**KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY**

COLLEGE OF ENGINEERING

DEPARTMENT OF COMPUTER ENGINEERING

KNUST

DESIGN OF A GSM-BASED SMART METERING SYSTEM

BY

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BSC (HONS.) ELECTRICAL AND ELECTRONIC ENGINEERING

NOVEMBER, 2012

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A THESIS SUBMITTED TO THE DEPARTMENT OF COMPUTER ENGINEERING

KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF PHILOSOPHY (MPHIL)

COMPUTER ENGINEERING DEPARTMENT

**COLLEGE OF ENGINEERING**

NOVEMBER, 2012

DECLARATION

This thesis is my own original research work undertaken at the Department of Computer

Engineering, College of Engineering, Kwame Nkrumah University of Science and Technology,

Kumasi, Ghana under the supervision of the undersigned.

All consulted works have been duly acknowledged and referenced.

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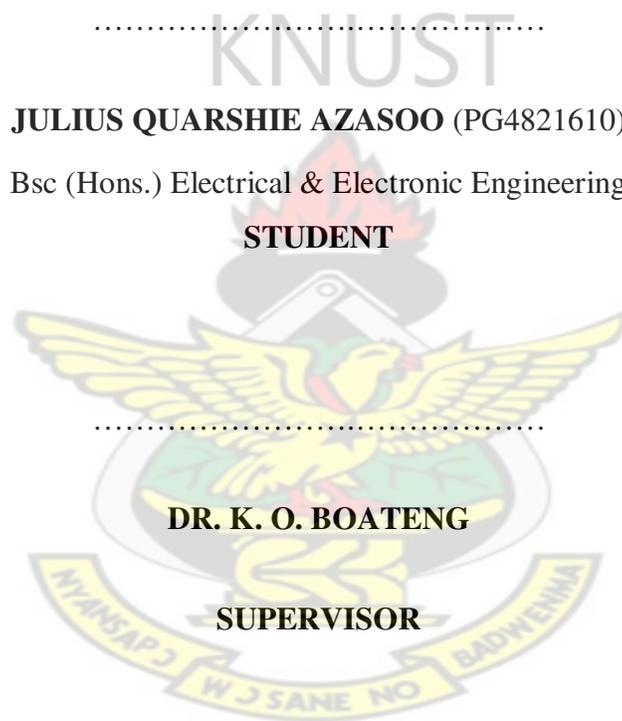
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CERTIFICATION

I certify that this thesis has been assessed and all corrections have been made in accordance with

the comments made by the Examiners.

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ABSTRACT

The essence of using prepayment meters, in the management of power is to help improve on cash flow, reduce credit and arrears collection costs, avoid deposits and monthly bills as well as reconnect charges, and many more. These benefits have not been fully explored due to the nature of many prepayment meter implementations where each customer has to disconnect his prepayment card and send to the vender before billing and other services can be implemented. With the spread of internet use and web based application, there is the need to focus on how prepayment meters and utility meters can be aided to stay online. This thesis presents the design and implementation of a Global System for Mobile communication (GSM)-Based Smart Metering System. Embedded functionalities of PICs and GSM module are used to design a meter which is capable of reading and storing electrical power consumptions and sends the readings and various statuses to a server periodically or in real time for billing and report generation purposes. Various requests and updates are also sent to the meter from the server through Short Messaging Service (SMS), General Packet Radio Service (GPRS) or both. Web based applications such as Client Web and SMS Access as well as Management Web Access are developed using C#, PHP and MySQL database to present both the consumers and the power companies with the ability to interact with the meter remotely. The GSM-Based Smart Metering System is capable of providing the power companies and the consumers the full benefit of the Prepayment Metering Systems as well as an enhancement of the Post-payment Metering Systems in Ghana. Remote control and other capabilities of the system are tested with the prototype GSM-Based Smart Meter connected to a normal household load. Full control of the meter is achieved and a granular consumption details are obtained and log of all metering activities registered on the Database Server.

DEDICATION

This work is dedicated to my wife Jennifer and son Eyram

ACKNOWLEDGEMENT

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LIST OF ACRONYMS

AC	*Alternating Current*
ADC	*Analog to Digital Convertor*
AMI	*Automatic Metering Infrastructure*
AMR	*Automatic Meter Reading*
ATM	*Asynchronous Transfer Mode*
BCCH	*Broadcast Control Channel*
BSC	*Base Station Controller*
BSS	*Base Station System*
BTS	*Base Transceiver Station*
CDMA	*Code Division Multiple Access*
COP	*Computer Operating Properly*
CP	*Communication Path*
CPE	*Customer Premises Equipment*
CPU	*Central Processing Unit*
CT	*Currant Transformer*
DRAM	*Dynamic Read Only Memory*
DWDM	*Dense wavelength division multiplexing*
EDGE	*Enhanced Data rates for GPRS Evolution*
EEPROM	*Electrically Erasable Programmable Read-Only Memory*
EPROM	*Erasable Programmable Read-Only Memory*
EU	*European Union*
FDMA	*Frequency Division Multiple Access*
GMSC	*Gateway Mobile Switching Center*
GPRS	*General Packet Radio Service*
GSM	*Global System for Mobile communications*
HO	*Handover*
HRL	*Home Location Register*
HTML	*Hypertext Markup Language*
IEC	*Dense wavelength division multiplexing*
IMSI	*International Mobile Subscriber Identity*
IOB	*Input and Output Bus*
IP	*Internet Protocol*
ISDN	*Integrate Services Digital Network*
LCD	*Liquid Cristal Display*
LED	*Light Emitting Diode*
LTE	*Long Term Evolution*
MCU	*Micro-Controller Unit*
MMSC	*Multimedia Messaging Service Centre*
MS	*Mobile Station*
MSC	*Mobile Switching Center*

MT	*Mobile Terminal*
O&M	*Operation and Maintenance*
OSS	*Operation Support Subsystem*
NCA	*National Communication Authority*
NSS	*Network and Switching Subsystem*
PHP	*Hypertext Preprocessor*
PIC	*Programmable Interface Controllers*
PLC	*Power Line Carrier*
PLMN	*Public Land Mobile Network*
RAM	*Random Access Memory*
RFID	*Radio-frequency Identification*
ROM	*Random Only Memory*
RUIM	*Reusable Identification Module*
SGSN	*Serving GPRS Support Node*
SIM	*Subscriber Identity Module*
SMS	*Short Message Service*
SMSC	*Short Message Service Centre*
SONET	*What is Synchronous Optical Network*
SRAM	*Static Random-Access-Memory*
SRP	*Send and Receive Pair*
TA	*Terminal Adapter*
TDMA	*Time Division Multiple Access*
TE	*Terminal Equipment*
TRX	*Transceiver*
UMTS	*Universal Mobile Telecommunications System*
UTRAN	*UMTS Terrestrial Radio Access Network*
VLR	*Visitor Location Register*
VMS	*Voice Mail System*
VT	*Voltage Transformer*

CHAPTER ONE - INTRODUCTION

1.1 Background

Energy is an increasingly important societal resource, for it directly correlates with the economic welfare of a populace [1]. Smart metering is the buzz in utility industries today especially the electricity. Many countries across the globe like United States of America, South Africa, Botswana [2], etc., are already involved in projects with smart metering on a demonstration scale or implementation. The last couple of decades have seen electric power being managed using different technologies [3]. The era in which we are now, is very much characterized by fast growing technologies [4]. These have found their way in power management. The essence of using prepaid meters in the management of power is to help improve on cash flow, reduce credit and arrears collection costs, avoid deposits and monthly bills as well as reconnect charges, and many more. These benefits have not been fully explored due to the nature of many prepaid meters that have been implemented so far in Ghana. With the spread of internet use and web based application [5], there is the need to focus on how prepaid meters can be aided to stay online through Mobile Communication Systems [6] available in Ghana. This system will also be used to disconnect the power supply to the house in case of non-payment of electricity bills or suspicion of fraud. A dedicated Global System for Mobile Communication (GSM) system [7] with Subscriber Identification Module (SIM) [8] or Reusable Identification Module (RUIM) [9] card for Code Division Multiple Access (CDMA) cellular system [10] will be required for each meter while providing consumers with mobility, accessibility and comfort.

The Mobile Communication System Based Smart Meter reading and monitoring solution will provide the power companies with a number of benefits, including:

- Lower costs: Labour costs, maintenance and troubleshooting costs kept to a minimum. Communications costs are kept low by using the public wireless network.

- More accurate information: Automating data collection eliminates the inevitable human error that occurs with manual loading of credit unto prepaid cards and the collection of data.

- Instantaneous monitoring is an added advantage coupled with the ability to shut down the meter remotely.

- More reliable power network: any breakdown in the network is quickly detected and remedied.

- Real-time or near-time registration of energy use

- Offering the possibility to read the meter both locally and remotely (on demand)

1.2 Problem Statement

- Consumers have to form long queues to buy credit for their Energy Meters.

- Those who do not use the prepaid meter have to wait for several days for them to be reconnected whenever there is disconnection.

- Some of the prepaid payment points are very far from the consumers.

- Fraudulent consumers could cheat without being detected for several years.

- Manual collection of data has to be done on the old energy meter before consumers are billed.

This research seeks to minimize all these problems if not to eliminate them completely.

1.3 Objective of the Research

The general objective of this work is to propose a GSM-based Smart Metering System for electricity utilities.

In order to achieve the general objective the following specific objectives are set.

1. To design a GSM-Based Smart Metering System

2. The system is to provide the following capabilities/services

   - **Remotely Connect/ Dis-connect power supply through meter:** The ability to configure a meter to be off (deactivated and not assigned to a customer account), to be on with a configured maximum capacity, and to be suspended (deactivated but remaining configured to a customer account).

   - **Providing Power Utilities Access through a Network Application:** Providing a display unit remotely from the meter itself. Equally this could be a web interface to the overall Database.

   - **Providing SMS and Internet Access to Customers:** Customer could use the mobile phones to interact with their meter by means of SMS or Website. They could also use their PCs to Access the meters online.

   - **Maintain usage records of all meter:** Maintain data records of the usage within the meter at configured intervals for a set amount of time or in real-time.

   - **Configurable Tarriffing:** Applying the tariff plan appropriate to that customer, customer type, retailer, etc. and creating the appropriate billing records for customer access or onward transmission to the customer.

- **Loss of Power Notification:** In the case of power outages, the meter can transmit a "last gasp" that alerts the distributor to a failure in the network.

The built up prototype will seamlessly monitor and control Electricity Meter using Mobile SMS/GPRS Technology remotely.

1.4 Scope of Work

The design of a Smart Meter capable of receiving instruction from a central database server, and sends meter readings and credit status information to the server. The Central Database Sever then makes available to both consumers and the power companies the information it receives from the meter upon request or based on schedule.

1.5 Justification

This research will make available a fully designed and constructed Smart Meter based on GSM technology to the Electricity Companies in Ghana.

The functionalities provided by the GSM-Based Smart Metering System, will provide the power companies the ability to monitor and control the new meter in real time. This will enhance efficient use of electricity by consumers as they become well aware of their electricity consumption patterns and peaks. The power companies will become more enabled to better serve their customers.

1.6 Main Contributions

The main contribution of this work is the design of a GSM-Based Smart Metering System with

the following specifications:

1. The Design of an Electricity Meter with a SIM Card interface that is compatible with any

   GSM SIM Card.

2. The Design of an Electricity Meter that is remotely accessible allowing:

   a. The collection of metering information remotely

   b. The implementation of Multi-tariffs

   c. The ability to detect Tempering and fraud

   d. Configurable as Pre-payment or Post-payment meter

   e. Disconnection and Reconnection to be done remotely

   f. In the case of pre-payment meter; credit can be purchased onto the meter remotely

3. Design of A software Application capable of receiving and sending Metering Information

   to and from the Smart Meter allowing:

   a. Provides management interface

   b. Provides user access (Web and SMS)

1.7 Outline of Thesis

Chapter 1 provides the necessary background information, statement of the problem as well as

the objective of the research and the overall scope of work and justification for this research.

Chapter 2 reviews literature of previous and related works on smart metering and the GSM.

Some critical components of smart meters and its respective communication components are

explored in this chapter. Chapter 3 deals with the design methodology and gives an overview of

the various systems that make up the GSM-based Smart Metering system. The various core components of the overall system are discussed in detail in Chapter 4 where design and implementation are presented. The testing of the implemented design is also discussed in this Chapter. This work is concluded in Chapter 5.

CHAPTER TWO - LITERATURE REVIEW

This chapter reviews related works and presents different types of meters. Smart Metering and its communication technologies were explored. An overview of Microcontroller units and the GSM network are presented. Finally the software applications used for the design are also introduced in this chapter.

2.1 Related works

Shang et al. [11] in their work; 'Development of a Smart Power Meter for AMI Based on ZigBee Communication' They designed and implemented a ZigBee-based smart power meter. Their Concept of the ZigBee-based Automatic Meter Reading System is represented in Figure 2.1 Shang ZigBee smart meter structure.
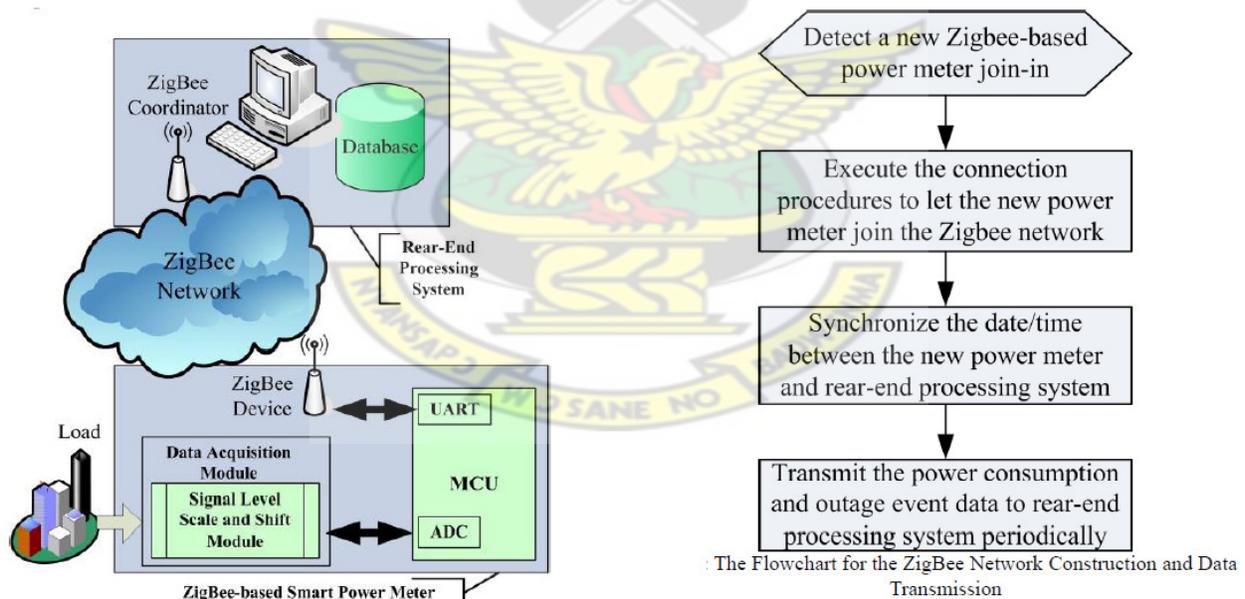
Figure 2. 1 Shang's ZigBee smart meter

Though Shang's system is a good elimination of manpower requirement for meter reading, it will require ZigBee network to be deploy across the country which could be very capital intensive.

Long et al. [12] did a research on the impact of smart metering on energy efficiency; they concluded that smart metering when implemented with the right policies will go a long way to enhance energy efficiency. Their paper gives a comprehensive review on the benefit of smart metering in power network such as energy efficiency improvement and reduction in greenhouse gas emission. The benefit is having smart meters to enhance assets management was also highlighted. Numerous case studies worldwide were looked at in their work. International engineering practices and policy were discussed but they fail to recommend any smart metering method.

Farhangi [13] in his work 'The Path of the Smart Grid' He emphasizes the rising cost of energy, the mass electrification of everyday life, and climate change as the major drivers that will determine the speed at which such transformations will occur. Regardless of how quickly various utilities embrace smart grid concepts, technologies, and systems, they all agree on the inevitability of this massive transformation. He sees smart metering as a move that will not only affect their business processes but also their organization and technologies.

Kistler et al. in their paper [14] describes an AMI based on ZigBee to build up home area networks of interconnected smart metering devices. The work focuses on how meters can be addressed and read out using existing metering application protocols. This paper presents an AMI that utilizes ZigBee to build up home area networks of connected metering devices. The work is conducted in the context of EnerBee, an industrial applied research project. EnerBee is partly influenced by the AMI group of the ZigBee Alliance and its efforts to create a Smart Energy application profile. They concluded that it is clear that the AMI application and its

requirements really put the ZigBee technology to a serious test and system must be secure and run autonomously for about 10 years, new devices should be integrated seamlessly and the network must automatically detect and inform in case of malfunctions.

In their work Adrianus et al. [15], they describe how the days of a quarterly drive by meter reading fails to meet the needs of a Smart Grid that can inform the generator of real time loads and can react to the demands placed upon it by the consumer. Their paper explores what they consider to be the two main methods of data transmission between meter and central database; power line carrier (PLC) and fixed wireless network. It is also been proposed the use of ZigBee technology to provide a link between the meter and an in home display for the consumer, which links to the second aforementioned reason for AMR, consumer empowerment through information. They go on to describe how this ZigBee link will provide a two way connection between energy consumer and provider, and how, because of this, if appliances were suitably equipped the utility company could remotely control home appliances or in the case of a consumer who failed to pay their bill on time, disconnect them remotely.

Luan et al. [16] present the design and implementation of a smart power meter. It is based on a Microchip dsPIC30F microcontroller and on the ZigBee interface for sending the data. They designed a ZigBee system and integrated it into the proposed power meter, and used to transmit the detailed power consumption data and outage event data to rear-end processing system.

Zhu et al. in their work [17] a novel AMR system based on IEEE 802.15.4 compliant wireless networks is proposed. Data collection can be done in a star topology or a peer-to-peer topology. The peer-to-peer solution was chosen due to its increased flexibility and robustness. They

concluded that security issue is a major challenge for a mesh networks and needs to be addressed and that AES security coprocessor is included in CC2430, could be utilized and implemented in their current prototype.

2.2 Electricity Meters

This meter is used for measuring the amount of electric power used or supplied by an electric power company.

2.2.1 Unit of measurement

The most common unit of measurement on the electricity meter is the kilowatt hour [kWh], which is equal to a load of one kilowatt over a period of one hour, or 3,600 kilojoules. Some electricity companies use the SI megajoule (MJ) instead, usually for factories and universities.

Demand is normally measured in watts, but averaged over a period, in modern days 15 minutes. Reactive power is measured in "thousands of volt-ampere reactive-hours", (KVARH). By convention, a "lagging" or inductive load, such as a fan, will have positive reactive power. A "leading", or capacitive load, will have negative reactive power [18].

Volt-amperes measures all power passed through a distribution network, including reactive and actual. This is equal to the product of root-mean-square volts and amperes.

Distortion of the electric current by loads is measured in several ways. Power factor is the ratio of resistive (or real power) to volt-amperes. A capacitive load has a leading power factor, and an inductive load has a lagging power factor. A purely resistive load (such as a filament lamp, heater or kettle) exhibits a power factor of 1 [19]. Current harmonics are a measure of distortion of the wave form. For example, electronic loads such as computer power supplies draw their

current at the voltage peak to fill their internal storage elements. This can lead to a significant voltage drop near the supply voltage peak which shows as a flattening of the voltage waveform. This flattening causes odd harmonics which are not permissible if they exceed specific limits, as they are not only wasteful, but may interfere with the operation of other equipment. Harmonic emissions [20] are mandated by law in EU and other countries to fall within specified limits.

2.2.2 Types of Meters

In recent times, the types of electric meter continuously operate to measure the instantaneous voltage and current and calculating the product of these to give out the instantaneous electrical power. The electric power is then integrated against time to give energy used. There are basically two types of electric meters, the Electromechanical and Electronic Electric meters. The Smart electric meter is a hybrid of the electronic meter.

2.2.3. Electromechanical Electric Meters

The electromechanical induction meter operates by counting the revolutions of an aluminium disc which is made to rotate at a speed proportional to the power consumed. The number of revolutions is proportional to the energy usage. The voltage coil consumes a small and relatively constant amount of power, typically not greater than 2 watts which is not registered on the meter. The current coil similarly consumes a small amount of power in proportion to the square of the current flowing through it, typically up to a couple of watts at full load, which is registered on the meter [21].

The metallic disc is acted upon by two coils. One coil is connected in such a way that it produces a magnetic flux in proportion to the voltage and the other produces a magnetic flux in proportion to the current. The field of the voltage coil is delayed by 90 degrees using a lag coil. This produces eddy currents in the disc and the effect is such that a force is exerted on the disc in

proportion to the product of the instantaneous current and voltage. A permanent magnet exerts an opposing force proportional to the speed of rotation of the disc. The equilibrium between these two opposing forces results in the disc rotating at a speed proportional to the power being used. The disc drives a register mechanism which integrates the speed of the disc over time by counting revolutions, much like the odometer in a car, in order to render a measurement of the total energy used over a period of time for a single phase AC electricity meter. Additional voltage and current coils are required for a three phase configuration [22].

Three-phase electromechanical induction meter, metering 100 A 230/400V supply. Horizontal aluminum rotor disc is visible in center of meter. The aluminum disc is supported by a spindle which has a worm gear which drives the register. The register is a series of dials which record the amount of energy used. The dials may be of the cyclometer type, an odometer-like display that is easy to read where for each dial a single digit is shown through a window in the face of the meter, or of the pointer type where a pointer indicates each digit. With the dial pointer type, adjacent pointers generally rotate in opposite directions due to the gearing mechanism [23].

The amount of energy represented by one revolution of the disc is denoted by the symbol which is given in units of watt-hours per revolution. The value 7.2 is commonly seen.

2.2.4 Electronic Meters

Electronic meters display the energy used on an LCD or LED display, and can also transmit readings to remote places. Apart from the amount of electricity used, the electronic electric meter type can also record other parameters of the load and supply such as maximum demand, power factor and reactive power used etc. some of the advanced kinds of electric meters also include electronic clock mechanisms to compute a value, rather than an amount of electricity consumed, with the pricing varying by the time of day, day of week, and seasonally. The technology used in

most of the solid state electric meter type is the use of a current transformer to measure the current. The main current-carrying conductors need to pass through the meter itself and so the meter can be located remotely from the main current-carrying conductors, which is a particular advantage in large-power installations [24].

2.2.4.1 Automatic Meter Reading (AMR) Electricity

AMRs offer additional functionality including a real-time or near real-time reads, power outage notification, and power quality monitoring and transferring that data to a central database for billing, troubleshooting, and analyzing [25]. They allow price setting agencies to introduce different prices for consumption based on the time of day and the season. This technology mainly saves utility providers the expense of periodic trips to each physical location to read a meter. Another advantage is that billing can be based on near real-time consumption rather than on estimates based on past or predicted consumption. This timely information coupled with analysis can help both utility providers and consumers to better control the use and production of electric energy consumption. AMR technologies include PLC, ZigBee, RFID, etc

2.2.4.2 PLC based Communication
Power line communications (PLC) systems operate by imposing a modulated carrier signal on the wiring system [26]. Different types of powerline communications use different frequency bands, depending on the signal transmission characteristics of the power wiring used. Since the power distribution system was originally intended for transmission of AC power at typical frequencies of 50 or 60Hz, power wire circuits have only a limited ability to carry higher frequencies. The data capacity and distance limits vary widely over many power line communication standards. This technology makes it possible for metering information be sent from a meter to a central point, usually a data concentrator.

2.2.4.3 ZigBee Based Communication

The ZigBee communication is usually a mesh network where meters themselves act as repeaters passing the data to nearby meters until it makes it to a main collector. The Swedish city of Gothenburg is having their electric meters connected in this manner, using the ZigBee Protocol. [27] A mesh network may save the infrastructure of many collection points, but is more data intensive on the meters. One issue with mesh networks it that battery operated ones may need more power for the increased frequency of transmitting. This method of communicating metering data requires that the AMR be receivers as well as transmitters potentially making individual transceiver cost higher. However, the additional cost may be outweighed by the savings of multiple collectors and repeater antennas and finding places to mount them this makes the GSM Based Smart Meter more advantageous.

2.2.4.3 RFID Based Communication

Radio-frequency identification (RFID) based AMR is the use of a wireless non-contact system that uses radio-frequency electromagnetic fields to transfer data from a meter for the purposes of automatically reading the meter by a moving vehicle or other nearby data concentrators for billing and planning purposes [28]. It uses a local power source and emits radio waves (electromagnetic radiation at radio frequencies).

2.2.4.4 Smart Meter

A smart meter is usually an electrical meter that records consumption of electric energy in intervals of an hour or less and communicates that information at least daily back to the utility for monitoring and billing purposes. Smart meters enable two-way communication between the meter and the central system [29]. Unlike home energy monitors, smart meters can gather data

for remote reporting. Smart Meters differs from traditional automatic meter reading (AMR) in that it enables two-way communications with the meter

2.3 Global System for Mobile Communications (GSM)

The creation of GSM started as far back as 1982 where a high level communication expert at the European Conference of Postal and Telecommunications Administrations. The idea then was to address cellular infrastructure in Europe, but rapidly expanded to other countries. Finally, GSM became the standard set developed by the European Telecommunications Standards Institute (ETSI) to describe technologies for second generation (or "2G") digital cellular networks. Developed as a replacement for first generation analogue cellular networks, the GSM standard originally described a digital, circuit switched network optimized for full duplex voice telephony . Data communications became part of GSM [30], first by circuit switched transport, then packet data transport via GPRS (General Packet Radio Services) and EDGE (Enhanced Data rates for GSM Evolution or EGPRS).

2.3.1 AT Commands
AT commands are instructions used to control a modules. AT is the abbreviation of ATtention. Every command line starts with "AT" or "at". That's why modem commands are called AT commands. Many of the commands that are used to control wired dial-up modems, such as ATD (Dial), ATA (Answer), ATH (Hook control) and ATO (Return to online data state), are also supported by GSM/GPRS modems and mobile phones. Besides this common AT command set, GSM/GPRS modules and mobile phones support an AT command set that is specific to the GSM technology, which includes SMS-related commands like AT+CMGS (Send SMS message),

AT+CMSS (Send SMS message from storage), AT+CMGL (List SMS messages) and

AT+CMGR (Read SMS messages).There are specific command set for various functionalities.

2.4 Software Applications

In information technology, an application is a computer program designed to help people

perform an activity. An application thus differs from an operating system (which runs a

computer), a utility (which performs maintenance or general-purpose chores), and a

programming tools (with which computer programs are created). Depending on the activity for

which it was designed, an application can manipulate text, numbers, graphics, or a combination

of these elements. Some application packages offer considerable computing power by focusing

on a single task, such as word processing; others, called integrated software, offer somewhat less

power but include several applications. This subchapter will focus on programming tools with

which computer programs are created.

2.4.1 Software Programming Tools

These are tools or software applications known as software development tools that are used to

create software applications. They can also be used to debug, maintain an existing application.

Some development tools are: Hypertext Preprocessor (PHP) and Microsoft Visual C#

CHAPTER THREE - DESIGN METHODOLOGY

3.1 Introduction

The design of a device such as a GSM based Smart meter could be considerably complex. Right from the design, the system has to be broken down into functional parts. There are two major functional parts identified with the GSM-Based Smart Meter which is aimed at communicating all metering information to and from a central database for processing. The System Design Architecture is shown in Figure 3.1
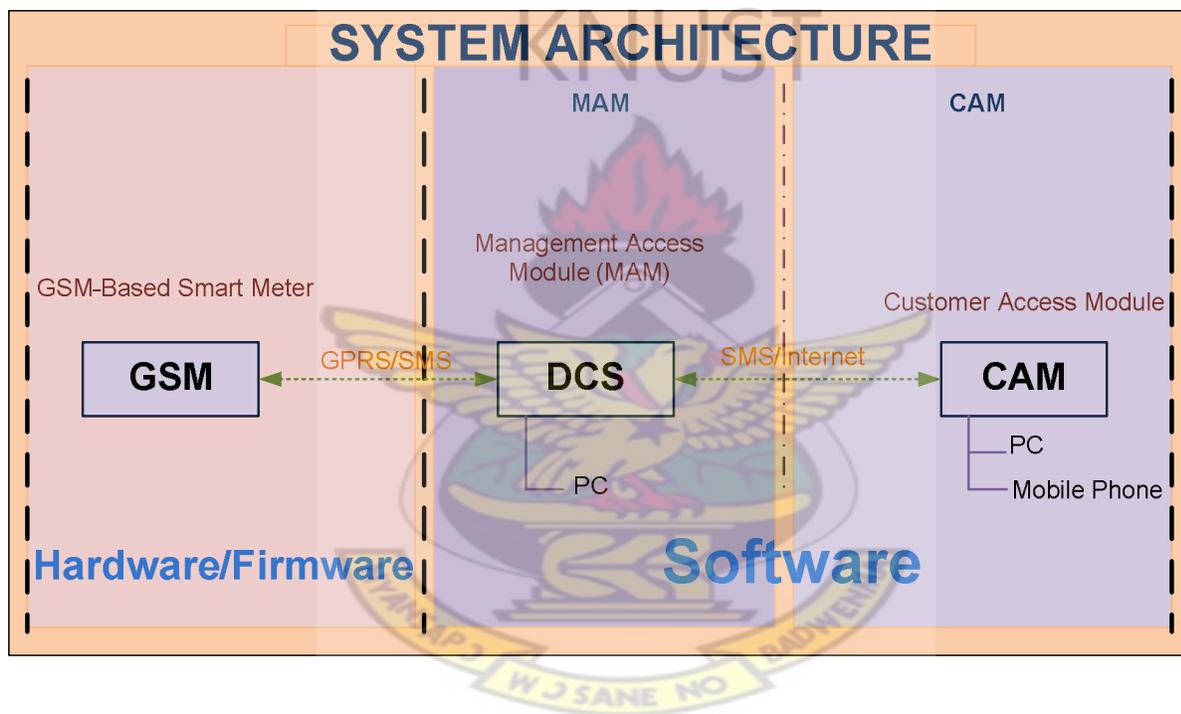
Figure 3.1 System Architecture

It can be viewed as having three blocks: GSM-Based Smart Meter (GSM), Database Communication Server (DCS) and Customer Access Module (CAM). For monitoring and control purposes, other connections to the DCS are necessary and all together make up the Management Access Module. DCS is therefore the core of the Software Sub-system. The System Architecture has two main parts: the hardware/firmware and the software.

3.2 The Hardware Design

The hardware design involves all the components and tools used to design the GSM Based Smart

Metering System. There are three Units/Interface involved in the hardware design stage;

Metering Unit, Processing Unit and Communication Interface. The block Diagram below gives

an overview of this stage and the flow of metering information.
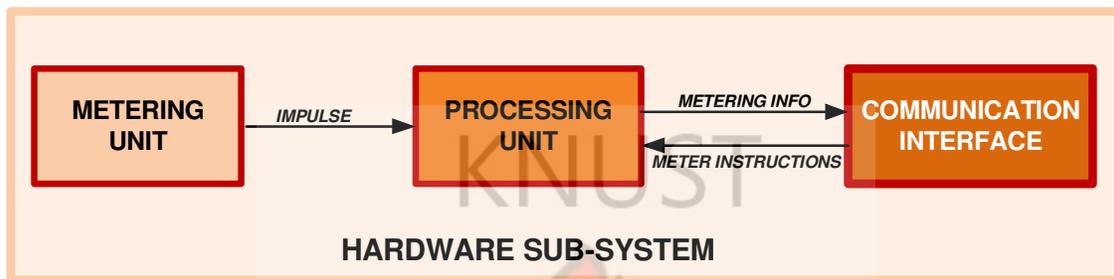
Figure 3.2 Hardware sub-system block diagram

3.2.1 Metering Unit

The metering system is responsible for measuring the amount of load connected to the meter and

forwarding it to the processing system for the necessary computation to be done with it. The

metering system uses a Voltage and Current Sensor connected to an Energy Metering Unit

(EMU) to measure average active real power.

3.2.2 Processing Unit

This system takes the pulse generated from the metering system and performs computation on it.

This system is subdivided into four blocks; Central Microcontroller (CM) block, EEPROM block

and Control Circuit block. The CM Block serves as the core of this system. Figure 3.3 show the

flow of information between the core (CM) and the three other blocks.
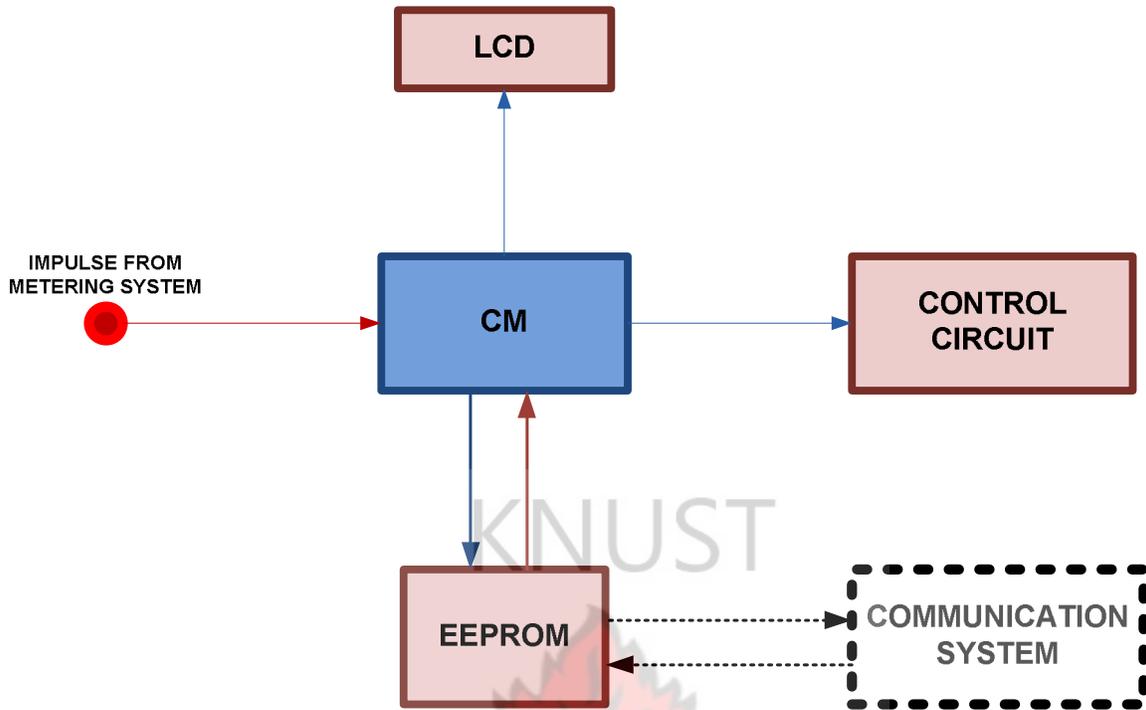
Figure 3.3 CM interactions with other Components

A. Microcontrollers

Microcontrollers are electronic circuits that can be programmed to carry out a vast range of tasks.

They can be programmed to be timers or to control a production line and much more. They are

found in most electronic devices such as alarm systems, computer control systems, phones, in

fact almost any electronic device. Many types of microcontrollers exist, although the best are

probably found in the Microchip range of programmable microcontrollers. These are

programmed and simulated by Circuit Wizard software.

B. Electrically Erasable Programmable Read-Only Memory (EEPROM)

EEPROM non-volatile memory used in computers and other electronic devices to store small

amounts of data that must be saved when power is removed. This was employed in the GSM

Based Smart Meter to store the meter reading, all metering information as well as metering instructions in the meter and retains them even when mains fails.

There are different types of electrical interfaces to EEPROM devices. Main categories of these interface types are; Serial bus and the Parallel bus. How they are used depends on the electrical interface available for the connecting peripheral controller. For this design, Serial bus is available on the microcontroller.

Most common serial interface types are Serial Peripheral Interface Bus (SPI), Inter-Integrated Circuit (I²C), Microwire (μWire), UNI/O [31]. These interfaces require between 1 and 4 control signals for operation, resulting in a memory device in an 8 pin (or less) package.

C. Power Switch (PS)

This is a simple circuit that takes control information from the Microcontroller and performs logic 0 (OFF) or logic 1 (ON) functions. It is the only point at which the supply or denial of electricity supply is done to a consumer or the customer. The circuit was designed using a relay and transistor as the main component. Resistor and transistor were used as protective components for the transistor in both directions.

D. A liquid crystal display (LCD)

LCD is a flat panel display, electronic visual display, or video display that uses the light modulating properties of liquid crystals. Liquid crystals do not emit light directly. The LCD serves as the direct visual interface on the meter where both customers and supplies can monitor the activities on the meter directly.

3.2.3 Communication Interface

This is the main point of interaction between the GSM Based Smart Meter and the Central

Database Server. This is achieved by the use of GSM Module coupled with a Microcontroller to

send and receive information to and from the Server. The major component of the

communication system is the GSM Module. The Microcontroller is responsible for sending the

appropriate Attention Command (AT) [32] to the module.

A. GSM Module

GSM Modules are similar to modems, but A GSM/GPRS Modem is an external equipment,

whereas the GSM Module is a module that can be integrated within an equipment. It is an

embedded piece of hardware. The microcontroller uses AT commands to control the GSM

Module.   GSM Modules support an extended set of AT commands. These extended AT

commands are defined in the GSM standards.

Figure 3.4.3 shows a block diagram of the communication process between the GSM Module

and the Microcontroller.
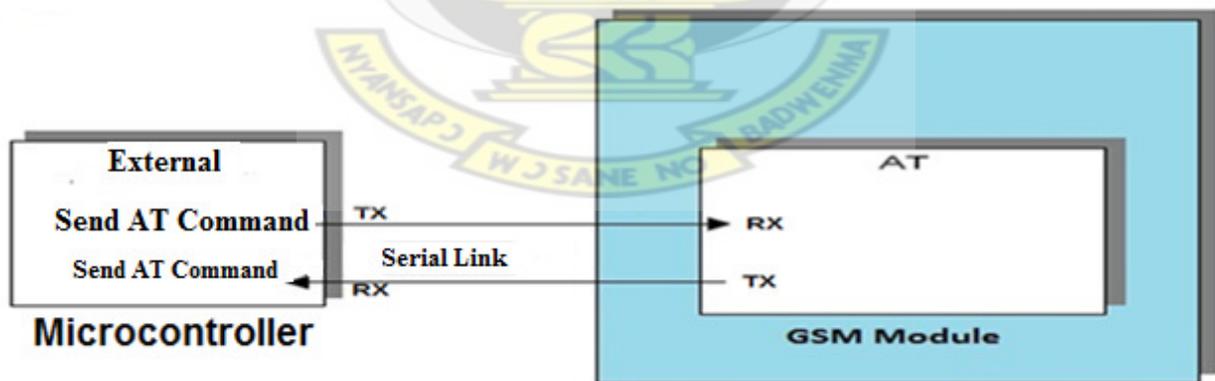
Figure 3. 4 GSM/Controller Communication Block Diagram

AT commands are instructions used to control a modem. AT is the abbreviation of ATtention.

Every command line starts with "AT" or "at". That's why modem commands are called AT

commands. Many of the commands that are used to control wired dial-up modems, such as ATD

(Dial), ATA (Answer), ATH (Hook control) and ATO (Return to online data state), are also supported by GSM/GPRS modules and mobile phones. Besides this common AT command set, GSM/GPRS modules and mobile phones support an AT command set that is specific to the GSM technology, which includes SMS-related commands like AT+CMGS (Send SMS message), and AT+CMGR (Read SMS messages) and GPRS related Commands include AT+CGATT=1 this is used to attached the module to the GPRS service. The command is sent by the PIC to the module depending on the communication path selected.

3.2.4 Meter/Server Communication Process

There are two main mode of communication between the server and the Meter; Short Messaging Services (SMS) and General Packet Radio Services (GPRS). Every communication is in two folds; send and receive. Every Send and Receive Pair (SRP) constitutes a Communication Path (CP). There are four CP identified with the GSM Based Smart Meter depending on the sending and receiving mode. Table 3.4 shows the Communication Paths with their respective Send and Receive Pairs.

Table 3.1 CPs and their SRPs

CP	SRP	
	SMS	GPRS
1	SEND	
	RECEIVE	
2	SEND	
		RECEIVE
3		SEND
	RECEIVE	
4		SEND
		RECEIVE

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3.3 Software Design

The software system comprises all the development and database application used to achieve the server side functionalities. Figure 3.5 shows the direction of data flow to and from the database.
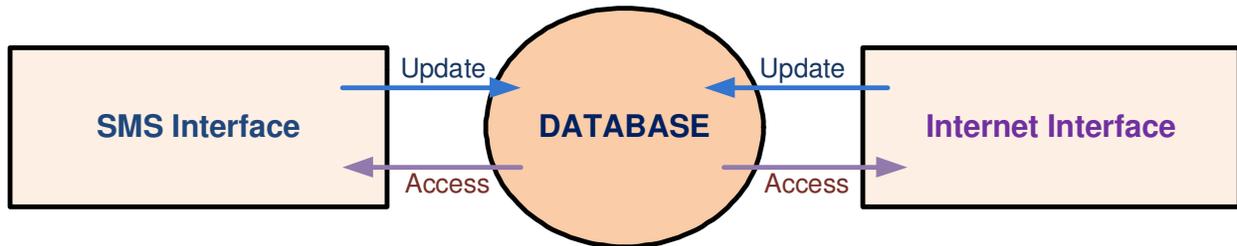
Figure 3.5 Direction of Data Flow

3.3.1 Database

This is the main engine of the software system. The various data tables and their corresponding contents were created using a DBMS. Some of the tables in the database include Customer Table, Meter table, User Table etc as shown in Table 3.2, Table 3.3 and Table 3.3 with sample details bellow.

Table 3.2 Customer Table

customer_id	customer_name	customer_email	telephone_number	mobile_number	residential_address
100001	Julius Azasoo	jazasoo@hotmail.com	0204004934	0204004934	-
100002	Julius Azasoo	jazasoo@hotmail.com	0208998990	0208998990	-

Table 3.3 Meter Table

meter_id	meter_number	meter_msisdn	install_date	longitude	latitude	geoid	district_code	meter_type	billing_type	billing_rate	customer_id	meter_pin	meter_status
A290E12M	800800	0260910267	2012-08-28 00:10:00	-	-	-	-	Prepaid	Residential	1	100001	1234	1

Table 3.4 Administrative User Table

UserAccountID	UserAccountName	Username	Password	UserGroupID	UserProfileID	UserStatusID
1	System Administrator	admin	d033e22ae348aeb5660fc2140aec35850c4da997	1	admin	1
2	User	user	12dea96fec20593566ab75692c9949596833adc9	2	user	1

3.3.2 SMS Interface

A software application is written to act between the GSM-Based Smart Meter and the Database. There is a GSM Modem connected to the server to serve as the interface between the Server and the incoming SMS as well as the outgoing SMS.

3.3.3 Internet Interface

The Server is connected to the internet to receive and send GPRS data through the TCP/IP connection between the Meter and the Server. The web access was created with the ability to interact with the Database for online access. Figure 3.3.3 shows the interconnection between the software system and the various access interfaces.
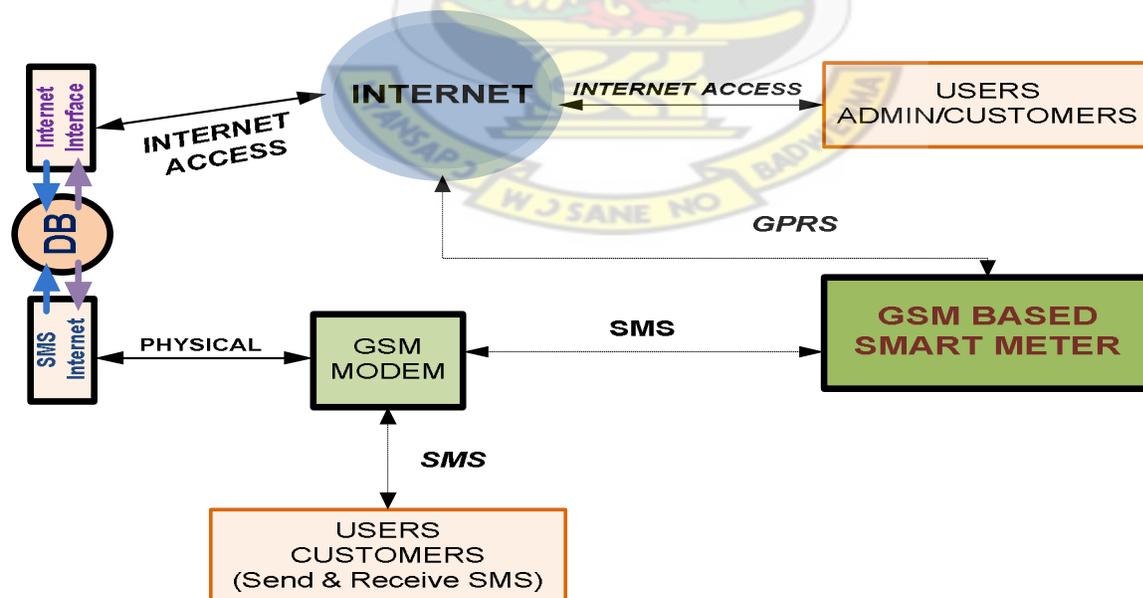
Figure 3. 6 Software Sub-System and the user access

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3.4 System Components

This sub-section introduces the Hardware Sub-system components and the Software Sub-system application.

3.4.1 Hardware Sub-system

The hardware sub-system comprises: Metering Unit, Processing Unit and Communication Interface.

A. Metering Unit Components

The core of the metering system is an EMU with MCP3905. It is an energy metering IC designed

by Microchip to support the IEC 62053 international metering Standard specification. It supplies

a frequency output proportional to the average active real power as well as a high frequency

output proportional to the instantaneous power for meter calibration [33].
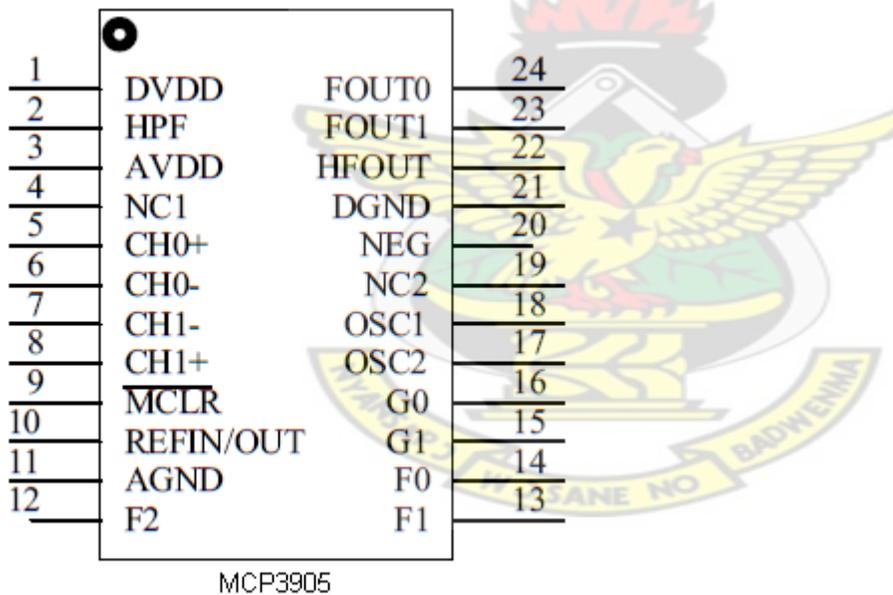
Figure 3.7 MCP3905 24-PIN SSOP Package
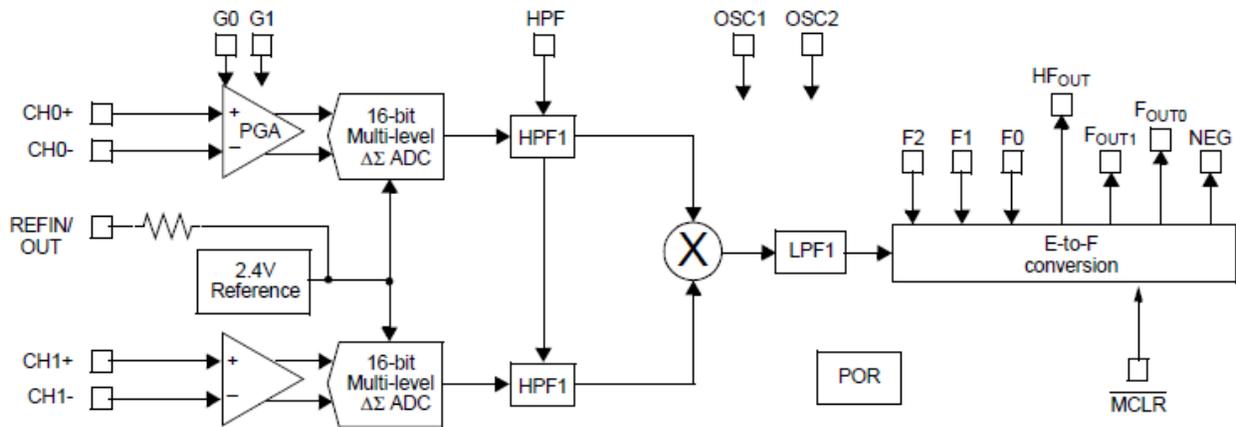
Figure 3.8 MCP3905 Functional Block Diagram

i. MCP3905 Description

Table 3.2.3 shows the device pin out and their functionalities.

Table 3.5 MCP3905 Pin-out Functionalities

PIN #	SYMBOL	FUNCTION
1	DV_{DD}	DIGITAL POWER SUPPLY PIN
2	HPF	HIGH-PASS FILTERS CONTROL LOGIC PIN
3	AV_{DD}	ANALOG POWER SUPPLY PIN
4	NC	NO CONNECTION
5	CH0+	NON-INVERTING ANALOG INPUT PIN FOR CHANNEL 0 (CURRENT CHANNEL)
6	CH0-	INVERTING ANALOG INPUT PIN FOR CHANNEL 0 (CURRENT CHANNEL)
7	CH1-	INVERTING ANALOG INPUT PIN FOR CHANNEL 1 (VOLTAGE CHANNEL)
8	CH1+	NON-INVERTING ANALOG INPUT PIN FOR CHANNEL 1 (VOLTAGE CHANNEL)
9	$\overline{MCLR}$	MASTER CLEAR LOGIC INPUT PIN
10	REFIN/OUT	VOLTAGE REFERENCE INPUT/OUTPUT PIN
11	A_{GND}	ANALOG GROUND PIN, RETURN PATH FOR INTERNAL ANALOG CIRCUITRY
12	F2	FREQUENCY CONTROL FOR HF_{OUT} LOGIC INPUT PIN
13	F1	FREQUENCY CONTROL FOR $F_{OUT0/1}$ LOGIC INPUT PIN
14	F0	FREQUENCY CONTROL FOR $F_{OUT0/1}$ LOGIC INPUT PIN
15	G1	GAIN CONTROL LOGIC INPUT
16	G0	GAIN CONTROL LOGIC INPUT
17	OSC1	OSCILLATOR CRYSTAL CONNECTION PIN1
18	OSC2	OSCILLATOR CRYSTAL CONNECTION PIN2
19	NC	NO CONNECTION
20	NEG	NEGATIVE POWER LOGIC OUTPUT PIN
21	D_{GND}	DIGITAL GROUND PIN
22	HF_{OUT}	HIGH FREQUENCY LOGIC OUTPUT PIN FOR CALIBRATION PURPOSES
23	F_{OUT1}	DIFFERENTIAL MECHANICAL COUNTER LOGIC OUTPUT PIN
24	F_{OUT2}	DIFFERENTIAL MECHANICAL COUNTER LOGIC OUTPUT PIN

ii.   DIGITAL VDD(DV$_{DD}$)

In the MCP3905 the DV$_{DD}$ serves as the power supply within the MCP3905. This pin must be couple with appropriate bypass capacitor and must be maintained at 5V±10% for this operation. This was achieved by the use of 7805 voltage regulator IC. Figure 3.2.3.1 shows the circuitry of the voltage regulator.
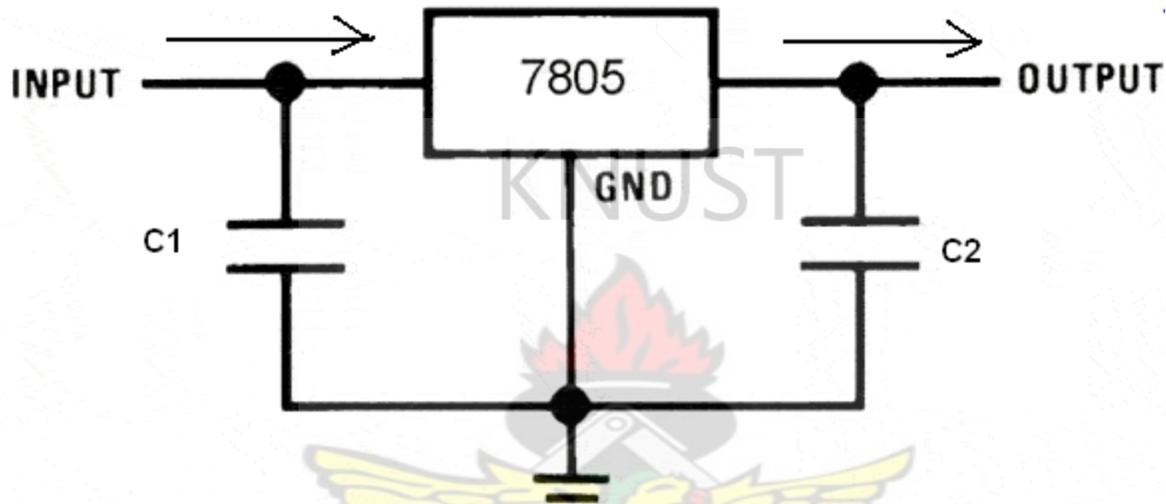
Figure 3.9 Circuit diagram of the 7805 voltage regulator

iii.   Analog VDD(AV$_{DD}$)

AVDD is the power supply pin for the analog circuitry inside the MCP3905. Just like the DVDD, the power supply requires appropriate bypass capacitor and the voltage must be maintained at 5V ±10%.

iv.   Current Channel (CHO-; CH0+)

These are fully differential analog voltage input channels for the current measurement, containing a PGA for small signal input, such as shunt current sensing. The linear and specified region of this channel is completely dependent on the *programmable-gain amplifier* (*PGA*) gain. This correspond to a maximum differential voltage of +or-470mV per Gain and a maximum

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absolute voltage, with respect to the Analog Ground of +or-1V and up to +or- 6V can be applied on these pins with no risk of permanent damage to the device.

v. Voltage Channel (CH-; CH+)

These are purely for differential analog voltage measurement. The linear and specified regions of these channels have a maximum differential voltage of ±660mV and maximum absolute voltage of ±1V.

vi. Reference (REFIN/OUT)

This has output for every interval of 2.4V reference. External reference can also be used by the application of voltage to this Pin in a specified range.

vii. Frequency Control Logic Pins (F0, F1, F2)

The Values of the constant FC and HFC are used to select high output and low output frequencies. These are the constants that define the period of the output pulse of the device.

viii. Gain Control Logic Pins (G1, G0)

G1 and G0 are used to select the *programmable-gain amplifier* (*PGA*) gain on channel from three different values: 1, 8 and 16.

ix. High Frequency Output (HF$_{OUT}$)

This is the high frequency output of the device and supplies the instantaneous real-power information. The output is a periodic pulse output, with its period proportional to the measured real power and to the HF$_C$ constant defined by F0, F1 and F2 pin logic states. This output is the preferred output for calibration due to faster output frequencies, giving smaller calibration times.

x. **Frequency Output (F_{OUT0}; F_{OUT1})**

The average of real power information sent out through these Pins. The outputs are periodic

pulse outputs, with its period proportional to the measured real power, and to the FC constant

which is defined by the F0 and F1 pin logic states (1 or 0).
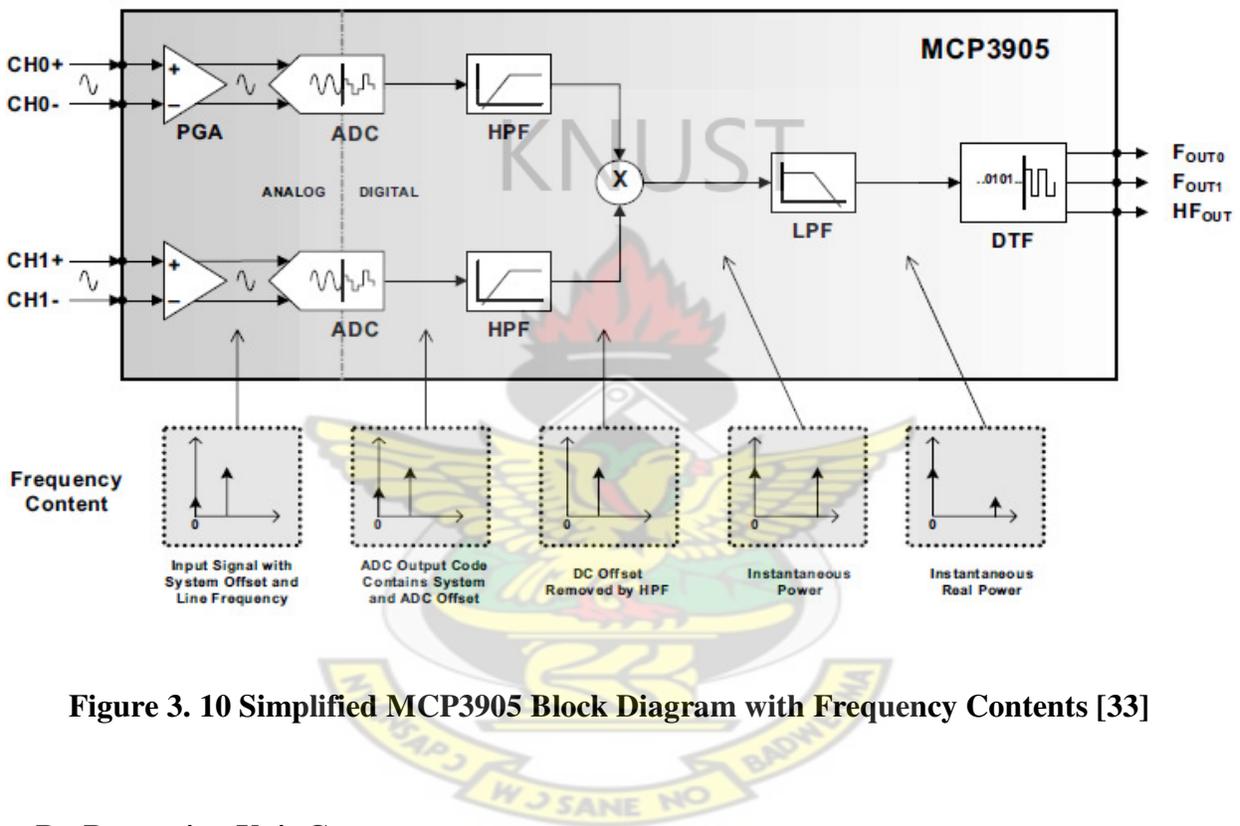
Figure 3. 10 Simplified MCP3905 Block Diagram with Frequency Contents [33]

B. Processing Unit Components
i. **Programmable Interface Controllers (*PIC)***

PIC microcontrollers (Programmable Interface Controllers), are electronic circuits that can be

programmed to carry out a vast range of tasks. They can be programmed to be timers or to

control a production line and much more. They are found in most electronic devices such as

alarm systems, computer control systems, phones, in fact almost any electronic device. Many

types of PIC microcontrollers exist, although the best are probably found in the Microchip range

of programmable microcontrollers. These are programmed and simulated by Circuit Wizard software.

The choice of MCU for the Control Systems was PIC18F4553. The PIC18F4553 offers the advantages of all PIC18 microcontrollers. Some of these advantages are high computational performance at an economical price with the addition of high-endurance, Enhanced Flash program memory. In addition to these features, the PIC18F4553 family introduces design enhancements that make these microcontrollers a logical choice for the control system of the GSM Based Smart Meter. The figure below shows the pin information of a 40-Pin Plastic Dual Inline Package (PDIP) PIC18F553 microcontroller.
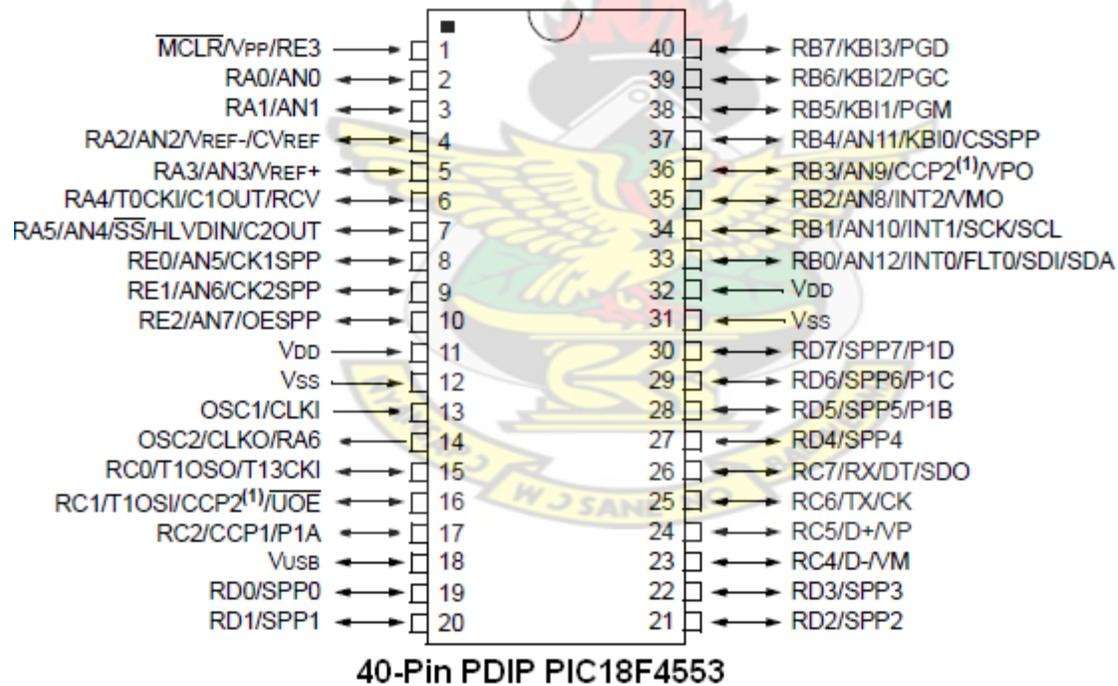
40-Pin PDIP PIC18F4553
Figure 3.11 Pin of PIC18F4553 [34]

The Pin information of PIC18F4553 is presented in table 3.3.1

Table 3.6 PIC18F4553 I/O PINS

PIN #	SYMBOL	(I/O) PIN	PIN #	SYMBOL	(I/O) PIN
1	MCLR/VPP/RE3	I ONLY	21	RD2/SPP2	I&O
2	RA0/AN0	I&O	22	RD3/SPP3	I&O
3	RA1/AN1	I&O	23	RC4/D-/VM	I&O
4	RA2/AN2/VREF-/CVREF	I&O	24	RC5/D+/VP	I&O
5	RA3/AN3/VREF+	I&O	25	RC6/TX/CK	I&O
6	RA4/T0CKI/C1OUT/RCV	I&O	26	RC7/RX/DT/SDO	I&O
7	RA5/AN4/SS/HLVDIN/C2OUT	I&O	27	RD4/SPP4	I&O
8	RE0/AN5/CK1SPP	I&O	28	RD5/SPP5/P1B	I&O
9	RE1/AN6/CK2SPP	I&O	29	RD6/SPP6/P1C	I&O
10	RE2/AN7/OESPP	I&O	30	RD7/SPP7/P1D	I&O
11	VDD	I ONLY	31	VSS	I ONLY
12	VSS	I ONLY	32	VDD	I ONLY
13	OSC1/CLKI	I ONLY	33	RB0/AN12/INT0/FLT0/SDI/SDA	I&O
14	OSC2/CLKO/RA6	I&O	34	RB1/AN10/INT1/SCK/SCL	I&O
15	RC0/T1OSO/T13CKI	I&O	35	RB2/AN8/INT2/VMO	I&O
16	RC1/T1OSI/CCP2(1)/UOE	I&O	36	RB3/AN9/CCP2(1)/VPO	I&O
17	RC2/CCP1/P1A	I&O	37	RB4/AN11/KBI0/CSSPP	I&O
18	VUSB	I&O	38	RB5/KBI1/PGM	I&O
19	RD0/SPP0	I&O	39	RB6/KBI2/PGC	I&O
20	RD1/SPP1	I&O	40	RB7/KBI3/PGD	I&O

i. Electrically Erasable Programmable Read-Only Memory (EEPROM)

EEPROM non-volatile memory used in computers and other electronic devices to store small amounts of data that must be saved when power is removed. This was employed in the GSM Based Smart Meter to store the meter reading, all metering information as well as metering instructions in the meter and retains them even when mains fails.

There are different types of electrical interfaces to EEPROM devices. Main categories of these interface types are; Serial bus and the Parallel bus. How they are used depends on the electrical interface available for the connecting peripheral controller. For this desing, Serial bus is available on the PIC.

Most common serial interface types are Serial Peripheral Interface Bus (SPI), Inter-Integrated Circuit (I²C), Microwire (μWire), UNI/O [31]. These interfaces require between 1 and 4 control signals for operation, resulting in a memory device in an 8 pin (or less) package.

ii.   EEPROM 24LC02B

This design makes use of 24LC02B from Microchip Technology Incorporated employing IIC technology between the PIC and the EEPROM. This EEPROM serves as a Central storage for all metering information from external and internal sources of the GSM Based Smart Meter. It can be accessed by the Processing System as well as the Communication System.

The 24LC02B is an 8 Pin device that supports a bidirectional, 2-wire bus and data transmission protocol. A device that sends data onto the bus is defined as transmitter, while a device receiving data is defined as a receiver. The bus has to be controlled by a master device which generates the Serial Clock (SCL), controls the bus access and generates the Start and Stop conditions, while the 24LC02B works as slave. Both master and slave can operate as transmitter or receiver, but the master device determines which mode is activated. The device is organized as one block of 256 x 8-bit memory totaling 2 Kbit Electrically Erasable PROM. Figure 3.3.2.1 Represent a block diagram of the 24LC02B EEPROM
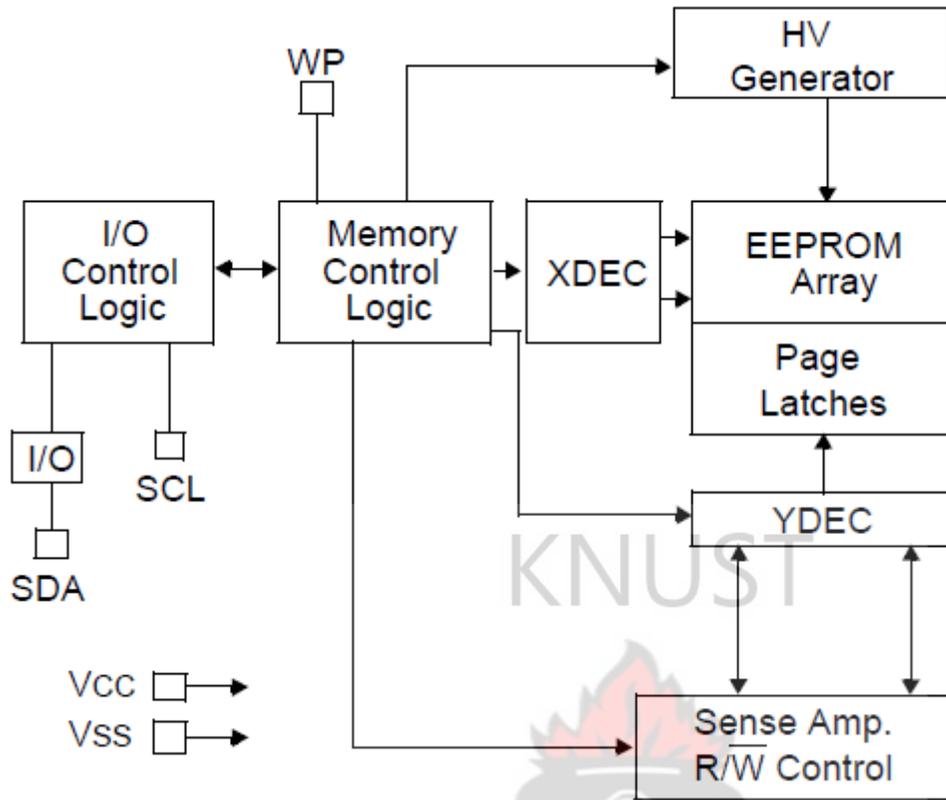
Figure 3.12 Block Diagram of 24LC02B

24LC02B PIN DESCRIPTION

Figure 3.3.2.2 shows the Pin symbols of the device
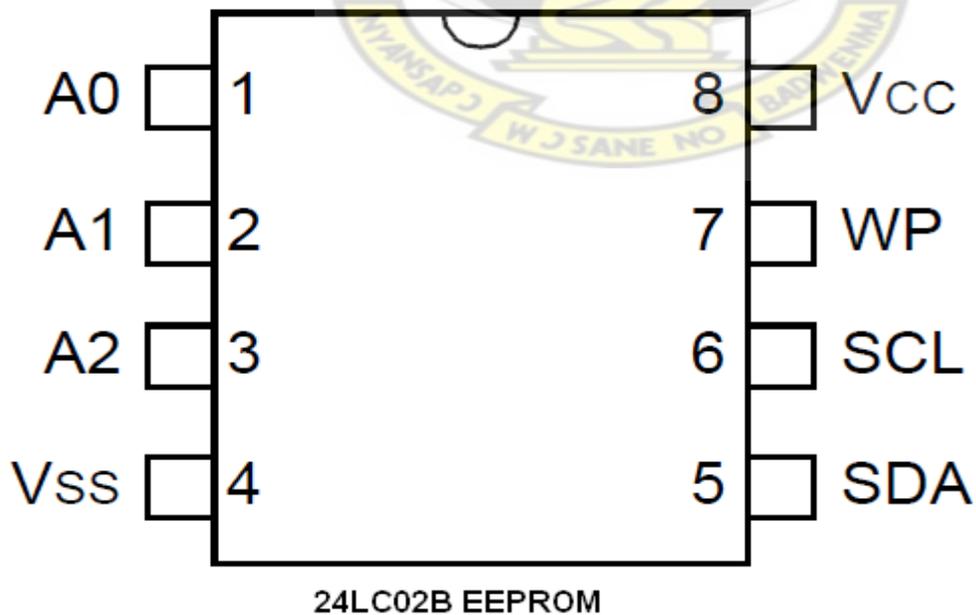
24LC02B EEPROM

Figure 3.13 Pin-out Symbols of 24LC02B

The descriptions of the EEPROM pins are listed in Table 3.3.2.2

Table 3.7 24LC02B Pin Description

PIN #	SYMBOL	DESCRIPTION
1	A0	N/A
2	A1	N/A
3	A2	N/A
4	VSS	DC GROUND
5	SDA	SERIAL ADDRESS/DATA I/O
6	SCL	SERIAL CLOCK
7	WP	WRITE PROTEC INPUT
8	VCC	POWER SUPPLY (+1.7V to 5.5V)

Serial Address/Data Input/Output (SDA)

SDA is a bidirectional pin used to transfer addresses and data into and out of the device. Since it is an opendrain terminal, the SDA bus requires a pull-up resistor to VCC For normal data transfer, SDA is allowed to change only during SCL low. Changes during SCL high are reserved for indicating Start and Stop conditions [35].

Serial Clock (SCL)

The SCL input is used to synchronize the data transfer to and from the device. It is connected to the SCL pin of PIC18F4553 and the Microcontroller in the Communication Systems.

Write-Protect (WP)

The WP pin must be connected to either VSS or VCC. If tied to VSS, normal memory operation is enabled (read/write the entire memory 00-FF). If tied to VCC, write operations are inhibited. The entire memory will be write-protected. Read operations are not affected. The write protection was not implemented in the design and hence the WP was tied to the DC ground.

iii.   PIC18F452

The PIC18F452 is responsible for sending AT commands to the GSM Module and interpret the

feedback as metering instruction and CP selection for onward storage onto the EEPROM

(24LC02B).

$\overline{MCLR}$/VPP	1	40	RB7/PGD
RA0/AN0	2	39	RB6/PGC
RA1/AN1	3	38	RB5/PGM
RA2/AN2/VREF-	4	37	RB4
RA3/AN3/VREF+	5	36	RB3/CCP2*
RA4/T0CKI	6	35	RB2/INT2
RA5/AN4/$\overline{SS}$/LVDIN	7	34	RB1/INT1
RE0/$\overline{RD}$/AN5	8	33	RB0/INT0
RE1/$\overline{WR}$/AN6	9	32	VDD
RE2/$\overline{CS}$/AN7	10	31	VSS
VDD	11	30	RD7/PSP7
VSS	12	29	RD6/PSP6
OSC1/CLKI	13	28	RD5/PSP5
OSC2/CLKO/RA6	14	27	RD4/PSP4
RC0/T1OSO/T1CKI	15	26	RC7/RX/DT
RC1/T1OSI/CCP2*	16	25	RC6/TX/CK
RC2/CCP1	17	24	RC5/SDO
RC3/SCK/SCL	18	23	RC4/SDI/SDA
RD0/PSP0	19	22	RD3/PSP3
RD1/PSP1	20	21	RD2/PSP2

PIC18F452 PIN INFO

Figure 3.14 PIC18F452 Pin-out information [36]

C. Communication Interface Components

The communication between the GSM and the Database Server Application will be achieved

using a GSM Module capable of handling SMS and GPRS Services. The GSM Module

employed is the Q24PL02 coupled with PIC18F452.

3.4.2 Software Sub-system and Tools

MySQL, Visual C# and PHP were used to implement the software sub-system. MySQL is used to develop the Database Application, the reception and the processing of SMS requests will be handled by the Visual C# and the network as well as the web access interface will be created using PHP.

A. Hypertext Preprocessor (PHP)

PHP is a general-purpose server-side scripting language originally designed for Web development to produce dynamic Web pages. It is one of the first developed server-side scripting languages to be embedded into an HTML source document rather than calling an external file to process data. The code is interpreted by a Web server with a PHP processor module which generates the resulting Web page. It also has evolved to include a command-line interface capability and can be used in standalone graphical applications. PHP can be deployed on most Web servers and also as a standalone shell on almost every operating system and platform free of charge

B. MS Visual C#

Microsoft Visual C# is Microsoft's implementation of the C# specification, included in the Microsoft Visual Studio suite of products. It is based on the European Computer Manufacturers Association (ECMA)/ International Organization for Standardization (ISO) specification of the C# language, which Microsoft also created. While multiple implementations of the specification exist, Visual C# is by far the one most commonly used.

C. MySQL Database

It is primarily an RDBMS and ships with no GUI tools to administer MySQL databases or manage data contained within the databases. Users may use the included command line

tools[37], or use MySQL [38] "front-ends", desktop software and web applications that create and manage MySQL databases, build database structures, back up data, inspect status, and work with data records. The official set of MySQL front-end tools, MySQL Workbench is actively developed by Oracle, and is freely available for use.

D. Apache Server

The Apache Server played a significant role in the initial growth of the World Wide Web. In 2009 it became the first web server software to surpass the 100 million website milestone. Apache was the first viable alternative to the Netscape Communications Corporation web server (currently named Oracle iPlanet Web Server), and since has evolved to dominate other web servers in terms of functionality and performance. It is simple to implement.
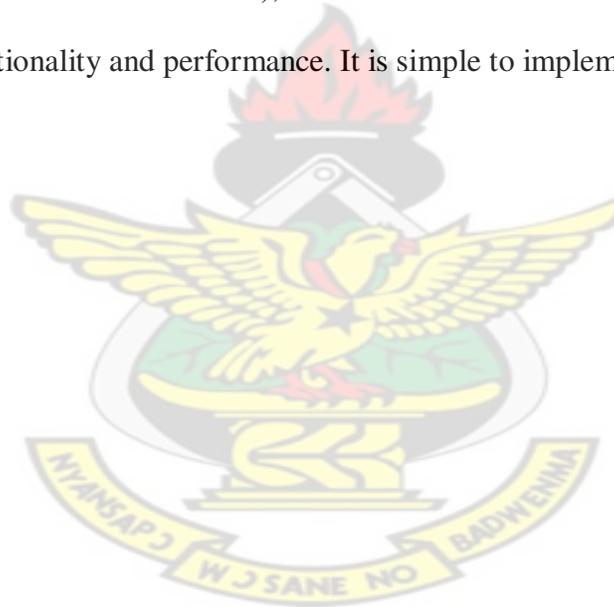
CHAPTER FOUR - IMPLEMENTATION AND TESTING

4.1 Introduction

This chapter looks at how the various functional systems of the GSM Based Smart meter were tested and connected together. The design steps were also outlined in this chapter. The software and the hardware were looked at separately and tested after which they were all tested together.

4.2 Hardware Implementations

The hardware design was implemented through the following steps.

1. Digital meter was implemented and tested

2. Communication Interface was implemented and tested

3. The Digital meter and the communication component were put together to form the GSM-Based Smart Meter System and the meter was tested.

4.2.1 Digital Meter

The digital metering section is divided into two stages. The block diagram in figure 4.2 shows block diagram of the stage 1 of the digital meter implemented. Where CT is Current Transformer, VT is Voltage Transformer, CR is the Calibration Resistors and LED represents the Light Emitting Diode.
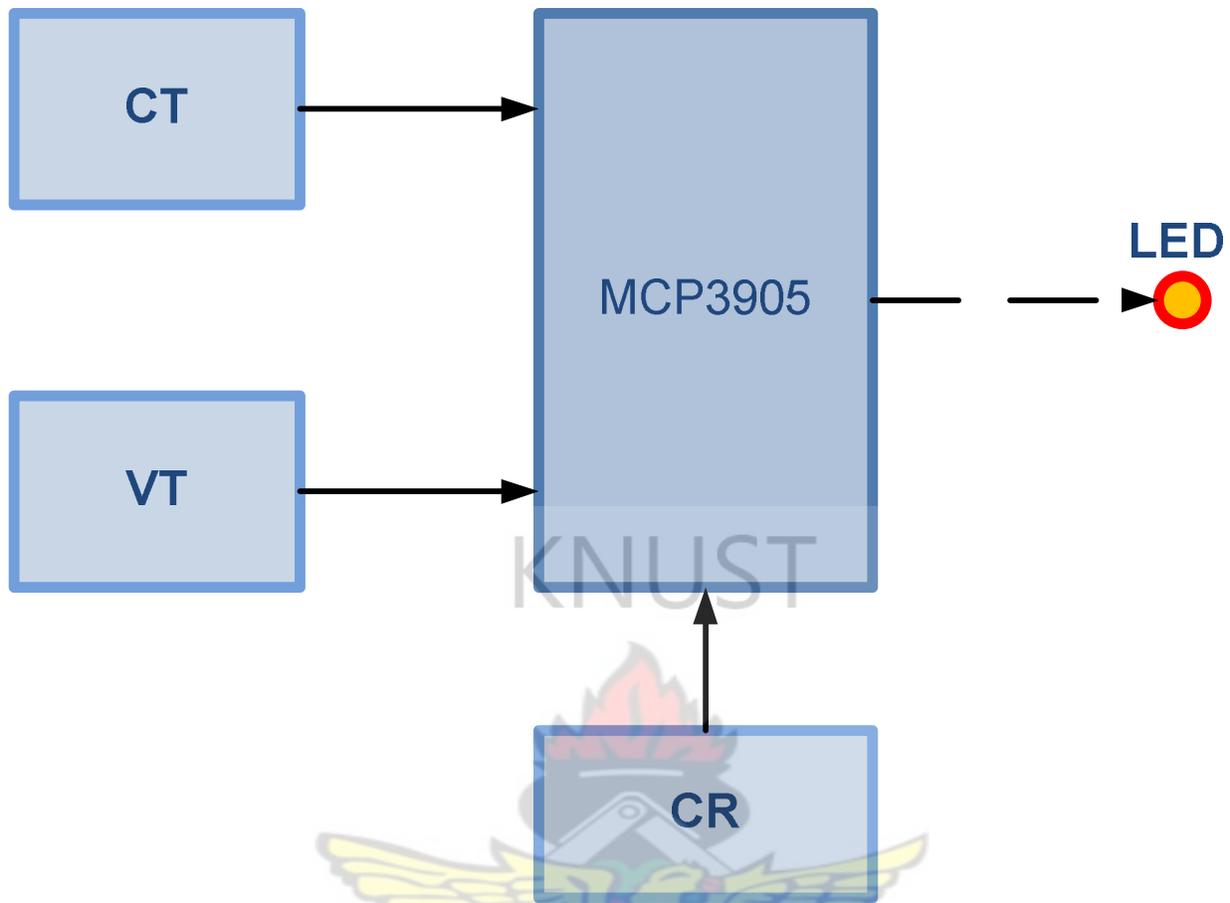
Figure 4.1 Block Diagram of Stage 1 Digital Meter

Stage 1

This is the stage at which the collection of active voltage and current are used to compute the effective load on the Meter. The CT is connected along the load path and the VT is directly connected across the load as shown in the circuit in Figure 4.2.1.
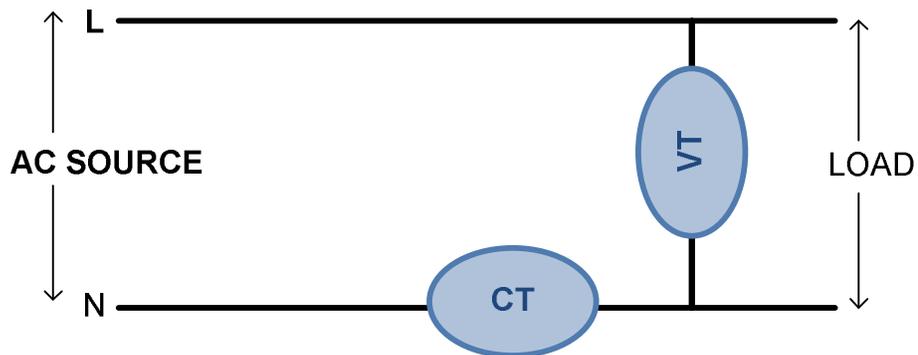
Figure 4. 2 VT and CT Connections

i.   Calibration and Testing

The stage1 meter is subjected to a load of 1KW so as to adjust the meter to produce 1000

Impressions every 1 hour. Instead of waiting for one hour before adjusting the CR, the following

calculations were made:

- We aspect that in one hour (3600 seconds) the LED will flash 1000 times, so the LED

  will flash once every 3600/1000 = 3.6 seconds.

- This implies that the LED will flash 10 times every 36 seconds

- This implies that the LED will flash 100 times every 360 seconds/6 minutes

- The test was conduct every 6 minutes which implies 100 impressions

- Every 6 minutes, the impulse is counted and the result was noted

- For every unsuccessful step, the CR was adjusted

- This process was repeated several times until 100 impulse was counted in 6 minutes

At this stage a meter with 1000imp/kWh has been implemented and tested successfully.

Stage 2

This is the stage where PIC is introduced into the metering system to make it digital. In this stage

PIC 18F4553 was used to receive the impressions from the meter and computation were done on

the received signals to produce a digital meter with LCD interface. The EEPROM was also

introduced at this stage. The circuit in Figure 4.2.2 reveals the working PIC, EEPROM and the

LCD circuit.
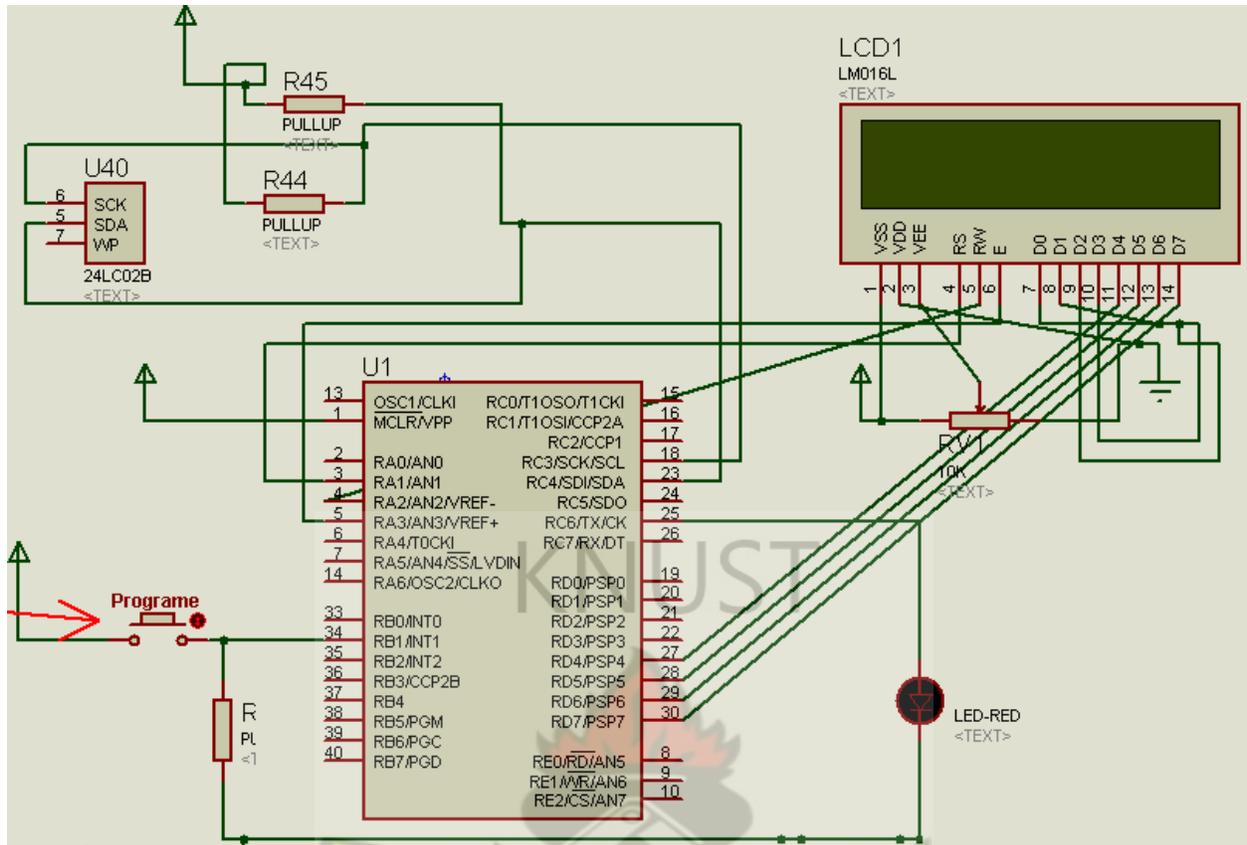
Figure 4.3 Metering PIC Circuit Diagram

4.2.2 Communication Interface Details

After the digital meter design and testing, the next logical step is the communication system. The two major components are the GSM Module and the PIC.

The GSM Module was connected to the microcontroller and the microcontroller was programmed to send specific AT commands to the module. The image in Figure 4.2.2 shows the PIN position of the module.

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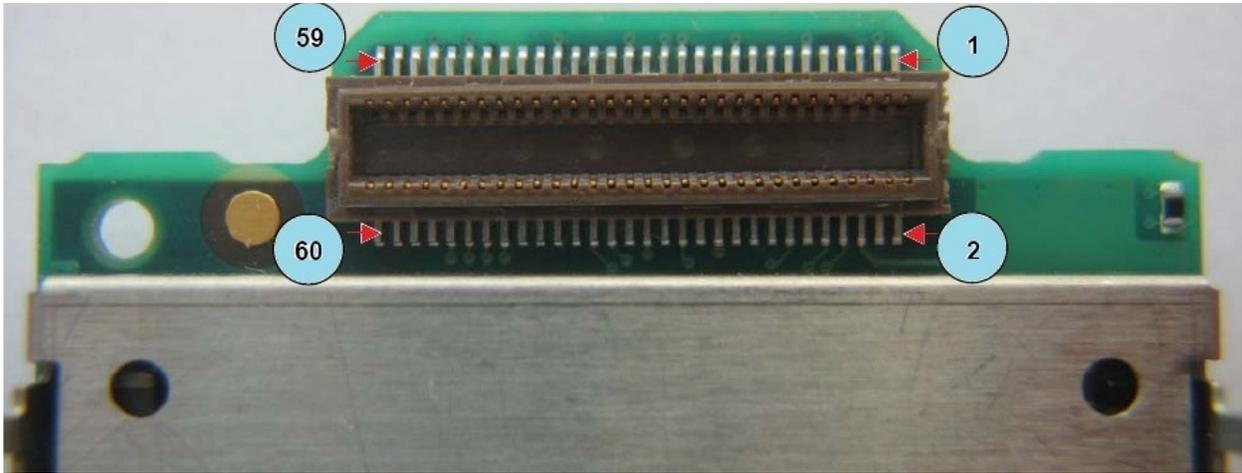
Figure 4. 4 Q24PL02 PIN positions

The EEPROM serves as the central storage for both Metering system and the communication system. The metering aspect stores the metering information; this information is accessed periodically for control purposes and for LCD display only. The diagram in Figure 4.2.2b shows the communication block with connection the EEPROM.
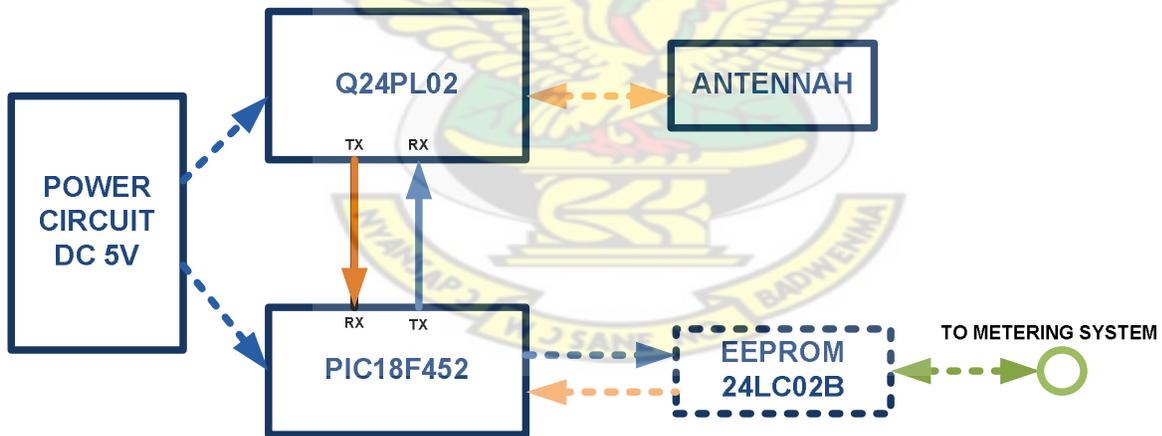
Figure 4.5 Communication Block Diagram

The pin configuration of the PIC and their functions were described in chapter 3.

The circuit in Figure 4.2.2c shows the inter-PIC communication with the EEPROM as tested on Proteus [39].
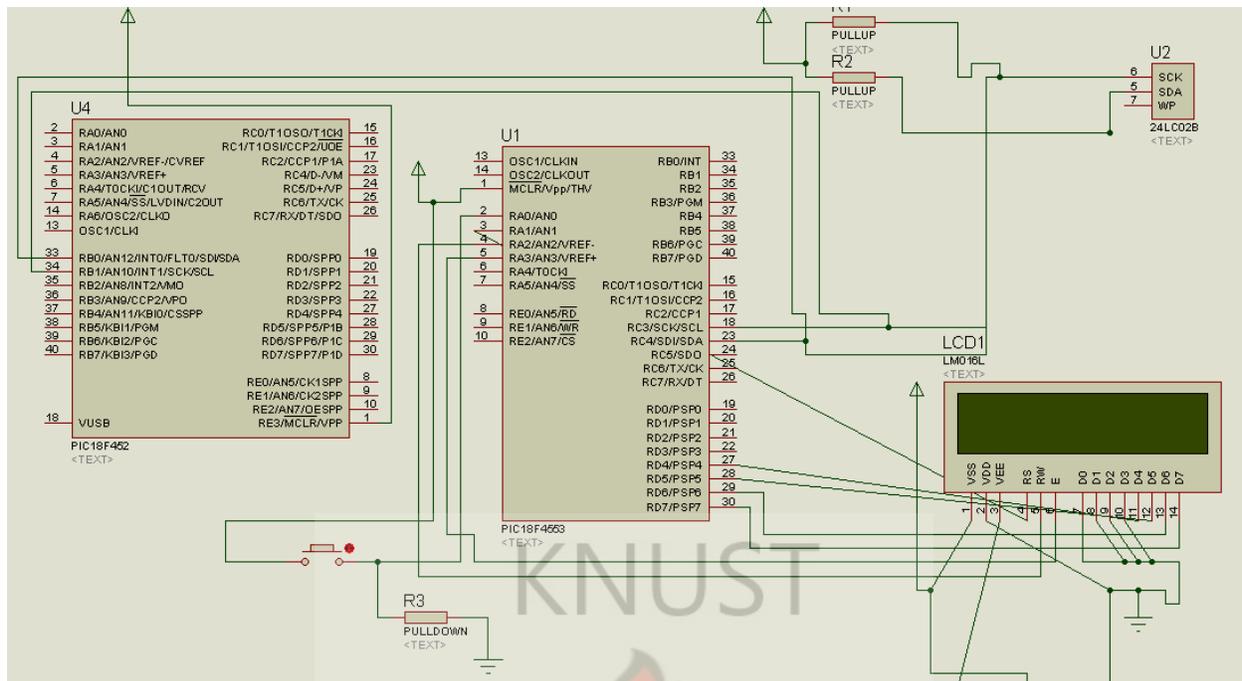
Figure 4.6 2 PICs to EEPROM Circuit Diagram

4.2.3 The Prototype GSM-Based Smart Meter

The metering circuit and the communication circuits were connected together as the built GSM smart meter. A default credit of 4GHS was left on the meter as start up credit for testing purposes.

Some attributes of the GSM Based Smart Meter (GN) designed and constructed are listed below:

1. Has a serial number and an ID

2. It will read meter details and communicate them to the server periodically or in real-time.

3. A kWh change is store in the EEPROM with date and time of change. This enables the graphical presentation of consumption.

4. Communication Path (SMS or GPRS) settings are received from the Server. CP Settings

5. Date and time of the meter is received from the server for synchronization purposes

6. Credit can be added to the meter only by the Server.

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7. Credit is reduced at the Server side only when the load on the meter consumes at least 1kWh for Real-time Updates (RU) to the Server. However, for Periodic Updates (PU), a minimum of 5 minutes to 30 days interval could be set on the Meter from the Server.

8. Meter can be made to supply power or stop supplying power regardless of credit availability or not for troubleshooting purposes only.

Figure 4.2.3a shows a PIC flow chart for Periodic and Real Time Update from GM to Server as implemented in the Microcontroller.
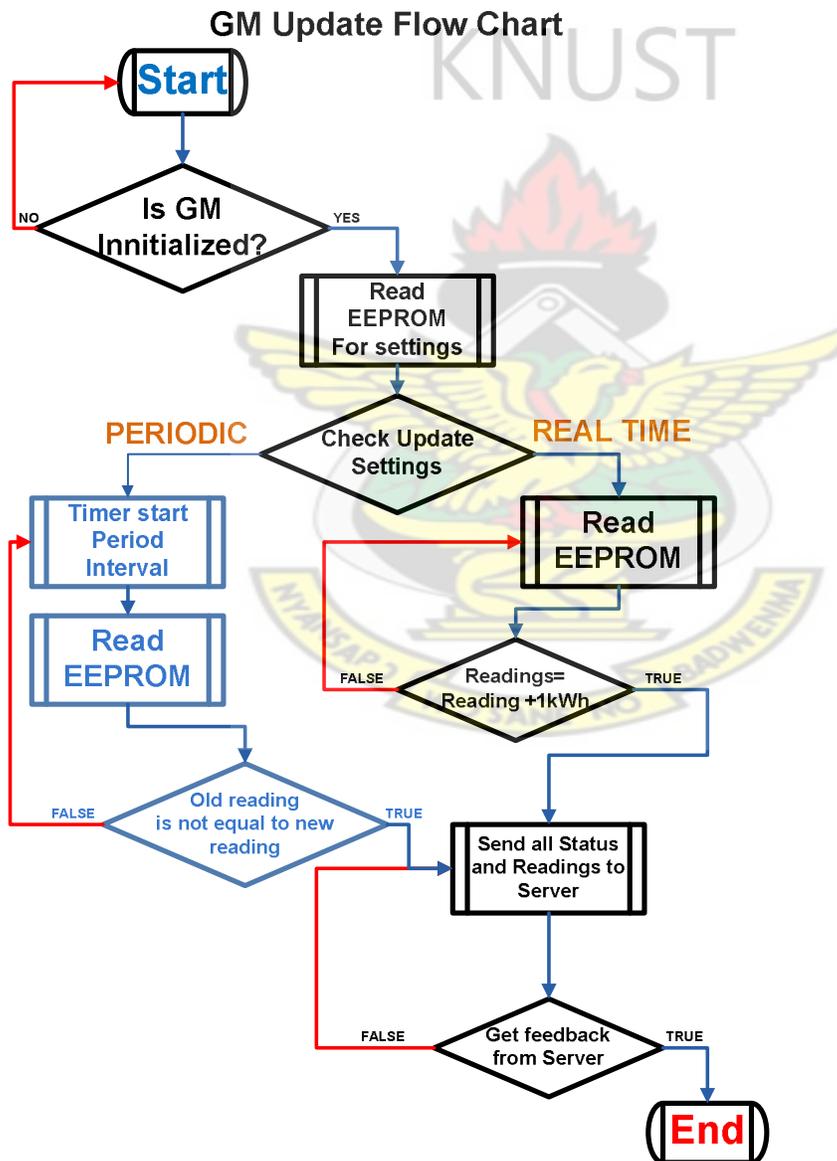
Figure 4.7 PIC Server Update Flow Chart

Figure 4.2.3a PIC Server Update Flow Chart

When the Server is updated from the GM for the first time, the next update starts from "Read EEPROM for settings" and runs to the end.

The picture in Figure 4.2.3b shows the built up circuit for PIC18F4553, PIC18F452 and the EEPROM

Figure 4.8 Microcontroller Circuit

The various test conducted will be discussed in the Testing and Results subchapter.

4.3 The software

The software aspect is responsible for all communications to the meter and user (Management Access and Customer Access).

The software system is divided into three methods, refers to as Connections. Figure 4.3 represents the Server and its connection.
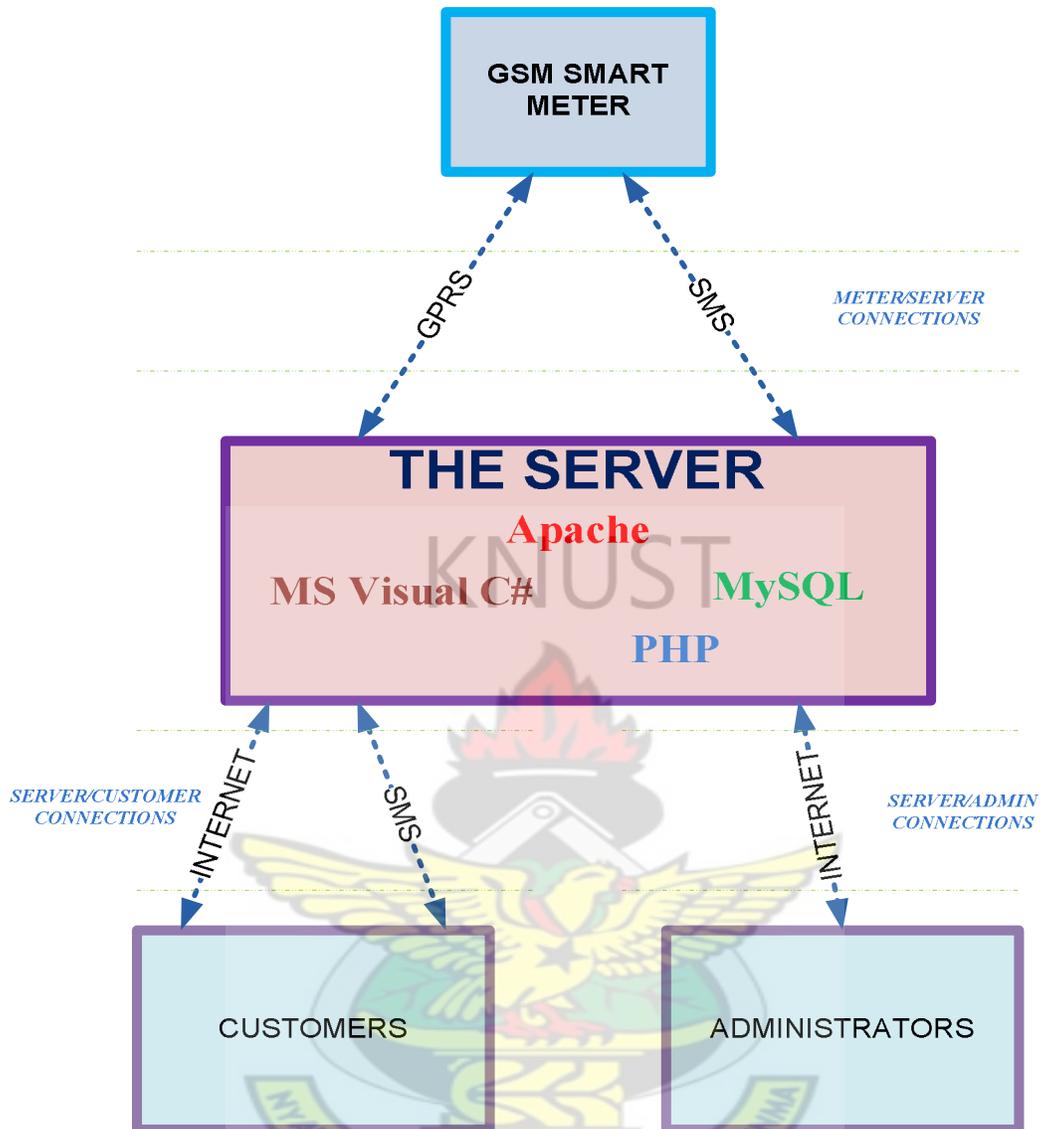
Figure 4.9 Server Connections

4.3.1 Meter/Server Connections

The meter communicates with the server by means of GPRS and SMS (CP)

The GPRS connection was achieved by a TCP/IP application written in MS Visual C# to listen to a particular port for incoming data. Authentication is performed on the data. The data is sent into the database running on the server and the appropriate fields are updated in the database. In the same manner information is fetched from the database and sent to the meter the GPRS when this method is selected by the Administrator.

The SMS communication on the other hand, was achieved by the meter sending specific SMS to the Mobile Number of the SIM card inserted into the modem connected to the server. The Server will then reply through a specific CP pre-selected by the administrators.

4.3.2 Server/Customer Connection

Customers can access their meters in two ways; SMS and Webpage. Depending on the option the activities that can be performed by a customer include; Recharging meters, Checking balance on meter, checking discrete meter consumptions, overall Energy consumed in a specified period and user can request to shutdown or turn on the meters. The customer access was purely achieved using PHP for the webpage design.

4.3.3 Sever/Administrator Connection

Administrators interact with server directly on the database or from a website. Authentication is required for access. Creation of Meters and their owners is done by the administrators; they can modify metering information of a particular meter. They are responsible for setting Billing Rates and Update type as well as Communication Path (CP) of a particular meter.

4.3.4 System Management Architecture

    a. Management Access

The *Management Access* is a website which requires internet access to establish connection to the Server (See system management architecture in Figure 4.3.4) This interface is the only interface that can be used to create Meters and their attributes onto the Server. It can delete and update Meter and or its attributes. Activation and De-activation of meters are also done on this terminal.
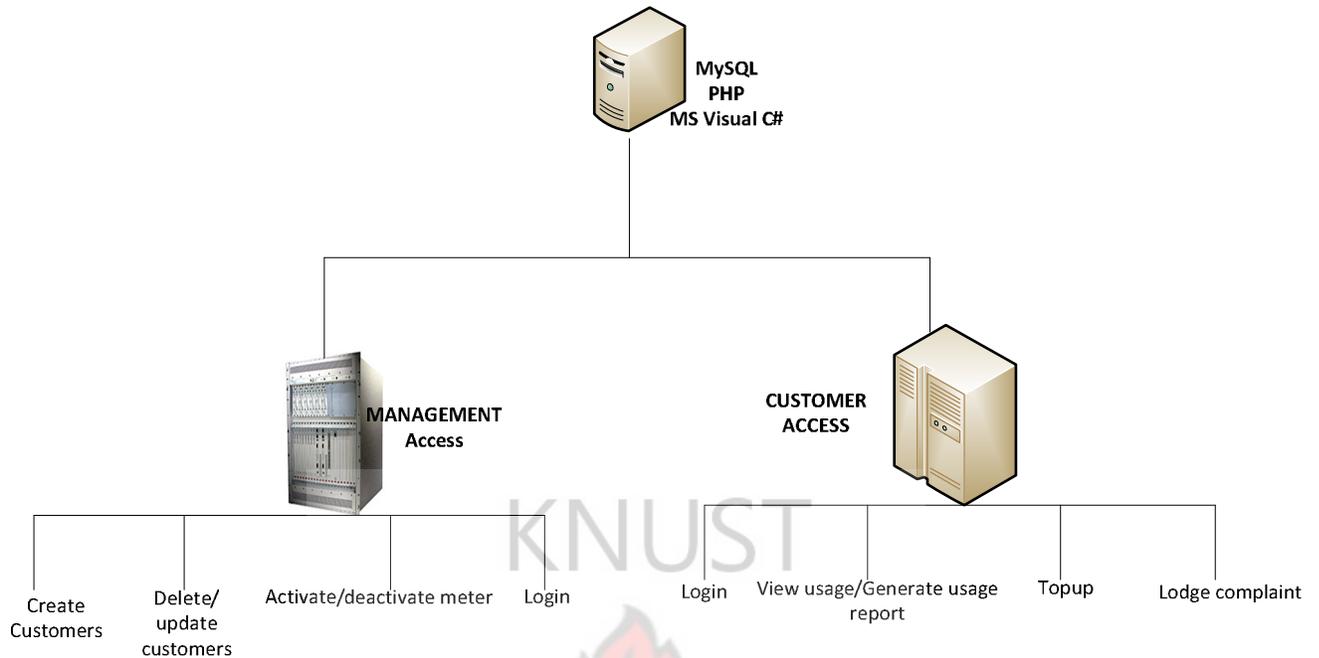
Figure 4.10 System Management Architecture

o Creation of Customer Web Access and SMS access IDs, Usernames and Passwords are all done on the Management Access. Authentication parameters of the Management Access are also set at this web terminal.

o The Management Access has full control over all other components.

b. Customer Access

The Customer Access is responsible for providing customer interaction with the meter through the Server. There are two parts of the Customer Access which are:

1. Web Access

2. Short Message Service (SMS)

i. Web Access

This is a website that customers could login and view their metering parameters and update the credit. Consumption graphs and data could be printed from here by the customer after authentication process has been completed. Customers are provided with their Username and Password for web access by the power company or the monitoring firm from the Management Access. Complaints and Shutdown requests could also be made by the customers from the Web Access.

ii. SMS

A special SMS Short Code is provided to the general public for metering information access by means of SMS from any network in the country. Format for sending various request will be provided the customers as well.

For example: For a customer to check his or her available credit, from the Server, he or she must send follow by the type of request*Meter Number*Customer Pin and in this case Balance Request to the Server. (Balance*800800*1234) The Server will then compare the 800800 and 1234 to confirm the Authentication before the reply is sent to the customer in this format: "Your Meter ID is A290E12M, and your available balance is GHS39.64. Thank you"

4.4 System Testing and Results

When all the various subsystems were built and put together, the Server and the GSM based smart meter was subjected to series of test. The overall system interaction for testing can be summed up in Figure 4.4
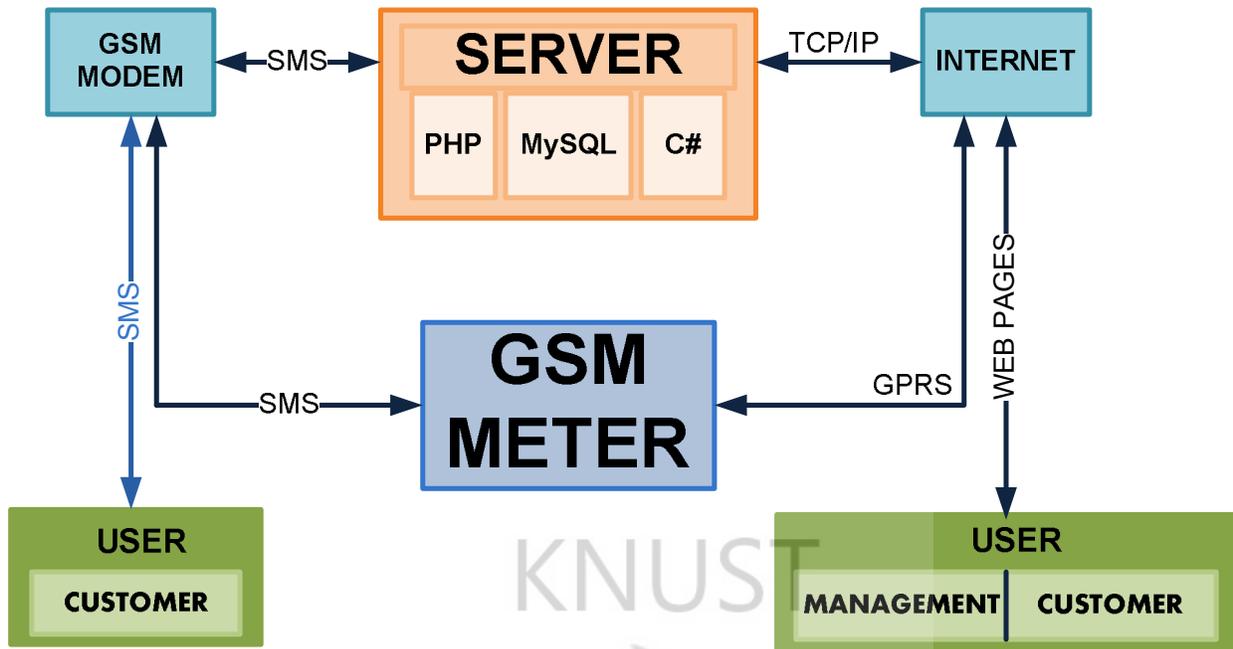
Figure 4.11 Testing Setup Block Diagram

Several tests were conducted at various stages of the design implementation. However, the most recent tests and results are presented here. There are three steps involved in setting up the system.

4.4.1 Administrative Setup Test

Figure 4.4.1a shows the login interface for the Administrator.

Figure 4.12 Administrator Login

1. Meter was created based on the Meter ID and Meter Number of the GSM Meter on the administrative terminal.

2. Customer was created to represent the owner of the meter. The screen shot of customer creation can be seen in Figure 4.4.1b

Figure 4.13 Screen Shot of Customer Creation

3. The last step in this stage is the select a CP; the default CP is CP1 i.e. SMS in; SMS out.

4.4.2 Meter Initialization Test

Initialization process does not need the meter to be on load. The test was conducted simply by powering the meter on. The meter was the subjected to load to monitor the update process. Figure4.4.2a and b Show the Admin interface of the Meter displaying the status before and after initialization.
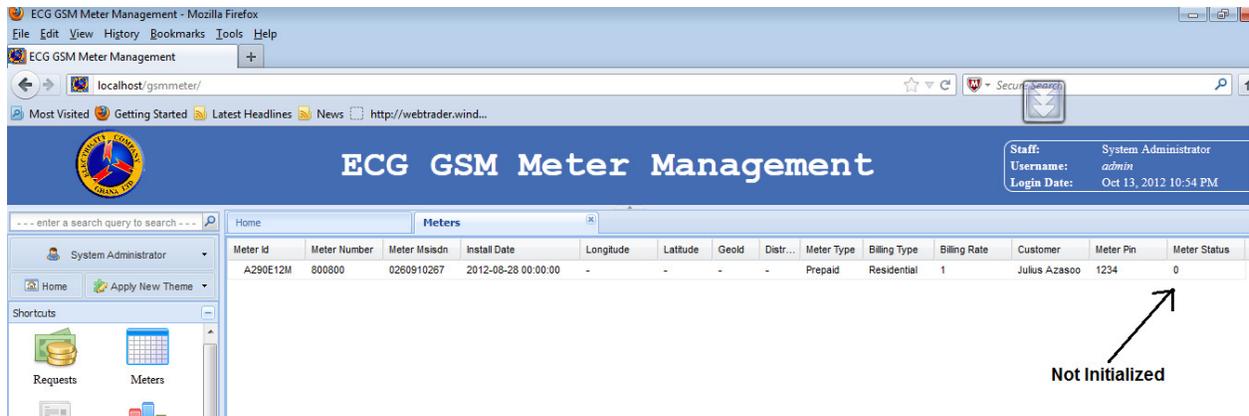
Figure 4.14 Waiting for Initialization

Figure 4.15 Initialized Meter info

It was observed from this test that the meter has initialized as designed

4.4.3 Results

Several tests were conducted at various stages of the design implementation. However, the most recent tests and results are presented here. The System was set up on no load and the meter Update Period Setting (UPS) was set to 1KW UPS from the Server. During the test the meter and the Server where all located in the same building and being fed by the same power supply it was difficult to get the outage time accurately. Therefore, there is the need to host the server at a more power dependable location for future test of performance.

- A credit of 100.00GHS was loaded onto the meter from the server on the CP1

The meter is then subjected to a household load by connecting the Life and Neutral Cables coming from the existing ECG meter to the input of the new meter to monitor the household consumption for period of five (4) days continuously at 240V / 50Hz

- The meter was monitored periodically to check the display on the LCD of the meter. The Database of the Server was also monitored periodically to see if all appropriate fields were updated as designed.

- At the second day, the following observations were made as shown in Table 4.2a

Table 4.1 Consumption after day2

Log	Reading/kWh	Date	Time	Duration	Duration/Min	BAL/GHS
1	127	19th	10:57	0	0	100
2	128	19th	13:30	2:32	152	98.53
3	129	19th	17:21	3:51	231	97.06
4	130	19th	21:32	4:11	251	95.59

For the 5 days metering, the following information was obtained as given in Table 4.2b where: 1kWh=1.47GHS

Table 4.2 Overall consumption after day5

Log	Reading/kWh	Date	Time	Duration	Duration/Min	BAL/GHS
1	127	19th	10:57	0	0	100
2	128	19th	13:30	2:32	152	98.53
3	129	19th	17:21	3:51	231	97.06
4	130	19th	21:32	4:11	251	95.59
5	131	20th	0:30	3:58	238	94.12

6	132	20th	4:47	4:17	257	92.65
7	133	20th	7:00	2:13	133	91.18
8	134	20th	10:33	3:33	213	89.71
9	135	20th	13:23	2:50	170	88.24
10	136	20th	16:27	3:04	184	86.77
11	137	20th	19:04	2:37	157	85.3
12	138	20th	21:27	2:23	143	83.83
13	139	21st	0:42	4:15	255	82.36
14	140	21st	5:02	4:20	260	80.89
15	141	21st	9:38	4:36	276	79.42
16	142	21st	19:06	9:28	568	77.95
17	143	22nd	1:32	6:26	386	76.48
18	144	22nd	3:45	2:13	133	75.01
19	145	22nd	7:10	3:25	205	73.54
20	146	22nd	11:40	4:30	270	72.07
21	147	22nd	15:14	3:34	214	70.6
22	148	22nd	20:19	5:05	305	69.13
23	149	22nd	23:16	2:57	177	67.66
24	150	23rd	5:22	6:06	366	66.19
25	151	23rd	8:54	3:32	212	64.72
26	152	23rd	11:53	2:59	179	63.25

These results could be used to generate consumption graphs for customers.

CHAPTER FIVE – CONCLUSION

5.1 SUMMARY

Smart metering is obviously the way forward in the pursuit of power efficiency on the part of the power companies as well as their consumers. The major issues that have been confronting the design and the implementation of smart meters have been the mode of communication between the meter and the server as well as the cost of implementation.

In this research a GSM-based Smart Metering System has been designed and a prototype implemented. This system includes a GSM-based Smart Meter which communicates with a central database server in real time or periodically. Meter status such as Available Credit and Power Availability are all sent to the server. Updates and Meter settings on the other hand are sent to the meter from the server. Power companies and their customers can use the system but only after a successful authentication by the server.

Prototype has been tested using existing telecom GSM infrastructure. Remote control capabilities and others were tested in line with the objective of the work. It was observed that the prototype design has met all the set objectives of the research.

5.2 RECOMMENDATION

The adoption of this metering technology across Ghana to improve both the prepayment and the post payment metering will go a long way to enhance energy consciousness and power efficiency among the citizenries. This technology can also be applied for water metering and gas measurements as well as home and industrial security and automation systems.

WIMAX could also be explored as a medium of communication between the meter and the server in case the TELCOs show limitations. The emphasis could also be on the use of WiFi to replace the existing Telco infrastructure.

Cloud computing could be deploy on the server side to allow any kind of metering service to be seamlessly integrated to benefit from the overall system so that multiple power companies and other metering such as water and gas could all together be controlled from a central Server.

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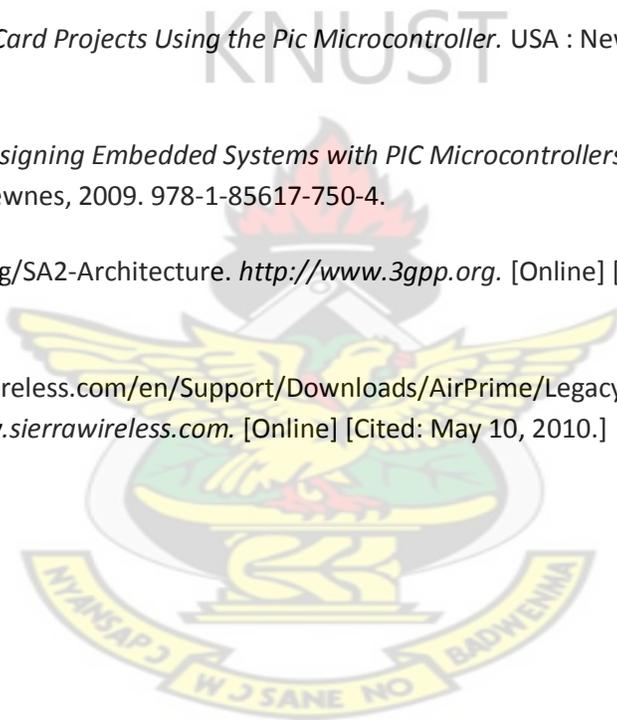
Appendix A: LCD Firmware

```
#define LCD_ENABLE_PIN  PIN_D1
    #define LCD_RS_PIN      PIN_D2
    #define LCD_RW_PIN      PIN_D3
    #define LCD_DATA4       PIN_D4
    #define LCD_DATA5       PIN_D5
    #define LCD_DATA6       PIN_D6
    #define LCD_DATA7       PIN_D7

#use delay(clock=4000000)
typedef struct
{                           // This structure is overlayed
   BOOLEAN enable;          // on to an I/O port to gain
   BOOLEAN rs;              // access to the LCD pins.
   BOOLEAN rw;              // The bits are allocated from
   BOOLEAN unused;          // low order up.  ENABLE will
   int     data : 4;        // be LSB pin of that port.
  #if defined(__PCD__)      // The port used will be LCD_DATA_PORT.
   int     reserved: 8;
  #endif
} LCD_PIN_MAP;

#if defined(__PCB__)
const LCD_PIN_MAP LCD_OUTPUT_MAP = {0,  0,    0,    0,       0};
 const LCD_PIN_MAP LCD_INPUT_MAP =   {0,  0,   0,    0,       0xF};
#endif



#ifndef LCD_ENABLE_PIN
   #define lcd_output_enable(x) lcdlat.enable=x
   #define lcd_enable_tris()   lcdtris.enable=0
#else
   #define lcd_output_enable(x) output_bit(LCD_ENABLE_PIN, x)
   #define lcd_enable_tris()  output_drive(LCD_ENABLE_PIN)
#endif

#ifndef LCD_RS_PIN
   #define lcd_output_rs(x) lcdlat.rs=x
   #define lcd_rs_tris()   lcdtris.rs=0
#else
   #define lcd_output_rs(x) output_bit(LCD_RS_PIN, x)
   #define lcd_rs_tris()  output_drive(LCD_RS_PIN)
#endif

#ifndef LCD_RW_PIN
   #define lcd_output_rw(x) lcdlat.rw=x
   #define lcd_rw_tris()   lcdtris.rw=0
#else
   #define lcd_output_rw(x) output_bit(LCD_RW_PIN, x)
   #define lcd_rw_tris()  output_drive(LCD_RW_PIN)
#endif

#ifndef LCD_DATA_PORT
   #if defined(__PCB__)
      #define LCD_DATA_PORT       0x06      //portb
```

```
        #define set_tris_lcd(x)    set_tris_b(x)
    #elif defined(__PCM__)
        #define LCD_DATA_PORT       getenv("SFR:PORTD")     //portd
    #elif defined(__PCH__)
        #define LCD_DATA_PORT       getenv("SFR:PORTD")     //portd
    #elif defined(__PCD__)
        #define LCD_DATA_PORT       getenv("SFR:PORTD")     //portd
    #endif
#endif


#if defined(__PCB__)
    LCD_PIN_MAP lcd, lcdlat;
    #byte lcd = LCD_DATA_PORT
    #byte lcdlat = LCD_DATA_PORT
#elif defined(__PCM__)
    LCD_PIN_MAP lcd, lcdlat, lcdtris;
    #byte lcd = LCD_DATA_PORT
    #byte lcdlat = LCD_DATA_PORT
    #byte lcdtris = LCD_DATA_PORT+0x80
#elif defined(__PCH__)
    LCD_PIN_MAP lcd, lcdlat, lcdtris;
    #byte lcd = LCD_DATA_PORT
    #byte lcdlat = LCD_DATA_PORT+9
    #byte lcdtris = LCD_DATA_PORT+0x12
#elif defined(__PCD__)
    LCD_PIN_MAP lcd, lcdlat, lcdtris;
    #word lcd = LCD_DATA_PORT
    #word lcdlat = LCD_DATA_PORT+2
    #word lcdtris = LCD_DATA_PORT-0x02
#endif


#ifndef LCD_TYPE
    #define LCD_TYPE 2              // 0=5x7, 1=5x10, 2=2 lines
#endif


#ifndef LCD_LINE_TWO
    #define LCD_LINE_TWO 0x40      // LCD RAM address for the second line
#endif


BYTE const LCD_INIT_STRING[4] = {0x20 | (lcd_type << 2), 0xc, 1, 6};


#if (defined(LCD_DATA0) && defined(LCD_DATA1) && defined(LCD_DATA2) && defined(LCD_DATA3)
&& !defined(LCD_DATA4) && !defined(LCD_DATA5) && !defined(LCD_DATA6) &&
!defined(LCD_DATA7))
    #define  LCD_DATA4     LCD_DATA0
    #define  LCD_DATA5     LCD_DATA1
    #define  LCD_DATA6     LCD_DATA2
    #define  LCD_DATA7     LCD_DATA3
#endif


BYTE lcd_read_nibble(void);


BYTE lcd_read_byte(void)
{
    BYTE low,high;

 #if defined(__PCB__)
    set_tris_lcd(LCD_INPUT_MAP);
```

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```
 #else
   #if (defined(LCD_DATA4) && defined(LCD_DATA5) && defined(LCD_DATA6) &&
defined(LCD_DATA7))
    output_float(LCD_DATA4);
    output_float(LCD_DATA5);
    output_float(LCD_DATA6);
    output_float(LCD_DATA7);
   #else
    lcdtris.data = 0xF;
   #endif
 #endif

   lcd_output_rw(1);
   delay_cycles(1);
   lcd_output_enable(1);
   delay_cycles(1);
   high = lcd_read_nibble();

   lcd_output_enable(0);
   delay_cycles(1);
   lcd_output_enable(1);
   delay_us(1);
   low = lcd_read_nibble();

   lcd_output_enable(0);

 #if defined(__PCB__)
   set_tris_lcd(LCD_INPUT_MAP);
 #else
   #if (defined(LCD_DATA4) && defined(LCD_DATA5) && defined(LCD_DATA6) &&
defined(LCD_DATA7))
    output_drive(LCD_DATA4);
    output_drive(LCD_DATA5);
    output_drive(LCD_DATA6);
    output_drive(LCD_DATA7);
   #else
    lcdtris.data = 0x0;
   #endif
 #endif

   return( (high<<4) | low);
}

BYTE lcd_read_nibble(void)
{
  #if (defined(LCD_DATA4) && defined(LCD_DATA5) && defined(LCD_DATA6) &&
defined(LCD_DATA7))
    BYTE n = 0x00;

    /* Read the data port */
    n |= input(LCD_DATA4);
    n |= input(LCD_DATA5) << 1;
    n |= input(LCD_DATA6) << 2;
    n |= input(LCD_DATA7) << 3;

    return(n);
  #else
    return(lcd.data);
  #endif
```

```
}

void lcd_send_nibble(BYTE n)
{
  #if (defined(LCD_DATA4) && defined(LCD_DATA5) && defined(LCD_DATA6) &&
defined(LCD_DATA7))
   /* Write to the data port */
   output_bit(LCD_DATA4, BIT_TEST(n, 0));
   output_bit(LCD_DATA5, BIT_TEST(n, 1));
   output_bit(LCD_DATA6, BIT_TEST(n, 2));
   output_bit(LCD_DATA7, BIT_TEST(n, 3));
  #else
   lcdlat.data = n;
  #endif

   delay_cycles(1);
   lcd_output_enable(1);
   delay_us(2);
   lcd_output_enable(0);
}

void lcd_send_byte(BYTE address, BYTE n)
{
   lcd_output_rs(0);
   while ( bit_test(lcd_read_byte(),7) ) ;
   lcd_output_rs(address);
   delay_cycles(1);
   lcd_output_rw(0);
   delay_cycles(1);
   lcd_output_enable(0);
   lcd_send_nibble(n >> 4);
   lcd_send_nibble(n & 0xf);
}

void lcd_init(void)
{
   BYTE i;

 #if defined(__PCB__)
   set_tris_lcd(LCD_OUTPUT_MAP);
 #else
  #if (defined(LCD_DATA4) && defined(LCD_DATA5) && defined(LCD_DATA6) &&
defined(LCD_DATA7))
   output_drive(LCD_DATA4);
   output_drive(LCD_DATA5);
   output_drive(LCD_DATA6);
   output_drive(LCD_DATA7);
  #else
   lcdtris.data = 0x0;
  #endif
   lcd_enable_tris();
   lcd_rs_tris();
   lcd_rw_tris();
 #endif

   lcd_output_rs(0);
   lcd_output_rw(0);
   lcd_output_enable(0);
```
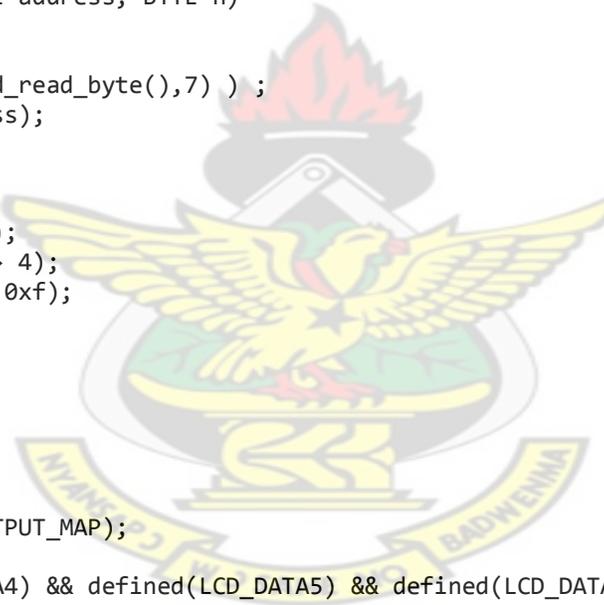
```c
    delay_ms(15);
    for(i=1;i<=3;++i)
    {
        lcd_send_nibble(3);
        delay_ms(5);
    }

    lcd_send_nibble(2);
    for(i=0;i<=3;++i)
        lcd_send_byte(0,LCD_INIT_STRING[i]);
}

void lcd_gotoxy(BYTE x, BYTE y)
{
    BYTE address;

    if(y!=1)
        address=LCD_LINE_TWO;
    else
        address=0;

    address+=x-1;
    lcd_send_byte(0,0x80|address);
}

void lcd_putc(char c)
{
    switch (c)
    {
        case '\f'   :  lcd_send_byte(0,1);
                       delay_ms(2);
                       break;

        case '\n'   : lcd_gotoxy(1,2);          break;

        case '\b'   : lcd_send_byte(0,0x10);  break;

        default     : lcd_send_byte(1,c);     break;
    }
}

char lcd_getc(BYTE x, BYTE y)
{
    char value;

    lcd_gotoxy(x,y);
    while ( bit_test(lcd_read_byte(),7) ); // wait until busy flag is low
    lcd_output_rs(1);
    value = lcd_read_byte();
    lcd_output_rs(0);

    return(value);
}
```
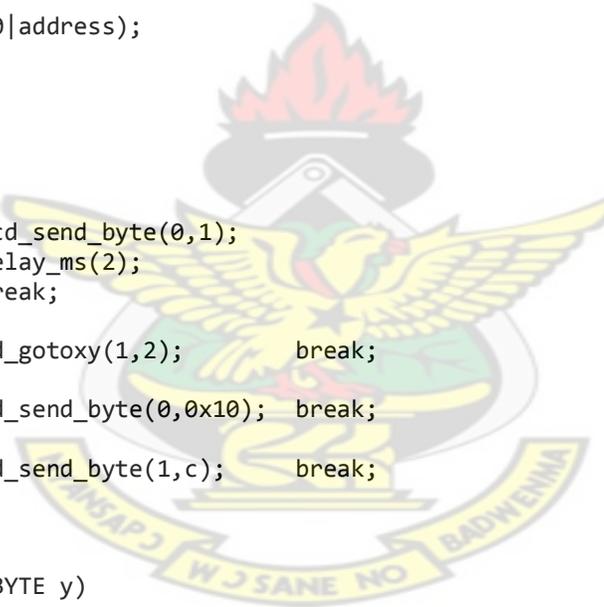
Appendix B: C Code for EEPROM Firmware

```c
#ifndef EEPROM_SDA

#define EEPROM_SDA  PIN_B0
#define EEPROM_SCL  PIN_B1

#endif


#use i2c(master, sda=EEPROM_SDA, scl=EEPROM_SCL,FORCE_HW)

#define EEPROM_ADDRESS BYTE
#define EEPROM_SIZE    1024

void init_ext_eeprom() {
    output_float(EEPROM_SCL);
    output_float(EEPROM_SDA);
}

BOOLEAN ext_eeprom_ready() {
    int1 ack;
    i2c_start();              // If the write command is acknowledged,
    ack = i2c_write(0xa0);  // then the device is ready.
    i2c_stop();
    return !ack;
}

void write_ext_eeprom(BYTE address, BYTE data) {
  // while(!ext_eeprom_ready());
    i2c_start();
    i2c_write(0xa0);
    i2c_write(address);
    i2c_write(data);
    i2c_stop();
}


BYTE read_ext_eeprom(BYTE address) {
    BYTE data;

  // while(!ext_eeprom_ready());
    i2c_start();
    i2c_write(0xa0);
    i2c_write(address);
    i2c_start();
    i2c_write(0xa1);
    data=i2c_read(0);
    i2c_stop();
    return(data);
}
float RD_FLOAT_XEEPROM(int address)
{ float dat ;
int q;
 for(q=0;q<4;q++)
 {
   *(((int*)&dat)+q)=read_ext_eeprom(q+address);
    delay_ms(10);
 }
```

```
   return dat;
}

void WR_FLOAT_XEEPROM(int address,float dat)
{          int p ;
        for(p =0;p<4;p++)
        {
          write_ext_eeprom(p+address,*(((int*)&dat)+p));
          delay_ms(10);

        }
}
```

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Appendix C: Code Snipes for GPRS Request and Initialization

```
///FOR SENDING GPRS REQUEST TO TH SERVER void SEND_REQUEST_GPRS();
void SEND_REQUEST_GPRS()
{
printf("AT+CIPSEND");
putchar(0x0D);
delay_ms(100);
printf("REG$0009129075$");
putchar(0x1A);
delay_ms(100);
putchar(0x0D);
}


//FOR SENDING SYNCH REQUEST void SEND_SYNCH_REQUEST_GPRS()
void SEND_SYNCH_REQUEST_GPRS()
{
if(GET_CONNECT_OK(0X45))
    {
    SEND_REQUEST_GPRS();
    if(GET_SEND_OK(0X0A))
       if(GET_AUT_GPRS(0X0A))
       {
       printf("AT+CIPSEND");
       putchar(0x0D);
       delay_ms(100);
       printf("SYN$");
       putchar(0x1A);
       delay_ms(100);
       putchar(0x0D);
       }

    }
}
```

```
   if(GPRS_INITIALIZE())
{
    if(GPRS_CONNECT_TO_SERVER())
       {
       delay_ms(100);
       SEND_REQUEST_GPRS();
       GET_AUT_GPRS(1);
       printf(lcd_putc,"\f AUTHENTICATED\m ");
       setdate_time(); // for setting GM TIME and DATE from the SERVER
       printf(lcd_putc,"\ NEW TIME");

       SEND_SYNCH_REQUEST_GPRS();
       if(GET_AUT_GPRS(0X45)) printf(lcd_putc,"\n AUTHENTICATED 123\m ");
       else   printf(lcd_putc,"\n NO AUTHENTICATED ");
       delay_ms(1000);
       }
```