° phase shift, interpolation is used between two samples. For these two samples, a voltage sample slightly more than 90 degrees before the current sample and a voltage sample slightly less than 90 degrees before the current sample are used. The application's phase shift implementation consists of an integer part and a fractional part. The integer part is realized by providing an N samples delay. A one-tap FIR filter realizes the fractional part. In the software, a lookup table provides the filter coefficients that are used to create the fractional delays.

After calculating the active and reactive power, each phase's apparent power is calculated by the following formula. In addition to calculating the per phase active and reactive power and energy, the cumulative sum of these parameters are calculated by the other four equations below.

$$P_{APP,ph} = \sqrt{P_{ACT,ph^2} + P_{REACT,ph^2}}$$

$$P_{ACT,Cumulative} = \sqrt{\sum_{ph=1}^{3} P_{ACT,ph}}$$

$$P_{REACT,Cumulative} = \sqrt{\sum_{ph=1}^{3} P_{REACT,ph}}$$

$$E_{ACT,Cumulative} = \sqrt{\sum_{ph=1}^{3} E_{ACT,ph}}$$

$$E_{REACT,Cumulative} = \sqrt{\sum_{ph=1}^{3} E_{REACT,ph}}$$

As for the power factor, it is calculated after the active and apparent power calculations are complete. The absolute value of the power factor is calculated using the equation below. The standard notation that is adapted in many areas is that if the power factor is positive it is corresponding to a capacitive load and that if it is negative it is an inductive load. The sign of the internal representation of the power factor is determined by whether the current lead or lags voltage, which is determined in the background process[9].

$$\text{Internal Representation of Power Factor} = \begin{cases} \dfrac{P_{ACT}}{P_{Apparent}}, \text{if capacitive load} \\ -\dfrac{P_{ACT}}{P_{Apparent}}, \text{if inductive load} \end{cases}$$

Background Process

The background process uses the sigma delta interrupt as a trigger to collect the voltage and current samples. The samples are used to calculate intermediate results.

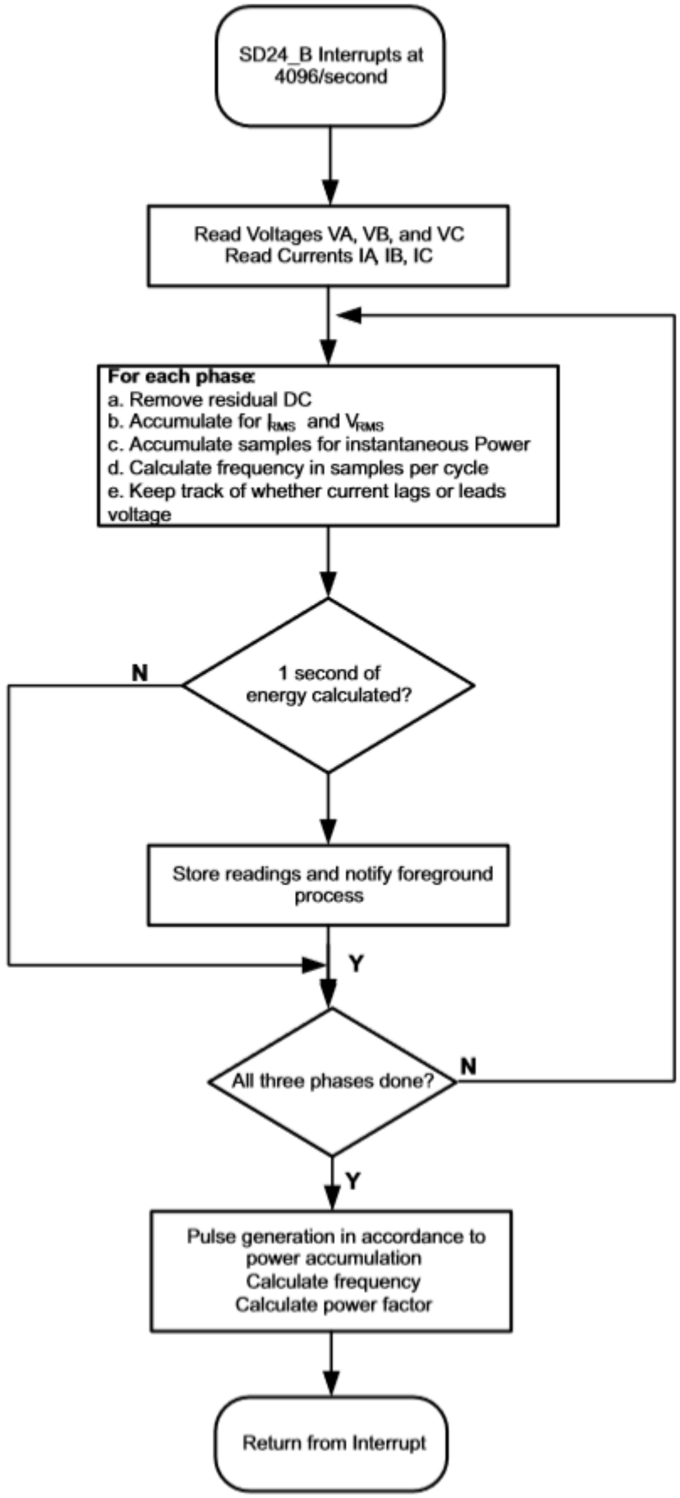


Figure 26 Background Process

Image Courtesy of Texas Instruments

The voltages for each phase is accumulated in 48-bit resistors, and the current, active power and reactive power go to 64-bit resistors. A counter is used to keep track of all the samples that are being processed. Around every second all the samples that are generated from the calculations get sent to the foreground process to develop value from their averages.

Ideally, the signal that is being read would be clean enough to just go through the process, however noise can cause inaccurate readings. These signal spikes will though off the pair of samples that are being read. The figure below demonstrates the difference between a good samples from a sample that is corrupted by noise. These voltage spikes due to noise can be eliminated by implementing a low pass filter[9].

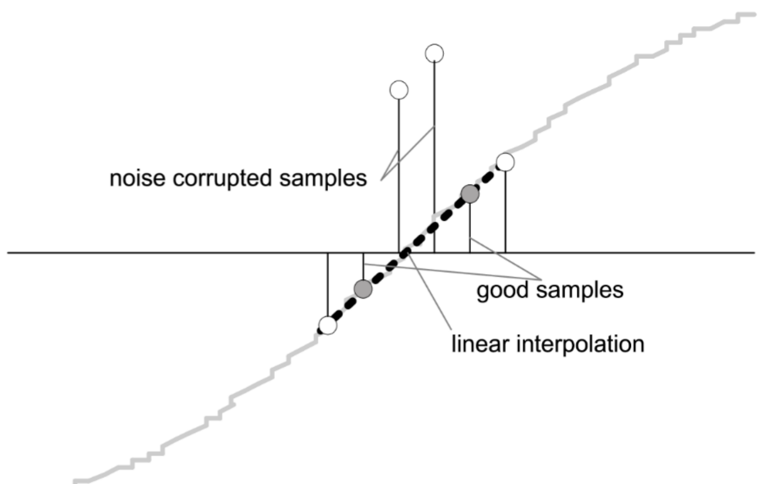


Figure 27 Frequency Measurement

Curtesy of Texas Instruments

4.6 Power Supply

While the power supply is one of the last blocks of the project to be implemented, it is still one of the most important components. It will need to provide various voltages to different devices, and be very efficient in order to support our low power design. We will discuss each component of the power supply and potential reference designs that are available to us.

4.6.1 Transformer

The power that is coming in from the wall is significantly higher than the voltage needed at the input of any of the components in the project. A step down transformer will be needed to obtain the desired input. The most common transformer works with coils that are winded to a certain turn ratio. The ratios of the turns designate the voltage increase or decrease at the output. The coil made by a wire wrap around creates a magnetic flux that surrounds it. Since we are dealing with a three-phase main line as the source for the power meter, a three-phase transformer is needed. The idea behind this is very similar to the idea of a single-phase transformer. Different turn ratios can be used to get different combinations at the output, however the turn ratios we need to be the same for the calculations later.

4.6.2 Switching Regulator

An efficient way of altering the output voltage to meet the requirements for the input of another device can be met with the use of a switching regulator. The switching regulator is very useful when stepping down or a up a voltage that is relatively high, where a linear regulator would not justify using.

The switching regulator works by opening and closing a switch in a circuit with an inductor. Since the purpose is to obtain a steady state DC output, the rate at which the switch opens and closes must be high. Several parameters have to be taken into considerations when dealing with switching regulators.

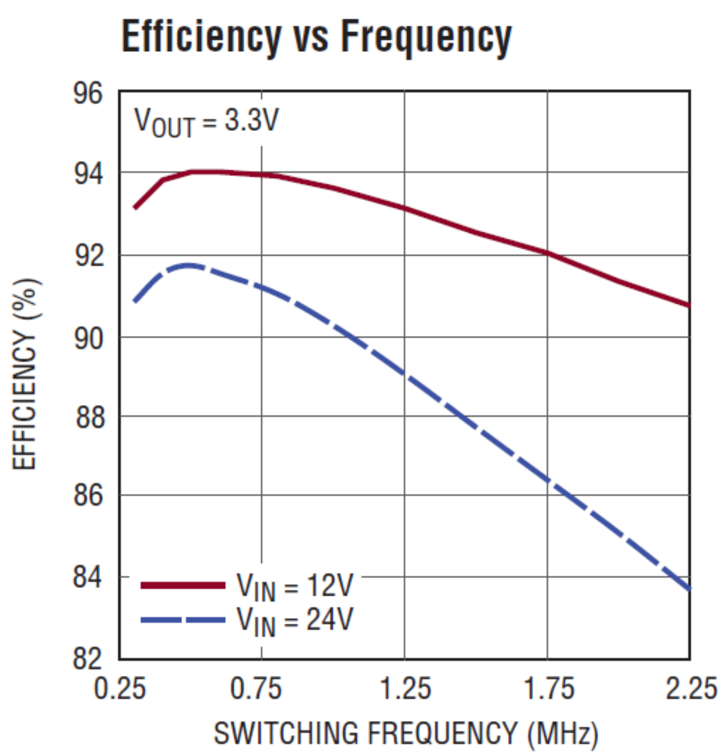


Figure 28 Efficiency vs. Frequency of a Switching Regulator

Image Courtesy of Texas Instruments

Here is a graph of the efficiency vs. frequency of a switching regulator. At the beginning, raising the frequency of the switching components raises the efficiency of the regulator, however eventually as the frequency goes up the efficiency decreases. This behavior of the efficiency dropping is due to the turn on and turn off losses that occur during each cycle also known as AC switch losses. If the rate of this increases the net loss also increases.

Another event that occurs at high frequency is electromagnetic interference or EMI since the inductor is being used at high frequencies it may act as an antenna and cause interference with the signals transmitted through radio frequency. This occurrence can be prevented using shielding. Since energy efficiency is always in mind when developing this project, a lower frequency will be used and then a linear regulator can take over and do the rest[9].

4.6.3 Linear Regulator

There are various situations where linear regulators will assist the project. For these situations, a linear regulator is actually better to use than a switching regulator. For starters, it is a very simple design that is adds minimal cost to the overall project. Due to the simplicity of the circuit, there a not much components needed. The concept behind linear regulators is very fundamental; a voltage is divided using a simple voltage division between the two resistors. Linear regulators are also advantageous to use when the output is noise sensitive.

For applications such as communications and radios, linear regulators are preferred because they can operate over a vast variety of frequencies where it can operate. This time parameter is not a necessity, but in other scenarios, it might. Linear regulators also have fast transient responses. In our project once, the voltage is regulated to a DC signal and is relatively close to the value of the voltage that is needed for the devices a linear regulator will help stabilize it to that value.

Since the objective behind this project is to help lower energy consumptions from users, it would only make sense to be conservative when designing out project and not wasting unnecessary energy. A linear regulator works by dissipating the excess energy as heat through a resistor. For minuscule differences in voltage this ideal because of the accuracy that you receive at the output. However if the difference is large than an abundant amount of energy is wasted and lowers your overall efficacy.

To obtain the advantage of having the accuracy that a linear regulator provides and still maintain an overall high efficiency for the power supply the project will more than likely use the linear regulator in conjunction with the switch regulator. They will be cascaded so that the linear regulator does not have to perform such a drastic step down in voltages.

4.6.4 Buck Converter

For an ideal buck converter, a given input voltage is stepped down to a lower voltage. The buck converter above is realized using active components such as operational amplifiers. The duty cycle of this converter is determined by the output of the error amplifier and the PWM ramp voltage as shown in the figure below. The on time starts on the falling edge of the pwm ramp voltage and stops when the ramp voltage equals the output voltage of the error amplifier. The output of the error amplifier is turn is se so that the feedback portion of the output voltage is equal to the internal reference voltage.

Here are some limitations to take into account when dealing with but converter the internal reference voltage is important. Normally a resistor divider network is used to feed back a portion of the output voltage to the inverting terminal of the error amplifier. This voltage is compared to the reference voltage and during steady regulation the error amplifier output will not go below the voltage required to maintain the feedback voltage.

After the power supply and between the components on the printed circuit board are going to include buck regulators. The buck regulators are going to be needed to step down the voltage at the output of the power supply so that the components obtain the desired input voltage. In the table below, there are specifications of several buck regulators[9]:

Part	Design	BOM Foot print(mm2)	BOM Cost ($)	Eff. (%)	Qty	Freq. (kHz)	V_o	Phase Margin (deg)
LM3151-3.3	SIMPLE SWITCHER(r) Controller	429	3.37	91	10	245	2.76	0
LM3150	SIMPLE SWITCHER(r) Controller	390	3.32	89	15	418	4.52	0
TPS40170	4.5V to 60V Input Synch. PWM Buck Controller	345	4.09	89	28	348	7.33	65
TPS40170-Q1	Automotive Qual 4.5-60V Input Synch. PWM Buck Controller	441	4.63	88	29	348	2.4	64

LM3152-3.3	SIMPLE SWITCHER(r) Controller	440	2.89	87	10	491	3.25	0
Part	**Design**	**BOM Footprint(mm2)**	**BOM Cost ($)**	**Eff. (%)**	**Qty**	**Freq. (kHz)**	**V_o**	**Phase Margin (deg)**
LM5116	100V Synchronous Buck Controller	406	0	87	22	526	20.07	66
LM25116	42V SYNC BUCK CONTROLLER	406	0	87	22	526	20.07	66
LM3489-Q1	Hysteretic controller	414	2.3	86	14	436	20.56	0
LM25117-Q1	42V, Wide input Range Synchronous Buck Controller	338	4.38	86	23	425	6.37	73
LM25117	42V, Wide input Range Synchronous Buck Controller	338	3.61	86	23	425	6.37	73

Temp(deg C)	Iout Max(A)	Vin Min(V)	Vin Max(V)	Vout Min(V)	Vout Max(V)	Min Freq(kHz)	Max Freq(kHz)IC Cost($)	IC Cost($)
47.26	12	6	42	3.3	3.3	250	250	1.62
49.2	15	6	42	0.6	40	100	1000	1.62

40.51	25	4.5	60	0.6	50	100	600	2.1
Temp(deg C)	**Iout Max(A)**	**Vin Min(V)**	**Vin Max(V)**	**Vout Min(V)**	**Vout Max(V)**	**Min Freq(kHz)**	**Max Freq(kHz)IC Cost($)**	**IC Cost($)**
40.51	25	4.5	60	0.6	50	100	600	2.46
57.37	12	6	33	3.3	3.3	500	500	1.62
44.15	20	6	100	1.215	80	50	1000	2.9
44.15	20	6	42	1.215	36	50	1000	2.04
66.03	4	4.5	35	1.239	35	50	3000	0.54
45.17	17	4.5	42	0.8	41	50	750	2.47
45.17	17	4.5	42	0.8	41	50	750	1.7

Table 18 Webench Results for Buck converter

4.6.5 Boost converter

Principles of Boost Converters are switching transistors and the flywheel circuit. Similar to the reason behind using a buck converter to lower the voltage due to having a device with a lower input voltage than the available supply, boost converters also come into use. When a device’s input voltage is higher than that of the supply a boost converter can be integrated in the power supply system. If a higher voltage is needed to be obtained but the physical dimensions of the show device does not allow room for extra batteries, a boost converter is useful.
Necessary Parameters of the Power Stage

The following four parameters are needed to calculate the power stage:

1. Input Voltage Range: VIN(min) and VIN(max)
2. Nominal Output Voltage: VOUT
3. Maximum Output Current: IOUT(max)
4. Integrated Circuit used to build the boost converter.

This is necessary, because some parameters for the calculations have to be taken out of the data sheet. If these parameters are known, the design of the power supply can take place. When designing most of the reference sheets include graphs that explain these calculations. The values that most of the technical documents contains ideal cases[9].

4.6.7 Power Factor Correction

Along with finding the right power supply comes the power factor associated with it. When connected, the project team and I need to find out if the current leads or lags the voltage and what is exact phase shift that they differ by. The power factor is a number between 0 and 1. The apparent power (which can be read by reading the volts and the amps and taking the product of the two). Another method of testing is to take the voltage and current wave forms at the output. Measure the phase shift in degrees and calculate the power factor by taking the cosine of the difference between them[31].

4.6.8 Reference Designs

PMP10164

The first reference design we came across was the PMP10164 power supply by TI. This design supplies 10.5 volts for the output with an output current of 1.8 Amps. A good thing about this is that it connects the AC mains and operates at a low power range. Since what we are, connecting it to have a fixed frequency the controller LM5021 performs a pulse skip mode. In this mode, the design is built for light loads. At the same time, the rectification controller UCC24630 has being integrated in the design to increase the efficacy. This design also does well in terms of thermal performance.

Below is a plot of the different efficacy at different frequencies. Fortunately, the application that we intend for this power supply is intended to an alternating voltage signal at a frequency of 60 Hz. This happens to be when the design operates to most effective[9].

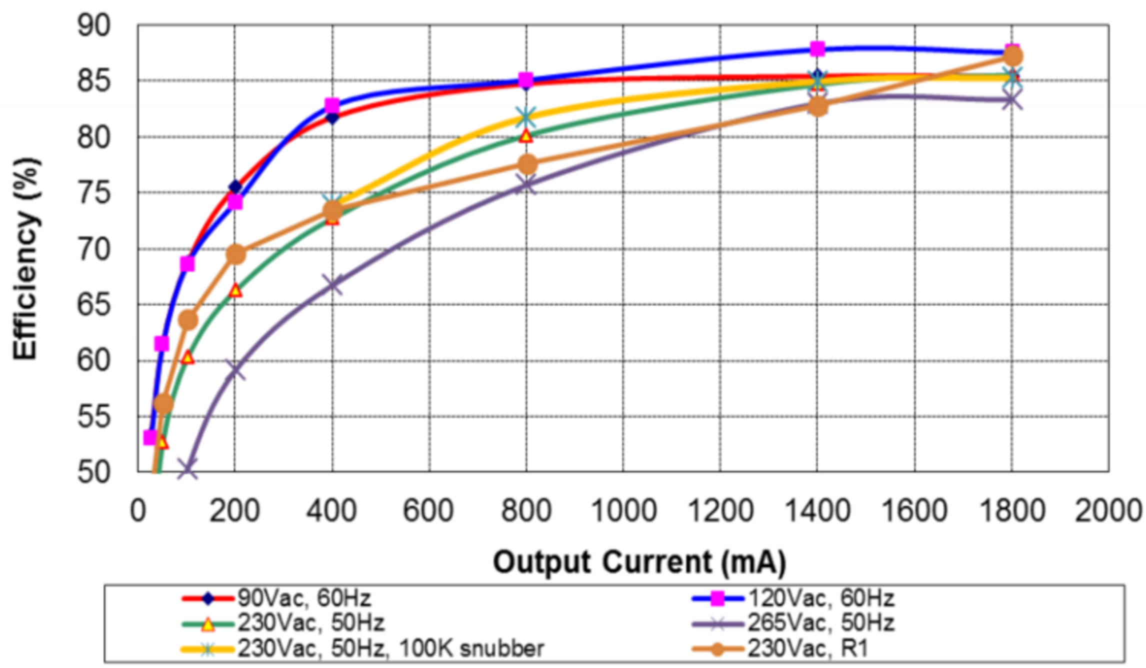


Figure 29 Efficiency vs Output Current

Iout(mA)	Vout(V)	Pout(W)	Pin(W)	Vin(Vac)	Ploss(W)	Eff(%)
0	10.642	0	0.126	120	0.126	0.00
27.0	10.642	0.287	0.542	120	0.255	53.01
51.1	10.642	0.544	0.885	120	0.341	61.45
102.0	10.641	1.085	1.582	120	0.497	68.61
200.8	10.641	2.137	2.883	120	0.746	74.11
401.4	10.641	4.271	5.162	120	0.891	82.75
800.5	10.641	8.515	10.010	120	1.495	85.06
1402	10.633	14.907	16.98	120	2.073	87.79
1803	10.631	19.168	21.90	120	2.732	87.52

Table 19 Test Results

As we can see from Figure 30 and Table 19, this power supply provides up to 1.8 A at an efficiency of 87%. It outputs a voltage of 10.5V, therefore we will be required to follow this design with a regulator to step the voltage down to the range of 3.3V.

PMP10804

The next reference design we are considering is the PMP10804 reference design by TI. It implements the UCC28630 PSR controller in a fly-back power supply. The

UCC28630 is capable of operating in both Continuous and Discontinuous Conduction Modes, which enables high efficiency while reducing inductor size and cost. Safety standards such as EN60950 require that any X-capacitors in EMC filters on the AC side of the bridge rectifier quickly discharge to a safe level when AC is disconnected. Typically, this requirement is achieved by including a resistive discharge element in parallel with the X-capacitor. However, this resistance causes a continuous power dissipation that affects the standby power performance. In order to reduce standby power and eliminate the standing loss associated with the conventional discharge resistors, the UCC28630 device incorporates active X-capacitor discharge circuitry. In this design, less than 100mW no load power consumption and over 88% converter efficiency is achieved. It boasts the following features:

- Utilize UCC28630 CCM/DCM PSR controller
- Over 86% average efficiency
- Optimized US line AC-DC power supply design
- 24V/4A rated output

This circuit is tested and includes a test report.

Below is a plot of the efficiency over a range of output power. Our project is estimated to use a output power range of 20 to 30 Watts. Figure 31 shows that this design will operate in the 88% efficiency range at this wattage.

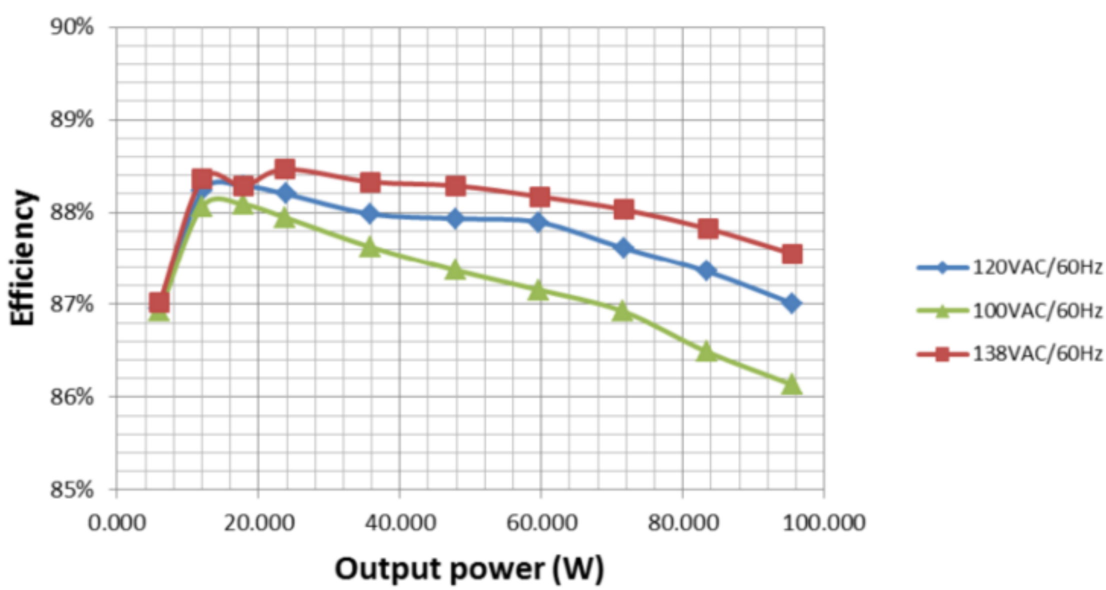


Figure 30 Efficiency vs. Output Power

Image Courtesy of Texas Instrument

Below is a table of the efficiency over a range of current inputs:

Vin(Ac)	Iin(A)	Pin(W)	Vout(V)	Iout(A)	Pout(W)	Eff.(%)
120.06	1.416	109.75	23.82	4.01	95.494	87.01
120.27	1.248	95.56	23.83	3.50	93.47	97.36
120.08	1.085	81.88	23.84	3.01	71.735	87.61
120.28	0.915	67.92	23.85	2.50	59.697	87.89
119.76	0.749	54.49	23.85	2.01	47.915	87.93
120.01	0.566	40.78	23.84	1.51	35.88	87.98
120.07	0.3988	27.03	23.84	1.00	23.84	88.20
120.19	0.308	20.19	23.83	0.75	17.825	88.29
120.01	0.217	13.601	24.00	0.50	12.00	88.23
120.17	0.121	6.926	24.090	0.25	6.023	86.95
120.35	0.01362	0.095	24.38	0.00	0.00	0.00
120.32	0.107	5.690	5.011	1.000	5.011	88.07
120.39	0.060	2.884	5.001	0.500	2.506	86.88
120.03	0.015	0.036	5.014	0.000	0.000	0.00

Table 20 Test Results

PMP10974

The next power supply design we are considering is the PMP10974 reference design by Texas Instruments. The PMP10974 is a quasi-resonant Flyback power supply based on the UCC28730 primary side regulation (PSR) controller. The elimination of the opt coupler using PSR topology promises higher reliability and lower system cost. The design achieves less than 40mW standby power losses and over 89% average efficiency. The design also features UCC2463x synchronous rectification controller. It has the following features:

- 85VAC to 265VAC, 50/60Hz input 5V/10A/50W output
- Over 89% average 4-point efficiency
- Over 85% efficiency at 10% load (5W)
- Less than 40mW standby power losses
- Protected against output short-circuits

As we can see from the graph in Figure 32, the design reaches an efficiency of 90% at an output current of 3A.

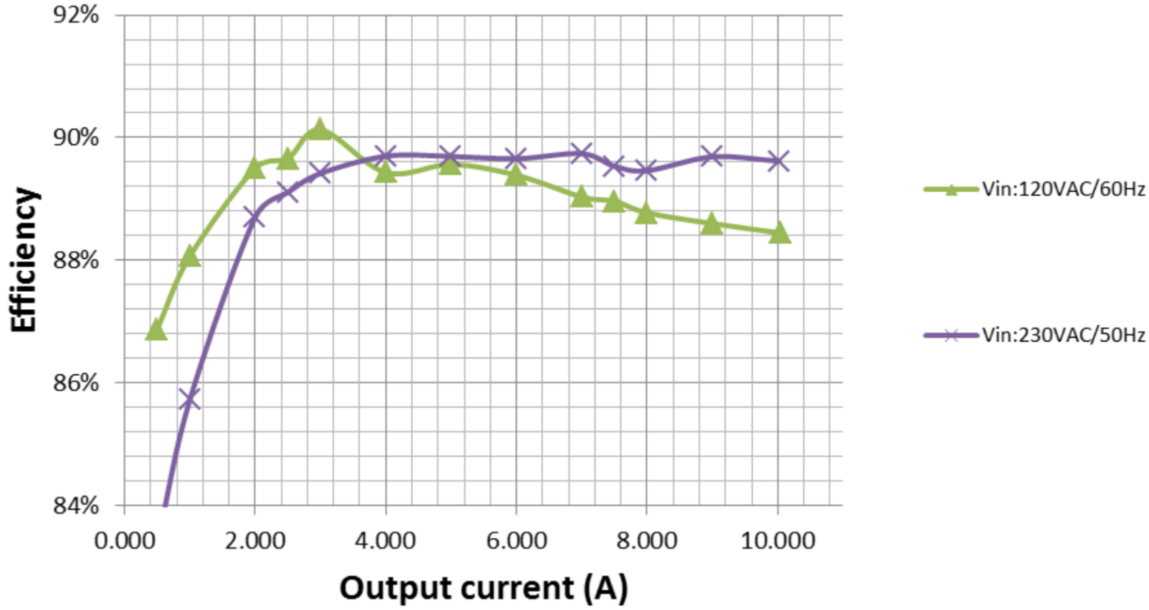


Figure 31 Efficiency vs Output Current

The table below shows the efficiency at different loads. It reaches a peak efficiency of 90% at an output current of 3A.

Vin(Ac)	Iin(A)	Pin(W)	Vout(V)	Iout(A)	Pout(W)	Losses	Eff.(%)
119.97	0.858	59.210	5.216	10.040	52.369	6.841	88.45
120.07	0.770	52.690	5.187	9.000	46.683	6.007	88.60
120.17	0.686	46.500	5.16	8.000	41.280	5.220	88.77
120.02	0.645	43.400	5.148	7.500	38.610	4.79	88.96
120.06	0.604	40.380	5.136	7.000	35.952	4.428	89.03
120.16	0.521	34.320	5.113	6.000	30.678	3.642	89.39
120.27	0.439	28.410	5.089	5.000	25.445	2.965	89.56
120.03	0.360	22.650	5.064	4.000	20.256	2.394	89.43
120.1	0.276	16.801	5.046	3.001	15.143	1.658	90.13
120.16	0.235	14.031	5.032	2.500	12.580	1.451	89.66
120.21	0.193	11.220	5.021	2.000	10.042	1.178	89.50
120.32	0.107	5.690	5.011	1.000	5.011	0.679	88.07
120.39	0.060	2.884	5.001	0.500	2.506	0.379	86.88
120.03	0.015	0.036	5.014	0.000	0.000	0.036	0.00

Table 21 Test Results

To reiterate, the most important factors to consider when designing the power supply is the input voltage, input current, output voltage, and output current. It must be able to provide enough voltage and current to each device in our system and at very high efficiencies (~90%). These factors will determine which reference design we decide to use.

High Performance Integrated High Voltage Driver
The final reference design in consideration is by ON Semiconductors. It's an integrated driver for high voltages. It provides an output of 12V and 20 A for an input between 90 - 264 V[9].

4.6 Liquid Crystal Display (LCD)

Liquid crystal is a term used to describe a substance that is between a solid and a liquid, but which exhibits properties of both. One of the most important characteristics of liquid crystals is that they are affected by electrical currents, and react predictably to them, making it easy to control the movement of light. The light can be taken in from an external source, or from a source within. The most common type of LCD used in electronics is the Active Matrix or Thin Film Transistor (TFT) LCD. TFT LCDs use a grid of transistors that are able to store a charge in each of their cells [30].

The LCD in our system will add a user interface so that the user can remain up to date on information. It will display a confirmation when the user makes a payment, so the user knows that their payment did in fact go through. It will also display their remaining balance, current usage, and estimated time remaining. It will blink 'low balance' whenever the user's balance drops below a certain threshold.

4.6.1 Capacitive touch LCD

A capacitive touchscreen is usually made of one insulating layer, such as glass, which is coated by a transparent conductive material. It uses the conductivity of the human body to sense the touch. As the user touches the screen, it causes a change in the screen's electrical field and is processed and the location of the touch is determined [28]. Capacitive touchscreen are very responsive to touch and can sense multiple touches at a time. However, due to its reliance on capacitance, the user cannot use a pen or other object.

With this type of LCD, the user will have more control over which information they would like to be displayed by pushing on the screen.

4.6.2 Resistive Touch LCD

A resistive touch LCD consists of two transparent layers, usually made of glass or acrylic, these layers are coated with a conductive and resistive material. They are separated, and when a finger presses on it, the top layer makes contact with the bottom layer and a grid system determines the precise location of the touch. Resistive touchscreens are more versatile as they can be used with a finger, pen, or any other object. They are cheaper than capacitive touch LCDs and have higher resolution, however they are less responsive, and since they layers must be moved they are more susceptible to breaking [29].

With this type of LCD, the user will have more control over which information they would like to be displayed by pushing on the screen. This would also increase the user experience using the project.

4.6.3 Segmented

Segment LCDs are monochrome, inexpensive displays that are used widely in industrial applications. They provide the following key features:

- Long life and high reliability
- High contrast ratio
- Wide viewing angle
- Fast response
- Inexpensive
- Simple I/O interface
- Low power consumption

The relatively low power consumption, reliability, and simple I/O interface of the segment LCD makes it a favorable solution for our systemThis is a simpler method because there are less possible combinations that the screen can be in. These fewer combinations allows for easier trouble shooting when it comes to implementing this in to the project. In our system, we will have the LCD scroll through the various parameters to be displayed, and when the user makes a payment it will display the confirmation. This is a simple, yet effective interface for the user, that requires relatively little programming [30].

4.7 Android

As mentioned earlier we replaced the passive transponder tag with the alternative option that is an active one. Having an active tag will enable us to use all three modes of NFC during testing and developing, moreover being an android phone. Android was chosen over iPhone since they have been using NFC since 2010 that means that more users that have androids in the past years will be able to benefit from this feature. The fact that this wireless communication feature has been integrated in Android devices for a longer time also means that there are more references that can be utilized to aid us in integrating this into our project. Another benefit would be towards the consumers since the iPhone 6 is a fairly new and expensive phone and therefore not a lot of consumers will be able to benefit from this system and utilize it.

On the other hand, the iPhone added NFC to their devices when the iPhone 6 came out, which has a release date of September 2014. Another reason that the project team and I chose to use Android instead of Apple was that the phone was inexpensive and there was no need to purchase a developer license which apple requires when developing apps. Along with the developer license that needs to be purchased the software needs to be coded on a Mac.

Since we are also going to develop an app for the user to have on their phone, and we have no computer engineer in our group android was also the better choice because it is open source with an abundance of APIs and has a huge online community that can be a ton of help for our development. Their online community consists of developers that are regular people trying to implement projects to professionals that have tips, hints and full explanations as to how to start developing on the android website. Android's programming language is based on java which is object oriented programming and the development environment they use is Android Studio. We will go more into details about Android Studio in a later section [5], [11].

4.7.1 Application

There are two powerhouse companies in the smart phone world, iPhone and Android therefore developing the application for our system is an immense factor in the decision of which phone to develop on. Being either an iOS apps developer or Android apps developer requires a specific set of tools to begin. To develop iOS apps one first needs a Mac computer with OS X 10.10 or better that can run the latest version of Xcode IDE being Xcode 7. Xcode works on swift programming language, and contains APIs as well as being able to have the user test and record the app in action. The next stage in being a developer is to choose a type of developer membership. The memberships are split in two main sections being individual or organizations and within each, there are more options. The cheapest and first type would fall under individuals section, which is free, and all one needs is an apple ID. The second type under individuals would be the apple developer program, which costs 99 USD per membership year. This includes access to beta OS releases, advanced app capabilities, and tools to develop, test, and distribute apps and Safari extensions. Then comes the second section, which is Organizations. Within organizations comes the same program, as individuals being the apple developer program the only difference is that the entire development team will receive the benefits too. The last type would be the Apple Developer Enterprise Program, which is the most expensive memberships for 299 USD per membership year. This program adds the feature of having the apps designed and distributed exclusively to that organization.

A table below will be provided to compare all the benefits and features of each membership program.

Benefits	Apple ID	Individual	Organization	Enterprise Program
Xcode Dev Tools	✓	✓	✓	✓
Xcode Beta Release	✓	✓	✓	✓
Dev Forums	✓	✓	✓	✓
Bug Reporter	✓	✓	✓	✓
Test on Device	✓	✓	✓	✓
Beta OS Releases		✓	✓	✓
Advanced App Capabilities		✓	✓	✓
App Store Distribution		✓	✓	
In House App Distribution				✓
Safari Extensions		✓	✓	
Developer ID		✓	✓	✓
Technical Support Incidents		✓	✓	✓
Team Management			✓	✓
TestFlight Beta Testing		✓	✓	
App Analytics		✓	✓	
Cost/year	Free	99 $	99 $	299 $
Requirement	13+	18+	DUNS Number	DUNS number

Table 22 Benefits of Each Membership

Being an Android developer also asks of the soon to be developer to have another type of specific tools. Although one still needs certain tools they are not as specific and heavy as being an iOS apps developer. The two main benefits and features of being an Android developer is that it is free and open source. Since it is both free and open source there is a huge amount of help on the internet from Android engineers having tips and help on the android website to complete videos and tutorials from every day people. The environment used in developing apps is

Android Studio and the programming language is based on Java as well as XML [5], [11].

4.7.2 NFC in Android

Since android is an NFC enabled device, just like the TRF7970A transceiver it also contains all three modes of NFC being Reader/Write, Peer to Peer, and Card Emulation. These features add extra design flexibility since both of our devices can operate in any of the three modes, just like the TRF7970A, Reader/Write mode will have the phone act as the initiator and the TRF7970A be in card emulation mode. In Peer to Peer mode both devices will be able to communicate with one another, and when the phone is in card emulation mode it will act as the tag and the TRF7970A will be in Reader/Write mode and will initiate the communication between both devices [5].

4.8 Wi-Fi Processor

We noticed the trend nowadays is moving towards device connectivity, and we wanted to implement that into our system. We decided to add a Wi-Fi module into our system so that the user can always remain connected to it, wherever they are in the world. As long as the user is connected to the internet, they will have access to information about their utilities at home. The system will send data to the user's smartphone through the internet so that the user can monitor their system on the go. It will also send alerts to the user if their balance gets low. We are going to implement this using one of TI’s network processors.

4.8.1 WL1837 Wi-Fi Module

The WL18xx family of Wi-Fi modules is one of TI’s older models for Wi-Fi connectivity. The WL1837 is a certified WiLink module that offers both Wi-Fi and Bluetooth in a power-optimized design. The device operates at a frequency of 2.4GHz and 5GHz with two antennas, and is FCC, IC, ETSI/CE, and TELEC certified. The WLAN baseband processor and RF transceiver supports IEEE standards 802.11a, 802.11b, 802.11g, and 802.11n. It has very low standby power consumption while connected to Wi-Fi (< 800uA).

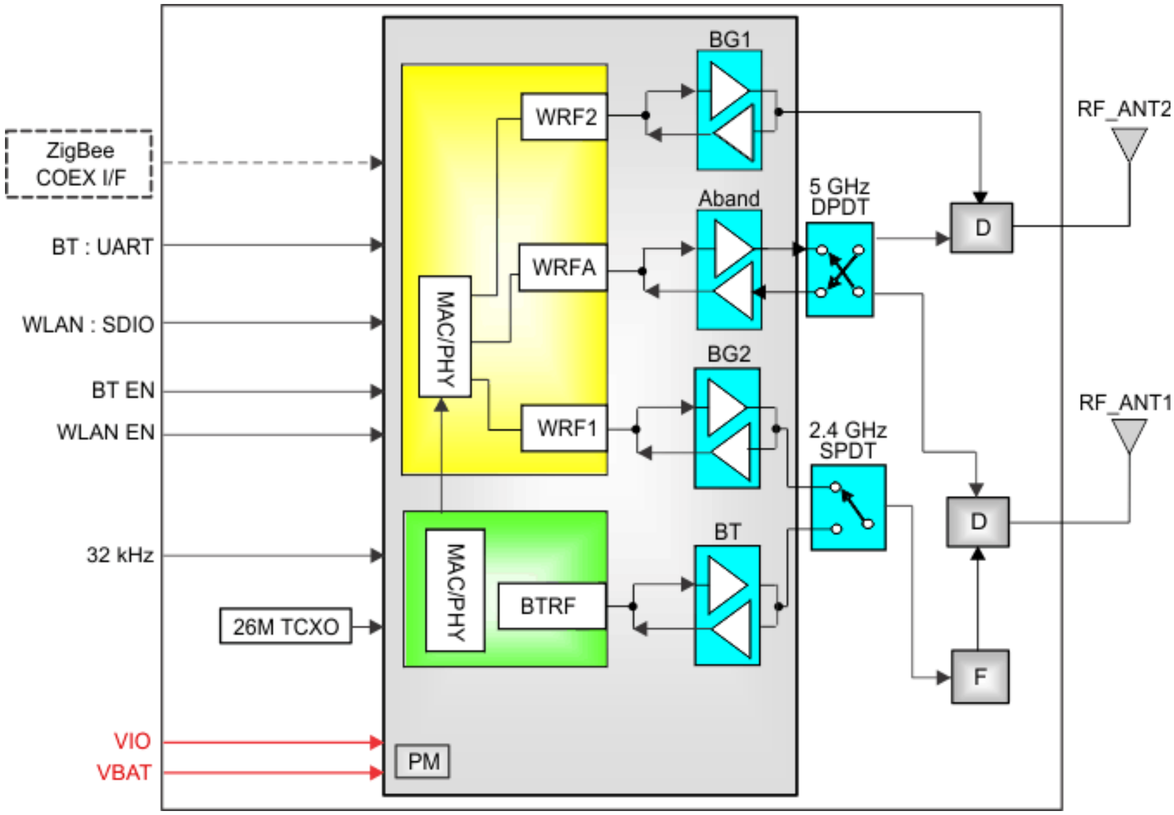


Figure 32 WL1837 Block Diagram

Image Courtesy of Texas Instruments

However, our system does not require Bluetooth, only Wi-Fi, therefore this chip would just increase power consumption without providing any extra benefit. Configuration of the WiLink modules also requires more Wi-Fi expertise than the CC family's SimpleLink setup.

4.8.2 CC3100 Network Processor

The CC3100 SimpleLink Wi-Fi Network Processor is an Internet of Things (IoT) solution by TI that allows any microcontroller to connect to the internet. It features a network subsystem and a power-management subsystem, and allows for connection to the host MCU via SPI or UART. Looking at Figure 34, the network subsystem features a dedicated ARM CPU that offloads the host MCU, an 802.1.1 b/g/n radio, MAC processor, baseband, and integrated internet and Wi-Fi protocols. The power-management subsystem includes integrated DC-DC converters that allow for a wide range of supply voltages, as well as various low power modes. The SimpleLink setup, along with the integrated internet and wifi protocols, will make setting up easy. Since we do not have any previous Wi-Fi experience, this is very important.

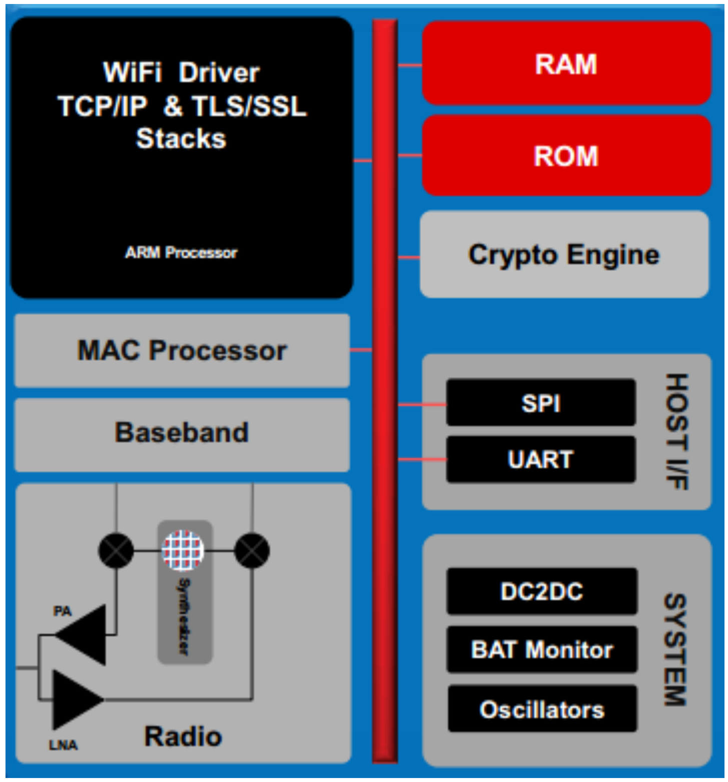


Figure 33 Hardware Overview

Image Courtesy of Texas Instruments

4.9 Software

While there is a lot of hardware implementation in this project, it is also very programming intensive. Once we have all the hardware in place, we will spend the majority of the time implementing software, testing, and debugging. We will be making use of the various software available to us to help us accomplish our task.

4.9.1 Energia

Energia is an open source and community-driven integrated development environment (IDE) & software framework. Based on the Wiring framework, Energia provides an intuitive coding environment as well as a robust framework of easy-to-use functional APIs & libraries for programming a microcontroller. Energia supports many TI processors, primarily those available in the LaunchPad development ecosystem, including the CC3200, MSP430, TM4C, and CC2000.

4.9.2 Code Composer Studio

Code Composer Studio is an integrated development environment (IDE) used for TI's microcontrollers. It features a C/C++ compiler, source code editor, and debugger. It allows us to single step code, inspect variables, and view registers, and is the IDE we are most familiar with.

4.9.3 Android Development Kit

The Development Kit that is used for android is Android Studio. Android Studio is the official IDE for android applications and it is based on IntelliJ IDEA which is a more intelligent Java IDE. Android Studio also allows the user different views of the application that is being developed, the default view being Android project view. This view shows a flattened version of the project's structure which will provide quick access to key source files of Android projects. This view shows the most important source directories at the top level of the module hierarchy, groups the build files for all modules in a common folder and it groups resource files for different locales, orientations, and screen types in a single group per resource type. Android Studio also provides a number of improvements to assist in debugging which includes an improved device management, inline debugging, and performance analysis tool. The Android Virtual Device Manager (AVD) gives the developer to emulate a phone of choice that will be able to run the application. This is done by installing Intel x86 Hardware Accelerated Execution Manager (HAXM) emulator accelerator. Inline debugging is another feature that enhances the code walk-throughs in the debugger view with the inline verification of references, expressions, and variable values. Moreover, Android Studio provides a memory and CPU monitor to easily monitor the application's performance and memory usage to track CPU usage, locate memory leaks, find deallocated objects and track the amount memory the device that is connected is using [5].

4.9.4 SimpleLink Studio

Simple Link Studio is a Windows based software for the development and programming of network applications for the CC3100 Network Processor. It supports any IDE like Code Composer Studio, Eclipse, and Visual Studio, and enables debugging of network applications. It comes with an array of reference applications, making previous Wi-Fi experience a non-requirement.

4.9.5 NFCLink

NFCLink is a complete firmware and software solution that has been developed by Texas Instruments and a third party. The total solution is intended to be used for developing NFC applications that require any of the modes of NFC. Moreover, it is intended to be used with a variety of operating systems such as windows and android. It is a library of NFC and HF RFID firmware using the Near Field Communication Interface and Protocol to communicate to a host OS or MPU. It supports all MSP430 5 series and 6 series devices.
Features:

- Supports NFC/HF RFID Reader/Writer functions for formatting, reading and writing.
- NFC Tag Type Platforms 2, 3, 4A, 4B and V (ISO15693).
- Supports NFC/HF RFID Peer to Peer functions using Simple NDEF Exchange Protocol.
- Supports Card Emulation functions as NFC Tag Type Platforms 4 A/B.
- Windows XP/7 based GUI with integrated stack for use with MSP-EXP430F5529 and TRF7970ATB hardware platform
- SPI driver for TRF7970A.

The figure below is a simplified block diagram of the NFC Link architecture. There are MSP430 object code and source code components, with the source code components being the necessary ones needed to be modified by us for different MSP430 MCUs, while the object code portions are specific to NFC and RFID functions that are completed, thus making it more simple for us to develop our own solution just to use it and not have to research and learn all about the low level details of how NFC or RFID works.

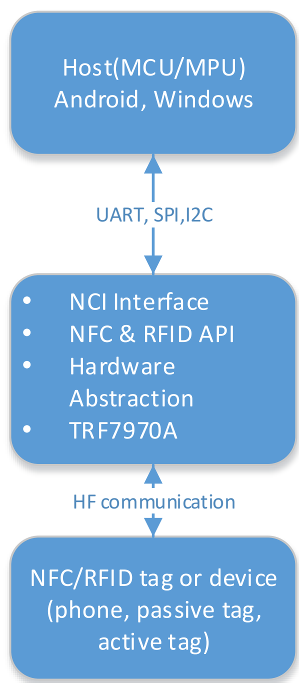


Figure 34 NFC Link Architecture

The complete NFC solution for our project will be shown in the figure below. This solution has four main parts the host, which in our case will be a computer with Windows Operating System, the source code and library format which will be part of NFCLink and ran by the MSP of choice which is the MSP430FR6989, the RFID transceiver of choice which is the TRF7970A, and the NFC or RFID device which will be the Samsung Nexus S.

The numbers 1, 2 and 3 on the picture show the source code, and that is the part of the code that will need to be modified for different MSP430s. Since the TI NFCLink user guide uses the MSP-EXP430F5529, we will have to adjust the code to work on our MSP430FR6989. In our case, the host will just be used for testing and programming the entire system, and not for the complete product [9].

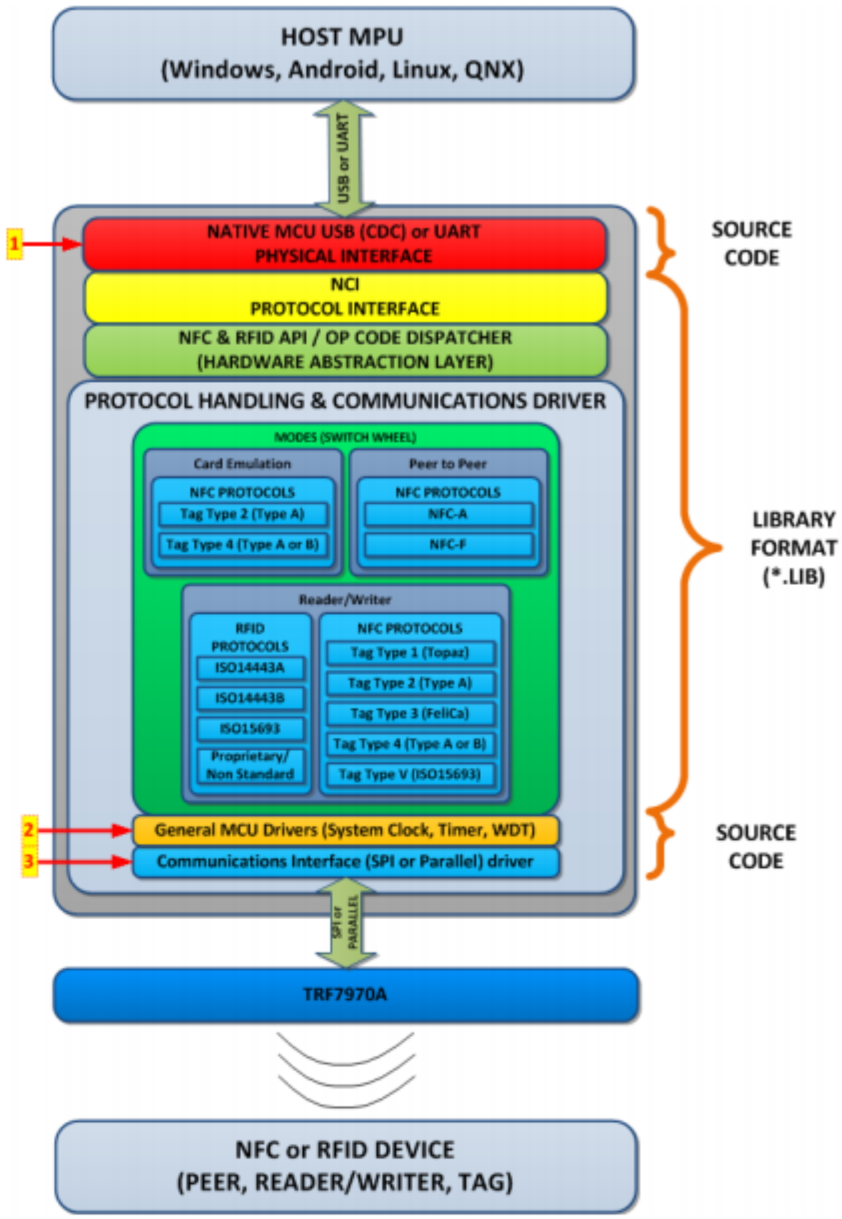


Figure 35 Complete NFC Flowchart

4.9.6 EagleCAD

The software we will be using to design our PCB is CadSoft's EAGLE PCB Design Software. We will be using the lite version since it is free, however this version comes with limitations. We can only use dimensions up to 100 x 80 mm or 4 x 3.2 inches. It also only allows for one layer to be designed as well as one sheet in the editor.

5.0 Design

Once research has been completed, we will begin the designing phase of our project. The designing section will be divided into hardware and software implementation subsections. Each component of our system will be designed individually and put together afterwards. These components are the power supply, microcontroller, RFID transceiver, Wi-Fi processor, solid-state relay, and LCD. Once hardware and software implementation is complete, we will begin the prototyping stage, and then finally the PCB.

5.1 Power Supply

The power supply is one of the last blocks of the project to be implemented since it relies on the other components to be completed first. It is one of the most important components of the design since proper operation of the system relies on sufficient power supply. It will need to provide various voltages to different devices, and be very efficient in order to support our low power design. As we can see from Figure 37, it will provide power to four of the devices. We will discuss in further detail the various components and specifications of this power supply design.

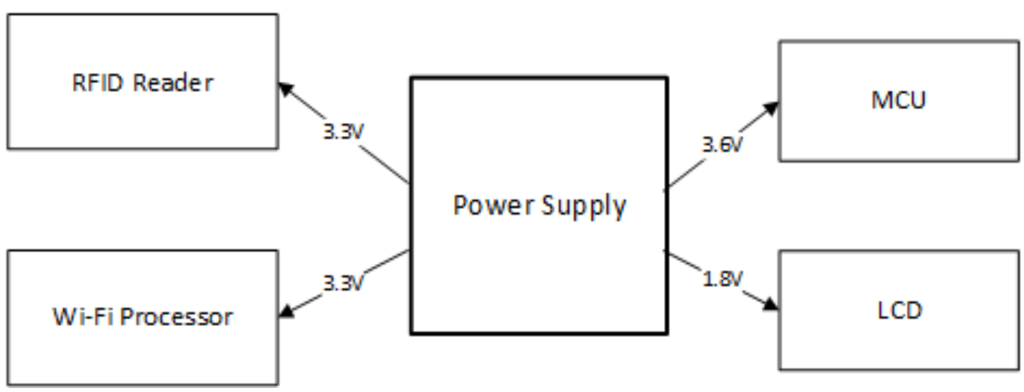


Figure 36 Power Supply Breakdown

5.1.1 Current Consumption

When designing the power supply, one of the most important parameters, as previously mentioned, is the maximum output current, Iout, which the power supply can provide. We must make sure that the power supply can provide enough current so that none of the devices are current starved at any time. If this occurs, system operation can become unreliable and unpredictable. Therefore, we must determine the maximum current consumption of every device in our design and calculate the overall maximum current consumption of the entire system. These values are commonly found in the device's datasheet. For easy comparison, a table has been compiled with the maximum current draw of each device[9]:

Device	**Maximum Current Consumption**
TRF7970 RFID Transceiver	150 mA
CC3200 Wi-Fi MCU	700 mA

Table 23 Maximum Current Draw

Device	Current	Voltage	Power Consumption
TRF7970 RFID Transceiver	150 mA	3.3 V	495 mW
CC3200 Wi-Fi MCU	700 mA	3.3 V	2.31 W

Figure 37 Power Consumption

The power supply will be responsible for supply current to four devices, the RFID chip, Wi-Fi chip, MCU, and LCD. As we can see from the table, a maximum of about 940mA can be drawn from the power supply during peak operating times. This was taken into account when considering the design for the power supply.

The maximum output power from the power supply is 120 watts. This is more than enough to power the 4 devices[9].

5.1.2 AC/DC Converter

For the AC to DC converter several parameters were important for this project. The main one is that the efficiency should be high. The project team and I figured that 90 percent or higher was a good number to try to achieve. Another specification was the size; we didn’t want a power supply to be enormous relative to the rest of the components. Cost was not so much of an issue; however, it was still kept in mind because our project should be high performance at a reasonable price.

For the most part the power supply will do most of the work of converting the wall’s AC voltage into a reasonable DC voltage. Since there are several components each with a different desired input voltage switching or linear regulators will in added to meet these specifications. Figure 38 provides an example flowchart of the powering process.

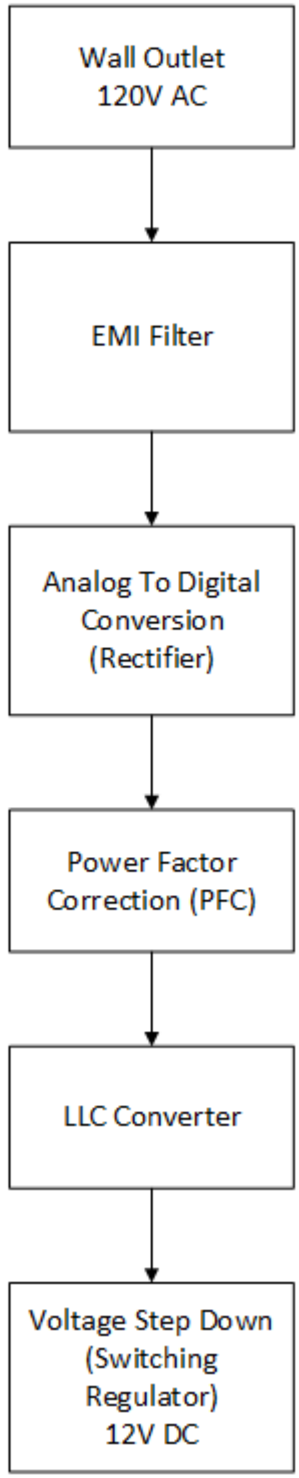


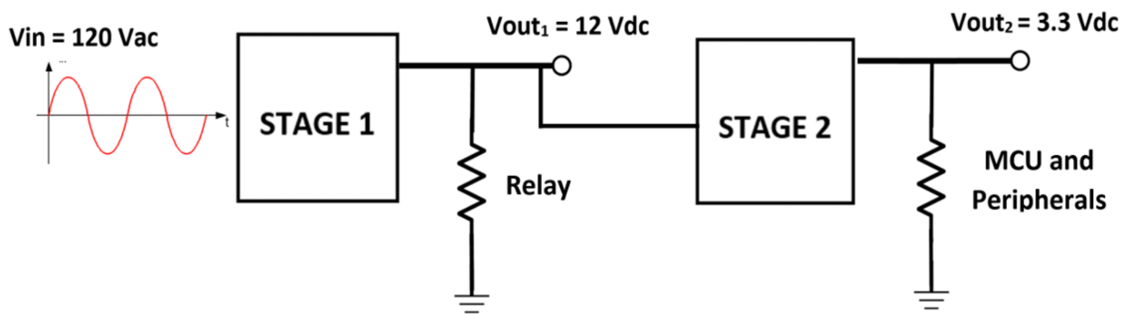
Figure 38 Power Supply Flowchart

5.1.3 Step-down Converter

Once the power supply converts the AC voltage from the wall to a DC voltage, we will use a switching regulator to step it down to 5V at high efficiency. From there we will be using linear regulators to go down to 3.6, 3.3, and 1.8V.

5.1.4 Power Supply Design

The power supply was divided into two stages, the first stage has an output voltage of 12 Volts and must be able to power the second stage along with the solid state relay. The second stage has to have an output of 3.3 volts and must be able to supply power to the CC3200 microcontroller and it's peripherals such as the Radio Frequency transceiver.



For the first stage a design from Texas Instruments reference page was used. The PMP8764 was used, it utilizes a Flyback topology. After looking at several designs they all follow a similar pattern as the architecture used when constructing these circuits. Most of the circuits had an IC chip that uses a feedback as well as pulse width modulation to regulate the output voltage. Several of these circuits start off with a full bridge rectifier, include a IC chip that has a feedback and a transformer.

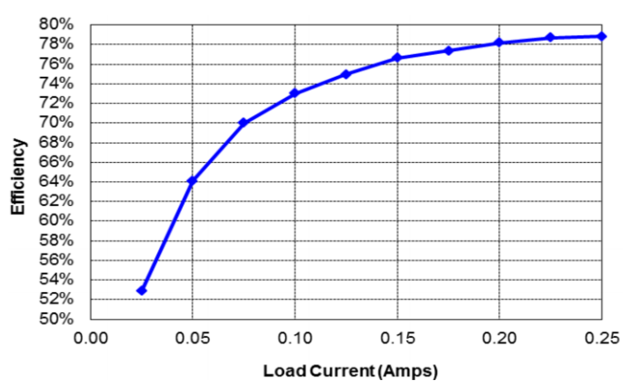


Figure Output Current

For the second stage a DC to DC buck converter with another IC chip was used. This design was exported from Webench. This one was choose because at lower currents such as 600 mA the efficiency was in the 95% range. Another benefit with going with this design is that if there are any fluctuations with the amount of current being drawn that the efficiency still stays around the same percentage.

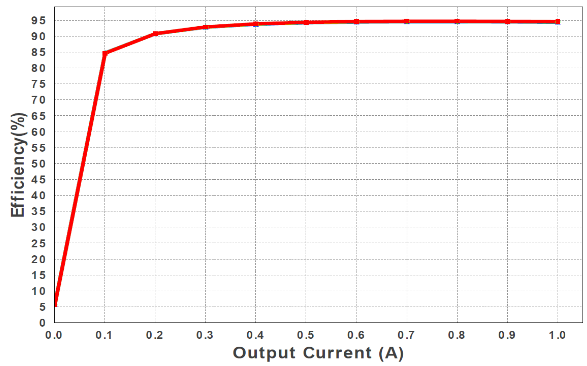


Figure Output Current

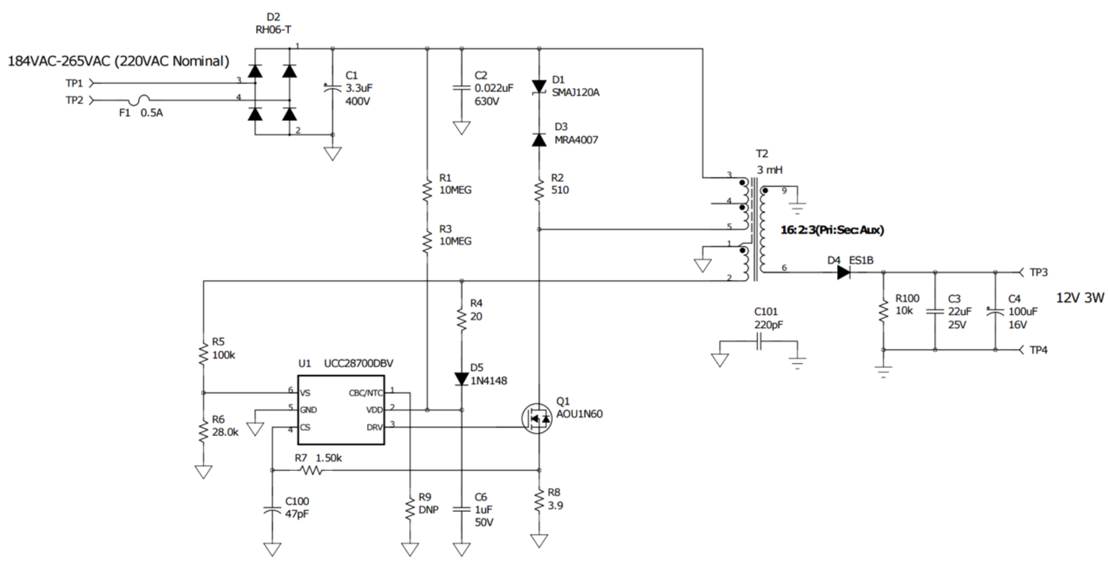


Figure 39 Design Schematic

Image Courtesy of Texas Instruments

5.2 Microcontroller Unit - CC3200

The microcontroller unit for our system lies at the center of our design. It is responsible for communication between the RFID transceiver, power meter, relay, and smartphone. We decided to go with TI's CC3200 wireless microcontroller (MCU) for our project since it features a network processor and robust MCU within a single chip. The applications MCU features an ARM Cortex-M4 core running at

80 MHz as well as 256KB of RAM. The network processor features another ARM Cortex core that offloads the application MCU. It runs at a supply voltage range of 3.3V so that we can maintain our one voltage rail.

5.2.1 Enhanced Universal Serial Communication Interface

In the MSP430FR6989, the Enhanced Universal Serial Communication Interface (eUSCI) modules are used for serial communication. It supports SPI, I2C, UART, and IrDA, but we will be using only SPI protocols for communicating. In SPI mode, data length can be 7 or 8 bits, and either LSB-first or MSB-first can be used for data transmission and receiving. For our system, three signals will be used for data exchange:

- UCxSIMO - Slave In, Master Out
    - UCxSIMO is the output line
- UCxSOMI - Slave Out, Master In
    - UCxSOMI is the input line
- UCxCLK - eUSCI SPI Clock
    - UCxCLK is an output

Communication between the CC3200 and RFID transceiver is done via SPI. Once the RFID transceiver detects that the user wants to make a payment, it sends an interrupt to wake up the MCU. Data is sent and received through the Master Out Slave In (MOSI) and Master In Slave Out (MISO) lines into and out of the transceiver's FIFO until the process is complete. When the MCU successfully receives the payment, it adds it to the user's current balance and flashes the LED to notify the user. At this time, the MCU will connect to an Simple Mail Transfer Protocol (SMTP) server to send the user a text message and e-mail confirmation.

Communication between the CC3200 and power meter is done via Wi-Fi. The power meter is interfaced to a CC3100 network processor that enables the power meter to host its own wireless network. The CC3200 retrieves metrology data from the meter at one minute intervals. When the timer interrupt is initiated on the MCU, it will disconnect from its current wireless network and connect to the wireless network of the power meter. The wireless network on the power meter is secured using Wi-Fi Protected Access 2 (WPA2) so that only the CC3200 will have access with pre-installed credentials. The network processor on the power meter hosts its own Hypertext Transfer Protocol (HTTP) web server which stores and displays the metrology data. To retrieve the data, the CC3200 acts as an HTTP client to the power meter's server and uses HTTP GET commands. GET commands are requests sent by the client to the server for specific token values. On the power meter side, when the server receives these requests, it responds by replacing the token with the values stored in memory. For example, if the CC3200 sends a request for the token "voltage," the power meter will replace this token with "120" and respond. The CC3200 then stores the values in memory to be displayed later, and deducts from the user's balance, if power has been consumed. When completed, the CC3200 reconnects to the internet and sleeps until the next interrupt. Conditional statements are set up so that if the user's balance drops below a specified threshold, the user will receive a text message alert.

Furthermore, the CC3200 hosts its own HTTP web server so that the user can access its webpages from their smartphone, or any web browser. These HTML web pages are stored within the flash memory of the CC3200. They display the following information: total kWh, current kWh usage, average kWh usage, estimated time remaining based on current load, estimated time remaining based on average load, relay status, number of payments made, and current balance. The smartphone retrieves the data similar to the power meter, by acting as a client and sending HTTP GET commands to the CC3200 server.

Finally, if the user's balance does drop to $0, the CC3200 toggles HIGH its GPIO pin connected to the relay to disconnect the load.

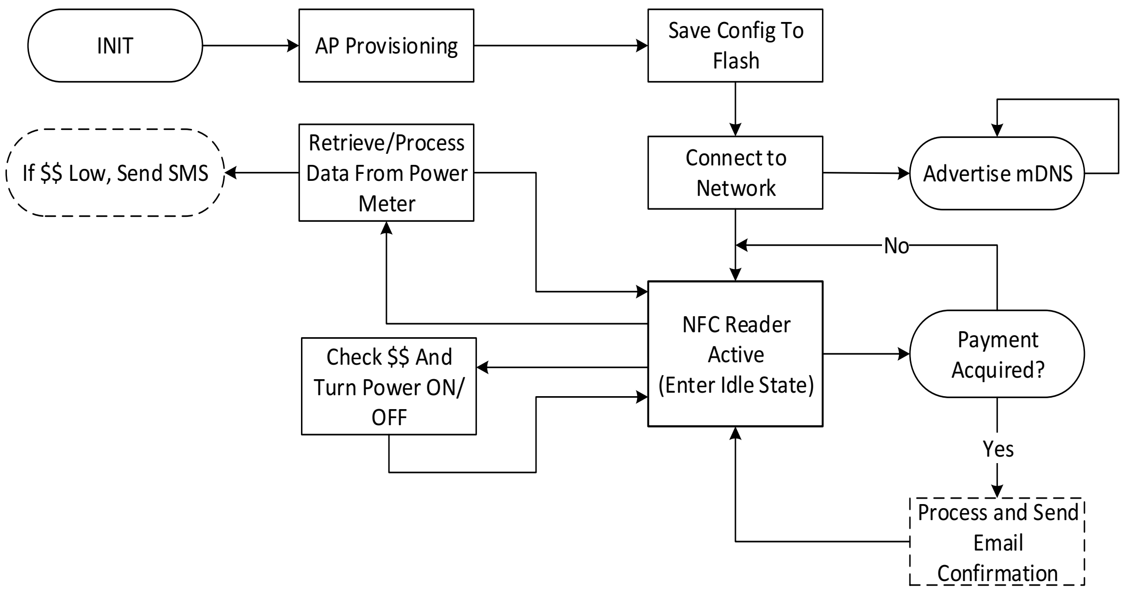
The software that accomplishes all of this features over 10,000 lines of code, utilizing extensive libraries including TI’s SimpleLink and NFC libraries. The software also features a real-time operating system (RTOS) which allows us to prioritize tasks and handle interrupts efficiently. The main.c source file includes over 2,000 lines of code and handles the calling of the Wi-Fi, NFC, and HTTP functions.

The main portion of the code utilizes a switch case statement structure to call the functions as seen below:

```
switch(AppState)
                    {
                    case CONNECT:
                    AppState = NFC_READER;
                            break;
                    case NFC_READER:
                    AppState = SEND_EMAIL;
                            break;
                    case SEND_EMAIL_sta:
                    AppState = GET_DATA;
                            break;
                    }
```

Fig. 41. Case Structure Example

The program loops in a while loop until an interrupt causes the AppState variable to change. The overall flow diagram of the software can be seen below:



5.2.3 Device Specifications

Table 26 shows the recommended operating conditions of the CC3200 microcontroller:

Recommended Operating Conditions:

		MIN	NOM	MAX	UNIT
VCC – Supply voltage ranged applied at all DVCC, AVCC, and ESIDVCC pins		1.8		3.6	V
VSS – Supply voltage applied at all DVSS, AVSS, and ESIDVSS pins		0	0	0	V
T_A – Operating free-air temperature		-40		85	C
T_J – Operating junction temperature					
C_{DVCC} - Capacitor value at DVCC and ESIDVCC		1			uF
f_{SYSTEM} – Processor frequency (Maximum MCLK frequency)	No FRAM wait states	0		8	MHz
	With FRAM wait states	0		17	
f_{ACLK} – Maximum ACLK frequency				50	kHz
f_{SMCLCK} – Maximum SMCLK frequency				80	MHz

Table 24 Recommended Operating Conditions (from TI's datasheet)

5.3 RFID Transceiver

The TRF7970A NFC/RFID will be the transceiver of choice. This transceiver supports ISO 14443A, ISO 14443B, JIS X 6319-4, ISO 15693, ISO 18000-3, and ISO 18092 which was the most amount of ISOs between the RFID transceiver choices. The TRF7970A also contains a 127 byte FIFO buffer is used after the framing engine in the transceiver performs parity checking, removes the end of frame and start of frame settings and then organizes the data in bytes for the specified protocol which is then ready to be delivered to the MCU through SPI. The method of communication between the RFID and MCU will be through SPI even though I2C is also available, and the mode of operation of the TRF7970A will be in Reader/Writer mode where the transceiver is the reader and the phone the emulated tag , which will dictate the NFC between the android and itself.

A table of the Pin Layout that will be used for the TRF7970A:

TERMINAL		**TYPE**	**DESCRIPTION**
NAME	Pin #		
VDD_A	1	OUT	Internal regulated supply (2.7 V to 3.4 V) for analog circuitry
VDD_RF	3	OUT	Internal regulated supply (2.7 V to 5 V), normally connected to VDD_PA (pin 4)
VDD_PA	4	INP	Supply for PA; normally connected externally to VDD_RF (pin 3)
TX_OUT	5	OUT	RF output (selectable output power, 100 mW or 200 mW, with VDD = 5 V)
VSS_PA	6	SUP	Negative supply for PA
VSS_RX	7	SUP	Negative supply for RX inputs
RX_IN1	8	INP	Main RX input
RX_IN2	9	INP	Auxiliary RX input
VSS	10	SUP	Chip substrate ground
BAND_GAP	11	OUT	Bandgap voltage (VBG = 1.6 V); internal analog voltage reference
ASK/OOK	12	BID	Selection between ASK and OOK modulation (0 = ASK, 1 = OOK) for Direct Mode 0 or 1.
IRQ	13	OUT	Interrupt request
MOD	14	INP	External data modulation input for Direct Mode 0 or 1
		OUT	Subcarrier digital data output (see registers 0x1A and 0x1B)
VSS_A	15	SUP	Negative supply for internal analog circuits; connected to GND
VDD_I/O	16	INP	Supply for I/O communications (1.8 V to VIN) level shifter. VIN should be never exceeded.

I/O_2	19	BID	TX Enable (in Special Direct Mode)
I/O_3	20	BID	TX Enable (in Special Direct Mode)
I/O_4	21	BID	Slave Select signal in SPI mode
I/O_5	22	BID	Data clock output in Direct Mode 1 and Special Direct Mode
I/O_6	23	BID	MISO for serial communication (SPI)
I/O_7	24	BID	MOSI for serial communication (SPI)
EN2	25	INP	Selection of power down mode.
DATA_CLK	26	INP	Data Clock input for MCU communication (parallel and serial)
SYS_CLK	27	OUT	System Clock Config
EN	28	INP	Chip enable input
VSS_D	29	SUP	Negative supply for internal digital circuits

Table 25 Pin Layout

We will be using a reference design from the TI user guide of the TRF7970A, which shows the TRF7970A application schematic optimized for ISO14443 systems using the Serial Port Interface (SPI). Short SPI lines, proper isolation of radio frequency lines, and a proper ground area are essential to avoid interference. The recommended clock frequency on the DATA_CLK line is 2 MHz

The figure shows matching to a 50-Ω port, which allows connecting to a properly matched 50-Ω antenna circuit or RF measurement equipment such as a spectrum analyzer or a power meter.

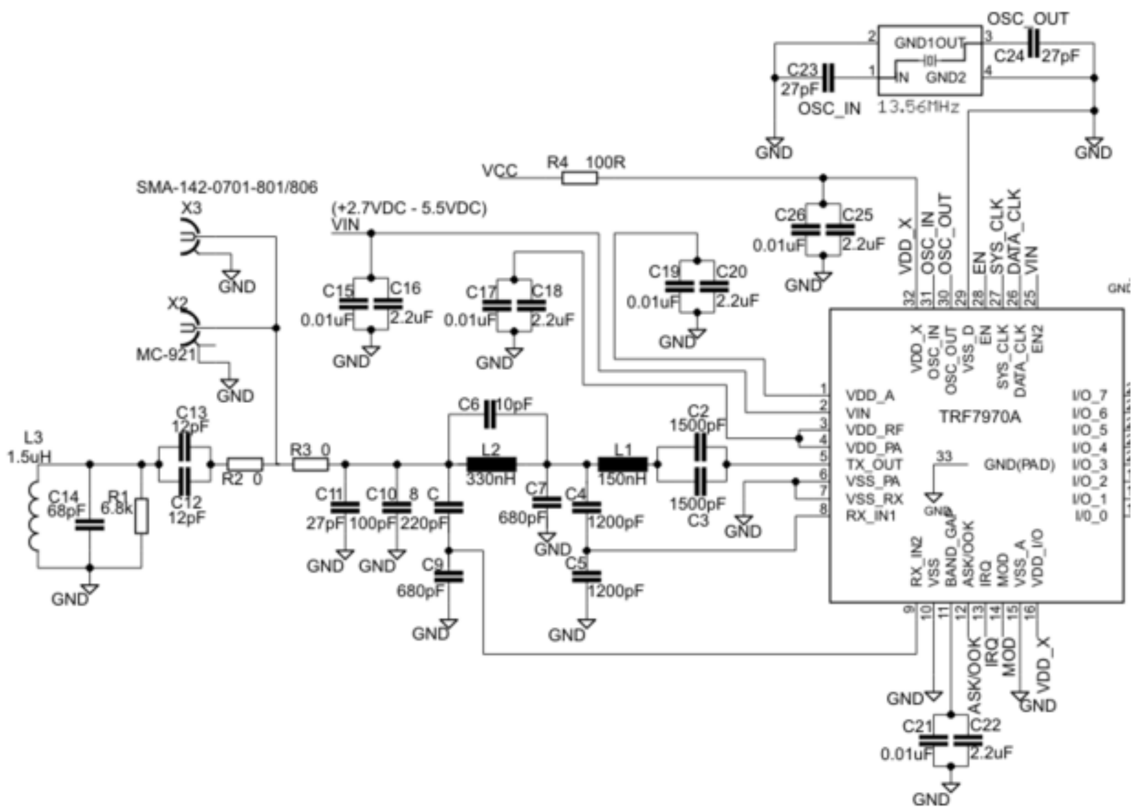


Figure 40 Schematic of TRF7970 Reference Design

Image Courtesy of Texas Instruments

The minimum MCU requirements depend on application requirements and coding style. If only one ISO protocol or a limited command set of a protocol needs to be supported, MCU Flash and RAM requirements can be significantly reduced. Recursive inventory and anti-collision commands require more RAM than single slotted operations. For example, current reference firmware for ISO15693 is approximately 8KB, using 512B RAM. Whereas for all supported protocols the reference firmware is approximately 12KB and uses a minimum of 1KB RAM [9].

5.4 Solid-State Relay

The circuit breaker system is being used to control the load. As long as the customers has a significant balance the switch is allowing power to flow to the load. If the balance were to reach zero, then the circuit breaker would cut the power to the load until there is a payment made by the customer. Therefore, the circuit breaker is acting as the electrical switch that determines when the customer has power or not.

In senior design, we researched about many relays such as Teledyne, Crydom. However, we couldn't incorporate these relays into our system because of the high cost and longer production time. Therefore, we investigated further in senior design 2. We decided on a single phase solid state relay (Fotek 75 DA-H) because it has a DC input control that could be easily connect and controlled by the microcontrollers.

Figure 44 Fotek 75 DA-H

Image Courtesy of Fotek

Fotek 75 DA-H comprises many features that are standard for our project. It can handle current up to 75 A. It has a DC control side which can be easily programmable. Also, output operating range is 90-480 V.

After running tests on the relay with a load, we quickly realized that our microcontroller could only supply a maximum voltage of 3.3 V, which was not sufficient enough to trigger the relay switch. The solution we came up with was to use a comparator circuit in order to increase our output voltage of the MCU, to be able to trigger the relay which needed a 12V input to turn on.

We used TL084 operational amplifier that made by Texas Instrument. The low power consumption is essential for our system and this operation amplifier contains this feature which is perfect for our system.

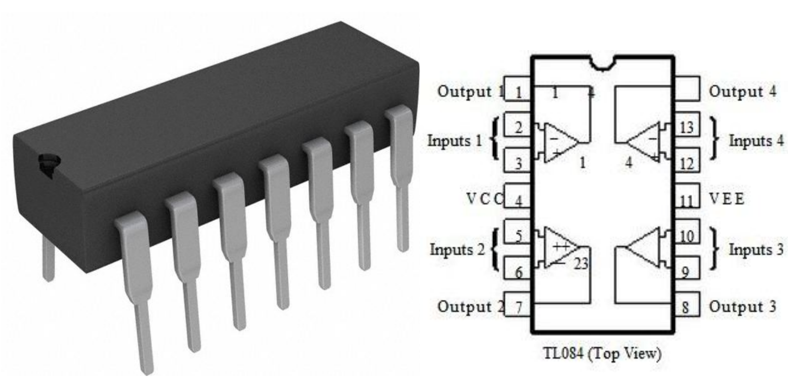


Figure 45 TL084

Image Courtesy of Texas Instruments

The MCU provides a 3.3 V to the comparator circuit which steps up the voltage to 12 V which opens the relay. The comparator circuit can take the 0V volt input instead of the 3.3 provided by the MCU in order to trigger the relay. We assume the relay will be open for the majority of its operations and can conclude that energy will be saved using it this way. In addition to increasing the voltage, a byproduct of using the comparator circuit was that it made the system more energy efficient.

Fig bellow show the simulation for the comparator circuit (achieved in Mulisim Circuit Simulation Software)

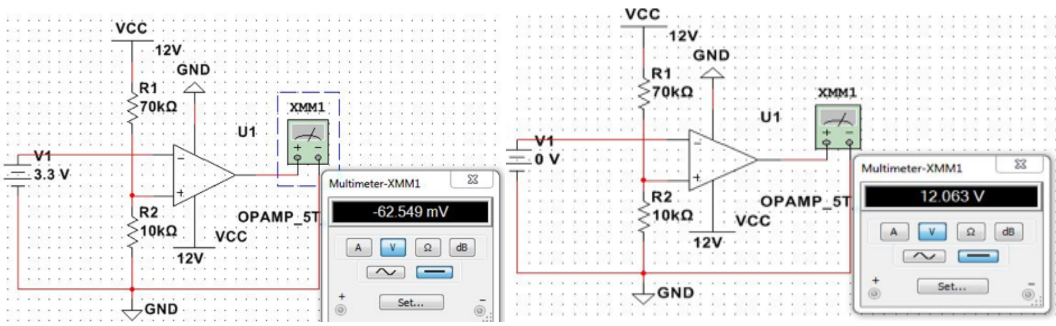


Figure 46 Circuit Simulation

5.5 LCD

For our final design, we opted out of using an LCD as the user interface and instead have decided to use the Android app as the main user interface.

5.7 Software

The majority of the software will be programmed on the host MCU, the CC3200. The processes can be split up into the background process and the foreground process. The background process includes calculating kWh usage and determining whether there is sufficient credit, and regulating the power. Figure 52 shows the flowchart for the background process:

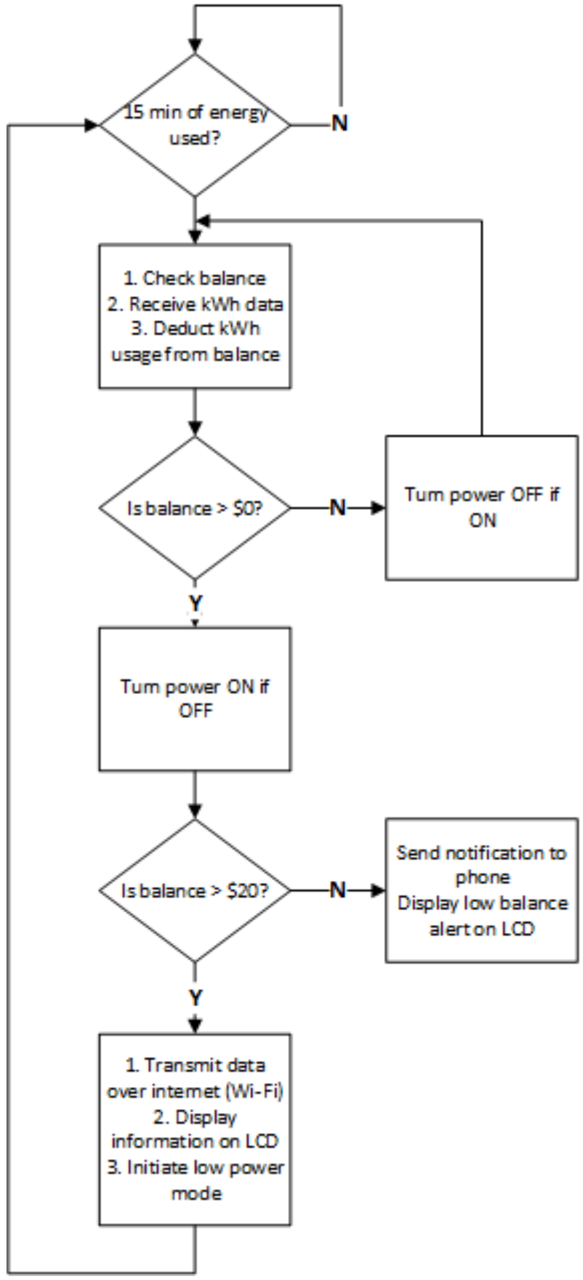


Figure 41 Background Process

The foreground process mainly consists of accepting payment from the user.

Figure 53 shows the flowchart for the foreground process:

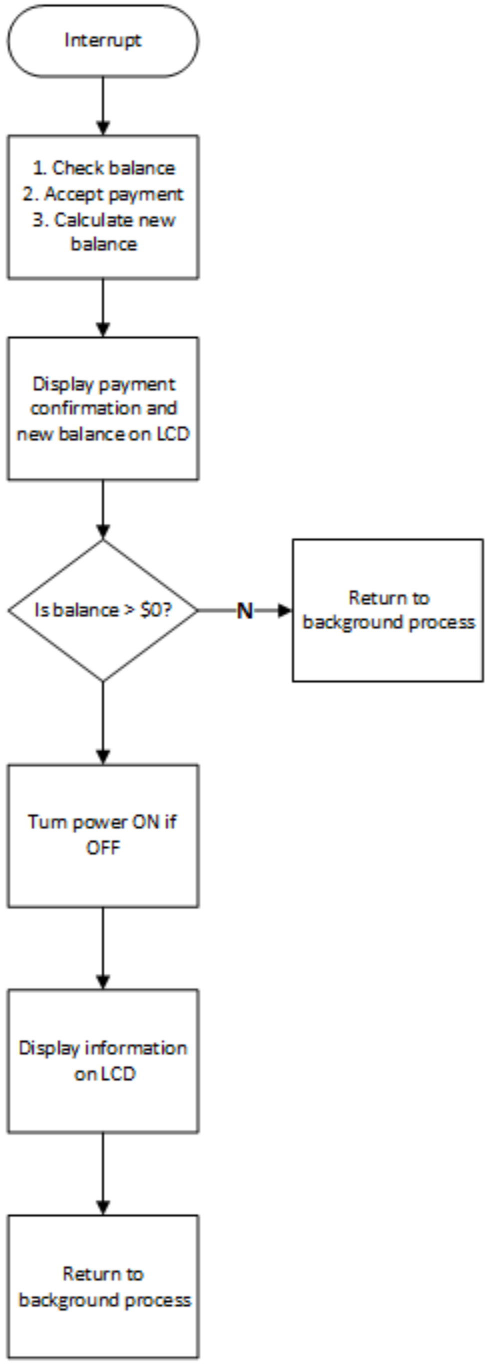


Figure 42 Foreground Process

5.8 Prototyping

For prototyping, we will be making use of TI's Booster Packs and LaunchPads. They incorporate a 40-pin header standard that makes connection between Booster Packs and LaunchPads very quick and simple. From there we will be using a surface mount device (SMD) for further prototyping and testing.

5.8.1 CC3200 Launchpad

For prototyping the CC3200 microcontroller, we will be using the CC3200 LaunchPad Development Kit. This evaluation module has onboard ez-FET emulation that will make programming and debugging easier. In addition to this, it has onboard buttons, LEDs, and a segmented LCD. It also has the 40-pin BoosterPack headers so that we can easily attach the 7970ABP Booster Packs. The LaunchPad and any additional Booster Packs will be powered via USB, so this eliminates the need to design a power supply.

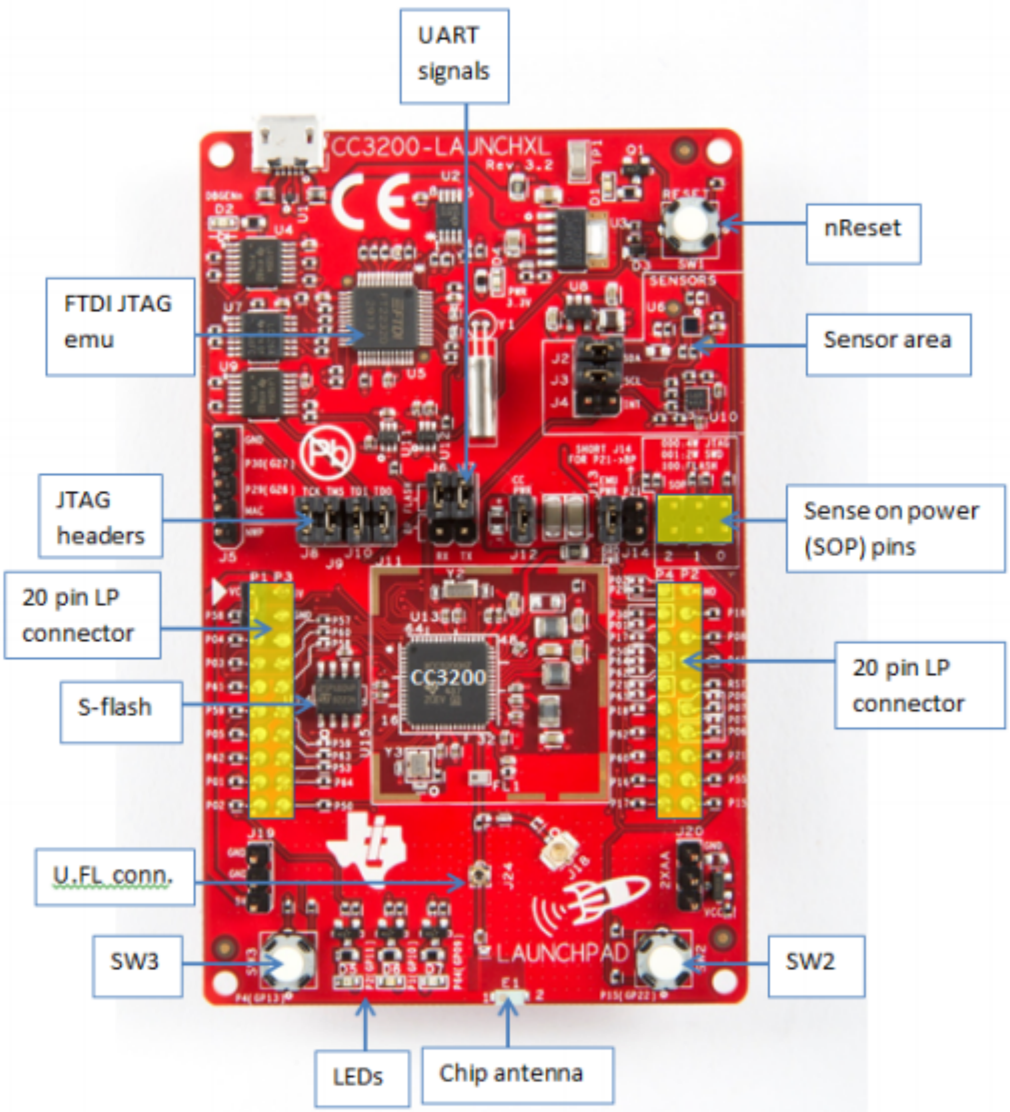


Figure 43 CC3200 Overview

Image Courtesy of Texas Instruments

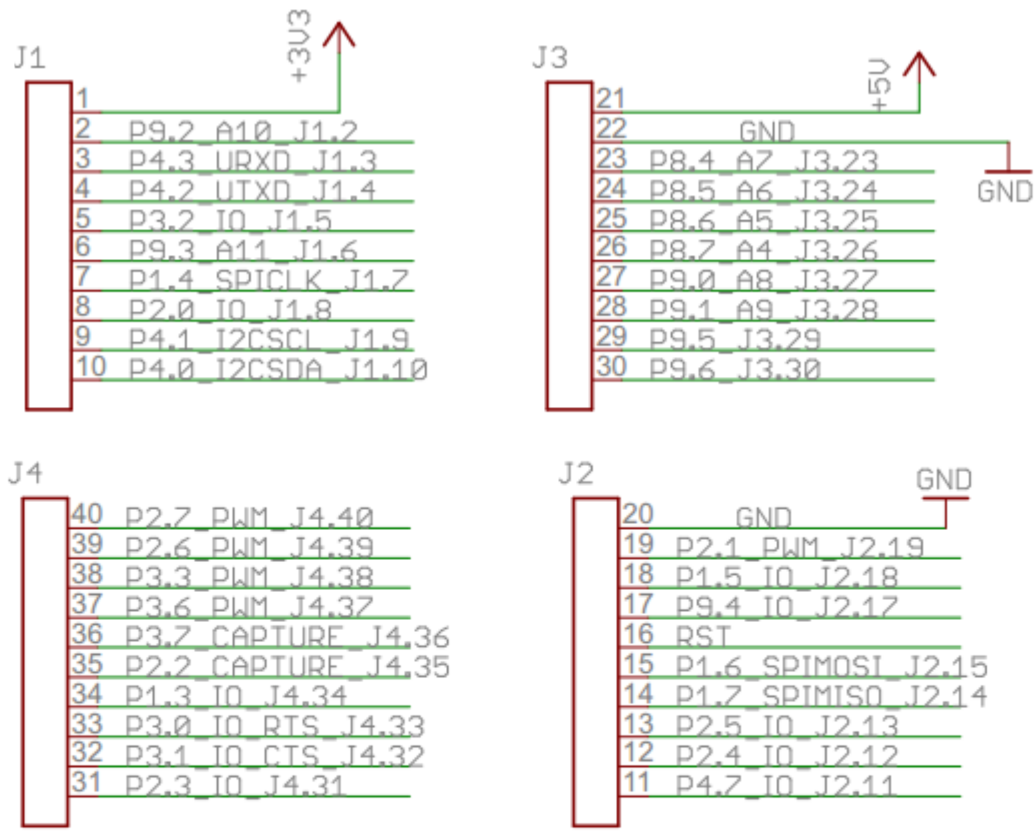


Figure 44 Schematic of BoosterPack Headers

Image Courtesy of Texas Instruments

As we can see from Figure 53, the Boosterpack will connect directly to the CC3200 LaunchPad using the 40-pin headers and will use SPI protocols for communication.

5.8.3 DLP-7970ABP Add-on Board

The DLP-7970 ABP, a 13.56 MHz HF RFID Reader/Writer, was chosen since Texas Instruments had multiple reference designs, and application notes that used this add-on board in multiple NFC modes as well as adding different features such as network security and encryption. An impedance-matching circuit from 4Ω to 50Ω is designed into the DLP-RFID module, and is connected to a tuned 50Ω antenna system that consists of an onboard five-turn coil with series and parallel passive elements being capacitors and a resistor. This will ease the design of our project as a whole since it mainly consists of programming.
On one of the TI documents that we have found through research, they use this add-on board and implement the AES authentication. Although they implement it with a smart card instead of the Android, it will still help guide the implementation of the AES algorithm in conjunction with the android phone. The DLP-7970 ABP

will allow us to test all three modes of NFC with the android since they both support the three modes. It will therefore have us determine which mode would be better to use, and easier to implement for our system to support all our desired features and be fully functional. This booster pack will help us ensure during prototyping that all our ideas and features we want our system to include will be implementable. This add-on board is compatible with NFCLink Library, C2000 LaunchPad, MSP430G2x LaunchPad, TIVA C Series LaunchPad, and Hercules LaunchPad. Supports ISO 15693, 18000-3, 14443A/B, and FeliCa standards. Moreover supports NFCIP-1 (ISO/IEC 18092) and NFCIP-2 (ISO/IEC 21481). Can be used in RFID/NFC Reader, NFC Peer, or in Card Emulation mode.

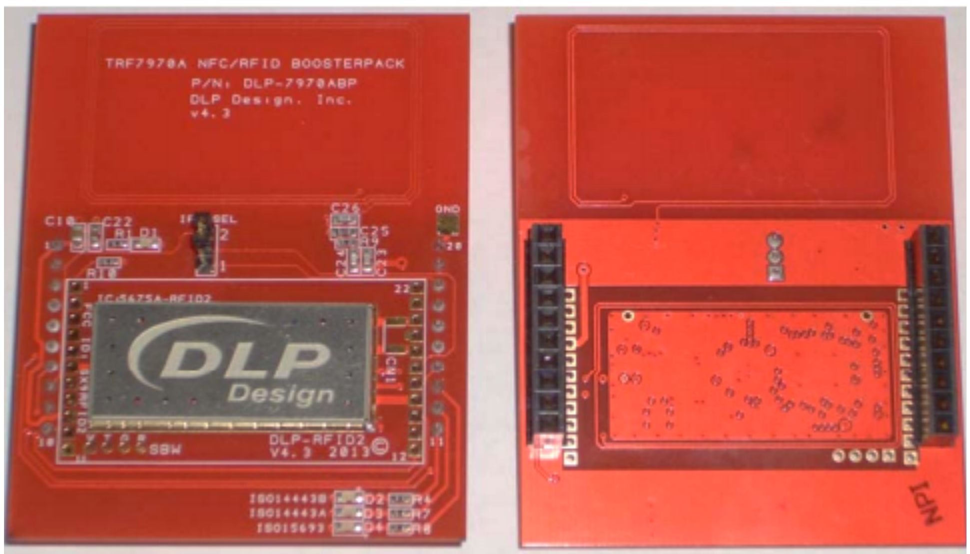


Figure 45 Front and Back of the Boosterpack

Image Courtesy of Texas Instruments

The DLP Design module has been modified from its original form by removing the onboard microcontroller (MSP430F2370) so that our desired MCU LaunchPad, which will be communicating with this module, can control the RF circuitry on the module. Additionally, the I/O pins required by the TRF7970A's SPI interface have been brought out of the DLP-RFID2 module for connection to the microcontroller on the LaunchPad. A table has been compiled below listing the pin connections from the 7970A BoosterPack to the MSP430FR6989 LaunchPad [9]:

Pin #	Description
1	VCC – 3V power from LaunchPad
2	P1.0 – Unused by the 7970A BoosterPack
3	UART RXD – Unused by the 7970A Boosterpack
4	UART TXD – Unused by the 7970A Boosterpack
5	P1.3 – Unused by the 7970A Boosterpack
6	P1.4 – Unused by the 7970A Boosterpack
7	DATA_CLK – Clock for the SPI interface

8	IRQ – Interrupt request from the 7970A to the MSP430FR6989 LaunchPad
9	Slave Select – Used by the SPI interface
10	EN – Used to enable the 7970A
11	P2.3 – I/O used to light an LED on the 7970A BoosterPack when an ISO14443B tag is present in the RFID field
Pin #	Description
12	P2.4 – I/O used to light an LED on the 7970A BoosterPack when an ISO14443A tag is present in the RFID field
13	P2.5 – I/O used to light an LED on the 7970A BoosterPack when an ISO15693 tag is present in the RFID field
14	MISO – SPI serial data from the 7970A to the MSP430FR6989 LaunchPad
15	MOSI – SPI serial data to the 7970A from the MSP430FR6989 LaunchPad
16	RESET
17	TEST – Unused by the 7970A BoosterPack
18	XOUT – Alternate interrupt source from the LaunchPad
19	XIN – Unused by the 7970A BoosterPack
20	GROUND

Table 26 7970ABP to MSP430 Connections

For reference, the schematic for the 7970A BoosterPack can be found below as well [9]:

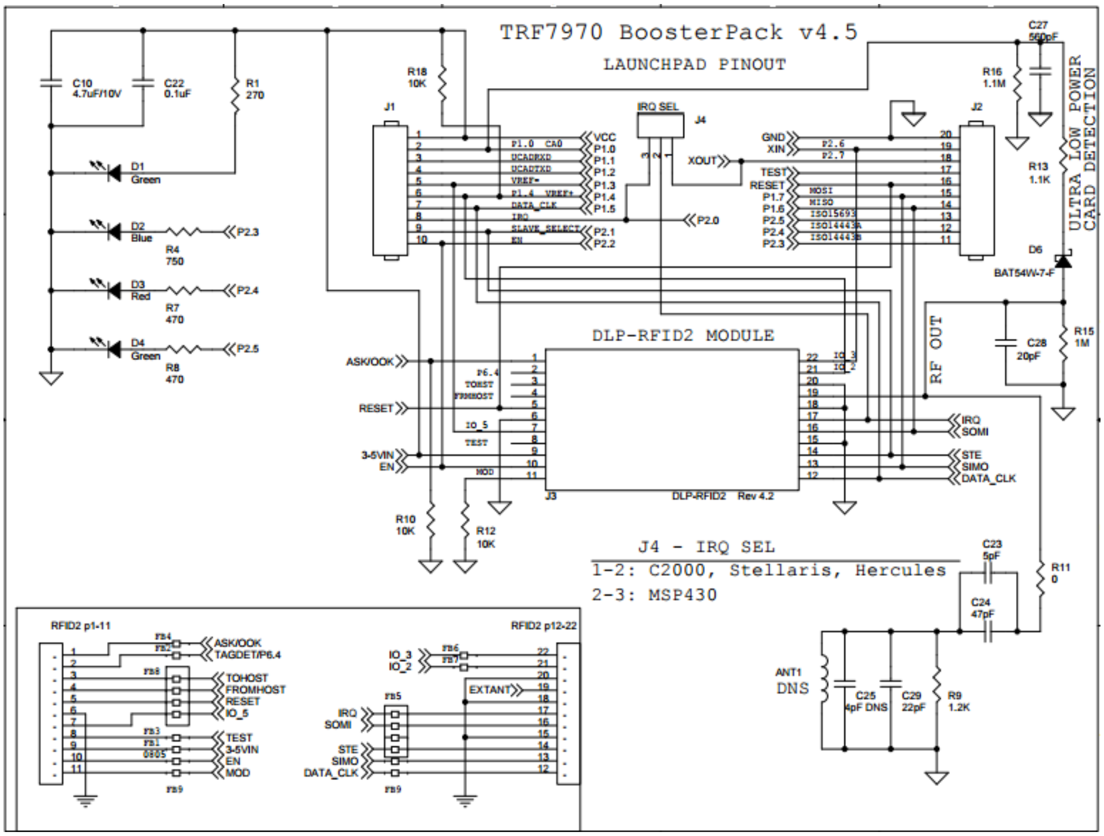


Figure 46 BoosterPack Reference

Image Courtesy of Texas Instruments

5.9 PCB

One of the requirements for the project is designing and building a printed circuit board. During the prototyping portion of the project the test were performed using the launch pad.

5.9.1 EagleCAD

One of the programs that the project team and I came across was Eagle Cad. This software is used by a plethora of engineers worldwide, and has a wider variety of features. The software as a free version that the whole project team downloaded. There are many different libraries that can downloaded free also there are many tutorial that one can easily learn how to design PCB with as many layer that need to satisfy senior design project or any other purpose. This software can be downloaded both MAC and PC with platform both 32-bit and 64-bit version available.

5.9.2 Altium

While searching for reference designs it came across the project team and I that the engineers that designed the power supplies preferred using the Altium software. Although the Altium software is not for free it does allow users to download it and run a free trial.

5.9.3 PCB Design

The system design except for the power supply and RFID transceiver is implemented on its own four-layer printed circuit board. The top and bottom layers were designed for signals, and the middle layers for ground and power. The RF section of the board took the highest priority and needed to be designed correctly in order to avoid performance degradation. We accomplished this by following TI’s design guidelines below:

1. Place the antenna on an edge or corner of the PCB.

2. Make sure that no signals are routed across the antenna elements on all the layers of the PCB.

3. Most antennas, including the chip antenna used on the BoosterPack, require ground clearance on all the layers of the PCB. Ensure that the ground is cleared on inner layers as well.

4. Ensure that there is provision to place matching components for the antenna. These need to be tuned for best return loss once the complete board is assembled. Any plastics or casing should also be mounted while tuning the antenna as this can impact the impedance.

5. Ensure that the antenna impedance is 50 Ω as the device is rated to work only with a 50 Ω system.

6. Ensure that the antenna has a near omni-directional pattern.

As can be seen by figure 61, the RF signal was kept free of any crossing signals and the planes below the antenna were hallowed out:

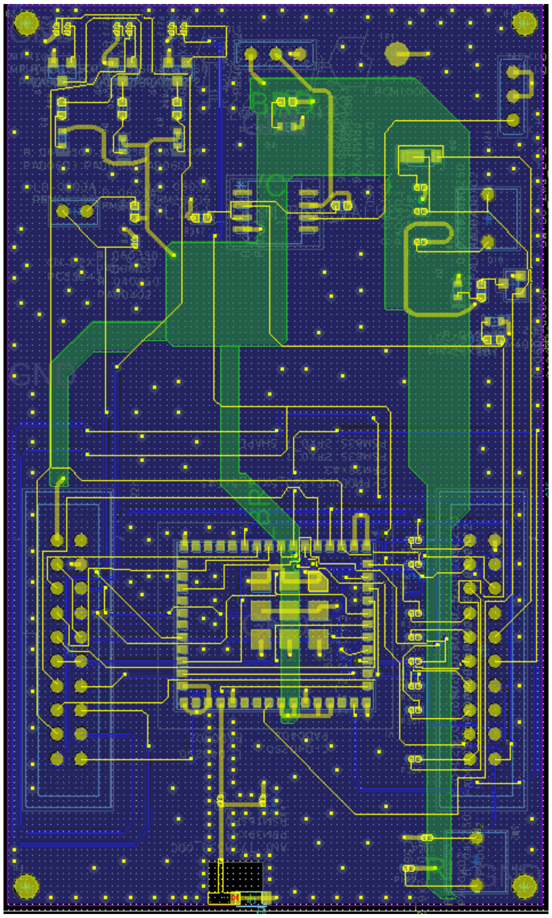


Figure 61 PCB Design Layout

For the MCU, we decided to use the CC3200MOD since it includes the flash memory module, clocks, RF switch, CC3200, and passives in a single chip. This module greatly simplified our PCB design. The design also includes the comparator circuit for the relay, as well as additional exposed pin headers for easy access to ground and voltage sources. The middle of the board was kept clear since the TRF7970 BoosterPack would be placed on top.

Once the design was completed, the board files were sent to OSH Park for manufacturing of the board. The front and bottom views of the four layer board can be seen below.

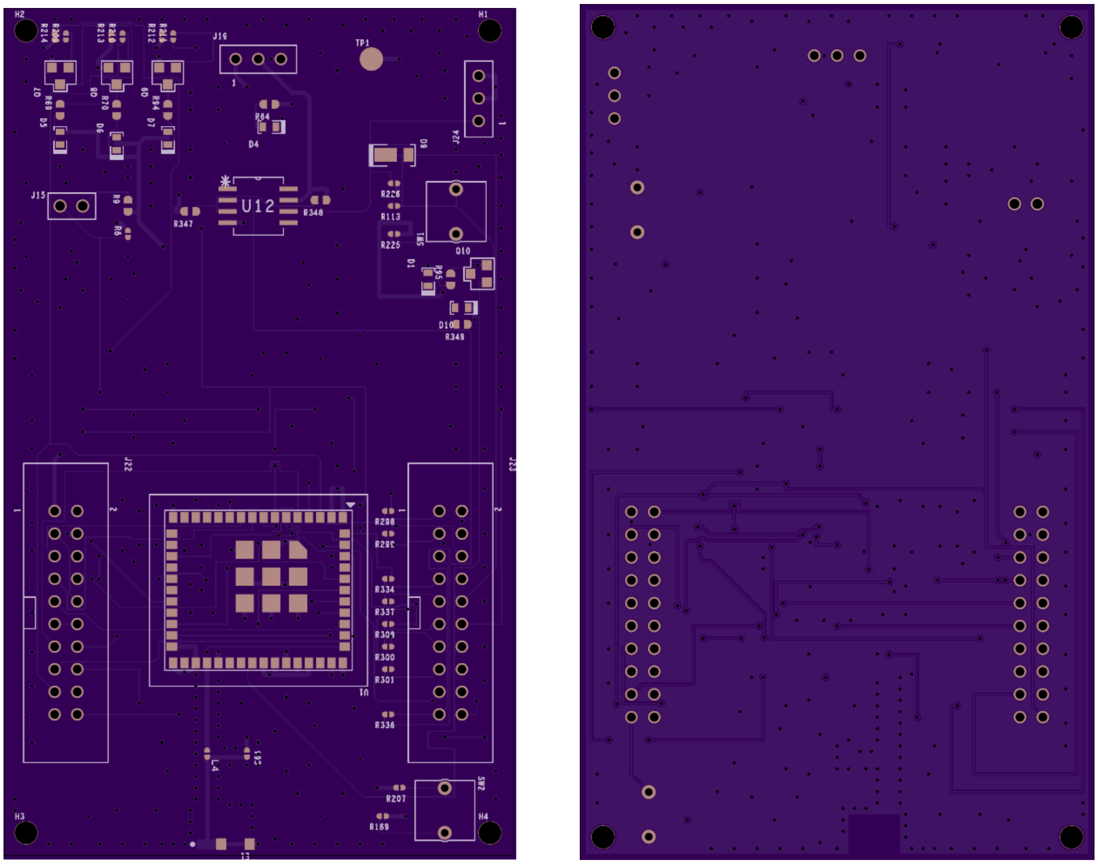
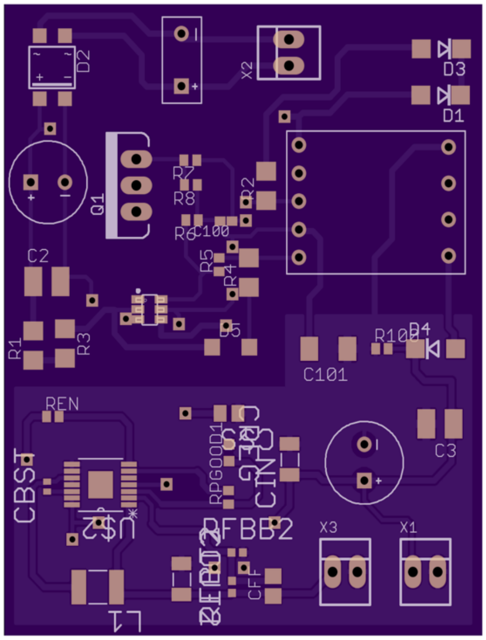
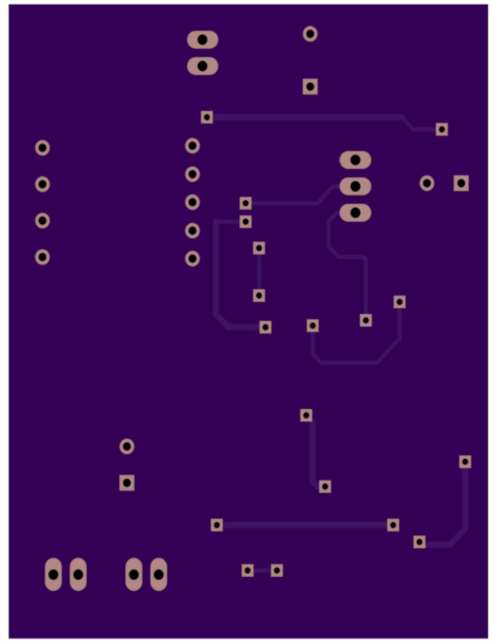


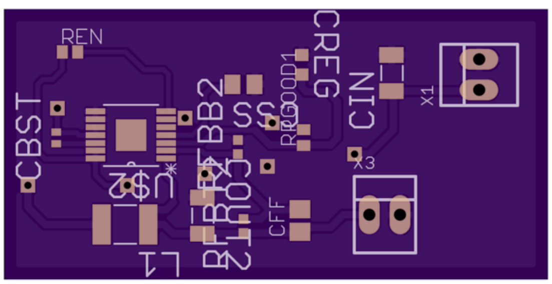
Figure 62 Final Board Layout

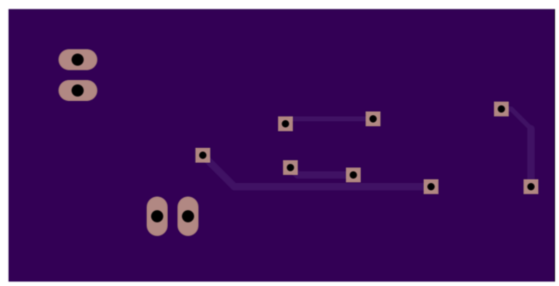
For the power supply both stages where placed on the same board. Diode “D4” and the ground plane isolate the two stages from each other. For the most part the board is comprised of surface mounted components.





The figure below is the DC to DC printed circuit board. This same components where used in the board above.





When designing the power supply there ware several things to keep in mind. Many times footprints are going to have to be manipulated in the libraries due to pins that were not included. When reviewing the board prior to sending it out to be manufactured all traces and pins need to match the ones in the schematic.

6.0 Testing

Once the design phase is out of the way the project will have to go through several tests before the finished product is complete. Testing will consist of connecting all the devices and seeing if they function properly with one another. We will first conduct individual testing for each of our main components, being the three phase power meter, power supply, the Microcontroller, the RFID transceiver, Wi-Fi chip, LCD, and the android application. Once individual testing is complete we will integrate the whole system and test it as a whole to ensure that the components can perform to our desires and the system will contain all the working features we wish it to have.

For convenience of testing the printed circuit board test pins are recommend to included. This helps when trouble shooting the board, there are times when voltages are needed to be measured across several passive components or pins on a microcontrollers.

6.1 Module Testing

Module testing will consist of the different tests that will be conducted on the individual systems in our project. Once they are all complete we will move to the next stage being the Beta test. This will include testing of the entire system as a whole.

6.1.1 Three-Phase Power Metering

For the three phase power meter it was quite difficult to find a proper area to test it out. With the permission of some of the faculty in the University of Central Florida we were allowed permission in a lab in the Engineering building. The lab includes a power breaker which is connected to a three phase line. In the lab with the breaker and three phase main lines we will connect the three phase power meter and run a couple of trail runs to see what the power is that it is reading. The data that is collected from the three phase power meter will be recorded into excel for further analysis. Once the test runs are performed in the lab and the data is all recorded, the following step is to compare the data with what is expected from the three phase power meter's technical documents that Texas instruments provided.

For testing purposes, the following AC voltage and currents can be applied at these points:

Pad LINE1 corresponds to the line connection for phase A.
Pad LINE2 corresponds to the line connection for phase B.
Pad LINE3 corresponds to the line connection for phase C.
Pad Neutral corresponds to the Neutral voltage.

- The voltage between any of the three line connections to the neutral connection can be up to 230 V ac at 50/60 Hz.
- I1+ and I1- are the current inputs after the sensors for phase A. When a current sensor is used, make sure that the voltage across I1+ and I1- does not exceed 930 mV.
- I2+ and I2- are the current inputs after the sensors for phase B. When a current sensor is used, make sure that the voltage across I2+ and I2- does not exceed 930 mV.

- I3+ and I3- are the current inputs after the sensors for phase C. When a current sensor is used, make sure that the voltage across I3+ and I3- does not exceed 930 mV.
- IN+ and IN- are the current inputs after the sensors for the neutral current. When a current sensor is used, make sure that the voltage across IN+ and IN- does not exceed 930 mV.

Figure 18 shows the various connections discussed in the above bullet points.

6.1.2 Energy Conversions and Calculations

Since the energy that is being purchased is going to be in kilowatt hours and the purchases are going to be made in dollars, some calculations must be integrated into the code. Different areas in the United States charge different prices for the utility companies' services. These inconsistencies have to be taken into consideration. To test this out the user will purchase a set of kilowatt hours and the power meter will reset, there will be devices drawing in power and once the power gets depleted, the amount of power used will get recorded. This data will then be used to check if the entry conversion and the formulas in the code are working properly.

6.1.3 Power Disconnect/Reconnect

We will test the relay switch by placing it across a single phase AC voltage connected to a load and applying a DC voltage to relay and seeing if it disconnects the power to the load. When we apply a DC voltage again, it should reconnect the power.

6.1.4 RFID Authentication and Payment

The method of testing for this subsystem will consist of mainly two parts, the first being the communication between the RFID transceiver and the phone, and the second part being the communication between the RFID chip and the microcontroller. Testing the communication between the RFID and the microcontroller will be the easier task since we will just see if the SPI communication between both units is working fine.

We will manually input certain values in the FIFO buffer of the trf7970A and then program both units to communicate via SPI. We will then check whether the MCU received those exact values by displaying them on the LCD or the HyperTerminal via UART. Once we have confirmed our results with several different values we would assume that the SPI communication between both chips is successful.

Once communication between the RFID and microcontroller has been established we will move on to the next stage of establishing the near field communication

between the phone and the RFID transceiver. We will test this option with three different methods, two of these modes are the inverse of each other, and one of these modes will be our main and ideal case which is Peer to Peer since it will have the most flexibility in data that is being sent. The other two modes will be for backup purposes if our first case does not end up working.
The first mode both devices will be in Peer to Peer mode and this will enable either devices to initiate the communication between them. In this mode we will mainly start the communication with the phone. When we first start testing this mode we will manually input data to the phone and program both devices to work in peer to peer mode, then get the phone in range of the chip and check if the data in the FIFO buffer is the same as the data that was inputted. This will ensure that a correct mode of communication is taking place.

The second method will have the RFID transceiver in card emulator mode and the NFC enabled smart phone in reader/writer, this method will limit the data that is being sent and reduce the flexibility of our system since the chip has to be pre-programmed as a tag to prompt the phone to do a certain task. We will start testing by programming the RFID chip.

6.1.5 Wi-Fi Connectivity

In order to have alerts and some of the special features that were added to the project. Wi-Fi connectivity is going to play a large role in this. To test out if the wireless internet is working properly several tests are going to have to be ran. One test that is going to be performed is checking if any information from the microcontroller can be obtained on the mobile device though the internet.

6.1.6 Android User Interface

The application that will be running on the Nexus 4 is going to go through a lot of test runs. The code will have to allow the phone to emulate a transponder tag to communicate with the RF transceiver. Another feature that the android app needs to include is the ability for the user to access the multiple features the application will provide such as purchasing Kilowatt Hours, receiving live data from the power meter as to how much energy is being spent and how much remains as well as receiving alerts when the amount of power the user has left is below a certain threshold.

The code will be written in android studio which is java based programming. We will first start by creating the framework and design of the app and then compile the code to make sure it will run. After the framework is done we will start by adding all the features we would love this app to have. The individual testing will be to make sure the code compiles and the app can be downloaded through the android app store.

Before the app is complete and is fully functional there are several test procedures on the code that will be done by using an android emulator of choice. The emulator will ease testing the application's codes and features since we would not need to keep downloading to the phone. First step in testing using the emulator is to add a main activity where the user will be able to type in the amount of pay with a decimal value. Once that is complete we will add a pay button and this button must take that value and process it, therefore for testing we will print out the value that was selected by the user to make sure that it was processed. If successful we will move on to the next stage where we would need to use a live phone instead of an emulator due to the fact that this stage will test the Host Card Emulation portion of the app.

Once this is complete we will then proceed to testing the app with the entire system and begin with receiving data from the system. We will manually program the MCU to send alerts to the phone, once the phone starts receiving alerts we will move on to the next part and program the MCU to send in data to the app at a certain rate and then check whether the graph and numbers on the app are in sync with the values that have been sent from the MCU.

When these two parts are running successfully we would have made sure that the app is able to receive data needed and display that data from the system. We will then proceed to taking care of the user using the app to decide on the amount of pay and the card of choice to pay with. Ideally we would love to link the app to android pay using their API's but since this is a senior project and this is not a commercial system, for testing purposes we will have a fake credit card option that we will be able to input an amount and this amount will be the actual amount a person would input in dollars. This stage will be tricky since there are multiple stages of communication in this process. Therefore, we will test every step of the way from the phone to the RFID buffer to the microcontroller and then the LCD. This will be done to pinpoint where the problem is coming from and be able to fix it.

6.1.6.1 User Experience

Since one of the goals is to make a simple to use alternative, we thought that the user experience is something that would be important to us. For this portion of the testing we will allow some of our class mates to test out the project and give us constructive feedback.

The feedback from others will be then considered and used to alter or add extra features to the application. Addition may be anything that ranges from more features in the application to a more optimal method of connecting the components that make up the project.

6.1.6.2 Logging In

When dealing with purchases it is always a necessity to have separate accounts with passwords in order to enhance the level of security for the client and the provider of the power service. Once the user will download the application, he will have to create his own username and password, we will make the user write a high security level password since they would be dealing with a system that they would want no one else to access.

We will test this feature ourselves by first adding the algorithm that will first ask for a password, and this password will have no minimum needs. In an instruction list that we will provide the user is recommended to make the password difficult enough for no one to guess. The code is then going to store these characters in a string for later attempt at logging in.

Once this is successful we will move on to adding a minimum amount of characters for the user's password which will further enhance the security. We will test this by first underwriting a password and disregarding some of the characters that must be present and then by meeting all the goals that the password requires the user to add.

6.1.6.3 Alerts

The alerts are a feature that the whole project team thought would of been very useful to incorporated into the project. There are a few alerts that will be included in the application that will be running on the mobile device. The main Alert will be when the user is below a certain threshold for the amount of energy that is being consumed in the house.

To test and troubleshoot the alert feature we will have two separate testing done. The first will be a simpler test to make sure that the phone is receiving notifications and alerts from the system, and this will be done by manually coding the MCU to send alerts to the phone, once that is a success we will move to the next part which is the actual alert feature we want to include.

Since the microcontroller will be the component that will decide when to send alerts we will set it up and write code that will send alerts once computations have been made we would be expecting the phone to not receive any alerts up until the data has reached below a limit and then we should receive our first alert on the phone. We will then add another piece of code to start sending alerts at a certain rate.

6.1.8 Power Supply

For the power supply there will be many test that it will run through before finalizing the project. These test include checking to see if the components can handle the load that is stated in their descriptions, checking to see how the circuits respond to non-ideal situations, and checking the efficiency of the power supply.

In the senior design lab along with the Texas Instruments innovation lab at the University of Central Florida are digital multi-meters and oscilloscopes that can be used to test out the circuits for the power supply. The power supply testing will have multiple small stages of testing and then a final complete test to make sure that all the processes between the input and output are performing. Since we will be going from AC to DC we will start by measuring the input to the supply using the oscilloscope. The power supply documents include data at specific loads, to test out real life situations the power supply will be connected with different loads and observed to see how it handles in the lab.

Another thing that has to be taken into account is that the power supply only gets close to the value required for the input voltage for the other components. The microcontroller's desired input voltage differs from the input voltage of the radio frequency chip, and that goes as well for the LCD. These values can be obtained using switching or linear regulators. These regulators will be tested to make sure that the voltages are met for their corresponding components on the PCB.
The efficiency is going to be tested for the power supply. The less power loss at the output the better the system. The power supplies from the reference design that were looked at all had values in the upper eighty percent range. The power supply also does not take into conservation that there will be regulators this is a good ball part to know what to expect, however to get better values the power supply will be connected to the PCB to see what the overall efficiency is.

$$\text{Efficiency} = \frac{\text{Power Out}}{\text{Power Input}} 100\ \%$$

6.2 Beta Testing

Beta testing will be the final part of testing where we connect all the individual components of the system after testing them separately and test as a whole system. We will start by having the system be off, opening the app, choosing the amount of pay and sending the data. Once the MCU receives the data it should turn on and display the amount charged as well as the amount remaining on the LCD. This will indicate to us that everything on the receiving end of the system is fully functional. We will then wait on the expected updates we should be receiving on the phone. This will then ensure that the MCU is functioning correctly by receiving the amount of power left from the meter and storing them in the memory and doing the computations to then send alerts and have the LCD display low power.

Next we will have to test the three different possibilities of the user recharging before losing power, the user recharging after losing power and the user not recharging at all. In the first case we will use the phone once more to repeat the process above and expect everything to run like the first go around.
In the second case we will expect for the system to shut down and cut the power it is supplying to the load that will be connected. After it is off we will pay and repeat the initial process.

The third case being the easiest is that we will let the system turn off and we will not pay thus having the power to the load cut for good. Once all the above tests are complete and are fully functional Beta testing will be over and we would finally be able to call it a complete product.

6.3 Project Operation Manual

1) For the complete user experience, the system should be connected to Wi-Fi. This will be accomplished using the SmartConfig app for Android.
2) Search for the system in the app and connect to it. Once connected, select the home network name and enter the password. The system will now store the credentials and automatically connect to the network.
3) The system is now fully functional, no more user input is necessary.
4) Purchase credit in-app on smart phone.
5) Bring phone within 3 cm of system to activate the system and initiate payment.
6) The system will automatically retrieve and process the payment. Once completed, the user will receive a confirmation via SMS and e-mail.
7) Once enough data is collected by the power meter, the system will send the information over the internet.
8) Energy usage statistics can now be viewed inside the app.
9) When additional credit needs to be added, repeat steps 4-6.

7.0 Administrative Content

Proper management and planning is crucial to achieving our objectives for this project. This consists of dividing roles and responsibilities, consulting with our advisors and seeking guidance, setting and meeting milestones, and managing funding. Each of these topics will be highlighted in further detail in their respective sections.

7.1 Roles and Responsibilities

Michael’s primary responsibility for the paper was the table of contents, executive summary, project description, and power supply section. He is also in charge of designing the power supply for our system, and plays a secondary role in the designing and implementation of the circuit breaker and power meter.

Md's primary responsibility for the paper was the project constraints, administrative content, and the sections for the power meter and circuit breaker. He is also in charge of designing and implementing the circuit breaker and power meter, and plays a secondary role in the implementation of the microcontroller and LCD.

Youssef's primary responsibility for the paper was the relevant standards, the android smartphone, authentication, and RFID. He is also in charge of designing and implementing the entire RFID module, as well designing and programming the Android App. He plays a secondary role in the designing of the power supply.
Sahin's primary responsibility for the paper was the related products, roles and responsibilities, the microcontroller unit, LCD, and Wi-Fi. He is also in charge of implementing the microcontroller, LCD, and Wi-Fi module. He plays a secondary role in the designing of the RFID module and the Android App.

To reiterate, a table has been compiled listing the roles and responsibilities of each group member:

Michael	**Md**	**Youssef**	**Sahin**
Table of Contents Executive Summary Project Description Three-Phase Power Linear Regulator Switching Regulator Current Transformer Efficiency	Project Constraints Administrative Content Power Meter Circuit Breaker Solid State Relay Electromechanical Relay	Relevant Standards Android Tags Authentication RFID NFC Antenna Matching	Related Products Roles Responsibilities Microcontrollers LCDs Wi-Fi Network Processor Funding

Table 27 Division of Labor

Block Diagram:

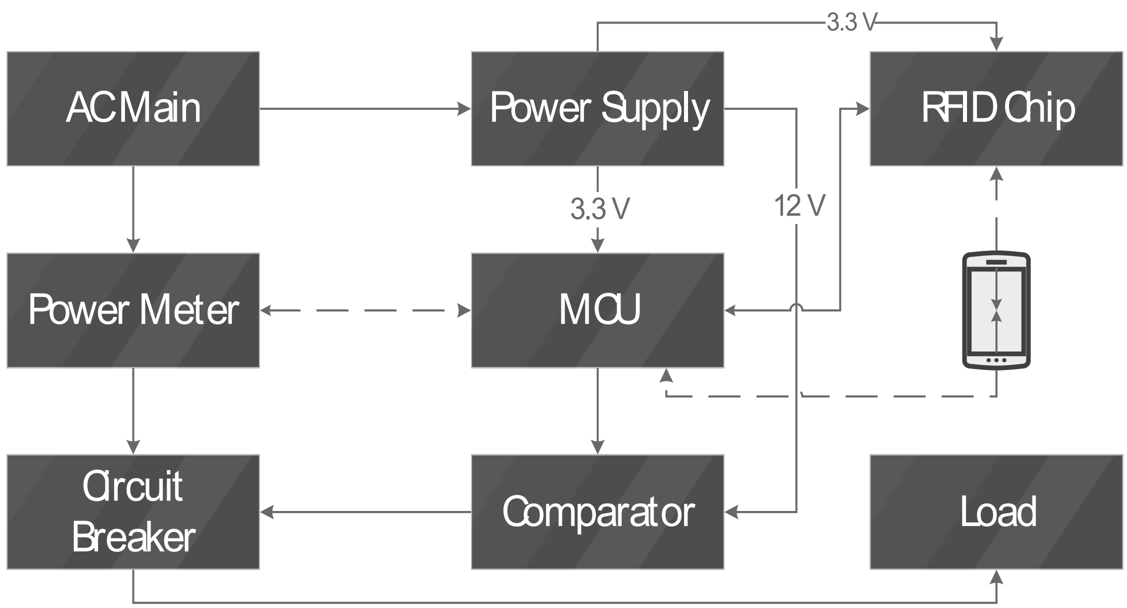


Figure 47 Project Breakdown

7.2 Consultants and Advisors

Advisors:

Dr. Samuel Richie
Dr. Chung-Yong Chan

Sponsor:

Texas Instruments

7.3 Milestones

In Senior Design 1:

- Week 3: Block diagram and system level design should be complete.
- Week 4-6: Research of RFID, NFC, power supply, circuit breaker, and three-phase system should be complete.
- Week 7-8: Research Bluetooth for communication between MCU and smart phone.
- Week 9-10: Complete app for Android smartphone.
- Week 11-12: Combine components together to achieve final system diagram.
- Week 13-15: Order parts and start implementing communication modules (Phone to microcontroller and Bluetooth).

In Senior Design 2

- Week 1-2: Complete communication schemes for payment (RFID and NFC).
- Week 3-4: Implement power meter and circuit breaker.
- Week 5-6: Troubleshoot any issues regarding circuit breaker and power meter and finalize those components.
- Week 7-8: Design PCB schematic.
- Week 9-10: Test communication systems to ensure proper functionality.
- Week 11-15: Troubleshoot PCB board and fine-tune any remaining issues and add any additional features.

7.4 Bill of Materials (BOM)

TRF7970A RFID Transceiver BoM

Quantity	Description	Manufacturer	Part Number
1	Header (JTAG), 2x6 PIN, (0.100 inch STR)	Molex	10-89-1121
1	Switch, Reset, 1P1T, 20mA	Panasonic	EVQ-PAC04M
1	Crystal, 13.56 MHz, (Xtal Load Cap = 18pF), (Ckt Caps = 27 pF	Crystek	017486 Rev A
1	Capacitor, 4.7uF, Tantalum, +/- 20% (10V)	Kemet	T491A475M010AS
6	Capacitor, 2.2uF, Ceramic, +/- 10%, X5R, (10V), (0603)	Kemet	C0603C225K8PACTU
3	Capacitor, 0.1uF, X7R, (25V), (0603	Panasonic	ECJ-1VB1E104K
6	Capacitor, 0.01uF, (or 10nF), X7R, (25V), (0603	Panasonic	ECJ-1VB1E103K
2	Capacitor, 1500pF, +/-10%, X7R, (50V), (0603)	Panasonic	ECJ-1VB1H152K
2	Capacitor, 1200pF, +/-10%, X7R, (50V), (0603)	Panasonic	ECJ-1VB1H122K

2	Capacitor, 680pF, +/- 5%, NPO, (50V), (0603)	Panasonic	ECJ-1VC1H681J
Quantity	**Description**	**Manufacturer**	**Part Number**
1	Capacitor, 220pF, +/- 5%, NPO, (50V), (0603)	Panasonic	ECJ-1VC1H221J
1	Capacitor, 100pF, +/- 5%, NPO, (50V), (0603)	Panasonic	ECJ-1VC1H101J
1	Capacitor, 56pF, +/- 5%, NPO, (50V), (0603)	Panasonic	ECJ-1VC1H560J
1	Capacitor, 47pF, +/- 5%, NPO, (50V), (0603)	Panasonic	ECJ-1VC1H470J
3	Capacitor, 27pF, +/- 5%, NPO, (50V), (0603)	Panasonic	ECJ-1VC1H220J
2	Capacitor, 10pF, +/- 5%, NPO, (50V), (0603)	Panasonic	ECJ-1VC1H100D
1	Inductor, 150nH, (Q = 45), (I_{dc} = 580 mA), (1008HS)	Coilcraft	1008CS-151XJLB
1	Inductor, 330nH, (Q = 45), (I_{dc} = 450 mA), (1008HS)	Coilcraft	1008CS-331XJLB
1	Resistor, 47K (0.1W), (0603)	Panasonic	ERJ-3GEYJ473V
5	Resistor, 10K (0.1W), (0603)	Panasonic	ERJ-3GEYJ103V
4	Resistor, 1K (0.1W), (0603)	Panasonic	ERJ-3GEYJ102V
6	Resistor, 560 ohms (0.1W), (0603)	Panasonic	ERJ-3GEYJ561V
1	Resistor, 100 ohms (0.1W), (0603)	Panasonic	ERJ-3GEYJ101V
1	Resistor, 0 ohms (0.1W), (0603)	Panasonic	ERJ-3GEYJ0R00V
12	Resistor, 0 ohms (0.063W), (0402)	Panasonic	ERJ-2GE0R00X
1	TRF7970A, HF RFID Reader, (-40 to 110 deg C), (32 pin QFN)	Texas Inst	TRF7970ARHBT

CC3200 BOM

QTY	DESCRIPTION	MANUFACTURER	MFN #
1	CC3200 LGA module	FOXCONN	95.1341T00
1	RES C SMD 0402 2.7Kohm 5% GP/HF	Yageo	RC0402JR-072K7L
7	RES C SMD 0603 270ohm 5% GP	YAGEO	RC0603JR-07270RL

1	HEADER PIN 1*2P 2.54mm DIP MALE ST GP	CVILUX	CH31022V202
1	CAP CER 1.0pF +-0.25pF 50V SMD 0402 GP/HF NPO T=0.55mm	WALSIN	0402N1R0C500LT
1	IND C 3.6nH 0.3nH 300mA 0.2ohm Q=8 SMD 0402 GP/HF	TAIYO	HK10053N6S-T
1	2.4G wifi ANT	Taiyo_Yuden	AH316M245001-T
2	CONN RCPT .100" 20POS DUAL TIN	Samtec	SSQ-110-03-T-D
5	RES C SMD 0402 10Kohm 1% GP/HF	Yageo	RC0402FR-0710KL
2	HEADER PIN 3P 2.54mm DIP MALE ST GP	CVILUX	CH31032V200
3	LED CHIP 45~180mcd R 624~638nm 2P SMD 1.6*0.8mm GP/HF	LITEON	LTST-C190KRKT
2	SW TACT 50mA 12V DIP ST GP	POWERWAY	DTST-61K-Q
1	DIODE SBD 30V 1.0A SMD POWER DI123 GP/HF	DIODES	DFLS130L-7
4	RES C SMD 0402 100Kohm 1% GP/HF	Yageo	RC0402FR-07100KL
1	RES C SMD 0402 0ohm 5% GP/HF	Yageo	RC0402JR-070RL
1	RES C SMD 0402 100ohm 5% GP/HF	Yageo	RC0402JR-07100RL
1	RES C SMD 0402 1Kohm 1% GP/HF	Yageo	RC0402FR-071KL
2	LED CHIP 60mcd O 605nm 2P SMD 1.6*0.8mm GP/HF LTST-C190KFKT	LITEON	LTST-C190KFKT
4	MOSFET N-CH 50V 200MA SOT-23	On Semi	BSS138LT3G/BSS138LT1G
1	LED CHIP 35mcd G 571nm 2P SMD 1.6*0.8mm GP/HF LTST-C190KGKT	LITEON	LTST-C190KGKT
1	JFET-COMPARATOR	TI	TL081ACD

Three-Phase Power Meter BoM

Quantity	Description	Manufacturer	Part Number
1	3 Phase Electronic Watt-Hour EVM	TEXAS INSTRUMENTS INC	EVM430-F6779

Power Supply DN05067 BoM

Quantity	Description	Manufacturer	Part Number
1	IND., 1 mH, 0.235 A, 7.6 × 7.6 (mm)	Cooper Buss.	DRA73−102−R
1	IND., 480 H, 200 kHz, CC30/19	Precision	019−8202−00R
1	CONN., 300 V, 10 A, 3Pin_3.5mm	Wurth Elek.	691214110003
2	BUSH, 54 A	Wurth Elek.	7461093
2	HEATSINK, 10 × 10 (mm)	Assmann WSW Comp.	V2017B
Quantity	**Description**	**Manufacturer**	**Part Number**

1	PowerChip, Offline, 12 V, 1.44 W, SO−8C	Power Integ.	LNK304DG−TL
1	MOV, 504 V, 3.5 kA, Disc 10.5 mm	Panasonic	ERZ−E08A561
1	LLC Controller, 16-SOIC	ON Semiconductor	NCP1397BDR2G
1	PFC Controller, CCM, 200 kHz, SO−08	ON Semiconductor	NCP1654BD200R2G
2	Synchronous Rectifier Driver, SO−08	ON Semiconductor	NCP4304BDR2G
1	Voltage Reference, SOT23	ON Semiconductor	NCP432BCSNT1G
1	Optoisolator, 5 kV, 4−SMD	Avargo	HCPL−817−50AE
1	X2 CAP. DIS., SOIC−8	ON Semiconductor	NCP4810DR2G
1	FUSE, SLOW, 250 V, 6.3 A	Littlefuse Inc	39216300000
2	MOSFET, N−CH, 40 V, 100 A, PG−TDSON−8	Infineon	BSC017N04NS G
1	Transformer, LLC, 240 W, 1 70 kHz – 200 kHz	Precision	019−7896−00R
3	Ferrite Bead, 60 @100 MHz, 500 mA, 0603	TDK	MMZ1608Y600B
1	Rectifier Bridge, 600 V, 8 A, D−72	Vishay	VS−KBPC806PBF
1	Thermal Pad, 0.9 W/m−K, 18.42 × 13.21 (mm)	Aavid Thermalloy	53−77−9G
1	Ferrite Core, 47 @100 MHz, 4.2 mm OD	Wurth Elek	74270012
2	RES., 220 k, 1/4 W, 1%, 1206	Yageo	RC1206FR−07220KL
1	RES., 1.8 M, 1/8 W, 1%, 0805	Rohm	KTR10EZPF1804
1	RES., 1.78 M, 1/8 W, 1%, 0805	Vishay	CRCW08051M78FKEA
1	RES., 10 , 1 W, 1%, 2010	Stackpole	RMCP2010FT10R0
1	RES., 2.05 k, 0.1 W, 1%, 0603	Yageo	RC0603FR−072K05L
1	RES., 13 k, 0.1 W, 1%, 0603	Yageo	RC0603FR−0713KL
1	RES., 13 k, 1/4 W, 5%, 1206	Panasonic	ERJ−8GEYJ133V
1	RES., 4.7 , 1/8 W, 1%, 0805	Rohm	KTR10EZPF4R70
1	RES., 4.7 k, 0.1 W, 1%, 0603	Rohm	MCR03ERTF4701
3	RES., 953 k, 1/8 W, 1%, 0603	Panasonic	ERJ−6ENF9533V
1	RES., 10 k, 1/8 W, 1%, 0805	Panasonic	ERJ−6ENF1002V
Quantity	**Description**	**Manufacturer**	**Part Number**

2	RES., 20 k, 0.1 W, 1%, 0603	Rohm	MCR03ERTF2002
2	RES., 5.9 k, 0.1 W, 1%, 0603	Yageo	RC0603FR−075K9L
2	RES., 0.56 , 1/8 W, 1%, 0805	Yageo	RL0805FR−070R56L
1	RES., 2.2 k, 0.1 W, 1%, 0603	Yageo	RC0603FR−072K2L
3	RES., 1 k, 0.1 W, 1%, 0603	Yageo	RC0603FR−071KL
1	RES., 14.7 k, 0.1 W, 1%, 0603	Panasonic	ERJ−3EKF1472V
1	RES., 13.7 k, 0.1 W, 1%, 0603	Panasonic	ERJ−3EKF1372V
1	RES., 750 , 0.1 W, 1%, 0603	Yageo	RC0603FR−07750RL
1	RES., 332 , 0.1 W, 1%, 0603	Vishay	CRCW0603332RFKEA
1	RES., 100 , 0.1 W, 1%, 0603	Yageo	RC0603FR−07100RL
1	RES., 7.5 k, 0.1 W, 1%, 0603	Yageo	MCR03ERTF7501
1	RES., 2 k, 0.1 W, 1%, 0603	Panasonic	ERJ−3EKF2001V
1	RES., 150 k, 0.1 W, 1%, 0603	Yageo	RC0603FR−07150KL
1	RES, 12.4 k, 0.1 W, 1%, 0603	Yageo	RC0603FR−0712K4L
1	RES, 6.8 k, 0.1 W, 1%, 0603	Yageo	RC0603FR−076K8L
3	RES., 0 , 0.1 W, 0603	Yageo	RC0603JR−070RL
2	RES., 24 k, 1/8 W, 5%, 0805	Yageo	RC0805JR−0724KL
2	RES., 4.7 , 0.1 W, 1%, 0603	Panasonic	P4.7AJCT−ND
2	RES., 2.2 M, 1/4 W, 5%, 1206	Yageo	RC1206JR−072M2L
2	RES., 10 , 1/4 W, 5%, 0805	Stackpole	RPC0805JT10R0
1	Diode, 1,000 V, 1 A, DO−214AC	Diode Inc	S1M−13−F
1	Diode, 600 V, 3 A, DO−214AB	Fairchild	S3J
1	Diode, SiC, 600 V, 2 A, TO220−2	Cree	C3D02060A
1	Diode, 600 V, 1 A, DO−214AC	Diode Inc	S1J−13−F
1	Diode, Ultra Fast, 600 V, 1 A, DO−214AC	Diode Inc	US1J−13−F
1	Diode, Ultra Fast, 600 V, 1 A, DO−214AC	Micro Commercial Inc.,	ES1J−LTP
1	Diode, Zener, 11 V, 0.5 W, SOD123	ON Semiconductor	MMSZ5241BT1G
Quantity	**Description**	**Manufacturer**	**Part Number**

2	Diode, 75 V, 0.15 A, SOD323F	Fairchild	1N4148WS
3	GaN HEMT, 600 V, 9 A, TO220	Transphorm	TPH3002PS
2	IND., 90 H, DCR< 40 m	Wurth Elek.	7447013
1	Common Mode Chk, 10 mH, 1.9 A, 22 × 15 (mm)	Wurth Elek.	744 824 310
1	IND., 1 mH, 70 mA, 1812	Wurth Elek.	744045102
2	CAP., X7R, 2.2 nF, 16 V, 10%, 0603	AVX	0603YC222KAT 2A
6	CAP., X7R, 1 F, 16 V, 10%, 0603	Taiyo Yuden	EMK107B7105 KA−T
1	CAP., X7R, 1.5 nF, 16 V, 10%, 0603	Kemet	C0603C152K4R ACTU
1	CAP., X5R, 2.2 F, 16 V, 10%, 0603	TDK	C1608X5R1C22 5K080AB
1	CAP., NP0, 100 pF, 50 V, 5%, 0603	AVX	C1608C0G1H1 01J080AA
3	CAP., NP0, 4.7 nF, 630 V, 5%, 1206	TDK	C3216C0G2J47 2J085AA
2	CAP., Film, 0.22 F, 630 V, 20%, 7 × 15 × 17.5 (mm)	Vishay	BFC233820224
3	CAP., X1Y2, 4.7 nF, 250 VAC, 20%, Rad.	Kemet	C947U472MYV DBA7317
2	CAP., Alum., 120 F, 450 V, 20%, Rad. 18 × 33.5 (mm)	Rubycon	450QXW120ME FC18X31.5
2	CAP., Alum., 3.3 F, 400 V, 20%, E3.5−8	Rubycon	400LLE3R3ME FC8X11R5
5	CAP., X7R, 0.1 F, 630 V, 10%, 1812	TDK,	C4532X7R2J10 4K230KA
7	CAP., X7R, 0.1 F, 25 V, 10%, 0603	Kemet	C0603C104K3R ACTU
1	CAP., X7R, 0.1 F, 25 V, 10%, 1206	Kemet	C1206F104K3R ACTU
2	CAP., X5R, 10 F, 16 V, 20%, 0805	Kemet	C0805C106M4 PACTU
2	CAP., Alum., 100 F, 16 V, 20%, Rad. 5 × 2 (mm)	Rubycon	16PX100MEFC TA5X11
1	CAP., Poly. Alum., 470 F, 16 V, 20%, E3.5−8	Nichicon	PLG1C471MDO 1

Quantity	Description	Manufacturer	Part Number
3	CAP., X5R, 4.7 F, 16 V, 10%, 0805	Kemet	C0805C475K4PACTU
1	CAP., X7R, 68 nF, 16 V, 10%, 0603	Yageo	CC0603KRX7R7BB683
3	CAP., Alum., 820 F, 16 V, 20%, E5−10.5	Panasonic	EEU−FC1C821
1	CAP., Alum., 680 F, 16 V, 20%, E3.5−8	Panasonic	EEU−FC1C681L
8	CAP., X5R, 100 F, 16 V, 20%, 1210	Taiyo Yuden	EMK325ABJ107MM−T
1	CAP., Film, 22 nF, 1 kV, 5%, 26 × 6.5 (mm)	Kemet	PHE450PD5220JR06L2
2	CAP., NP0, 330 pF, 50 V, 5%, 0805	Kemet	C0805C331J5GACTU
1	CAP., X7R, 10 nF, 16 V, 10%, 0603	TDK	CGJ3E2X7R1C103K080AA
1	CAP., X7R, 1 nF, 16 V, 5%, 0603	Kemet	C0603C102J4RACTU
2	CAP., NP0, 10nF, 630V, 5%, 1206	TDK	C3216C0G2J103J160AA
2	CAP., Film, 0.47 F, 630 V DC, 20%, 10 × 16.5 × 17.5 (mm)	Vishay	BFC233920474
1	CAP., Poly. Alum., 820 F, 16 V, 20%, E5−10.5	Nichicon	PLG1C821MDO1
1	CAP., Flim, 2.2 F, 450 V, 5%, 18.8 × 12.8 (mm)	Panasonic	ECW−F2W225JA
1	RES., 110 k, 0.1 W, 1%, 0603	Vishay	CRCW0603110KFKEA
1	RES., 75 k, 0.1 W, 5%, 0603	Vishay	CRCW060375K0JNEA
3	RES., 2.37 M, 1/8 W, 1%, 0805	Yageo	RC0805FR−072M37L
2	RES., 3.3 k, 0.1 W, 1%, 0603	Stackpole	RMCF0603FT3K30
1	RES., 60 m, 1 W, 1%, 2512	Vishay	WSL2512R0600FEA

Quantity	Description	Manufacturer	Part Number
2	RES., 11 k, 0.1 W, 1%, 0603	Panasonic	ERJ−3EKF1102 V
2	RES., 23.2 k, 0.1 W, 1%, 0603	Panasonic	ERA−3AEB2322 V

Table 28 Bill of Materials

Quantity	Description	Manufacture	Part Number
1	75A, 600 VAC	Teledyne	E3P48A75

7.5 Funding

Part	Cost
Three Phase Power Meter	$ 300.00
Part	**Cost**
TRF7970A	$ 15.00
Wireless MCU	$ 15.00
Android phone(Nexus S)	$ 50.00
Power supply	$ 100.00
LCD controller	$ 20.00
Circuit breaker	$ 50.00
PCB board	$ 100.00
TOTAL	$ 650.00

Table 29 Funding

8.0 Summary

This project has provided the team with lots of information in the area of power metering as well as in wireless communications. While conducting research, the team has learned about various power supplies and their components, including EMI filters, power factor correctors, regulators, and converters. The team has also learned a lot about NFC and Wi-Fi communication and their protocols. The software side of the project has been much easier than the hardware. The team has been able to utilize sample codes and software like SimpleLink, NFCLink, and Android Studio in order to help with the prototyping.

The team will continue to prototype and eventually begin testing within the upcoming weeks. The aim of this project is to provide a viable solution for pre-payment of electric utilities with a finalized product by the end of Senior Design II. In addition to submitting a project for you course we hope to enter a completion that is held by Texas Instruments.

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Soikat
To: Udomsri, Nathan
Re: about choosing relays

Today at 4:39 PM

MR

Hi,
I am currently studying University of Central florida. For my senior design project i need to use 3 phase relays. so, I need permission to use some of your reference pic and specification. Please let me know if it is ok , also I ned help about relay. Please let me know as soon as possible. My phone number is 4074554121.
Thanks

See More from Udomsri, Nathan

Udomsri, Nathan
To: Soikat
RE: about choosing relays

December 2, 2015 at 5:21 PM

UN

Hello,

Yes I can help with choosing a 3 Phase Solid State Relay.
May I ask where you are located so I can direct you to the appropriate region.

Thank you,
Nathan Udomsri
Field Applications Engineer
Teledyne Relays
12525 Daphne Ave.
Hawthorne, CA 90250
323.241.1206

See More from Md Rahaman

Soikat
To: onhelp@onsemi.com
Re: need help with the schemetic - Service Request #187978

Today at 4:41 PM

MR

Hi,
I need permission to use some of your pictures and specification for my senior design ? Please let me know if it is ok?
Thanks

See More from onhelp@onsemi.com

onhelp@onsemi.com
To: Soikat
Re: need help with the schemetic - Service Request #187978

Today at 7:06 AM
All Mail (Google) - Google (All Mail)

O

Response From ON Semiconductor Service Request #187978
ON Semiconductor Technical Support Center

Voice Mail: 800-282-9855 (US & Canada)
Web Site: http://www.onsemi.com/pub/tech_support
****
Please do not reply to this email. Please submit any additional questions via our web site or by calling the ON Semiconductor Technical Support Center. Thank you.
****

Hello MD Rahaman,

Thank you for contacting ON Semiconductor.

You can find the whole documentation for the NCP1397GANGEVB eval board at:

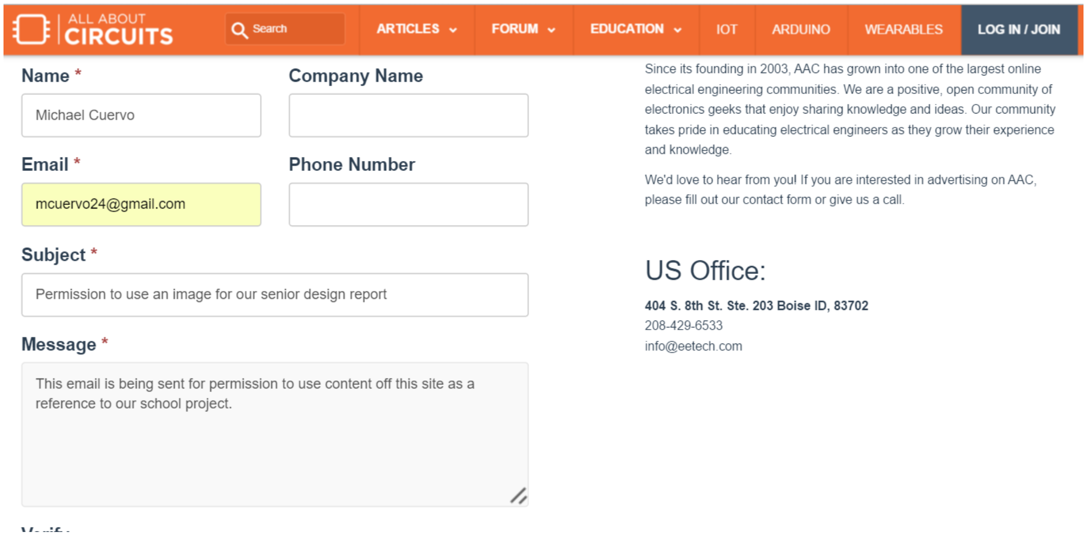
http://www.onsemi.com/PowerSolutions/evalBoard.do?id=NCP1397GANGEVB

You can also find some links for data sheets and other technical documents related to the design note DN05067/D on the page 15 at:

http://www.onsemi.com/pub_link/Collateral/DN05067-D.PDF

If you have any further questions, please do not hesitate to contact us back.

Regards,
Mario Vyzvary



Appendix B – References

[1] ADVANCED ENCRYPTION STANDARD (AES) ALGORITHM: https://www.ecs.csus.edu/csc/iac/docs/students/bahram_hakhamaneshi_project%20report.pdf

[2] NFC Forum: http://nfc-forum.org/

[3] International Organization for Standardization: http://www.iso.org/iso/home.html

[4] Near Fields Communication and Mobile Technology Provided by Professionals: http://www.nfc.cc/

[5] Android Development: http://developer.android.com/develop/index.html

[6] Lecture 8: AES https://engineering.purdue.edu/kak/compsec/NewLectures/Lecture8.pdf

[7] Sony FeliCa: http://www.sony.net/Products/felica/NFC/

[8] Stack Overflow: http://stackoverflow.com/

[9] Texas Instruments: http://www.ti.com/

[10] ON Semiconductor: http://www.onsemi.com/

[11] Apple Development: https://developer.apple.com/programs/

[12] DoE Status of State Energy Codes (HVAC):
http://www.energycodes.gov/implement/state_codes/index.stm

[13] EPA (health): http://www.epa.gov/

[14] Noise Control Codes:
http://www.portlandonline.com/bds/index.cfm?&a=18493&c=38052

[15] Thermal Pollution (environmental):
http://www.esmagazine.com/CDA/ArticleInformation/features/BNP__Features__Item/0,250 3,132219,00.html

[[16] US Government Web Portal: http://www.firstgov.gov/
Occupational Safety & Health Administration (U.S. Department of Labor):
http://www.osha.gov/

[17] U.S. Consumer Product Safety Commission: http://cpsc.gov/

[18] American National Standards Institute: http://www.ansi.org/

[19] A National Resource for Global Standards: http://www.nssn.org/

[20] National Institute of Standards and Technology: http://www.nist.gov/

[21] ASME Codes & Standards: http://www.asme.org/Codes/

[22] http://www.physics.unlv.edu/~bill/PHYS483/ssr.pdf

[23] http://www.teledynerelays.com/pdf/industrial/e3p.pdf

[24] http://www.onsemi.com/pub_link/Collateral/AND9068-D.PDF

[25] http://blog.atlasrfidstore.com/rfid-vs-nfc

[26] http://www.rfidjournal.com/site/faqs

[27] https://learn.sparkfun.com/tutorials/serial-communication

[28] http://scienceline.org/2012/01/okay-but-how-do-touch-screens-actually-work/

[29] http://www.ti.com/lit/an/slyt209a/slyt209a.pdf

[30] http://www.nxp.com/files/training_pdf/VFTF09_AZ137.pdf

[31] http://www.linear.com/products/ldo_linear_regulators

Appendix C – Datasheets

TRF7970A - http://www.ti.com/product/TRF7970A/datasheet
MSP430FR6989 - http://www.ti.com/lit/ds/symlink/msp430fr6989.pdf

CC3100 - http://www.ti.com/lit/ds/symlink/cc3100.pdf

EVM430-F6779 - http://www.ti.com/lit/pdf/slaa577

MSP430FR6989 LaunchPad - http://www.ti.com/lit/ug/slau627a/slau627a.pdf

CC3100 BoosterPack - http://www.ti.com/lit/ug/swru371b/swru371b.pdf

DLP-7970ABP - http://www.ti.com/lit/ds/slos743k/slos743k.pdf

Appendix D – Software

Code Composer Studio - http://www.ti.com/tool/ccstudio

NFCLink - http://www.ti.com/tool/nfclink

SimpleLink -
http://www.ti.com/lsds/ti/wireless_connectivity/simplelink/overview.page

Android Studio - http://developer.android.com/sdk/index.html

SmartConfig-Android -
http://www.ti.com/tool/SmartConfig?keyMatch=smartconfig%20android%20setup&tisearch=Search-EN-Everything

Microsoft Visio - https://products.office.com/en-us/visio/flowchart-software

SimpleLink Wi-Fi Starter-Android - http://www.ti.com/tool/wifistarter