Final Year Project

Remote Power Meter

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Declaration

I, the undersigned, hereby declare that the work contained in this report is my own original work unless indicated otherwise.

Daniel Zinner

Date

Abstract

With the increasing cost of electricity, there is a growing requirement to reduce electricity consumption. For this reason, there is a need to monitor, verify and analyse the efficiency and usage of household appliances. This project investigates the design and implementation of a *Remote Power Meter* which can monitor a number of appliances in a household simultaneously. It makes use of the Trinity Modem and SMART platform enable remote viewing of consumption data from any internet enabled device with a compatible browser. The *Remote Power Meter* was able to monitor appliances successfully and it was proved to be an adequate solution to remotely monitor appliances within a household.

Uittreksel

Met die toename in elektriese koste is daar n algemene neiging om elektrisiteit verbruik te probeer verminder. Dus is daar'n behoefte om die doeltreffendheid van toestelle in 'n huishouding te monitor, verifieer en te analiseer. Hierdie projek ondersoek die ontwerp en implementasie van 'n *Remote Power Meter* wat 'n aantal van toestelle kan monitor in 'n huishouding. Dit maak gebruik van die Trinity modem en SMART platform om die verbruik vanaf enige internet-enabled toestel te sien met 'n versoenbaare browser. Die Remote Power Meter was in stan om toestelle suksesvol te monitor en dit het getoon dat dit 'n voldoende oplossing toestelle te in 'n huishouding te monitor.

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Acronyms

AC	Alternating Current
ABS	Acrylonitrile Butadiene Styrene
CE	Chip Enable
CSN	Chip Select Not
CT	Current Transformer
DC	Direct Current
EMIC	Energy Metering Integrated Circuit
ESMPS	Embedded Switch Mode Power Supplies
FFT	Fast Fourier Transfer
GPRS	General Packet Radio Services
GSM	Global System For Mobile Communications
GUI	Graphical User Interface
I2C	Inter-Integrated Circuit
IDE	Integrated Development Environment
IC	Integrated Circuit
IO	Input Output
IRQ	Interrupt
KWh	Kilo Watt Hour
MHz	Mega Hertz
Mbps	Megabits Per Second
OLED	Organic Light-Emitting Diode
PCB	Printed Circuit Board
W	Watt
RF	Radio Frequency
RMS	Root Mean Square
Rx	Receiver
SPI	Serial Peripheral Interface
SDA	Data Line
SCL	Clock Line
SRM	Successive Refinement Model
Tx	Transmitter
UART	Universal Asynchronous Receiver/Transmitter
Wi-Fi	Wireless Fidelity

Symbols

I	Current
m	Meter
P	Power
Q	Charge
R	Resistance
V	Voltage

1 Introduction

In light of the increasing cost of electricity and the Global Warming campaigns to reduce general electricity usage, there is a growing interest in analysing power consumption in households. By analysing the electricity usage of each individual appliance separately, more accurate conclusions can be drawn on their efficiency and need for replacement[1, 2]. Furthermore this can also determine whether an appliance is drawing unusually high amounts of power when turned off and whether it should rather be unplugged. In this way electricity consumption and cost can be reduced.

1.1 Problem Statement

Most conventional prepaid power meters currently installed in households only display the total real time usage of its power and the amount of electricity available. There is no way to see what the day's,week's or month's consumption was on these meters and often these power meters are placed in an inconvenient location which makes regular viewing somewhat difficult. These power meters also lack the ability to monitor appliances individually; thus hiding vital information about individual appliances.

1.2 Project Objectives and Scope

A Smart Meter is required which can analyse multiple appliances in a household getting readings such as Voltage, Current, and Power. With the help of a GPRS modem the device can connect to the MTN network and the gathered information can be uploaded and processed by Trinity's SMART platform. The data can then be displayed on the platform's graphical web-based user interface. The platform allows users to access the data from any internet enabled device with a compatible browser. To reduce cost the system requires Satellite Units that can communicate with the Base Station wirelessly in such a way that only one GPRS modem is needed for a household containing many monitored appliances. Furthermore it is required that the current information regarding the appliances can also be viewed on a local display with a menu interface.The Remote Power meter will be considered to be successful if the following criteria are met:

- GPRS Communication between Base Station and Web Interface
- Correct measurements of Voltage, Current and Power
- A working user interface on the Base Station with a Display and Menu
- A working dashboard showing measured results on the web-based user interface
- Reliable wireless communication between Base Station and Satellite Units

If time permits, the following additional features may be added so as to improve the project, keeping in mind that omission of these features will not affect operation.

- Building safe mechanical structure to package the Base Station
- Building safe mechanical structure to isolate the Satellite Units
- To increase power efficiency of the device and to minimise power usage when appliance is turned off

1.3 Constraints

This section attempts to set out factors which influences project priorities and restrictions. The diagram below is a high level representation of the System Context Diagram.

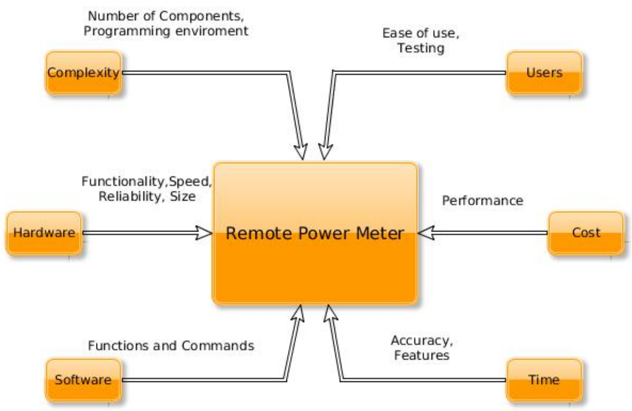


Figure 1: System Context diagram

Considering the factors above, the project is constrained by the following:

- Budget: The project budget is R750.00 + R2000.00 from the project sponsors;Trinity and MTN respectively.
- Time: Date of completion is 4 November 2013 at 12:00pm.
- Availability: Less expensive components may not be available in the Republic of South Africa.
- Reliability: Wireless devices must give reliable communication within a household.
- Size: The size of the Base Station and Satellite Units must be as small as reasonably possible.

The greatest constraints will be time and cost. These will be given priority when making decisions concerning parts and complexity.

1.4 Report Overview

Chapter One introduces the problem and proposed solution. Chapter Two is a literature review about components used in the project, existing solutions, a case study and conclusions that can be drawn from the literature review. Chapter Three describes the high-level system design. Chapter Four describes the detailed electronic design of the individual components. Chapter Five describes the detailed software design focusing on the software at a low level. Chapter Six describes the hardware design, including the manufacture and design of the PCB and mechanical housing. Chapter Seven describes the practical verification of the system showing results from testing. Chapter Eight describes the conclusions and recommendations with regard to this project.

2 Literature Review

This section aims to analyse examples and other similar systems relating to the remote power meter to gain some more insight on this project and possible solutions.

2.1 Power Meter

A Power meter is a device which monitors the electrical power consumption in a home. Most households already have a version of a power meter that measures the total power consumption in KWh; in this way electrical companies are able to charge according to usage. It is advantageous to have a device that can measure individual appliances or devices and log the information. Power meters like this are often also known as Smart meters. Papers have been published that states that Power Meters (specifically smart meters) can help save power[1, 2]; thus making third party power meters attractive.

Figure 2: Figure of a widely used prepaid meter in South Africa

2.2 Power Measurement

Power is a measure of work done per unit of time

$$P = \frac{V.Q}{t} = V.I$$

Where P is power Q is charge, V voltage, t is time and I is current. Using ohms law we can rewrite the above equation as:

$$P = I^2.R = \frac{V^2}{R}$$

However when working with alternating currents we have real and imaginary power. For real power only the first equation needs to be altered to:

$$P = V_{rms} I_{rms} \cos\theta$$

Where V_{rms} and I_{rms} are the respective root-mean-square voltage and current and θ is the phase shift between Voltage and current. Since the objective is to measure different appliances in a household, the last equation is most relevent and it is needed to measure both Voltage and Current. The easiest would be to sample Voltage and Current always multiplying and adding them and then after having been sampled over 2-3 periods divide by sampling rate. This will resut in the average power over 2-3 periods.However this method has a disadvantage in that it will give the apparent power instead of having the real power and reactive power components. A better way of receiving the power measurement, in order to obtain the apparent, reactive and real power, is to perform a Fast Fourier Transform on the sampled signals. It can then be analysed in the frequency domain. In this way the magnitude of the current and voltage as well as its phase shift can be gained and are thus able to obtain apparent, reactive and real power components.

2.2.1 Measuring Current

There are different ways to measure current. The simplest way would be to measure the voltage drop across a Shunt Resistor. A Shunt Resistor has the property of having a very small resistance (in the milliohm range) and it is able to handle a considerable amount of current. In this way there is hardly any Voltage drop over the resistor and very little power loss. The disadvantage is that the circuit that is used for measuring will not be isolated from mains.
Another method would be to use a Hall Effect sensor. The Hall Effect is the build up of a voltage difference across a conductor, transverse to the current and the magnetic field perpendicular to the current. The Hall Effect sensor uses this property of voltage build up to measure the current in a conducting wire. An advantage to a hall effect sensor is that it is an isolated measurement. Commonly, an hall effect sensor has a amplifier circuit in it to amplify the small signal created by the Conducting Wire in question. These sensors are the least expensive method when it comes to measuring large currents, as shunt resistors and current transformers increase to encompass the proportion of current that they can handle[13]. There is however a disadvantage to these sensors. Often circuits containing solenoids, motors or an electromagnetic field can affect the Hall Effect sensor significantly to not give an accurate reading[13]. Another method for current measuring is to use a current Transformer. These are similar to Hall Effect sensors as they also use the magnetic field created by the conducting wire, however, they use it to induce a current in

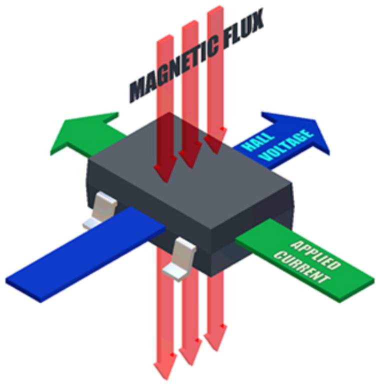


Figure 3: Figure showing how a Hall Effect on the Hall Effect sensor

a wound coil in that the signal produced is considerably larger than that of a Hall Effect sensor. Just like the Hall Effect sensor this method also has complete isolation. The disadvantage of a CT is that it is often bulky and its size is dependent on the current range of interest. The CT can also only operate with AC currents where as a Shunt Resistor and Hall Effect sensor can function with DC as well as AC currents.

2.2.2 Measuring Voltage

To measure Voltages, there are two different methods to consider: The first method is to use a voltage divider. A voltage divider is composed of a few resistors arranged in series between the two nodes in question, to divide the voltage into a measurable level. In this way a 5V logic circuit can be used to measure a voltage of 230V. The result needs to be multiplied by an appropriate constant to get the actual value. The second method is to measure the current over a large known resistor between the two points of interest. By Ohm's law:

$$V = IR$$
$$I = \frac{V}{R}$$

By putting a large resistor between the two points in question and then measuring the current using the methods mentioned in section *2.2.1* the voltage can then be calculated. The first method can be performed in complete isolation if applied over a transformer however this only applies to alternating current. By first converting the voltage of interest over a transformer, isolation is achieved and a desired voltage can be measured. The disadvantage however, is that distortion and phase shifts can be added by using a transformer which can affect the accuracy. In this way a choice has to be made between isolation and accuracy.

2.2.3 Energy Metering IC

An Energy Metering IC is a small microprocessor that can effectively do all of the calculations required for measuring power. As an advantage, tedious and complex calculations do not need to be done but instead they can be simply read from the registers of the EMIC. These chips are generally not isolated from mains but by using a simple opttocoupler the rest of the circuit can be isolated. The general circuitry with regards to Voltage and current measurements as mentioned in section *2.2.1* and *2.2.2* are still required.

2.3 Wireless Communication

Wireless communication is the transfer of information between two nodes that are not physically connected. There are many different types of wireless communication. With regards to the remote power meter there are a few that might be useful.
Bluetooth is a wireless communication standard for exchanging information using the short-wavelength radio transmissions in the ISM band from 2400–2480 MHz. It is very widely used and is found in mobile phones, headsets, printers and many other devices. There are also many bluetooth breakout boards that work well and have a large amount of information online but are expensive in comparison to other technologies. Bluetooth also has limited range with its class 3 having a range of 1m and class 1 a range

of 100m.
Another wireless communication technology is Wi-Fi. It is similar to Bluetooth in that it operates on the same bandwidth around 2.4GHz. It is a popular technology for connecting devices to the internet. It also has a farther range than Bluetooth and can easily communicate reliably over a distance of 1000m line of sight[?].
There are also many Radio frequency communication devices in the 315MHZ and 470MHz band width; however they have very low data rates. Typical application for these are remote controls for cars and gates.

	Aruindo Bluetooth module	Nordic Semiconductor Wi-Fi module	RF Module 315-470MHz
Range	1-100m	35-1200m	20-200m output power dependent
Cost	High	Low	Low
Power	High	Low	Low
Speed	up to 2MB/s	up to 2MB/s	up to 10KB/s

Table 1: Table comparing specification of readily available wireless breakout boards

A further important form of wireless communication is GPRS. It is used predominately in mobile phones for data service on the 2G and 3G cellular communication system's GSM. It is not only used for mobile phones, however it does require a service provider to make use of internet and messaging services. Other examples of use are remote surveillance, home automation and general information logging on remote sites that do not have any other means of communication. GPRS communication is a favorite choice for hobbyist as it is a easy way to add internet to a project.

2.4 Existing Solutions

There are a number of Power meters and Smart meters currently on the market, the two most notable being the *Kill A Watt* system and the *TED 5000* which will be introduced in the following.

2.4.1 Kill A Watt Electricity

The *Kill A Watt* is a power monitoring tool that fits between a household plug and an appliance. It plugs straight into a wall socket and monitors the appliance connected to it. It has some great features such as Power, Voltage, Current and Frequency measurement and a calculator that shows the total cost that went into operating the appliance in question and can forecast the operating cost of the appliance. It displays all of this information on a big readable LCD screen. The *Kill A Watt* system is rather cheap and can be purchased for around $ 20. However it does have some limitations. Firstly it only uses NEMA 5-15 plug and only rated at 125volts AC limiting the global use[14]. It also has no means of extracting the information to a computer for analysis which can be a problem if the appliance is not plugged in at an easily accessible point.

2.4.2 TED 5000

The *TED 5000* is a Power meter which connects directly into a home's circuit breaker panel and monitors each individual breaker. It connects to the internet via a router or modem and can be synced with Google power meter to display some graphics on usage and patterns as well as real time electricity usage [11]. It also includes a smaller wireless display for local viewing. Although being a powerful analytical tool it does have some limitations. The device measures entire breakers which could hold several appliances and it focuses more on the entire household's electricity use rather than each individual appliance. Also there is a need for a physical internet connection to get the full potential out of this product which can be problematic in countries like South Africa where not everyone can afford or has wired internet access. It also requires a risky installation[12] that must be carried out by a qualified electrician, adding additional cost. Another disadvantage of this product is that it is very expensive, with the entry level version costing around $ 240.

2.5 Similar Solution: Wireless Power Meter

The "Wireless Power Meter", is a project done by Ivan Sergeev who is an Embedded Software Engineer at Kumu Networks and Graduate Student (Masters) at MIT. His project measures the power from an appliance and sends the information wirelessly to a computer to display it. The ATmega88p was his choice for a microprocessor and the ZigBee was used for wireless communication between the micro controller and computer. He used the Allegro ACS712 Hall-Effect sensor for current measuring and used a voltage divider over a transformer for AC voltage measurement. Using this setup he was able to completely isolate his circuit from mains.

He encountered the following problems[17]:

- Measuring the Voltage over a Transformer adds a phase shift which is not desired when trying to measure the power factor or when the real power measurement is needed.
- The Hall Effect sensor was inaccurate as the magnetic field created by the PCB's power supply caused and imposed a waveform onto the sensor.

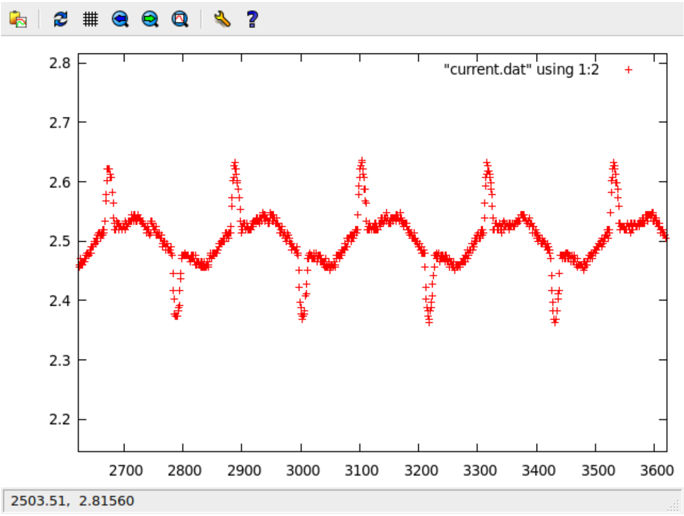


Figure 4: Figure showing contaminated waveform due to transformer

Finally he added that a more common commercial method used for power measurement are energy metering ICs.

2.6 Conclusion

From the literature review it can be concluded that an EMIC will be used for power measurements and calculations. From the case study it is clear that a Hall effect sensor is not a very reliable method as it can be effected easily by other magnetic devices and as such the project will use either a Shunt Resistor or CT for current measurement. Voltage measurement will be done using a voltage divider. For wireless communication the best option will be Wi-Fi as bluetooth is too expensive and normal RF is too slow. The project will aim for something between the two existing solutions mentioned as the *Kill A Watt* is to lacking in features and the *TED 5000* is too expensive and dangerous to install. A system in between the two is needed that uses the *Kill A Watt* ease of use and installation and combines it with a web-interface and data logging ability.

3 System Design

In this section the general system design will be explained.

3.1 Overview

The Remote Power Meter consists of four main parts. The Base Station, the Satellite Units, GPRS modem and a web-interface. The Diagram below shows how these parts all interact with each other.

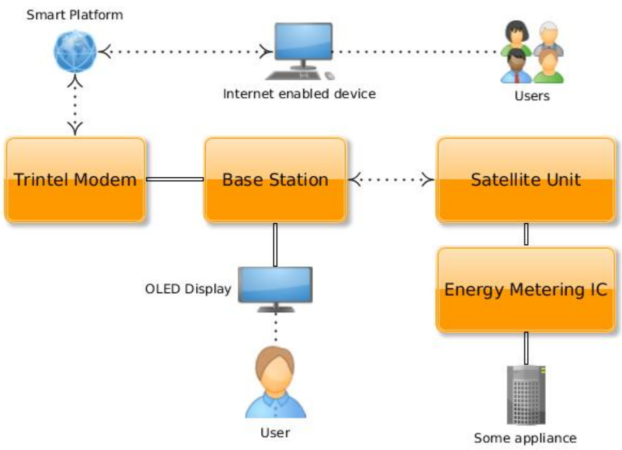


Figure 5: Figure showing how the parts interact

3.2 Base Station

The Base Station is responsible for collecting data and then sending it to the web-interface. It also has a small Display that can show all the relevant information along with a small menu interface. The Base Station requests information from the Satellite Unit via wireless communication. The Satellite Unit then sends the information back to the Base Station. The Base Station then forwards this information on to the Trinity's SMART platform via the GPRS modem. This process happens in regular intervals which can be set in the menu interface. Because the Base Station and the Satellite Units are separate a single system can comprise of many Satellite Units. The advantage of this is that the cost to monitor another additional appliance is low because only the Satellite Unit needs to be purchased.

3.3 Satellite Unit

The Satellite Unit has the task of taking power measurements when requested and sending them then to the Base Station. It waits for a request from the Base Station via Wi-Fi. When a request is received it reads the measurements from the EMIC and then sends this information back to the Base Station.

3.4 Trinity Modem

The Trinity GPRS modem links up the web-interface to the Base Station. It's purpose is to connect the whole system to the web-interface making the information remotely viewable. The modem was designed to simplify development and reduce time to market. The modem is a stand alone system that uses simple At-commands to communicate to. The modem is pre-set up to communicate to Trinity's SMART platform therefore simplifying communication to the system.

3.5 Web-Interface

The web-interface is on the smart-platform. It allows the user to view the current energy measurements from any device that is internet enabled with a compatible browser.

3.6 Stand Alone Base Station

The system was also designed so that wireless communication can be omitted as well as the microprocessor from the Satellite unit to have a stand alone system that is cheaper but as a result can only monitor a single device. The Base Station then talks directly to the energy metering IC via a wired link to a bare Satellite Unit.

4 Detailed Electronic Design

In this section the individual components will be presented and the way in which they interact with the entire section will be shown. In addition, the reason that the specific components were chosen over others will be discussed.

4.1 Base Station

The Base Station acts like a central hub that collects all the data from the surrounding Satellite Units such as Power, Current and Voltage to upload onto the SMART Platform. It also acts as a local user interface where users can view current information and change certain settings. The base station consists of five main parts: The microprocessor, a RS232 Chip, Modem, Wi-Fi chip and a OLED display. These can be seen in the Diagram below.

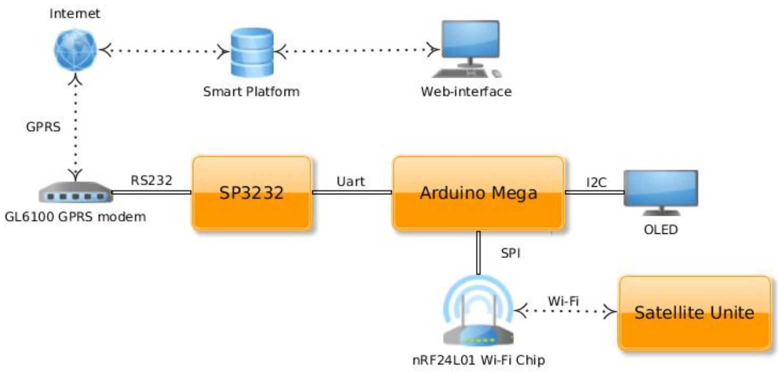


Figure 6: Picture showing the interaction between components of the Base Station

The microprocessor(Arduino Mega) receives the relevant data from the Satellite Unit via the Wi-Fi chip through SPI communication. The microprocessor shows this information on a display (OLED) using I2C communication and also sends this information to the GPRS modem using UART and a RS232 Transceiver (SP3232). The GPRS modem then uploads this information to the SMART platform which can then be displayed on the web-interface.

4.1.1 Microprocessor

A microprocessor is needed in order to communicate with all the devices. It needs to suppors I2C, SPI and needs to have at least two UART ports. The reason it needs at least two UARt ports is that if the Base Station is operating in Stand Alone mode it needs to communicate to both the EMIC as well as the GPRS Modem which both use serial communication. The microprocessor also needs to have an easy to use IDE that can be understood quickly to save development time. There were three microprocessors under consideration.
The STM32F4Discovery is a very powerful ARM based processor that has the following:

- 140MHz 32bit ARM Cortex-M4F core
- Two I2C channels
- Two SPI channels
- USB OTG
- 1 MB Flash, 192 KB RAM

The disadvantage however of this processor is the IDE environment μVision4 from Keil. It does not have much support and seems to be more complex in comparison to other IDEs such as the Arduino IDE. Another processor that was considered was the UNO32 which has a very similar layout and IDE as Arduino but has an advantage of having:

- 32 bit PIC32M processor which has a clock speed of 80MHz

- 512K Flash memory
- 32K SRAM

It has a IDE based on the Arduino IDE. Yet not all Arduino example codes, libraries and devices are compatible. Another disadvantage of the UNO32 is that it is more expensive than other microprocessors such as the Uno or STM32F4Discovery
The Arduino Mega seemed to be perfect for this project as it has four UART ports, SPI and I2C communication and was by far the cheapest from the boards considered. The main reason for the project to be Arduino based is that it is cost effective and easy to program. The reason the Mega was chosen over other Arduino boards is that the Mega is the only board to have more than one serial communication port. With the Arduino Mega having four Serial ports it is able to communicate with the GPRS modem, the EMIC, (if configured as *Stand Alone*) and with a Computer while programming or testing. The only real disadvantage of the Arduino Mega is that it only has a 16MHz processor which has considerably less power than the other considered processors. However, seeing that not much processing power is needed the Arduino Mega will be able to complete the tasks at hand.

4.1.2 RS-232 Transceiver

The Base Station needs to communicate with the GL6100 GPRS modem from Trintel. This modem uses RS232 for communication, the microprocessor on the other hand only has serial communication. A chip is needed that can convert serial to RS232. The first choice was the MAX3232 from Texas instruments. The SP3232 from Sipex is an alternative[7] that is more widely available and cheaper and as such this IC was chosen over the MAX3232. The chip takes TX and RX from the microprocessor and converts it respectively to and from RS232 communication levels. In this way the chip makes communication between the two devices possible.

4.1.3 GPRS Modem

A modem is needed to communicate with the internet so that the information gathered by the Base Station can be displayed remotely. The two modems under consideration were the GL6100 from Sierra Wireless and the Arduino GSM Shield. The Arduino GSM shield allows a device to be connected to the internet through GPRS. All that is needed is a Sim card. At its core the shield uses the radio modem M10 by Quectel. The modem uses standard At-commands over UART to communicate. The Arduino GSM shield can be plugged into most Arduino boards including the Arduino Mega without any additional wires. The GSM shield also has the advantage that there is a large amount of information, tutorials and libraries available through the Arduino community. The only real disadvantage that the GSM shield has is that it does not have a web-interface which would need to be designed if chosen. The other modem under consideration was the GL6100 from Sierra Wireless. The modem also uses standard AT-commands however uses RS232 to communicate to other devices. There are also some specific AT-commands to this modem that are not standard. It also has the advantage of detecting baud rates automatically [10]. The modem is supposed to simplify and shorten development time compared to other development boards because it has an integrated web-interface through the SMART platform. Very little needs to be setup prior and there is also no need for web-design and hosting. The only disadvantage with regard to this project is that the GL6100 needs its own power supply and uses RS232 as communication. These two factors make the Base Station larger. The Arduino GSM Shield in comparison can connect directly to the Arduino Mega and draw its power from it making it a more compact design. The GL6100 was donated to this project and it was decided to be used as the factors of time and money savings outweighed the smaller size benefit from the Arduino GSM shield. The modem from Sierra Wireless is plug and play [10] and as such allowed for more time to be devoted to other parts of the project.

4.1.4 Wireless Communication

There were a few wireless communication devices under consideration. These were discussed in the literature review. According to the review, it was evident that for cost and performance purposes the nRF24L01 from Nordic semiconductors was the best suited wireless communication chip. See Table 2. The nRF24L01 from Nordic semiconductors is a small Wi-Fi chip that is affordable and reliable to use. It has speeds of up to 2MB/s and a range of up to 100m on the low power version which is more than sufficient to transmit a few bytes within a household. The chip uses SPI to communicate with the microprocessor. Although the chip operates at 3.3V logic it is 5V compatible which lowers the number

Figure 7: Picture showing the Trinity GPRS modem with RS232 cable and Antenna

of components on the PCB, as a level converting chip is not needed for it to communicate with the microprocessor. Each chip has a configurable 5byte address giving a total of 32 addresses[?]. It can also change between 125 channels so that if a certain channel is saturated in an area another can be used instead. Another great feature of this device is its power management. It draws as little as 22uA in Stand-By mode and 900nA in power down mode. It also has a configurable power output so that if devices are all in close proximity the power output of the antenna can be decreased. As size is also an important consideration in this project the breakout board has another advantage over the other wireless solutions as it only has a size of 34mm X 17mm. This chip has become very popular by hobbyists and within the Arduino community and as such there are many examples and libraries concerning the chip's usage. The library used in this project was the RF library written by J. Coliz. The code "Getting started" was edited to suit the need of this project.

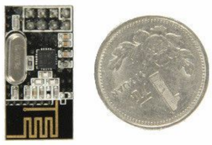


Figure 8: Picture showing the size of the nRF24L01 breakout board

4.1.5 Display

A display is needed that can show all the relevant information such as voltage, current, power and the status of an appliance. It also needs to show a menu for changing settings. There were two displays under consideration. The TC1602A-01T is a 16x2 Character LCD display. It has a eight wire interface for communication. It is possible to reduce the amount of pins needed by using a LCD driving IC but this would mean that more space would need to be sacrificed. Being an LCD screen, a back light is needed if there is poor visibility as the contrast is not high enough to be readable without one. Another disadvantage of this Display is that it can draw as much as 150mA when operating[9]. An advantage that this display has over others is that it is easily and readily available at most electronic stores. The SSD1306 OLED display from Solomon Systech was the second considered display. Being an OLED it does not need a back light as the contrast is high enough making it very readable in even poorly lit environments. It also only draws a maximum current of 30mA making it a very efficient display[8]. The display has a few different types of communication options such as UART, I2C and SPI. It also has the advantage of being much smaller than the LCD screen in consideration, but being able to display much more(16x8 characters). Being a very popular display among hobbyists and the Arduino community there are many libraries and examples of usage available. With low power usage, cost and size in mind, it was decided to use the SSD1306 OLED as the Display for this project.
The OLED break out board used for this project is a Crius OLED display purchased off e-bay. These boards need a total of 4 pins for communication and power: SDA, SCL, GND and 5V. The advantage of the breakout board is that level shifting from 3.3V to 5V is not needed and also there is no need to solder on a ribbon cable, that the bare modules have. The library for this display was modified from Adafruit industries to suit this project's needs.

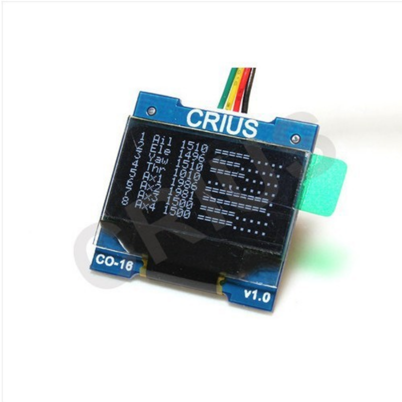


Figure 9: Picture showing the OLED breakout board from Crius

4.2 Satellite Unit

The Satellite Unit is responsible for reading the measurements of the EMIC and relaying this information once requested from the Base Station wirelessly. The Satellite Unit is composed of three main parts. The microprocessor, the EMIC and a Wi-Fi module. The Satellite Unit was designed in such a way that it can be connected directly to the Base Station with wires to operate as a stand alone system. In this configuration the Satellite unit does not need a microprocessor or Wi-Fi chip which can reduce costs for users only wanting to monitor a single appliance.

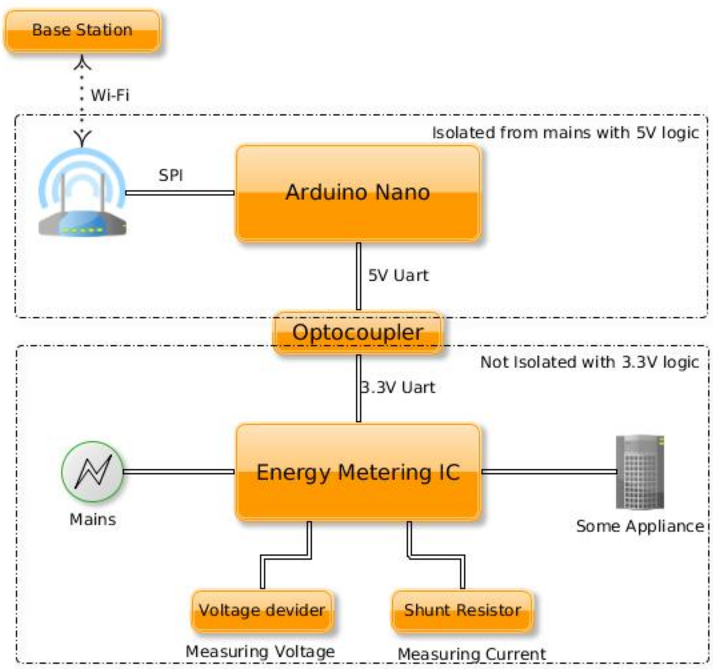


Figure 10: Picture showing the interaction between components of the Satellite Unit

The Microprocessor(Arduino Nano) uses SPI communication to communicate to the Wi-Fi chip which in turn communicates to the Base Station. The Arduino Nano also needs to communicate to the EMIC. As the Arduino Nano needs isolation from Mains, optocouplers were used. The Optocouplers are also able to do the necessary level shifting as the Arduino Nano and EMIS operate at different logic levels. The EMIC connects to the mains and to the appliance and can measure the voltage and current using a voltage divider and shunt resistor.

4.2.1 Microprocessor

The choice of microprocessor for the Satellite Unit also had to be Arduino based to minimise complexity and to have unity in microprocessor choice. The Nano was chosen from the different available Arduino based boards because it is the smallest with a built-in programmer. The Nano has all the same features of the Mega but with fewer IO pins. It also only has one Serial communication port which is needed for the energy metering IC as well as for programming. Because of this, a dip switch was needed to do in-circuit programming. While programming, switching off the dip switch will cut the communication with the EMIC and during normal operation the dip switch is switched back on to reinstate communication.

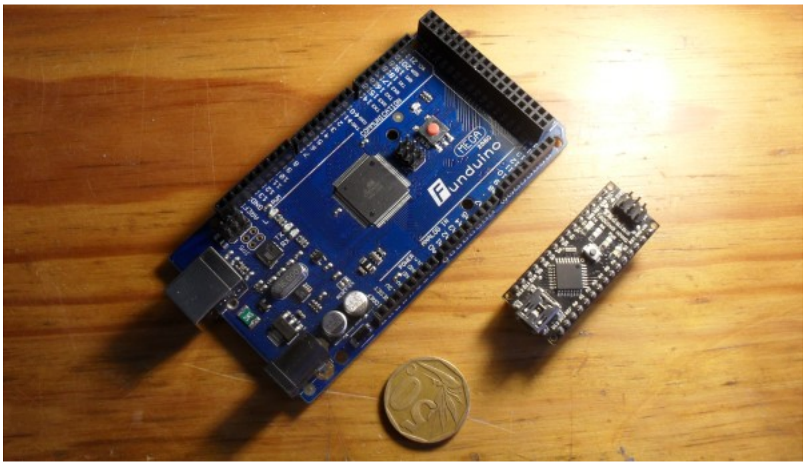


Figure 11: Picture showing the size difference of the Mega(left) and Nano(right)

4.2.2 Energy Metering IC

From the literature review it was clear that an easy way to measure power was to use an EMIC as no further calculations are needed and nothing else needs to be taken into consideration. An EMIC only needs to be set up and calibrated and then the registers can be read to get the relevant information. There were a few EMICs under consideration such as the MCP3903 from microchip. It uses SPI communication with a total of 8 pins dedicated to communication (SCK,SDO, SDI,CS, Reset and 3 data ready lines). Most EMICs used SPI communication. However the one logic chip that stood out was the CS5490 from CIRRUS LOGIC. It uses UART for communication and seems to be more powerful than other EMICs. Some of the features that this IC has are:

- Energy Measurement Accuracy of 0.1%
- Supports Shunt Resistor and CT
- On-chip Measurements/Calculations:
  - Active, Reactive, and Apparent Power
  - RMS Voltage and Current
  - Power Factor and Line Frequency
  - Instantaneous Voltage, Current, and Power
- Over current, Voltage Sag, and Voltage Swell Detection
- Ultra-fast On-chip Digital Calibration
- UART Serial Interface
- On-chip Temperature Sensor
- Single 3.3 V Power Supply
- Low Power Consumption: ¡13 mW

Another problem with other EMICs was that there are only two companies in South Africa that stock EMICs and these were only available on request. Fortunately Mr Booysen donated four CS5490 EMICs to the project thus saving time and money.The CS5940 only requires 3 pins in total Rx,Tx and Reset. EMICs are generally connected to mains to get the voltage readings and as such there is a need to isolate the IC from the microprocessor communicating with it. Optocouplers were used in this project to establish an isolated connection between the Arduino and the IC. The optocoupler can isolate two circuits from each other as it transmits the data using light and it has a light sensitive transistor all housed in a small package. Conveniently this also operates as a level shifter as the Arduino operates at 5V logic and the energy metering IC at 3.3V logic solving two problems with one device.
The EMIC does require some circuitry to do the measurements. For Voltage measurement a voltage divider was used between the two lines and for current measurement a shunt resistor was used. The IC can take a maximum of 500mV peak to peak[3] on both the voltage measurement and current measurement inputs so the CT or Shunt Resistor, and voltage dividers must be chosen in such a manner that the maximum values will never be reached otherwise the IC can break.

4.2.3 Wi-Fi

The Wi-Fi chip is exactly the same as used in the Base Station see section *4.1.4*

4.2.4 Optocouplers

The microprocessor has a logic level of 5V whereas the EMIC has a 3.3V logic level and as such a level shifter is needed. Furthermore the energy metering IC is connected to the mains however it has to have the microprocessor and Wi-Fi chip isolated from the mains because the noise from the mains can damage the microprocessor and especially the reliability of the Wi-Fi chip. So there is a need for a device that can do both isolation and level shifting. Fortunately an optocoupler can do precisely this. A light source in the optocoupler is switched on when a signal is transmitted to it. This light source activates a transistor connecting both ends on the receiving side. The choice of optocoupler was mainly due to availability and size. Another important factor was the rise and fall time of transferring the signal across the optocoupler. The EMIC is set up to have a default baud rate of 600. Because the baud rate is so low, optocouplers can be in the microsecond range. The optocoupler for this project was the KB817; it has rise and fall times of 3 and 4 us respectively [5]and as such it is acceptable to communicate reliably at a baud rate of 600. It was also chosen as it was easily available and had a small package with only 4 pins.

4.2.5 Shunt Resistor

A shunt resistor was chosen as it is more stable than a Hall Effect sensor and smaller than a Current Transformer(see Section X.X.X). The shunt resistor had to be in a range in that if maximum allowable current is drawn from a device the voltage drop over the shunt resistor is less than 500mV peak to peak as this is the EMICs max current voltage input.

$$V_{max} = I_{max}.R$$

$$\therefore R \leq \frac{V_{max}}{I_{max}}$$

choosing I_{max} as $10A$ and V_{max} as $250mV$ it follows

$$R \leq 25m\Omega$$

So any shunt resistor that is smaller than or equal to $25m\Omega$ will be sufficient. Unfortunately the only shunt resistors that were in stock and were readily available were $10 - 5m\Omega$. As this was the case it was decided to use one $10 - 5m\Omega$ shunt resistor. The EMIC has an internal adjustable gain of 50x so that a smaller shunt resistor can be used which also has the benefit of less power dissipation on the resistor.

4.3 Power supply

A very efficient power supply was needed to minimise power consumption of the power meter; another benefit would be if the power supply was also minimal with respect to additional components needed and size. Embedded switch mode power supplies(ESMPS) seemed like the power supply of choice, having very high efficiency with no external components needed. Other supplies under consideration were cellphone chargers and normal Transformers with rectifying circuits however these seemed to be rather bulky and with size being an important factor it seemed to be a more reasonable decision to chose the ESMPS. The 5V RAC03 ESMPS from Recom has an efficiency of up to 71%. It takes 230V AC and transforms it to 5V DC needing no external components at all. Although the ESMPS is very efficient and no external components are needed there is still a small ripple on the output[15]. In the design it was chosen to filter this noise out by putting a capacitor to ground on the output to filter out high frequency and an inductor in series to filter out low frequency. Both Base Station and Satellite Unite use the ESMPS. The Satellite Unit however needed an additional 3.3V power supply for the energy metering IC that was isolated from the 5V power supply. To save costs a simple transformer with a rectifier and a voltage regulator was used. The Schematics of the power supply can be seen in section Appendix D.

5 Detailed Software Design

5.1 Overview

There are two software applications; one is on the Base Station and the other is on the Satellite Unit.

5.1.1 Base Station

The Base Station's application was designed in such a way that a user can select the mode of operation. The Base Station can either operate in Wi-Fi mode or Stand Alone mode. In this way the same software can be loaded on each board and can then be configured by the user at a later stage.

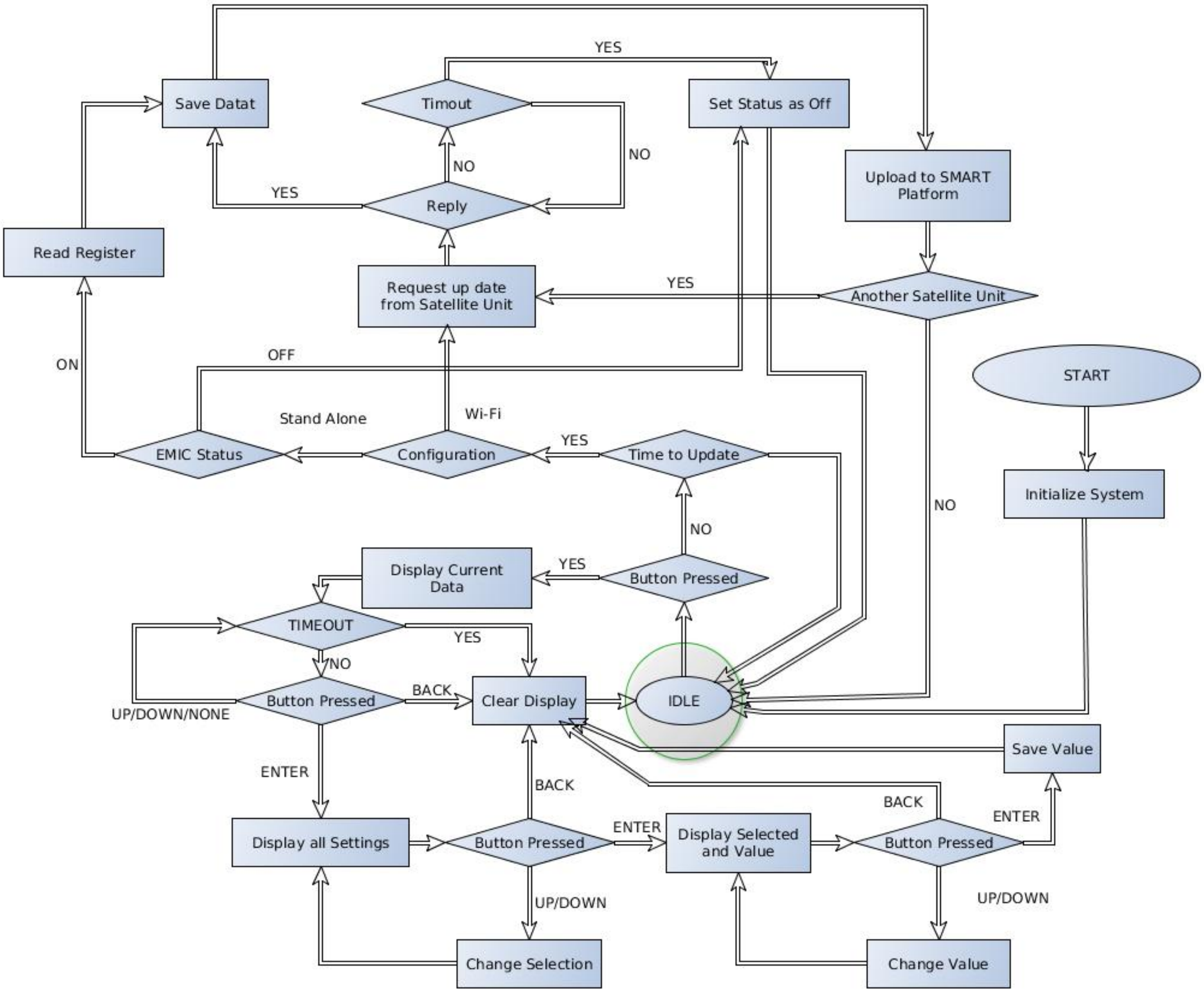


Figure 12: This Figure shows the flowchart of the Base System

The flow chart above explains how the Base Station's Software was designed. When the station receives power it first initialises and then goes into idle state. It will only exit the idle state if either a button is pressed or if it is time to update. If a button is pressed it enters the menu showing relevant information on the OLED display. The user is then also able to change certain settings using the push buttons. If left alone for 10seconds the Display will clear and return to idle state. If idle and it is time to update it will exit idle state and depending on operation mode either request information from a Satellite Unit or from the EMIC. Once this process is completed it sends the data to the SMART platform via the GPRS modem and will then return to the idle state.

5.1.2 Satellite Unit

The Satellite Unit was designed to link the Base Station to the EMIC via Wi-Fi. When it receives power it will initialise and go into an idle state. It will remain in this state until a request for data has been sent. When a request is received it initialises the EMIC, reads the data, relays it to the Base Station and returns to idle state. The flowchart below shows a graphical representation of the software.

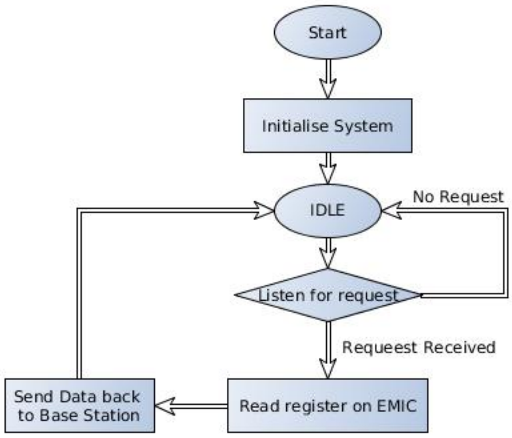


Figure 13: This Figure shows the flowchart of the Satellite Unit

5.2 The SMART Platform

Trinity Telecommunications made the SMART platform available to this project. This online based web-interface is used to send and receive data as well as certain commands. The advantage of using the SMART platform is that it shortens development time. It allows the user to develop and setup a user interface between the user's device and the web-interface. The storage of data and the visualisation there of is also handled by the SMART platform with the help of the Dashboard.

5.2.1 Setting Up

The SMART platform needs to be configured first before online use. The configuration is done through Airvantage which is an eclipse based IDE. Airvantage allows the user to configure their Assets with regard to:

- Number of variables
- Type of variables
- Commands
- Status

In this project the Asset had four variables namely Power, Voltage, Current and Temperature; which were configured along with a status variable. Once this is done it can be uploaded to the SMART platform.

5.2.2 The Dashboard

SMART sight is a tool built into the SMART platform and it was used to create a dashboard. The dashboard can be used to display the data in different ways such as graphs, numerical values or the data can be processed through certain functions. Since it was so easy to use. With the ease of use time was saved in this part of the project.

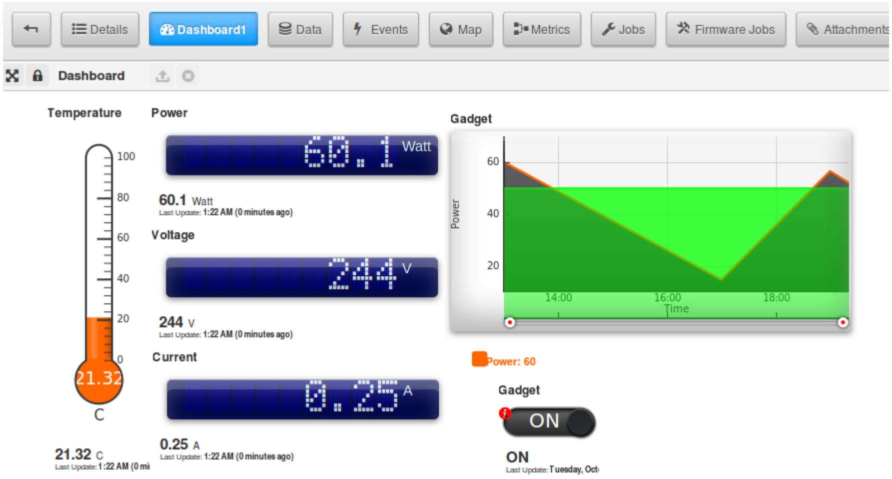


Figure 14: This Figure shows the dashboard on the SMART platform

The above figure shows the final Dashboard used for this project. There are four numerical representations of the data as well as a graph for the power consumption and a status for the system.

5.3 Wireless Communication

The nRF24L01 2.4GHz Radio/Wireless Transceiver uses SPI as communication. Besides the three SPI pins setup by the Arduino environment an additional three pins are needed to be set namely: chip enable(CE),chip select not(CSN) and interrupt(IRQ). Although provisions for the interrupt pin were made in the hardware design it was not implemented in the software design. On the Mega the CE and CSN pins were chosen as 48 and 47 respectively and on the Nano pins 9 and 10. The **Wire** library built into the Arduino environment is responsible for handling communication with SPI enabled devices the SPI pins for this library are predefined. The Library used for communicating with the Wi-Fi chip was the RF24. This library allows the user to handle everything needed communication wise with only a few functions. The functions from the library used for the project are listed below.

Function	Description
`RF24 radio(int CE,int CSN);`	Declair which pins are used for CE and CSN
`radio.begin()`	Initialises Radio
`radio.setRetries(int dly,int re);`	Set `re` as number of retries and `dly` as delay between retries
`radio.openReadingPipe(int numb, int addr)`	Opens pipe number `numb` with address `addr`
`radio.openWritingPipe(int addr);`	Open pipe with address `addr`for writing to
`radio.startListening()`	Listen for incoming
`radio.stopListening()`	Stop listening
`radio.write(*addr, int size)`	Write from address `addr` of length `size`
`radio.read(*addr, int size)`	Write to address `addr` of length `size`
`radio.available()`	returns true if there is incoming data

Table 2: Table showing the Wi-Fi functions used in this project

There were a few options on how to control the communication between the Base Station and the Satellite Unit. The one option would be to have the Satellite Units send the data continuously to the Base Station every few seconds. When the Base Station does not receive data in a certain amount of time it assumes that the Satellite Unit is off. However this could be problematic if a household has many Satellite Units which all start up at the same time and try to send. According to the data sheet the Wi-Fi module only allows up to 6 devices to communicate to the same Wi-Fi chip simultaneously[?].

To maximise the amount of devices being able to communicate to the base Station another more organised method was needed. Another option was to have the Satellite Unit stay in listening mode and wait for a request from the Base Station. When the Base Station wants data it sends a request to the Satellite Unit and then goes into listening mode. The Satellite Unit receives the request. It then retrieves information from the EMIC and then is set to write mode to send the data back to the Base Station after which the Satellite Unit is set back to listening mode. The Base Station receives the data and goes back into idle state or asks a different Satellite Unit. If the Satellite unit does not respond the Base Station will timeout and return to idle state. It will be assumed that if a Satellite Unit does not reply that the Appliance in question is turned off. This assumption is acceptable because the system is designed so that if a wall socket is switched off the Satellite Unit will not get any power. This method maximises the amount of appliances that are able to communicate to the Base Station as the Satellite Units are all called one at a time allowing up to 31 Satellite Units to be connected to the system.

5.4 OLED Display

The Displayed used in this project was the SSD1306 from Solomon Systech attached to an I2C breakout board from Crius. It uses the Library from WWW.WIDE.HK. The Arduino Mega uses digital pins 20 and 21 for SDA and SCL to communicate to the Display. The project only made use of the following functions in the Library:

Function	**Description**
`void i2c_OLED_init()`	Initialises the OLED
`void clear_display(void)`	Clears the OLED display
`void setXY(int i,int j)`	Sets the cursor of the OLED
`void sendStr(unsigned char *string)`	Writes a string on the display
`void sendcommand(char com)`	Send a command to the OLED

Table 3: Table showing the byte structure when communicating to IC

An additional function `void init_OLED` was added to the library. This function called `i2c_OLED_init()` sets the Memory address mode, page addressing mode and sets the display as normal using the `void sendcommand(char com)` functions.

5.4.1 Interface

The Interface uses four buttons located on the Base Station. From left to right the buttons are: *UP*, *DOWN*,*BACK* and *ENTER*. These buttons are used to navigate through the menu and display. The functioning of the interface is best explained using the flowchart below.

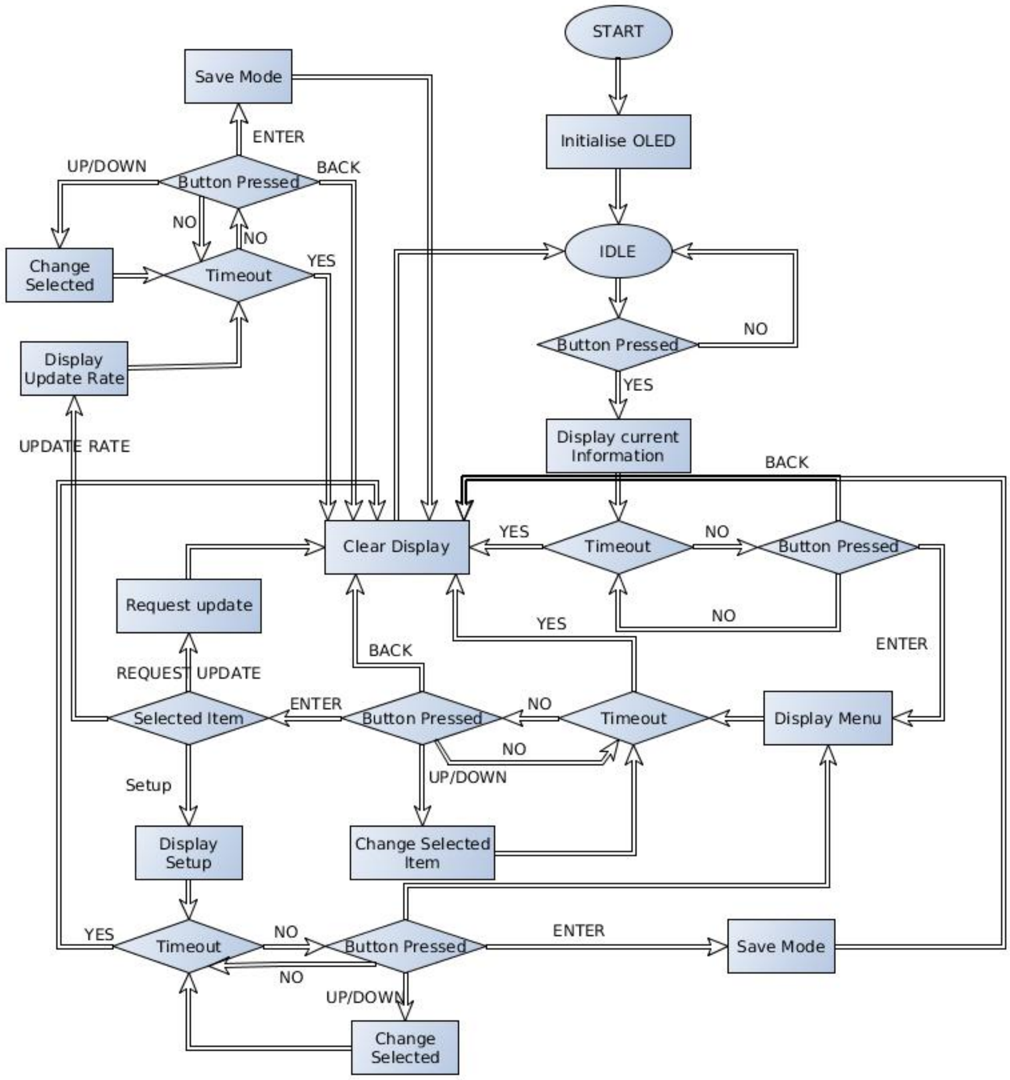


Figure 15: This Figure shows the flowchart of the Base System

The display first powers up and enters the idle state. This is the same state as described in the overview. When a button is pressed the OLED display turns on and shows the information such as Power, Current, Voltage, Temperature and the Status from the last update. The display will clear if the back button is pressed or if a timeout occurs. If the enter button is pressed it will display the menu. The menu has three items to chooses from:

- Update Rate
- Setup
- Request Update

The user can navigate through these items by using the up and down arrows. A small arrow next to the item indicates which item will be selected if enter is pressed. When Update rate is selected the user can change the frequency of updates to the system using the up and down buttons. Pressing enter saves the current value, clears display and returns to idle. If Setup is selected the user can change the configuration to either *Stand Alone* or *Wi-Fi*. The third item, if selected, will request an update of the appliance. This is used if the user wants the current status of the appliance.

5.5 Energy Metering IC

The EMIC does all its own calculations. All that needs to be done once the IC starts up is to reset it, calibrate it and then set it for continuous conversion. After this, the EMIC will automatically update the registers and a flag will be set if new data is available. The EMIC uses serial UART communication with a default baud rate of 600 (can be changed in configuration register). A active low Reset pin is also needed in addition to the the Rx and Tx pins for communication. The EMIC has a 12bit address system. the first 6 bits determine on which page the register is and the last 6 determine the address on the page in question. To access a certain register, first the page number needs to be set and then the address. The EMIC processes 1 byte at a time. The first two bits determine if a read, write, command or page select byte is being sent. If a read register byte is sent the EMIC replies with 3 byte from the register in question. If a write byte is sent the IC waits for an additional 3 byte. For this project the interested registers were Voltage, Current, Power and Temperature. By placing a finger on the IC, a temperature change could be noticed thus validating its functionality. This is the main reason the Temperature register was requested. It also allowed some basic testing of the system without connecting the entire system to mains and thus minimising the risk of shock.

Function	**Binary Structure**	**Note**
Read from Register	00A5A4A3A2A1A0	A[5:0] specifies the register address.
Write to Register	01A5A4A3A2A1A0	A[5:0] specifies the register address.
Page Select	10P5P4P3P2P1P0	P[5:0] specifies the page.
Instruction	11C5C4C3C2C1C0	C[5:0] specifies the instruction.

Table 4: Table showing the byte structure when communicating to IC[3]

The register and page addresses can be found in the data sheet[3]. The following registers, pages and commands used in this project are in the table below.

Register/Instruction	**Byte**	**Note:**
Voltage	0b00000111	Read RMS Voltage
Current	0b00000110	Read RMS Current
Power	0b00000101	Read Active Power
Temperature	0b00011011	Read Temperature
Page 16	0b10010000	Set page for above registers
config0	0b00000000	Read Configuration register
Page 0	0b10000000	Page for config0
SoftReset	0b11000001	Software reset command
Standby	0b11000010	Standby Command
wakeup	0b11000011	Wake up command
ContinuousConv	0b11010101	Start doing calculations

Table 5: Table showing the different bytes that need to be sent for reading and setting up

All the code written for the EMIC are found in the power.pde file included with the CD. The functions written are:

- `power_init()`
- `temp_request()`
- `volt_request()`
- `current_request()`
- `power_request()`
- `serial_check()`

The `power_init()` function initialises the EMIC by doing the following: First it resets the IC by setting the reset pin low for one millisecond and then high again. Then it sends the software reset command via Serial1 on the Base Station if in *Stand Alone* configuration and via Serial on the Satellite Unit. After this it sets the EMIC for continuous conversion. After the `power_init()` function has been called either of the request functions can be called. The request functions all work in the same mannar. They first set the page and then send the register they would like to read from. The `serial_check()` function then runs in the background waiting for a reply from the EMIC. If a reply has been received the `serial_check()` sets a `newdata` flag so that the requested register can be saved.

5.6 The GL6100 GPRS modem

The GL6100 GPRS modem uses RS232, along with Hayes command set, which is also frequently referred to as AT commands, to communicate with the Base Station. In the electrical design it was decided to uses a SP3232 chip to convert UART to RS232. The Serial2 port on the Arduino Mega was used for Tx and Rx pins for communication. AT commands consist of strings of characters that are sent to and from the modem to tell the modem what to do. Trinity gave a workshop on using the Trinity modem and also supplied a list of At commands used by the modem. The following AT commands were used in this project and are described in the Table below

Command	Description
`at+awtda=d*`	send the user all the data that the modem does not understand, needs to be set after modem reset
`at+awtda=c*`	send the user all the commands, needs to be set after modem reset
`at+boot?`	this is used to check if the modem has been reset or not
`at+awtda=d, "Appliance",1,"Temperature,INT32,%d"`	This command was used to update the temperature. The same structure was used for other variables.
`at+cfun=1`	resets the modem
`at + ipr = 115200;&w`	Sets the baudrate of the modem
`at+wdwl`	set for receive mode/File/Transfer/ Xmodem/send/*select file

Table 6: Table showing some of the AT commands used in this project

The modem sends `+AWTDA:` as an unsolicited response every few seconds. If a command is sent it replies with the same command and then follows with an `OK` or `ERROR` depending on whether everything went well or not. The commands used for this project are all found in the GPRS section of the code. The function `int_GPRS()` sets up the modem and returns true if the modem responded with an `OK` and false if the modem responded with `ERROR`. The function `update()` is called after new values have been read from the EMIC. It is also a boolean function which returns true if the modem responded with an `OK` and false if there is an `ERROR`.

6 Detailed Mechanical Design

This section explains the mechanical design steps concerning PCB and Mechanical housing.

6.1 PCB Design and Manufacture

The design and layout of the PCB was done in Eagle Cad which is a well known PCB design in industry. For this project the free student version was used. It is just as powerful as the full version with the limitation of board size(10x10cm) and layers(max double layer). To save time and money the PCBs were produced by the author with the simple press and peel method.

6.1.1 PCB Design

The PCB design flow used was the Successive Refinement Model(SRM) and went through 4 iterations. In the SRM design approach a product goes through a few iterations. At each iteration a Version is designed, verified and evaluated. All design error corrections and adjustments are then made in the following iteration. This process is then repeated until a satisfactory product is obtained. For example, the Satellite Unit was designed using the SRM method as follows: The first iteration of the Satellite Unit was a Vera board version of the PCB. Once the components were tested and adjustments were made a PCB version was produced in the second iteration. To save space and money the PCB was designed to be double layer (meaning both top and bottom were printed) with surface mount components. After testing the second iteration it was found that a Current Transformer was not the best option and that surface mount components proved somewhat difficult to solder. The space and cost saving over through hole in this design was minimal so it was decided to use through hole components over surface mount in the final iteration. The third iteration was another Vera board version. In the third iteration it was found that there was a need to be able to cut the connection to the serial communication so that in-circuit programming could be done. The fourth version was a single layer through hole PCB. In those areas where lines would have crossed, jumpers were used in the form of wires on the top layer. Corrections were also done on the pin layout of the Wi-Fi chip and two dip switches were added to cut the communication of the EMIC as well as power during programming. A Shunt Resistor was also chosen over a CT as it proved to be less expensive and smaller in size. It was also found from the first PCB that when the tracks were made too small, tears could form during the etching process which would cause the tracks to not conduct. Another observation was that the pad size had to be increased to make sure that pads where not ripped out when drilling for the through hole components. In the final version the tracks were made thicker and the pads larger.

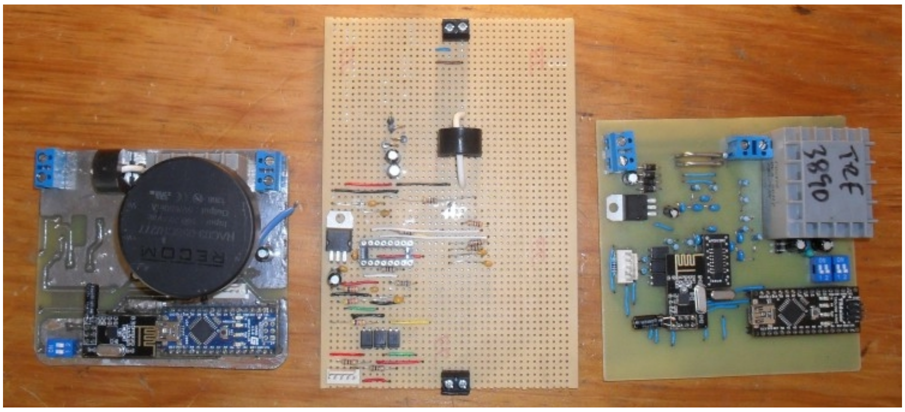


Figure 16: Picture showing the iterations of the SRM (from left) 2, 3 and 4 of the Satellite Unit

6.1.2 PCB Manufacture

The PCBs were manufactured using the Press and Peel method. The PCB, once finished being designed, is printed in solid black lines as a mirror image onto transfer paper. The paper is then placed onto a standard PCB copper clad board. An iron is then used to transfer the image by heat onto the copper board. At this stage the PCB can be seen as black tracks on the copper. The board is then placed into a bowl containing Ferric Chloride. This is a very corrosive solution. The solution etches all the copper except for the copper that was covered in black ink from the transfer. It was found during the iterations that agitating as well as heating the solution above room temperature shortened the process time. After the etching process the board is cleaned and the final step is to drill the holes and solder the components to the board.

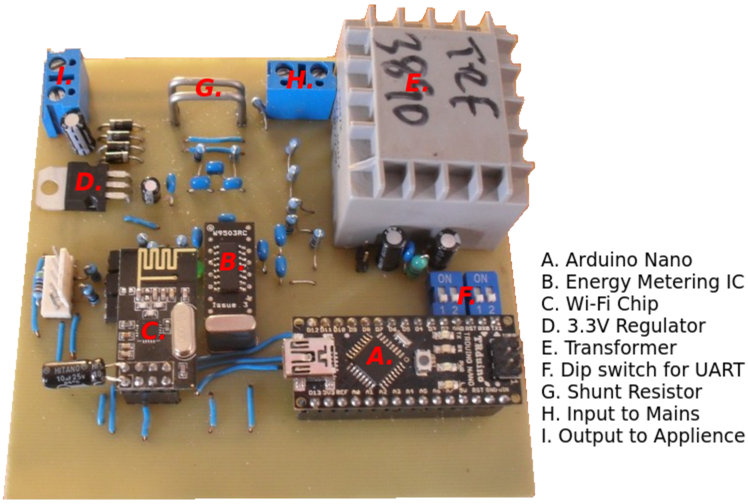


Figure 17: Picture showing the final version of the Satellite Unit and it's components

6.2 Mechanical housing

A mechanical structure is needed to house the Base Station as well as the Satellite Unit. It also needs to serve as an electrical insulating medium, especially in the case of the Satellite Unit as it contains tracks connected to mains which could cause a person to be shocked if that person touches the tracks. The material selected for this project was Acrylonitrile Butadiene Styrene. ABS is a common plastic used in electrical insulation and is easily and cost effectively manufactured with injection moulding [4]. Autocad was used to design the mechanical housings.

6.2.1 Satellite Unit

A simple housing was designed with a BS 546 type M(SABS 164-1) Socket and plug. These sockets and plugs are currently standard in South Africa[16]. The housing of the Satellite Unit plugs directly into a BS546 type M wall socket and in turn an appliance plugs into it. In this way there is no need for a complex installation therefore it is a plug and play solution. It was designed with ease of manufacture and a low number of parts in mind. Unfortunately due to time constraints there was not enough time to build a prototype however a simple version of the housing was designed.

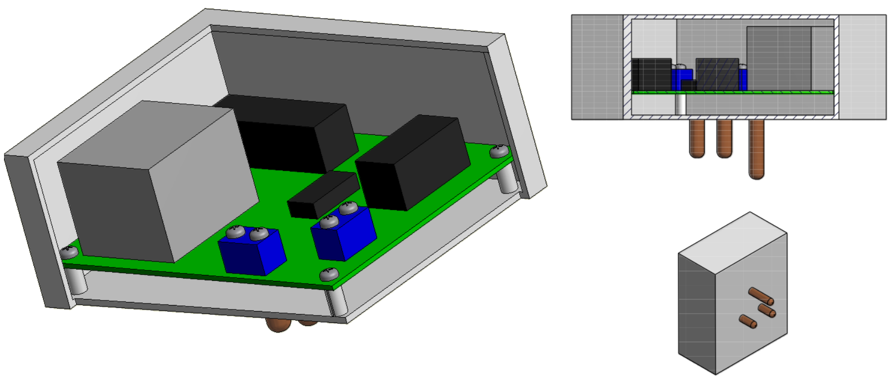


Figure 18: Picture showing a sliced view of the Satellite housing with the board inside

In the design the ground pin and terminal on the socket are directly connected with a 20A conducting wire. The Live and Neutral pins are first connected to the board at the "Line In" socket using 20A conducting wire. This is needed to give the Satellite Unit power as well as to measure the Voltage and Power of the appliance. The "Line Out" socket is then connected to the Live and Neutral terminals of the housings socket. Electrical insulation and thus prevention of shock is guaranteed through the insulating material ABS. An off-the-shelf BS 546 type M socket with blocking shutter is used to ensure that the Live, Neutral and Ground terminals are insulated on the housing's socket even when no appliance is connected.

6.2.2 Base Station

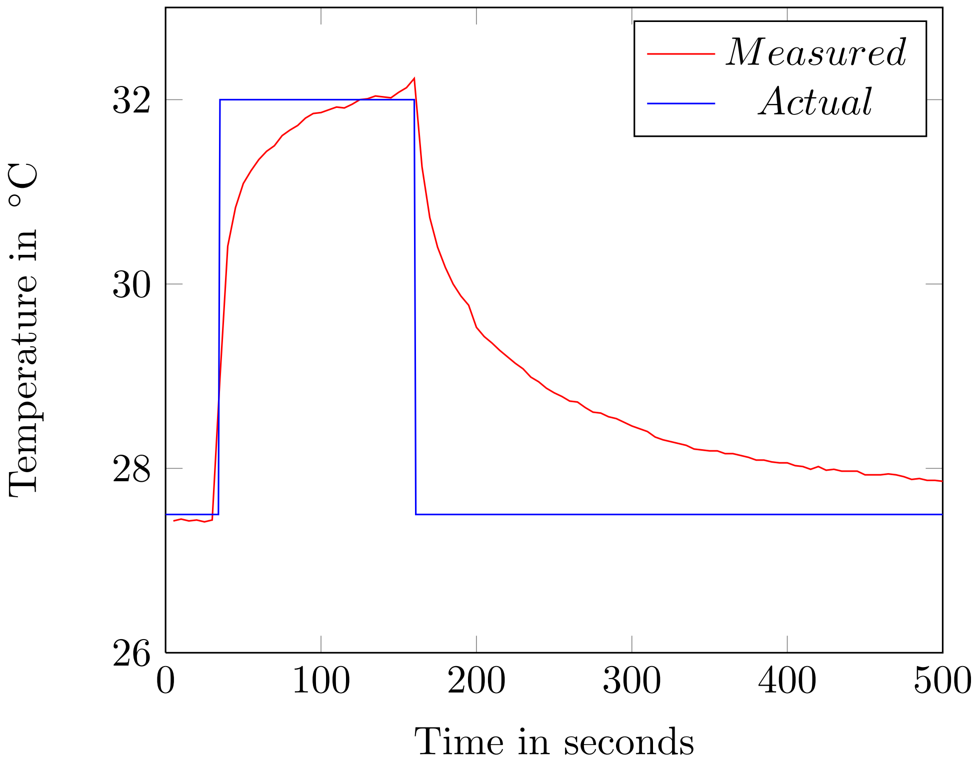
Unfortunately due to time constraints a housing was not designed for the Base Station.

7 Practical Verification

In this section the practical working of the system was verified. First some individual components were tested and validated and at the end the whole system was validated.

7.1 Temperature Reading

The temperature sensor was used to verify that the EMIC was communicating correctly before connecting it to the mains. In this way if something were to happen to the EMIC there would be at least some data to show. In this experiment the Base Station was configured to be in the*Stand Alone* mode. The Base Station set up the EMIC and did a serial read from its temperature register every 5 seconds. It then sent its result to the serial port of the computer to capture the data. The system was not connected to mains. After reading the Temperature Register seven times a finger was placed on the IC to validate change in Temperature. The room temperature at the time was 27.5 °C and the external body temperature of the finger added was 32 °C.The following result was obtained



The red line in the graph shows the measured temperature of the EMIC. The blue line shows the actual temperature measured from a thermometer. The increase and decrease of the blue line is when the finger was placed and removed from the EMIC. The reason for the slow decay of the measured value is that the finger warmed up the EMIC and it had to dissipate the heat first before it could measure the actual room temperature again. From the data it is clear that the EMIC was functioning correctly and could now be connected to mains.

7.2 Updating The Dashboard

This section aims to verify the GPRS communication as well as the Dashboard in the SMART platform. In this setup the Base Station was not connected to the Satellite Unit nor was there Wi-Fi communication.

The Base Station was only connected to the GPRS modem. Dummy values were sent to the GPRS modem every 30 seconds from the Base Station to update the temperature variable on the SMART platform. The initial starting time was at 00:33:59. The time difference was noted to try and determine the delay between sending and receiving at the SMART platform. The following data was obtained.

Time stamp	Data number
2013-11-02 00:33:59	1
2013-11-02 00:34:29	2
2013-11-02 00:34:59	3
2013-11-02 00:35:29	4
2013-11-02 00:35:59	5
2013-11-02 00:36:29	6
2013-11-02 00:36:59	7
2013-11-02 00:37:29	8
2013-11-02 00:37:59	9
2013-11-02 00:38:29	10
2013-11-02 00:38:59	11
2013-11-02 00:39:30	12
2013-11-02 00:40:00	13
2013-11-02 00:40:30	14
2013-11-02 00:41:00	15
2013-11-02 00:41:30	16
2013-11-02 00:42:00	17
2013-11-02 00:42:30	18
2013-11-02 00:43:00	19
2013-11-02 00:43:30	20
2013-11-02 00:44:00	21
2013-11-02 00:44:30	22
2013-11-02 00:45:00	23
2013-11-02 00:45:30	24
2013-11-02 00:46:00	25
2013-11-02 00:46:30	26
2013-11-02 00:47:01	27
2013-11-02 00:47:31	28
2013-11-02 00:48:01	29
2013-11-02 00:48:31	30
2013-11-02 00:49:01	31
2013-11-02 00:49:31	32
2013-11-02 00:50:01	33
2013-11-02 00:50:31	34
2013-11-02 00:51:01	35
2013-11-02 00:51:31	36
2013-11-02 00:52:01	37
2013-11-02 00:52:31	38
2013-11-02 00:53:01	39
2013-11-02 00:53:31	40

Table 7: Table showing data number and the time stamp there of

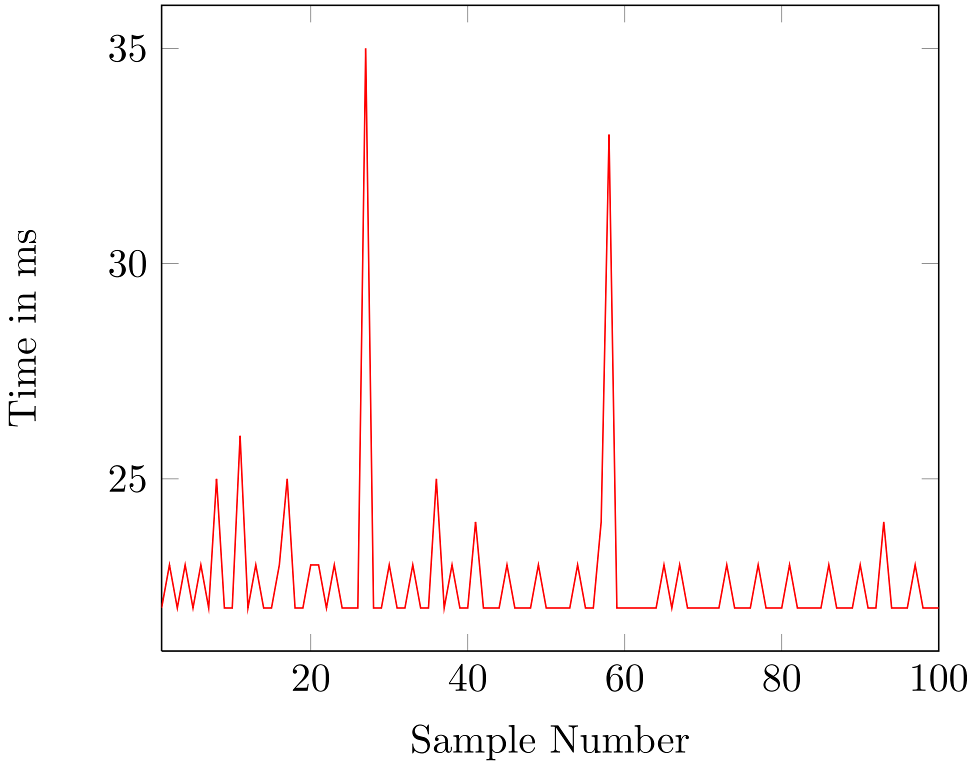
Unfortunately the time stamp only shows seconds and therefor nothing can be said about the latency as it appears to be in the millisecond range. However 40 packets were sent and 40 packets were received making the communication very reliable. The Dashboard was able to update the data every 30seconds and the data was reliably transmitted to the SMART platform. The GPRS communication through the GL6100 modem was reliable.

7.3 Wi-Fi

In this section the reliability and latency of the Wi-Fi chip were tested.

7.3.1 Latency Test

For this test both the Base Station as well as the Satellite Unit were equipped with the nrf24L01 Wi-Fi chip. The boards were placed 30m apart in an environment with many metal structures. It should be noted that no intervening walls were present in this test as it is only validating the latency of the device. The Base Station as well as the Satellite unit were loaded with the RF24's *Getting started* code. The Base Station sent 4 bytes to the Satellite unit. The Satellite Unit then replied with the same 4 bytes. The time difference between sending and receiving was then printed out on the Serial port so that the data could be captured. This is generally known as a ping test often used in networking to determine the reachability of a host. The following data was observed during testing.



Statistics	
Min	22ms
Max	35ms
Range	13ms
Median	22ms
Mode	22ms
Average	22.65ms

Table 8: Table showing the statistics of the Nordic Semiconductor Wi-Fi module

7.3.2 Coverage

For this test the Base Station and Satellite Unit were once again loaded with the *Getting started* code. The Base Station was set at a fixed location and the Satellite Unit was moved to various different locations in a house. The walls in the house are made out of concrete and brick on the ground floor and out of wood on the first floor. The brick walls were 0.26m and the wooden ones were 0.20m thick. At each location the Base Station sent 100 packets (each packet consisting of 4 bytes of data) and waited for replies. Each time a packet timed out it was noted and the following results were obtained.

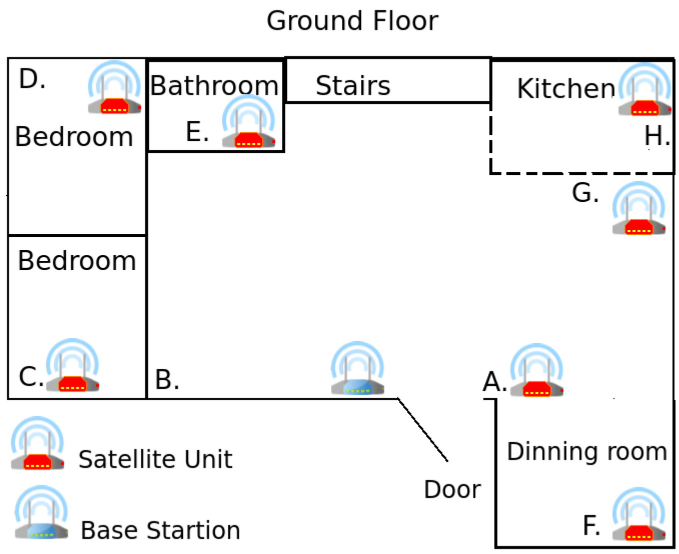


Figure 19: Picture showing where in the house on the ground floor the Satellite Unit and Base Station were placed

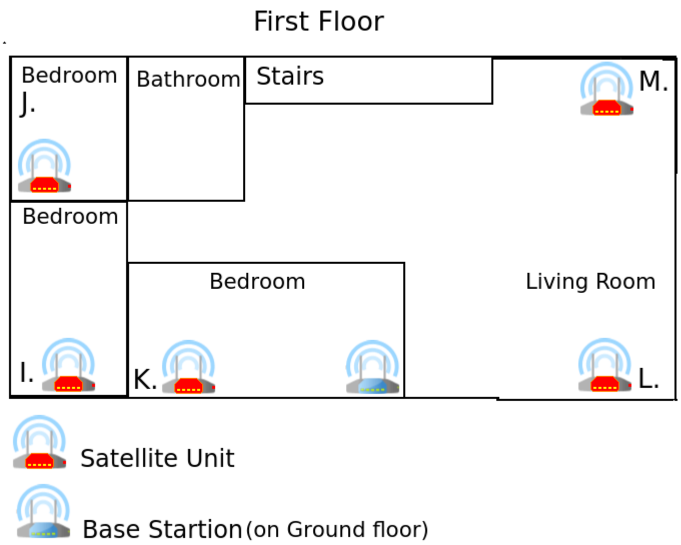


Figure 20: Picture showing where in the house on the first floor the Satellite Unit and Base Station modem were placed

Location	Packets received
A	100
B	100
C	100
D	95
E	100
F	100
G	100
H	98
I	99
J	75
K	100
L	100
M	45

Table 9: Table showing packets received at various locations out of 100

On the ground floor the Wi-Fi module had great coverage. It was only missing five packets at *D* and two at *H*. It should be noted that these locations were in the corners of the ground floor at the farthest distance from the Base Station. On the first floor the modem did not perform to expectation, it only received all the packets at two of the five locations. At point *B* 55 packets were lost at the farthest point from the Base Station. It seems that walls do make a great difference in performance. In the previous test about latency there were no timeouts at all however the signal from the Wi-Fi did also not need to travel through walls.

7.4 Display & Menu

To test the OLED display and menu interface the Author and two users were asked to test it by navigating through the menu and noting if any errors were present and by commenting on the display. There were no errors found by either users regarding the interface and display. The display is very readable in both bright as well as dark environments. The response to pressing a button and changing states was immediate, meaning that no delay could be noticed. The only negative feedback from one of the users was that the display was small and that the user had to wear glasses to read it. In general the OLED display performed to expectation.

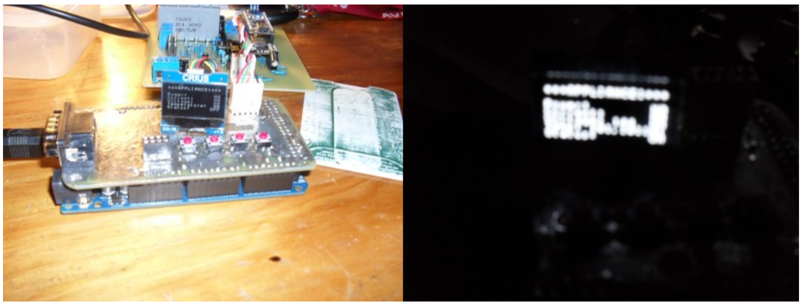
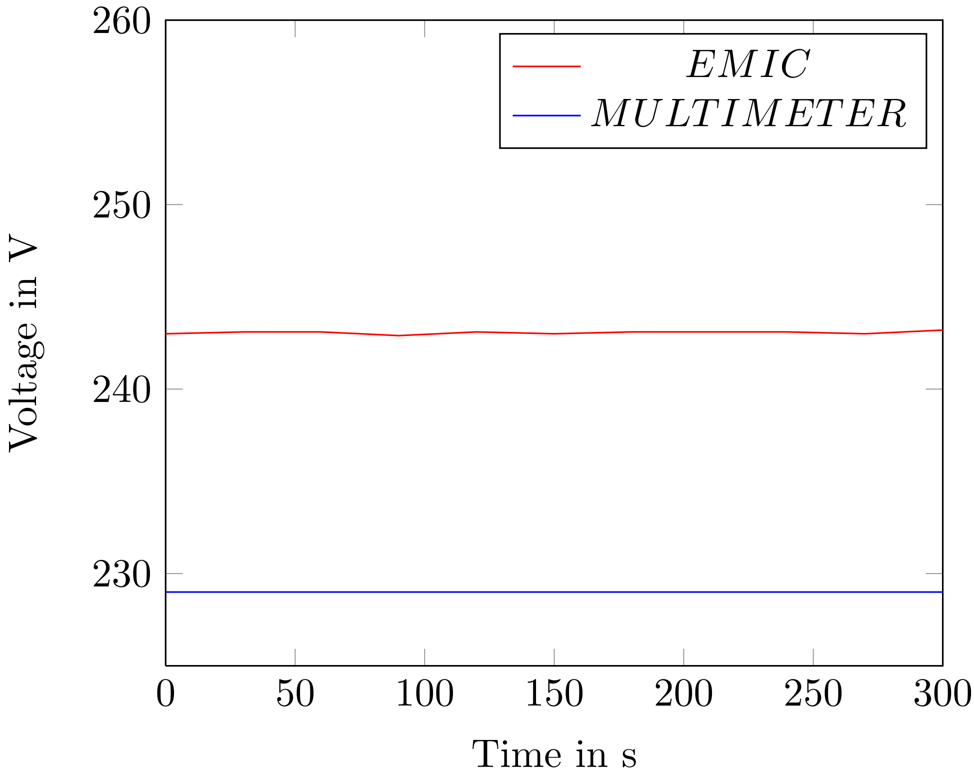


Figure 21: Picture showing the OLED display in a very bright(left) and dark(right) environment

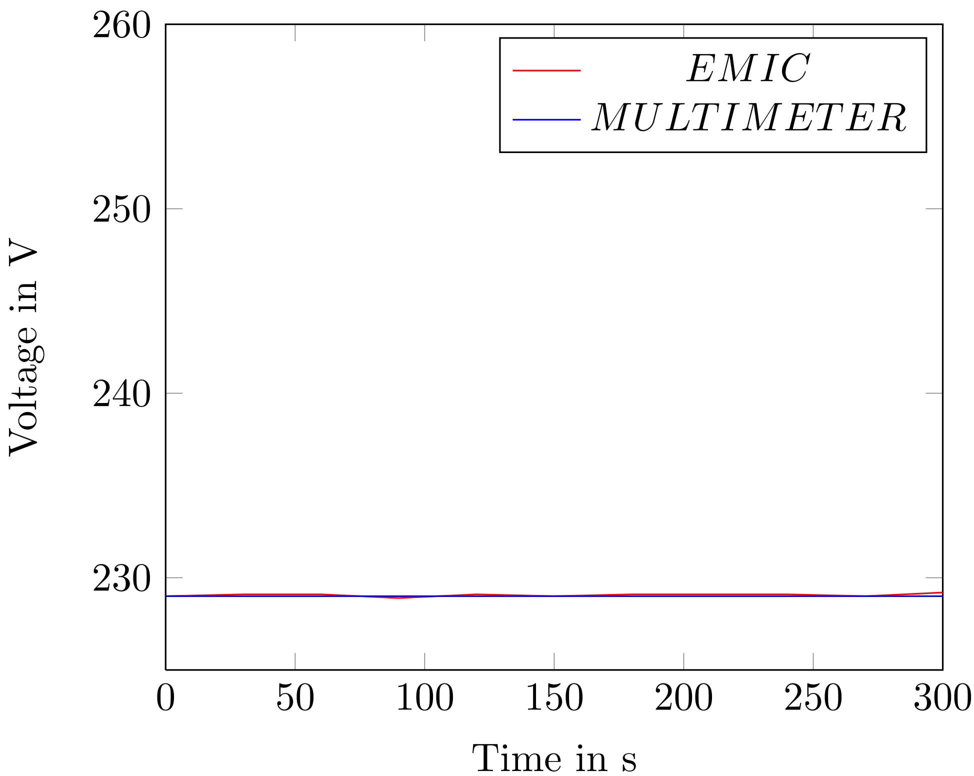
The picture above shows that the OLED display is very readable in both dark and bright environments. Please note that the right picture is out of focus because no flash was used when taking the picture.

7.5 Voltage Measurement

In this verification the system was set up in the *Stand Alone* configuration. A 14W desk lamp light bulb to the Satellite board and connected to mains. Voltage measurements were taken every 30seconds and send to the Serial port to capture the data. The following data was obtained:



From the graph it is clear that the measurement is off. However the problem lies with the gain and not it's accuracy. After correcting the gain and running the same test again the result was as follows



The multimeter did not have the needed resolution to verify the accuracy of the EMIC. however according to the graph the EMIC is just as accurate as the mulitmeter.

7.6 Entire System Test

Knowing that the individual components worked a final test needs to be done with the entire system. It was decided to run this last test in the *Stand Alone* configuration as the Wi-Fi component had already been verified and there was a need to save time. The Base Station was connected to the Satellite Unit via a wired link. The Base Station was configured to take measurements every on request, upload these values to the SMART platform and display the values on the OLED display. The time out function was disabled to ensure the OLED Display stays on so that it could be captured on photo. A 14W desk lamp was used to test. The figure below shows the final setup.

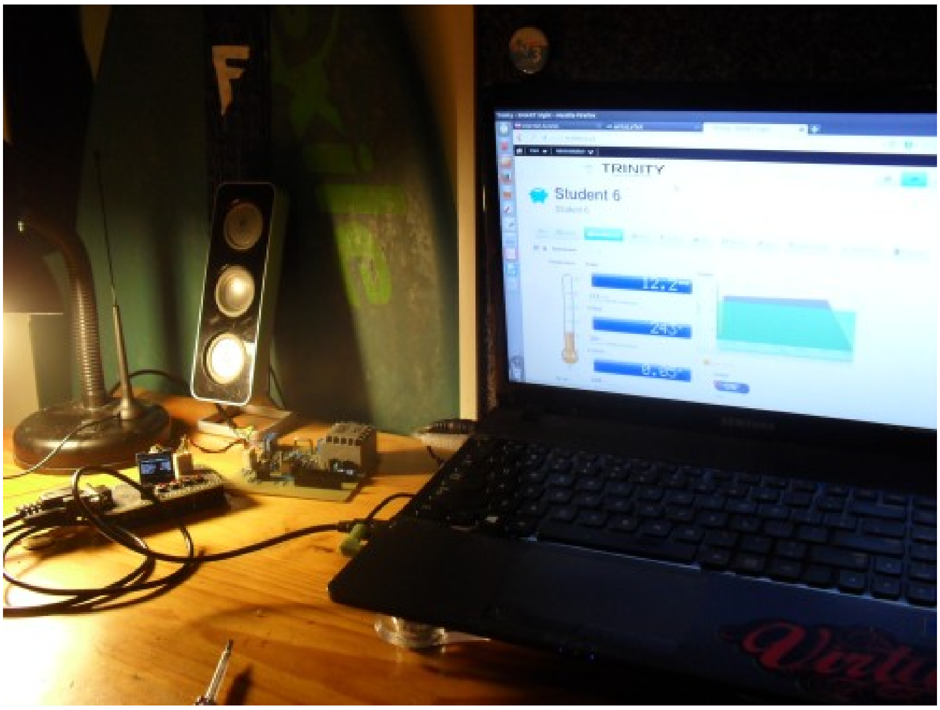


Figure 22: Picture showing the final setup and Dashboard

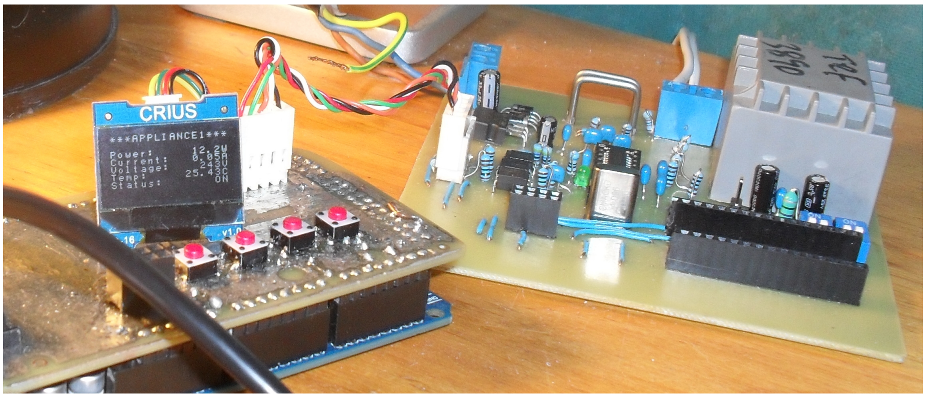


Figure 23: A close up on the OLED showing that both the Dashboard and OLED are displaying the same measurements

Figure 22 shows the desk lamp used in this test as well as the Satellite Unit, Base Station, Antenna of the modem and the Dashboard on the Laptop. Figure 23 is just another picture zoomed in on the OLED to verify that both the Dashboard and OLED were displaying the same results. The final test work which was expected as all the components had worked on their own.

8 Conclusions and Recommendations

The Remote Power Meter performed satisfactory. There was communication between the Base Station and Web Interface uploading and updating the data almost instantaneously with no data ever lost in the tests. The data was displayed correctly on the SMART platform. The measured values of voltage and current proved to be just as accurate as the multimeter. The OLED display along with the menu interface performed as expected. The Wi-Fi communication was reliable to an extent. In the testing phase it was found that there were a few locations in the tested household that did not get full reception and as such had none reliable communication. However the majority of locations in the household had full reception losing none of the packets sent and proved to be reliable. A mechanical design of the Satellite Unit's housing was done but not manufactured.

The one problem this project had was the size factor. Initially the Satellite Unit was considered to be a small device that is about the same size as an adapter plug, which plugs straight into the wall without any leads connecting to it. It was intended to be no bigger than a 55mm x 55mm x 30mm cube. One of the limitations as to why the final Satellite Unit was 100mm x 100mm x 40mm in size was because of the component choice. The Arduino Nano, although small, is still reasonably big in comparison to the desired size of the whole system. A smaller system could be achieved if, the board were to be multilayered, surface mount technology was used, no break out boards were used (as with the Arduino Nano and Wi-Fi module) and most importantly all the components should be integrated into a single PCB. Another recommendation would be to use an external Antenna with nrf24L01 Wi-Fi chip. It's performance was great but only with in a limited range. The five locations in the household could probably be covered if an external Antenna was used.

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Appendix A: Project Planning

Date	Research	Design	Optimise	Manufacture	Testing	Report
Week 1	X					
Week 2	X					
Week 3	X					
Week 4	X	X				
Week 5	X	X				
Week 6		X				
Week 7		X	X	X		
Week 8		X	X	X		X
Week 9			X	X	X	X
Week 10			X	X	X	X
Week 12					X	X
Week 13					X	X
Week 14						X

Table 10: Table showing the Project Plan

The Table above shows the project planning. In the run of the project however the Design phases took longer than expected caused the testing phase to be shifted into the final week. However the project was still completed in time.

Appendix B:
Project Specification

Appendix C: Outcomes Compliance

Outcome	Reference
1. Problem solving: Demonstrate competence to identify, assess, formulate and solve convergent and divergent engineering problems creatively and innovatively.	2.2, 4.2.2, 4.2.3
2. Application of scientific and engineering knowledge: Demonstrate competence to apply knowledge of mathematics, basic science and engineering sciences from first principles to solve engineering problems.	2.2, 5.5, 6.1
3. Engineering Design: Demonstrate competence to perform creative, procedural and non-procedural design and synthesis of components, systems, engineering works, products or processes.	4, 5, 6
4. Investigations, experiments and data analysis: Demonstrate competence to design and conduct investigations and experiments.	2, 7
5. Engineering methods, skills and tools, including Information Technology: Demonstrate competence to use appropriate engineering methods, skills and tools, including those based on information technology.	4, 5, 6
6. Professional and technical communication: Demonstrate competence to communicate effectively, both orally and in writing, with engineering audiences and the community at large.	Throughout the report
9. Independent learning ability: Demonstrate competence to engage in independent learning through well	Throughout the report

Appendix D: Board Design

The design of both board layout and schematics for the Satellite Unit as well as for the Base Station are displayed here

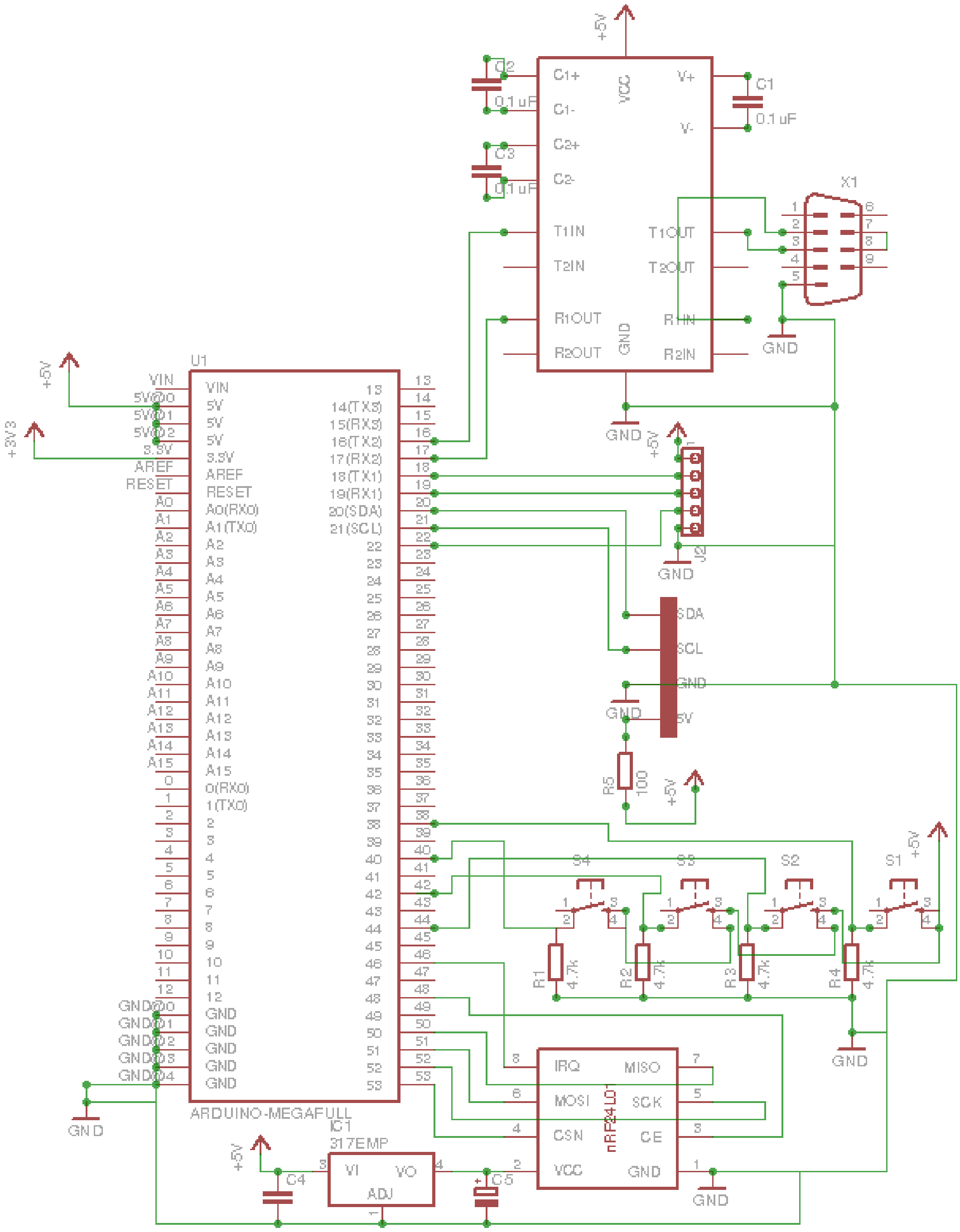

Figure 24: This is the schematic of the Base Station

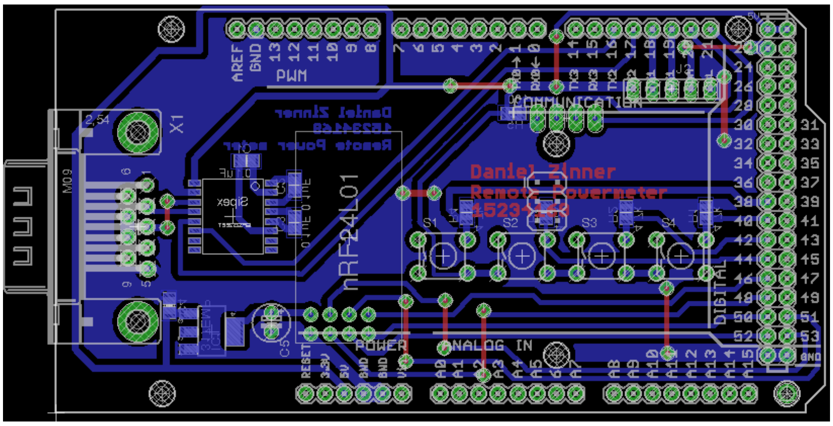

Figure 25: This is the layout of the Base Station

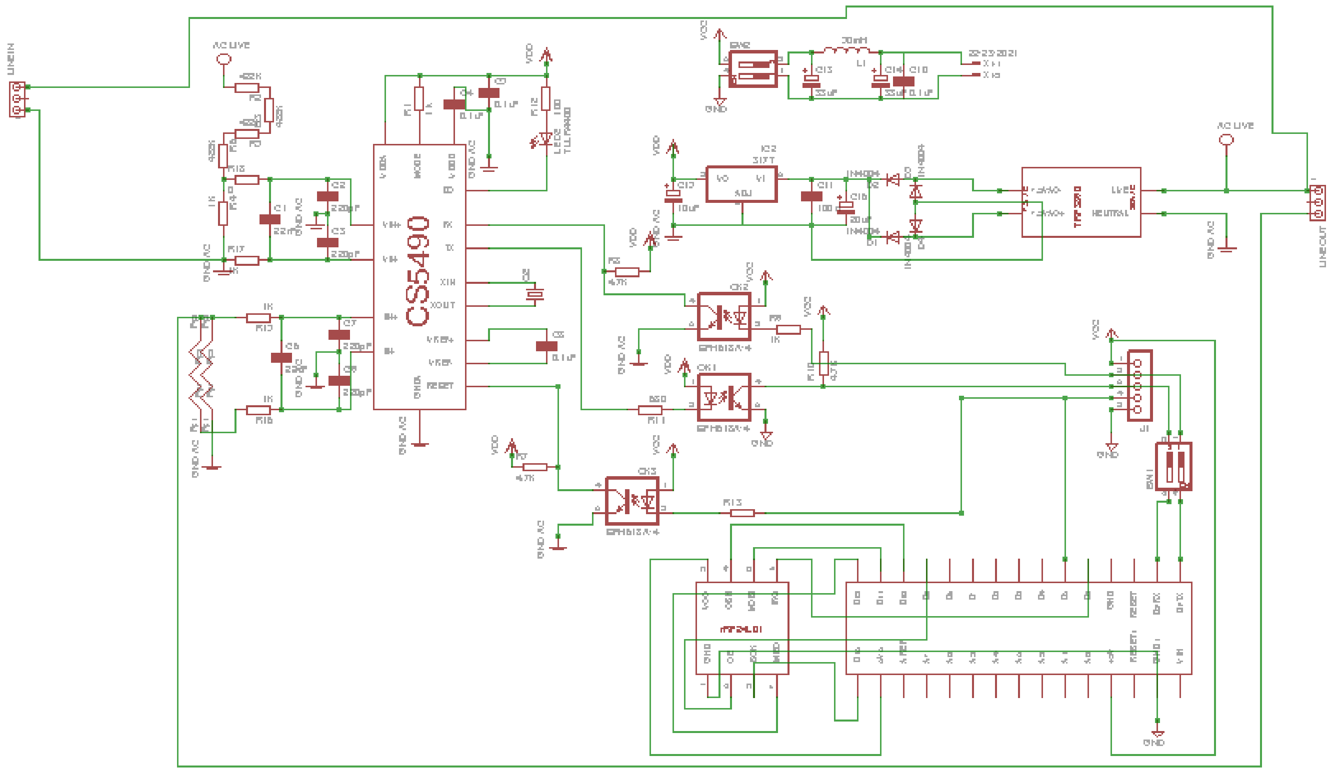

Figure 26: This is the schematic of the Satellite Unit

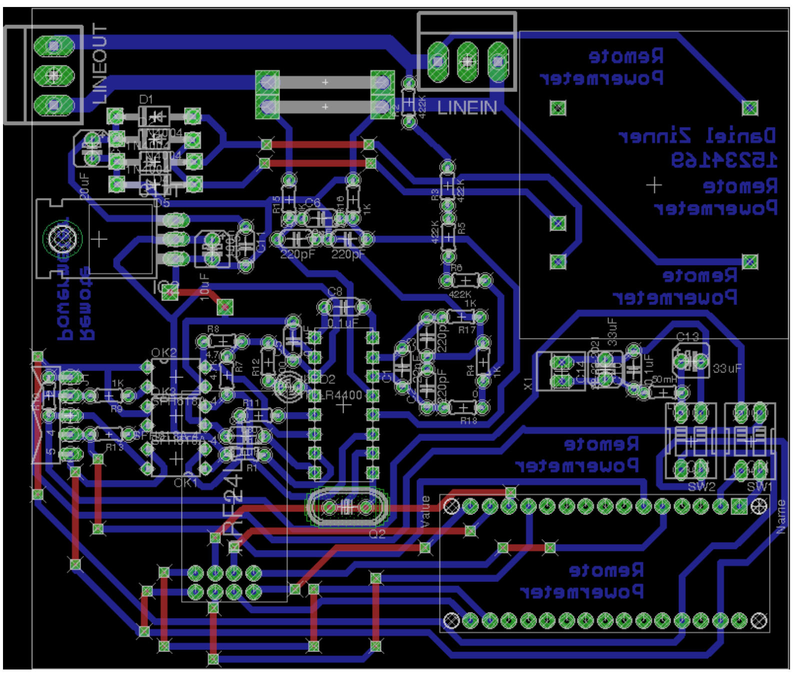

Figure 27: This is the layout of the Satellite Unit

Appendix E:

The following appear on the CD included with this document.

Appendix F: Source Code

Appendix G: Libraries

Appendix H: Datasheets