DESIGN AND CONSTRUCTION OF A PORTABLE POWER METER

BY

EMENIKE CHRISTIAN CHUKS
2004/21144EE

DEPARTMENT OF ELECTRICAL & COMPUTER ENGINEERING

NOVEMBER, 2008.

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A THESIS SUBMITTED TO THE DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING IN PARTIAL FUFILMENT OF THE AWARD OF BACHELOR OF ENGINEERING (B.ENG) IN ELECTRICAL AND COMPUTER ENGINEERING.

NOVEMBER, 2008.

DEDICATION

This project is dedicated to the Holy Spirit, my helper, strengthener, standby, comforter, my friend and everything who helped me through this journey of academic success.

Also to my parents Mr. and Mrs. Patrick Emenike and to my Brother Mr. Ifeanyi Emenike who contributed immensely to my education.

I LOVE YOU ALL.

ATTESTATION

I, Mr. EMENIKE CHRISTIAN CHUKS declare that this work was done by me and has never been presented elsewhere for the award of a degree. I also hereby relinquish the copyright to the Federal University of Technology, Minna.

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ACKNOWLEDGEMENT

I genuinely express my heart-felt gratitude to God, my parents Mr. and Mrs. Patrick Emenike, my Brothers: Mr. Ifeanyi Emenike and Emmanuel Emenike, my sisters: Miss Nonye Emenike, Miss Ukamaka Emenike, and Miss Ngozi Emenike.

Also to my Pastors: Pastors Chris & Anita Oyakhilome, Pastor Uzoma Nwaigwe, Pastor Harrish Okposio, Pastor Prosper Obioma, Pastor Zunny Abu (PZA), Pastor Tunde Oyinbo for teaching me the word of grace with simplicity.

My sincere appreciation to my humble project supervisor, Engr. Emmanuel Eronu for giving me the necessary guidelines to achieving a presentable thesis, and the advices he gave me on achieving greater successes in life. Sir, thank you very much and God Bless you.

ABSTRACT

The portable power meter is a device used in the measurement of power consumed by a particular electrical appliance. It helps in energy conservation by identifying major energy users or devices that consume excessive standby power. The portable power meter also detects little less energy like the energy of appliances when they are on standby.

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CHAPTER ONE

Introduction

1.1 Background

A portable power meter is a device that measures the amount of electrical energy an appliance is using. It falls under the types of energy meters. Energy meters measure the amount of electrical energy supplied to or produced by a residence, business or machine.

The most common type is more properly known as a kilowatt hour meter or a joule meter. When used in electricity retailing, the utilities record the values measured by these meters to generate an invoice for the electricity. They may also record other variables including the time when the electricity was used.

Electricity has different unit of measurement. The most common unit of measurement of the power meter is kilowatt hour, which is the amount of energy used by the load (appliance) of one kilowatt over a period of one hour. Demand is normally measured in watt, but averaged over a period, most often a quarter or half hour. Reactive power is measured in "volt-amperes reactive "(VARh) in kilovar-hours. A lagging or inductive load, such as motor, will have negative reactive power but a capacitive load "Leading" will have positive reactive power.

Volt –ampere 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. Power factor is the ratio of resistive (real power) to volt-ampere. Ampere-hour meters measures the amount of charge (coulombs) used. Some other meters measures only the length of time for which current flowed, with no measurement of the magnitude of voltage or current being made.

Modern electricity meters operate by continuously measuring the instantaneous voltage and current and finding the product of these to give instantaneous electrical power which is then integrated against time to give the energy used.

The portable energy meter can also be called a plug in electricity meter (plug load meter).

1.2 Objective

The portable power meter helps in energy conservation by identifying major energy users or devices that consume excessive standby power.

It is used to find out just how much energy it takes to run any electrical appliance say a microwave, TV set, laptop, refrigerator, DVD and so on. You can hence figure out what requires the most energy and give it a break.

The portable power meter also detects little less energy like the energy of appliances when they are on standby.

In so doing electrical appliances that increase bills can be checkmated and electrical bills reduced.

1.3 Methodology

The method of implementing the portable power meter involves basic digital techniques.

Power is voltage times current. The current and voltage consumed by a facility are scaled appropriately. A low-resistance shunt is used to measure the current. A 68:1 voltage divider is used to make the peak- to- peak voltage fall within the 5 volt range that the is able to capture and then buffered using an op-amp and then sent to the microcontroller as inputs so that it can perform the calculation and transmit the final value of the computed power on the four digit LED segment display. The scheme is as shown in figure 1.1

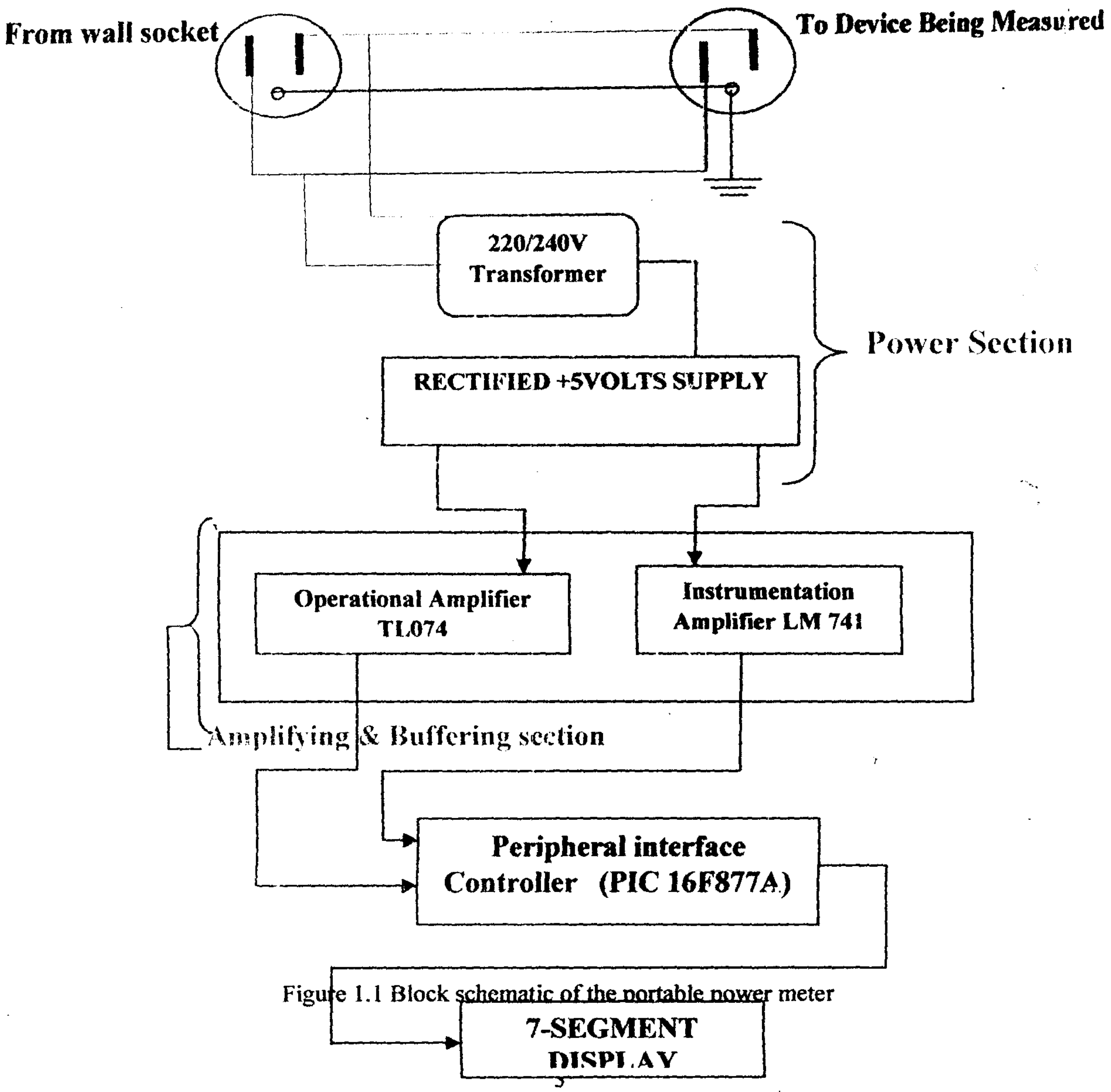

Figure 1.1 Block schematic of the portable power meter

1.4 Source of materials

When building electronic projects, the hardest thing can sometimes be sourcing the parts. This is especially true if one resides in a town with little or no special electronic stores. Sometimes there may be local surplus shops but they might not have what is needed. The components for this project were acquired from different sources. The microprocessor, Vero board, resistors were purchased at Ejosytech Consult Limited while the rest from different shops. The use of data book came into play for alternatives to components which are not readily available. It was on these bases that the materials for this project were sourced.

CHAPTER TWO

Literature Review/Theoretical Background

2.1 Introduction

Modern electricity meters operate by continuously measuring the instantaneous voltage (volts) and current (amperes) and finding the product of these to give instantaneous electrical power (watts) which is then integrated against time to give energy used (joules, kilowatt-hours etc). The meters fall into two basic categories, electromechanical and electronic.

2.1.1 Electromechanical meters

The most common type of electricity meter is the Thomson or electromechanical induction watt-hour meter, invented by Elihu Thomson in 1888.[1][2]

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. The number of revolutions is thus proportional to the energy usage. It consumes a small amount of power, typically around 2 watts.

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. [1]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 - this acts as a brake which causes the disc to stop spinning when power stops being drawn rather than allowing it to spin faster and faster. This causes the disc to rotate at a speed proportional to the power being used.

The type of meter described above is used on a single-phase AC supply. Different phase configurations use additional voltage and current coils.

The aluminium 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. It should be noted that with the dial pointer type, adjacent pointers generally rotate in opposite directions due to the gearing mechanism.

The amount of energy represented by one revolution of the disc is denoted by the symbol *Kh* which is given in units of watt-hours per revolution. The value 7.2 is commonly seen. Using the value of *Kh*, one can determine their power consumption at any given time by timing the disc with a stopwatch. If the time in seconds taken by the disc to complete one revolution is t, then the power in watts is $P = \frac{3600 \cdot Kh}{t}$. For example, if $Kh = 7.2$, as above, and one revolution took place in 14.4 seconds, the power is 1800 watts. This method can be used to determine the power consumption of household devices by switching them on one by one.

revolution took place in 14.4 seconds, the power is 1800 watts. This method can be used to determine the power consumption of household devices by switching them on one by one.

Most domestic electricity meters must be read manually, whether by a representative of the power company or by the customer. Where the customer reads the meter, the reading may be supplied to the power company by telephone, post or over the internet. The electricity company will normally require a visit by a company representative at least annually in order to verify customer-supplied readings and to make a basic safety check of the meter.

In an induction type meter, creep is a phenomenon that can adversely affect accuracy, that occurs when the meter disc rotates continuously with potential applied and the load terminals open circuited. A creep test is when the meter is tested for the error due to creep.

2.1.2 Solid state meters

Some newer electricity meters are solid state and display the power used on an LCD, while newer electronic meters can be read automatically.

In addition to measuring electricity used, solid state meters can also record other parameters of the load and supply such as maximum demand, power factor and reactive power used etc. They can also include electronic clock mechanisms to compute a value, rather than an amount, of electricity consumed, with the pricing varying of by the time of day, day of week, and seasonally.

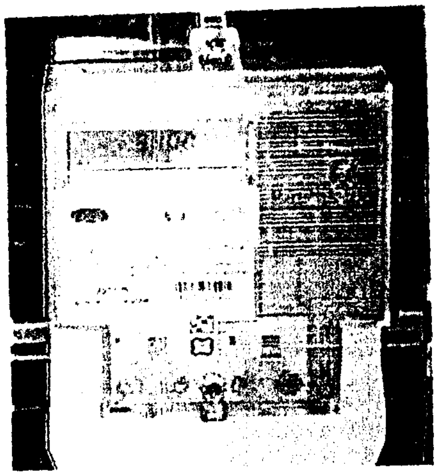

Figure 2.1 Solid state electricity meter used in a home in Holland.

Most solid-state meters use a current transformer to measure the current. This means that the main current-carrying conductors need not 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. It is also possible to use remote current transformers with electromechanical meters though this is less common.

Historically, rotating meters could report their power information remotely, using a pair of contact closures attached to a *KYZ* line. In this scheme, line "K" is attached to two single-pole single-throw switches "Y" and "Z". "Y" and "Z" open and close as the meter's disk rotates. As the meter rotates in one direction, Y closes, then Z closes, then Y opens, then Z opens. When it rotates in the opposite direction, showing export of power, the sequence reverses. KYZ outputs were historically attached to "totalizer relays" feeding a "totalizer" so that many meters could be read all at once in one place.

KYZ outputs are also the normal historical way of attaching electric meters to programmable logic controllers, HVACs or other control systems. Some modern meters also supply interfaces to PLCs, or a contact closure that warns when the meter detects a demand near a higher tariff.

High end electronic meters may now be equipped with a range of communication technologies including Low Power Radio, GSM, GPRS, Bluetooth, IrDA apart from the now conventional RS-232 and RS-485 wired link. They now store the entire usage profiles with time stamps and relay them at a click of a button. The demand readings stored with the profiles accurately indicate the load requirements of the customer. This load profile data is processed at the utilities and renders itself to a variety of representations, all sorts of graphs, reports et el. Remote meter reading is an application of telemetry. Often, meters designed for semi-automated reading have a serial port on that communicates by infrared LED through the faceplate of the meter. In some apartment buildings, a similar protocol is used, but in a wired bus using a serial current loop to connect all the meters to a single plug. The plug is often near the mailboxes.

In the European Union, the most common infrared and protocol is "FLAG", a simplified subset of mode C of IEC 61107. In the U.S. and Canada, the favoured infrared protocol is ANSI C12.18. Some industrial meters use a protocol for programmable logic controllers. The most modern protocol proposed for this purpose is DLM/COSEM which can operate over any medium, including serial ports. The data can be transmitted by Zigbee, WiFi, telephone lines or over the power lines themselves. Some meters can be read over the internet.

Some meters have an open collector S0 output that gives 32-100 ms pulses for an constant amount of used electrical energy. Usually 1000-10000 pulses per kWh. Output is limited to max 27 V DC and 27 mA DC. The output usually follows the DIN 43864 standard. [3] [4]

2.2 Automatic reading

AMR (Automatic Meter Reading) and *RMR* (Remote Meter Reading) describe various systems that allow meters to be checked by without the need to send a meter reader out. This can be effectively achieved using off-site metering, that is an electronic meter is placed at the junction point where all the connections originate, inaccessible to the end-user, and it relays the readings via the AMR technology to the utility.

Design

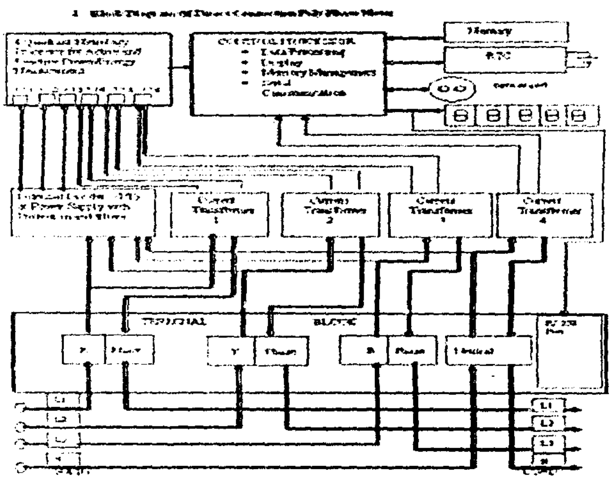

Figure 2.2 Basic Block Diagram of an Electronic Energy Meter

As in the block diagram, the meter has a **power supply**, a **metering engine**, A processing and communication engine i.e a **microcontroller**, other add-on modules such as **RTC, LCD display, communication ports/modules** etc.

2.2.1 Metering engine

The metering engine is given the voltage and current inputs and has a voltage reference, samplers and quantisers followed by an ADC section to yield the digitised equivalents of all the inputs. These inputs are then processed using a **Digital Signal Processor** to calculate the various metering parameters such as powers, energies etc.

The largest source of long-term errors in the meter is drift in the preamp, followed by the precision of the voltage reference. Both of these vary with temperature as well, and vary wildly because most meters are outdoors. Characterizing and compensating for these is a major part of meter design.

2.2.2 Processing and communication section

This section has the responsibility of calculating the various derived quantities from the digital values generated by the metering engine. This also has the responsibility of communication using various protocols and interface with other addon modules connected as slaves to it.

RTC and other add-on modules

These are attached as slaves to the processing and communication section for various input/output functions. On a modern meter most if not all of this will be implemented inside the microprocessor, such as the Real Time Clock (RTC), LCD controller, temperature sensor, memory and analog to digital converters.

2.3 Multiple tariff (variable rate) meters

Electricity retailers may wish to charge customers different tariffs at different times of the day. This is because there is generally a surplus of electrical generation capacity at times of low demand, such as during the night

Some multiple tariff meters use different tariffs for different amounts of demand. These are usually industrial meters.

2.3.1 Domestic Variable-rate meters

Domestic variable-rate meters normally only permit two tariffs ("peak" and "off-peak") and in such installations a simple electromechanical time switch may be used. They are commonly used in conjunction with electrical storage heaters.

Multiple tariffs are made easier by time of use (TOU) meters which incorporate or are connected to a time switch and which have multiple registers.

Switching between the tariffs may happen via a radio-activated switch rather than a time switch to prevent tampering with a sealed time switch to obtain cheaper electricity.

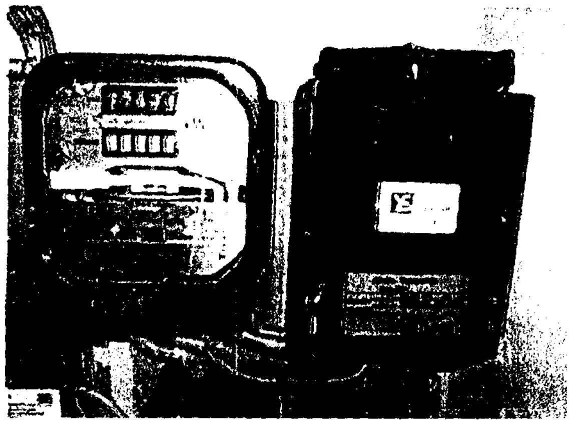

Figure 2.3 Economy 7 Meter and Teleswitcher

Radio-activated switching is common in the UK, with a nightly data signal sent within the longwave carrier of BBC Radio 4, 198 kHz. The time of off-peak usage is between 12.30am - 7.30am, and this is designed to power storage heaters and immersion heaters. In the UK, such tariffs are branded *Economy 7* or *White Meter*. The popularity of such tariffs has declined in recent years, at least in the domestic market, due to the (perceived or real) deficiencies of storage heaters and the low cost of natural gas.

Some meters using *Economy 7* switch the entire electricity supply to the cheaper rate during the 7 hour night time period, not just the storage heater circuit. The downside of this is that the daytime rate will be a touch higher, and standing charges may be a little higher too. For instance, normal rate electricity may be 7p per kWh, whereas *Economy 7*'s daytime rate might be 7.5p per kWh, but only 2.8p per kWh at night. Timer switches installed on washing machines, tumble dryers, dishwashers and immersion heaters may be set so that they switch on only when the rate is lower.

2.3.2 Commercial usage

Large commercial and industrial premises may use electronic meters which record power usage in blocks of half an hour or less. This is because most electricity grids have demand surges throughout the day, and the power company may wish to give incentives to large customers to reduce demand at these times. These demand surges often corresponding to meal times or, famously, to advertisements in popular television programmes.

2.4 Appliance energy meters

Plug in electricity meters (or "Plug load" meters) measure energy used by individual appliances. They can help in energy conservation by identifying major energy users, or devices that consume excessive standby power. Examples of plug in meters include various Kill A Watt and Watts Up[2] Meters.

2.4.1 In-home energy use displays

A potentially powerful means to reduce household energy consumption is to provide real-time feedback to homeowners so they can change their energy using behavior. Recently, low-cost energy feedback displays, such as The Energy Detective, wattson[6], or Cent-a-meter, have become available. A study using the similar PowerCost Monitor[7] deployed in 500 Ontario homes by *Hydro One* showed an average 6.5% drop in total electricity use when compared with a similarly sized control group. *Hydro One* subsequently offered free power monitors to 30,000 customers based on the success of the pilot.[8]

2.4.2 Smart meters

Smart meters go a step further than simple AMR (automated meter reading). They offer additional functionality including a real-time or near real-time reads, power outage notification, and power quality monitoring. They allow price setting agencies to introduce different prices for consumption based on the time of day and the season.

These price differences can be used to reduce peaks in demand (load shifting), reducing the need for additional power plants and in particular the higher polluting and costly to operate natural gas powered peaker plants. The feedback they provide to consumers has also been shown to cut overall energy consumption.

Another type of smart meter uses Nonintrusive load monitoring to automatically determine the number and type of appliances in a residence, how much energy each uses and when. This meter is used by electric utilities to do surveys of energy use. It eliminates the need to put timers on all of the appliances in a house to determine how much energy each uses.

2.5 Prepayment meters

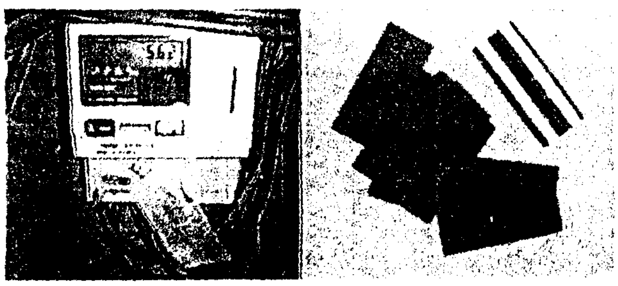

Figure 2.4 Picture of a prepayment meter

Prepayment meter and magnetic stripe tokens, from a rented accommodation in the UK. The button labeled **A** displays information and statistics such as current tariff and remaining credit. The button labeled **B** activates a small amount of emergency credit should the customer run out.

The standard business model of electricity retailing involves the electricity company billing the customer for the amount of energy used in the previous month or quarter. In some countries, if the retailer believes that the customer may not pay the bill, a prepayment meter may be installed. This requires the customer to make advance payment before electricity can be used. If the available credit is exhausted then the supply of electricity is cut off by a relay.

In the UK, mechanical prepayment meters used to be common in rented accommodation. Disadvantages of these included the need for regular visits to remove cash, and risk of theft of the cash in the meter.

Modern solid-state electricity meters, in conjunction with smart card technology, have removed these disadvantages and such meters are commonly used for customers considered to be a poor credit risk. In the UK, one system is the PayPoint network, where rechargeable tokens (Quantum cards for natural gas, or plastic "keys" for electricity) can be loaded with whatever money the customer has available.

Figure 2.5 Picture of a Prepayment key

A similar system, with 2 way communication smart cards, has been used for more than 1 million meters by Elektromed in Turkey.

In South Africa and Northern Ireland prepaid meters are recharged by entering a unique, encoded twenty digit number using a keypad. This makes the tokens, essentially a slip of paper, very cheap to produce.

Around the world, experiments are going on, especially in developing countries, to test pre-payment systems. In some cases, a lack of social acceptance has led to non-implementation of this technology.

There are various groups, such as the Standard Transfer Specification (STS) association, which promote common standards for prepayment metering systems across manufacturers.

2.6 Time of day metering

Time of Day metering (TOD), also known as Time of Usage (TOU) metering involves dividing the day, month and year into tariff slots and with higher rates at peak load periods and low tariff rates at off-peak load periods. While this can be used to automatically control usage on the part of the customer (resulting in automatic load control), it is often simply the customers responsibility to control his own usage, or pay accordingly (voluntary load control). This also allows the utilities to plan their transmission infrastructure appropriately. See also Demand-side Management (DSM).

TOD metering normally splits rates into two segments, peak and off-peak, with peak typically occurring during the day (non-holiday days only), such as from 1 pm to 9 pm

Monday through Friday during the summer and from 6:30 am to 12 noon and 5 pm to 9 pm during the winter.

Large commercial users can purchase power by the hour using either forecast pricing or real time pricing. Prices range from we pay you to take it (negative) to $1000/MWh (100 cents/KWh) .[5]

Some utilities allow residential customers to pay hourly rates, such as Illinois in USA, which uses day ahead pricing.[6][7]

2.7 Power export metering

Many electricity customers are installing their own electricity generating equipment, whether for reasons of economy, redundancy or environmental reasons. When a customer is generating more electricity than required for his own use, the surplus may be exported back to the power grid. Customers that generate back into the "grid" usually must have special equipment and/or safety devices to protect the grid components (as well as the customer's own) in case of faults (electrical short circuits) or maintenance of the grid (say voltage potential on a downed line going into an exporting customers facility).

This exported energy may be accounted for in the simplest case by the meter running backwards during periods of net export, thus reducing the customer's recorded energy usage by the amount exported. This in effect results in the customer being paid for his/her's exports at the full retail price of electricity. Unless equipped with a detent or equivalent, a standard meter will accurately record power flow in each direction by simply running backwards when power is exported. Such meters are no longer legal in the UK but instead a meter capable of separately measuring imported and exported energy is required. Suppliers offer different rates for imported and exported electricity while meters that go backwards provides a different area of risk for the industry.

Lately, upload sources typically originate from renewable sources (e.g., wind turbines, photovoltaic cells), or gas or steam turbines, which are often found in cogeneration systems. Another potential upload source that has been proposed is plug-in hybrid car batteries (vehicle-to-grid power systems). This requires a "smart grid," which includes meters that measure electricity via communication networks that require remote control and give customers timing and pricing options. Vehicle-to-grid systems could be installed at workplace parking lots and garages and at park and rides and could help drivers charge their batteries at home at night when off-peak power prices are cheaper, and receive bill crediting for selling excess electricity back to the grid during high-demand hours.

2.7.1 Ownership

Due to the deregulation of electricity supply markets in many countries, the company responsible for an electricity meter may not be obvious. Depending on the arrangements in place, the meter may be the property of the electricity distributor, the retailer or for some large users of electricity the meter may belong to the customer.

The company responsible for reading the meter may not always be the company which owns it. Meter reading is now sometimes subcontracted and in some areas the same person may read gas, water and electricity meters at the same time.

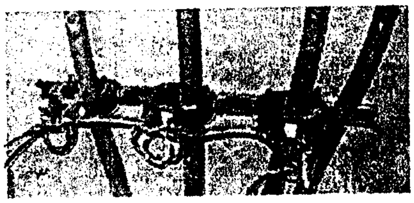

Figure 2.6 Current transformers used as part of metering equipment for three-phase 400 A electricity supply.

Current transformers used as part of metering equipment for three-phase 400 A electricity supply. The fourth neutral wire does not require a current transformer because current cannot flow in this wire without also flowing in one of the three phase wires.

Commercial power meter

The location of an electricity meter varies with each installation. Possible locations include on a power pylon serving the property, in a street-side cabinet or inside the premises adjacent to the consumer unit / distribution board. Electricity companies may prefer external locations as the meter can be read without gaining access to the premises but external meters may be more prone to vandalism.

Current transformers permit the meter to be located remotely from the current-carrying conductors. This is common in large installations. For example a substation serving a single large customer may have metering equipment installed in a cabinet, without bringing heavy cables into the cabinet.

2.7.2 Connection

In North America, it is common for smaller electricity meters to plug into a standardised socket. This allows the meter to be replaced without disturbing the wires to the socket. Some sockets may have a bypass while the meter is removed for service. The amount of electricity used without being recorded during this small time is considered insignificant when compared to the inconvenience which might be caused to the customer by cutting off the electricity supply.

In the UK, the supply and load terminals are normally provided in the meter housing itself, at least for smaller meters (up to around 100 A).

2.8 Tampering and security

Meters can be manipulated so as to make them under-register, effectively allowing power use without paying for it.

The enforcement actions enabled by modern anti-tampering meters are inexpensive compared to the revenue losses and public inconveniences they prevent. Power companies may install remote-reporting meters specifically to enable remote detection of tampering, and specifically to discover theft of energy.

When tampering is detected, the normal tactic, legal in most areas, is to switch the subscriber to a "tampering" tariff charged at the meter's maximum designed current. At US$ 0.095/KWh, a standard residential 50 A meter causes a legally collectible charge of about US$ 5,000.00 per month. Meter readers are trained to spot signs of tampering, and with crude mechanical meters, the maximum rate may be charged each billing period until the tamper is removed, or the service is disconnected.

A common method of tampering is to attach magnets to the outside of the meter. These act in addition to the braking magnets already installed in the meter, causing the meter to under-register. Rectified DC loads will not cause the meter to under-register the amount of power used to a significant degree, nor will a combination of capacitive and inductive load. An electricity meter registers real power (watts), not apparent power (VA); changing the reactive load has no effect on the meter. Similarly, a meter will not run backwards unless you are generating power and feeding it back on the grid from your house (and if detent equipped, will not run backward even then). This is called "net metering", and is commonly used where homeowners have photovoltaic or wind energy systems installed.

The owner of the meter normally secures the meter against tampering. Revenue meters mechanism and connections are sealed. Meters may also measure VAR-hours (the reflected load), neutral and DC currents (elevated by most electrical tampering), ambient magnetic fields, etc. Even simple mechanical meters can have mechanical flags that are dropped by magnetic tampering or large DC currents.

Newer computerized meters usually have counter-measures against tampering. AMR (Automated Meter Reading) meters often have sensors that can report opening of the meter cover, magnetic anomalies, extra clock setting, glued buttons, reversed or switched phases etc. These features are normally present in computerized meters.

Some fraud perpetrators bypass the meter, wholly or in part. This normally causes an increase in neutral current at the meter, which is detected and billed at normal rates by standard tamper-resistant meters. However, most residential meters in use in the United States are single-phase 240 volt meters that are coupled only to the energized lines with the neutral bypassing the meter entirely. This common setup is unable to detect neutral currents.

Even if the meter's neutral connector is completely disconnected, and the building's neutral is grounded to the phantom loop, causing an unsafe house or building, metering at the substation can alert the operator to tampering. Substations, interties and transformers normally have a high-accuracy meter for the area served. Power companies normally investigate discrepancies between the total billed and the total generated, in order to find and fix power distribution problems. These investigations are an effective method of discovering tampering.

CHAPTER THREE

Design And Implementation

3.1 COMPONENTS OVERVIEW

This project is built on a minimal number of components. These are:

1. A 5volts power supply
2. 2 Ceramic Capacitors of 0.1uF each
3. One Instrumentation amplifier (LM 741)
4. One Microchip PIC (PIC 16F877A)
5. One 4-channel general purpose Op-amp (TL 074)
6. One potentiometer of value 10k
7. Two ¼ -watts 1% resistors of value 1.5k each
8. Two ¼-watt 1% resistors of value 1k each
9. One ¼-watt 1% resistor of value 10k
10. One ¼-watt 1% resistor of value 2.2k
11. Four ¼-watt 5% resistors of values 470R
12. One ¼-watt 1% resistor of value 500k
13. One ¼-watt 1% resistor of value 680k
14. One low-resistance shunt (~ 8 inches of 18ga wire) of value approximately 0.01R
15. One segmented LED display (SunLED DMR14A4-A)

3.1.1 PIC 16F877A

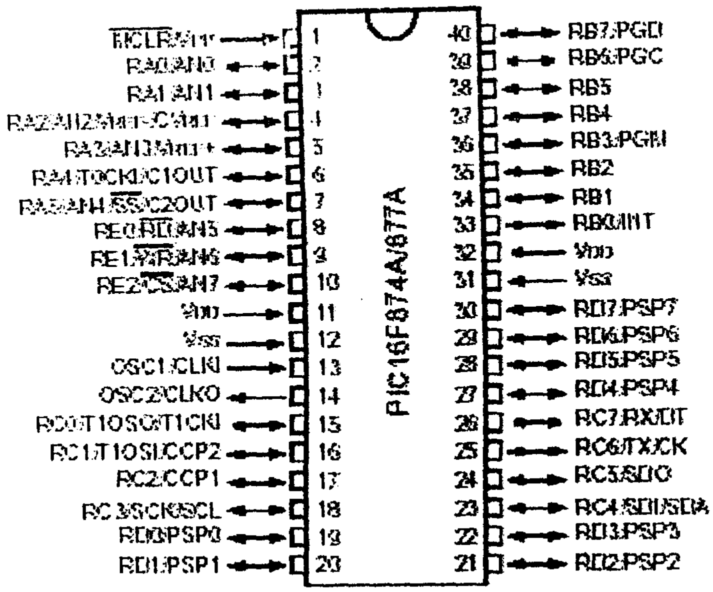

Figure 3.1 Microchip PIC16F877A Microcontroller

PIC. PIC16F877A consists of all of the following I/O :

1. SPI (Serial Peripheral Interface) uses 3 wires (data in, data out, clock).

2. I2C uses 2 wires (data and clock), Master/Slave. There are lots of cheap I2C chips available.

3. UART (Universal Asynchronous Receiver/Transmitter) with baud rates of 300bps to 115kbps, 8 or 9 bits, parity, start and stop bits. Outputs 5V hence an RS232 level converter (e.g. MAX232) is required.

4. Timers, both 8 and 16 bits.

5. TRIS sets whether each pin is an input or an output.

6. ADCs (Analogue to Digital Converter) pin are used to detect analogue signal such as voice, voltage, temperature and so on. Sampling process is carried out to convert analogue signal to digital data.

3.1.2 Instrumentation amplifier

An instrumentation (or instrumentational) amplifier is a type of differential amplifier that has been outfitted with input buffers, which eliminate the need for input impedance matching and thus make the amplifier particularly suitable for use in measurement and test equipment. Additional characteristics include very low DC offset, low drift, low noise, very high open-loop gain, very high common-mode rejection ratio, and very high input impedances. Instrumentation amplifiers are used where great accuracy and stability of the circuit both short- and long-term are required.

Instrumentation amplifiers can be built with individual op-amps and precision resistors, but are also available in integrated circuit form from several manufacturers (including Texas Instruments, Analog Devices, Linear Technology and Maxim Integrated Products). An IC instrumentation amplifier typically contains closely matched laser-trimmed resistors, and therefore offers excellent common-mode rejection.

The most commonly used instrumentation amplifier circuit is shown in the figure. The gain of the circuit is. The ideal common-mode gain of an instrumentation amplifier is zero

$$\frac{V_{out}}{V_2 - V_1} = \left(1 + \frac{2R_1}{R_{gain}}\right)\frac{R_3}{R_2}$$

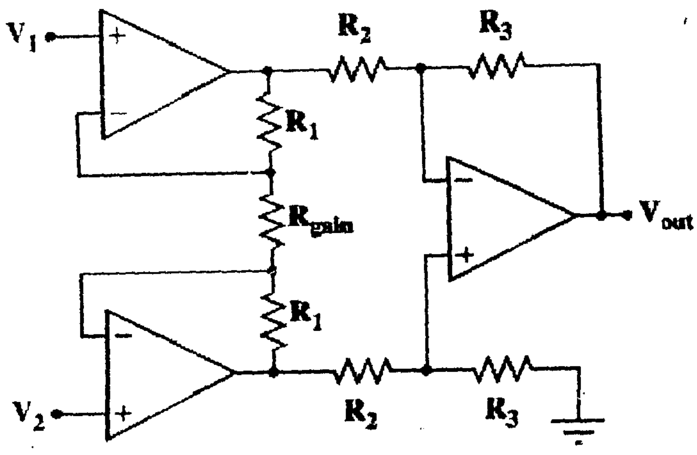

Figure 3.2 Typical instrumentation amplifier schematic

3.1.3 Operational amplifier

An operational amplifier, often called an op-amp , is a DC-coupled high-gain electronic voltage amplifier with differential inputs and, usually, a single output. Typically the output of the op-amp is controlled either by negative feedback, which largely determines the magnitude of its output voltage gain, or by positive feedback, which facilitates regenerative gain and oscillation. High input impedance at the input terminals and low output impedance are important typical characteristics.

The op-amp is one type of differential amplifier. Other types of differential amplifier include the fully differential amplifier (similar to the op-amp, but with 2 outputs), the instrumentation amplifier (usually built from 3 op-amps), the isolation amplifier (similar to the instrumentation amplifier, but which works fine with common-mode voltages that would destroy an ordinary op-amp), and negative feedback amplifier (usually built from 1 or more op-amps and a resistive feedback network).

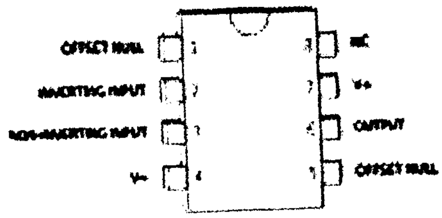

Figure 3.3 LM741 pin assignment (Dual in-line package).

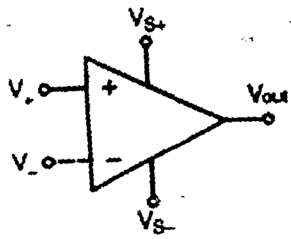

Figure 3.4 Circuit diagram symbol for an op-amp

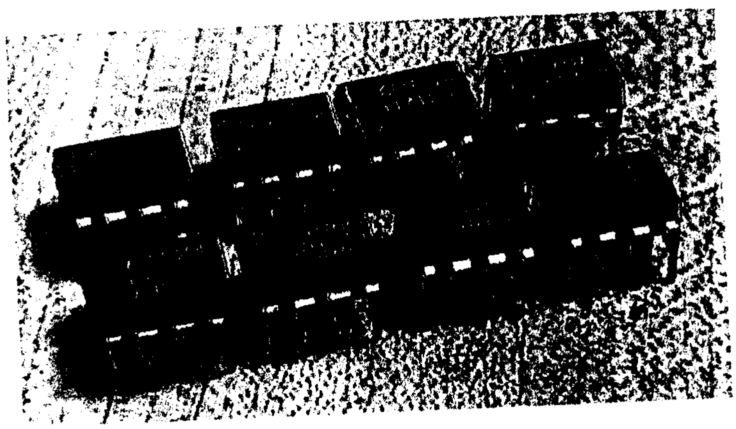

Figure 3.5 Op-amp ICs (some single, some dual) in 8-pin dual in-line packages ("DIPs")

3.1.4 Potentiometer

A potentiometer is a three-terminal resistor with a sliding contact that forms an adjustable voltage divider.[1] If only two terminals are used (one side and the wiper), it acts as a variable resistor or Rheostat. Potentiometers are commonly used to control electrical devices such as a volume control of a radio. Potentiometers operated by a mechanism can be used as position transducers, for example, in a joystick.

Potentiometers are rarely used to directly control significant power (more than a watt). Instead they are used to adjust the level of analog signals (e.g. volume controls on audio equipment), and as control inputs for electronic circuits. For example, a light dimmer uses a potentiometer to control the switching of a triac and so indirectly control the brightness of lamps

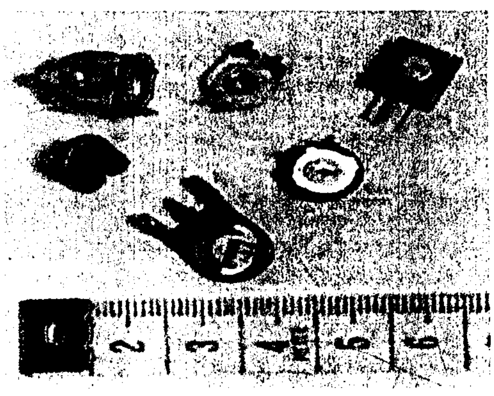

Figure 3.6 PCB mount trimmer potentiometers, or "trimpots", intended for infrequent adjustment.

3.1.5 Resistor

A resistor is a two-terminal electronic component designed to oppose an electric current by producing a voltage drop between its terminals in proportion to the current, that is, in accordance with Ohm's law: $V = IR$. The *resistance R* is equal to the voltage drop V across the resistor divided by the current I through the resistor.

Resistors are characterized primarily by their resistance and the power they can dissipate. Other characteristics include temperature coefficient, noise, and inductance. Practical resistors can be made of resistive wire, and various compounds and films, and they can be integrated into hybrid and printed circuits. Size, and position of leads are relevant to equipment designers; resistors must be physically large enough not to overheat when dissipating their power. Variable resistors, adjustable by changing the position of a tapping on the resistive element, and resistors with a movable tap ("potentiometers"), either adjustable by the user of equipment or contained within, are also used.

Potentiometer

Resistor

Variable Resistor

Figure 3.7 Resistor symbols (American)

3.1.6 Ceramic capacitor

A ceramic capacitor is a capacitor constructed of alternating layers of metal and ceramic, with the ceramic material acting as the dielectric. Depending on the dielectric, whether Class 1 or Class 2, the degree of temperature/capacity dependence varies. A ceramic capacitor often has (especially the class 2) high dissipation factor, high frequency coefficient of dissipation. Ceramic capacitors come in various shapes and styles, including:

- disc, resin coated, with through-hole leads
- multilayer rectangular block, surface mount
- bare leadless disc, sits in a slot in the PCB and is soldered in place, used for UHF work
- tube shape, not popular now

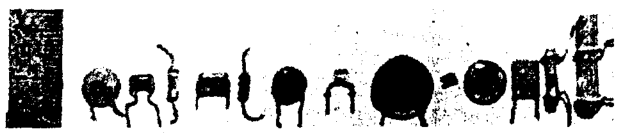

Figure 3.8 Ceramic capacitors

3.1.7 seven-segment display

A seven-segment display (abbreviation: "7-seg(ment) display"), less commonly known as a seven-segment indicator, is a form of electronic display device for displaying decimal numerals that is an alternative to the more complex dot-matrix displays. Seven-segment displays are widely used in digital clocks, electronic meters, and other electronic devices for displaying numerical information.

A seven segment display, as its name indicates, is composed of seven elements. Individually on or off, they can be combined to produce simplified representations of the Hindu-Arabic numerals. Often the seven segments are arranged in an *oblique*, or *italic*, arrangement, which aids readability.

Each of the numbers 0, 6, 7 and 9 may be represented by two or more different glyphs on seven-segment displays.

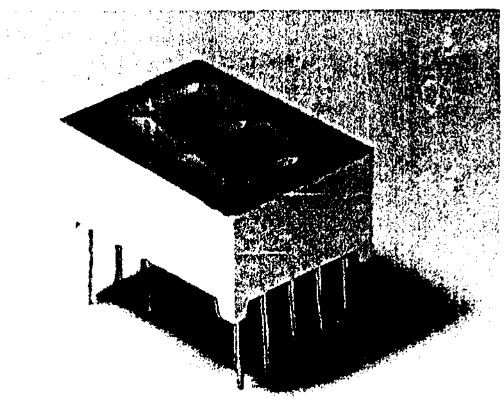

Figure 3.9 Typical 7-segment LED display component, with decimal point.

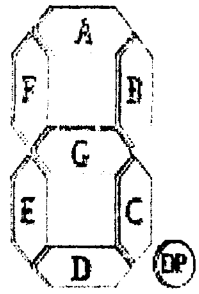

Figure 3.10 The individual segments of a - Seven- segment display

3.2 Functional Unit

3.2.1 Power supply unit

Knowing fully well the relevance of a power supply in virtually all circuits, it is with this motion that a well regulated power supply was built. One of the most important applications of diodes is the design of rectifier circuits. A diode rectifier forms an essential building blocks of the dc power supply required to power electronic equipment. A block diagram is shown below. The first block in a dc power supply is the power transformer. It consists of two separate coils wound around an iron core that magnetically couples the two winding. The primary winding having N1 turns is connected to the 220v ac supply and the secondary winding having N2 turns is connected to the circuit of the dc power supply. Thus an AC voltage of 120(N2/N1)V (rms) develops between the two terminals of the secondary winding. By selecting particular is an appropriate turns ratio (N1/N2) for the transformer, the designer can step the line voltage down to the value required to yield the particular dc voltage output of the supply. For instance, a secondary voltage of 8-Vrms may be appropriate for a dc output of 5V. This can be achieved with a 15:1 turns ratio.

In addition to providing the appropriate sinusoidal amplitude for the dc power supply, the power transformer provides electrical isolation between the electronic equipment and the power-line circuit. This isolation minimizes the risk of electrical isolation minimizes the risk of electric shock to the equipment user. The diode rectifier converts the input sinusoid vs to a unipolar output, which can have the pulsating waveform. Although this waveform has a nonzero average or a DC component, its pulsating nature makes it unsuitable as a dc source for electronic circuits, hence the need for a filter. The variations in the magnitude of the rectifier output are considerably reduced by the filter block.

The output of the rectifier filter, though much more constants than without the filter, still contains a time dependent component, known as ripple. To reduce the ripple and to stabilise the magnitude of the dc output voltage of the supply against variations caused by changes in load current, a voltage regulator is employed. Such a regulator can be implemented using the Zener shunt regulator configuration.

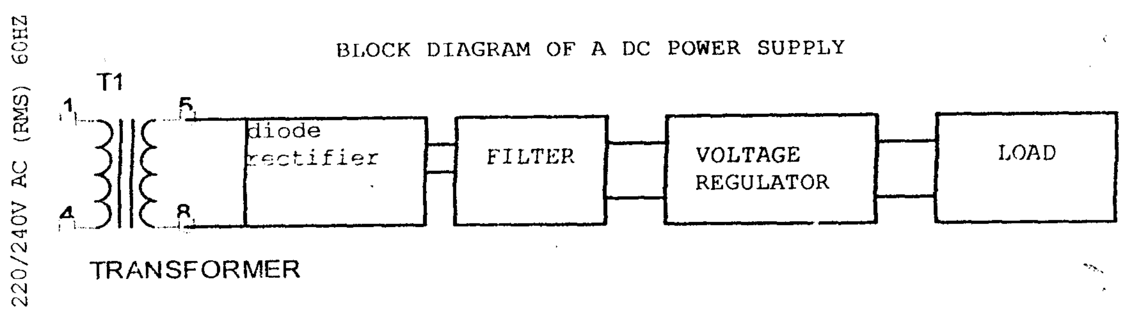

Figure 3.11 block diagram of a DC power supply

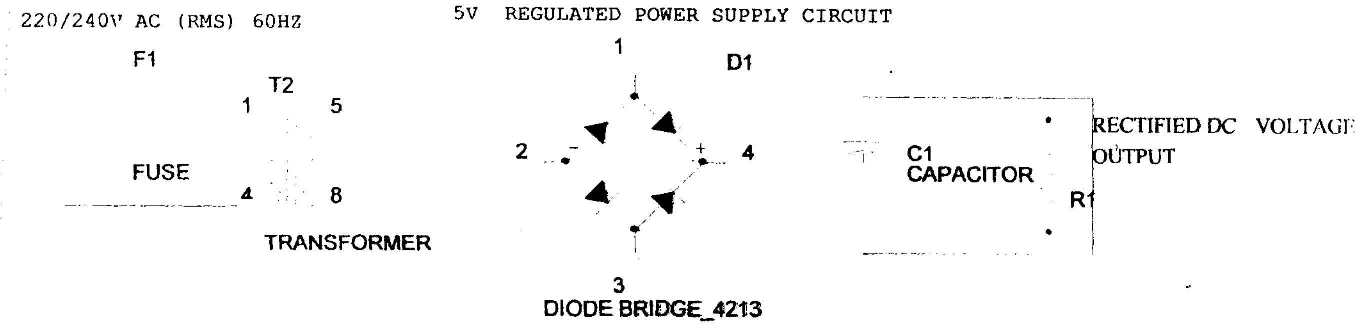

Figure 3.12 block diagram of a 5 volts regulated power supply circuit

3.2.2 Current Sensing

The portable power meters uses a very low-resistance shunt to measure the current. Ohm's law states that the voltage across a resistor is proportional to the current running through it. We can exploit this to create a very cheap and effective current-to-voltage converter. The shunt resistor, R7, that I used is a length of about 8 inches of 18-gauge wire. This is actually about the size of the wire in some extension cords, so the voltage drop across it is quite small, so this "resistor" gives off virtually no heat. To amplify the voltage, I used a high-precision instrumentation amplifier (IC3), the LM 741. This mighty chip can amplify many thousands of times with almost no distortion or noise.,

3.2.3 Voltage Detection

The voltage is much more straightforward to get into a useable form. A 68:1 voltage divider (R5 and R6) is used to make the peak-to-peak voltage fall within the 5-volt range that the PIC is able to capture. This voltage is then buffered using one channel of our op-amp (IC1-d) before being sent to the PIC. The portable power meter can be modified to work with 240-volt AC simply by changing R6 to 1.5Mohm.

3.2.4 Voltage References

R1, R2, R3, and R4 form a voltage divider with outputs at a nominal 1.5, 2.5, and 3.5 volts DC. These voltages are buffered with the remaining three channels of the opamp, IC1-a through IC1-c. These form reference voltage outputs Vref+ (3.5v), Vref0 (2.5v), and Vref- (1.5v). I know the naming is a little confusing. Note that these voltages are nominal, the exact values aren't critical because the PIC has calibration factors that can correct for imprecision.

Vref+ and Vref- are only used by the PIC as the high and low voltage references for the A/D converter. In other words, a signal at 1.5v or less will be converted to 0x000 by the ADC and a signal at 3.5v or above maps to the maximum value, 0xFFF. This has to be done because the instrumentation amplifier can't output a voltage within about 1.5 volts of its supply rails.

Vref0 is connected to the neutral AC line. This means that the 0VDC power supply rail is about 2.5 volts *below* neutral and the +5V rail is about 2.5 volts *above* neutral.

3.2.5 Circuit Operation

The analog circuit measures the voltage and current traveling through the mains. These are converted from large voltages (120VAC) and currents (0-20 A) to small voltages that can be read by the microcontroller and then displayed on the LED display.

The analog circuit connects with the digital circuit through 5 signals:

center voltage reference

about 2.5 volts. The center tap voltage for the AC signals voltage and current

voltage

an AC signal between vref- and vref+. Proportional to the voltage on the mains line that we are measuring.

current

an AC signal between vref- and vref+. Proportional to the current on the mains line that we are measuring.

vref- and **vref+**

voltage range that the voltage and current will always be within.

All of the signals are connected to the PIC's **analog to digital converters**. vref- and vref+ are used by the converters as the minimum and maximum range for the other 3 signals. These sample the voltage of each signal at around 2khz with a resolution of 10 bits (possible values are 0-1023). These samples are then used to compute the power consumed and the output is displayed on the LED display.

3.2.6 Mathematics

Power is computed by multiplying the voltage and current and then averaging these values. This calculates the real power.

First, the voltage reference is subtracted from the samples read from voltage and current. This is because they are sine waves whose center is at voltage reference. These centered values are multiplied together and then added to a total for calculating an average. The values are sampled or measured about 1000 times per second. Each reading is currently 256 samples long. The averages are then fed through a 5 value running average to provide a more stable reading. This running average is the value displayed.

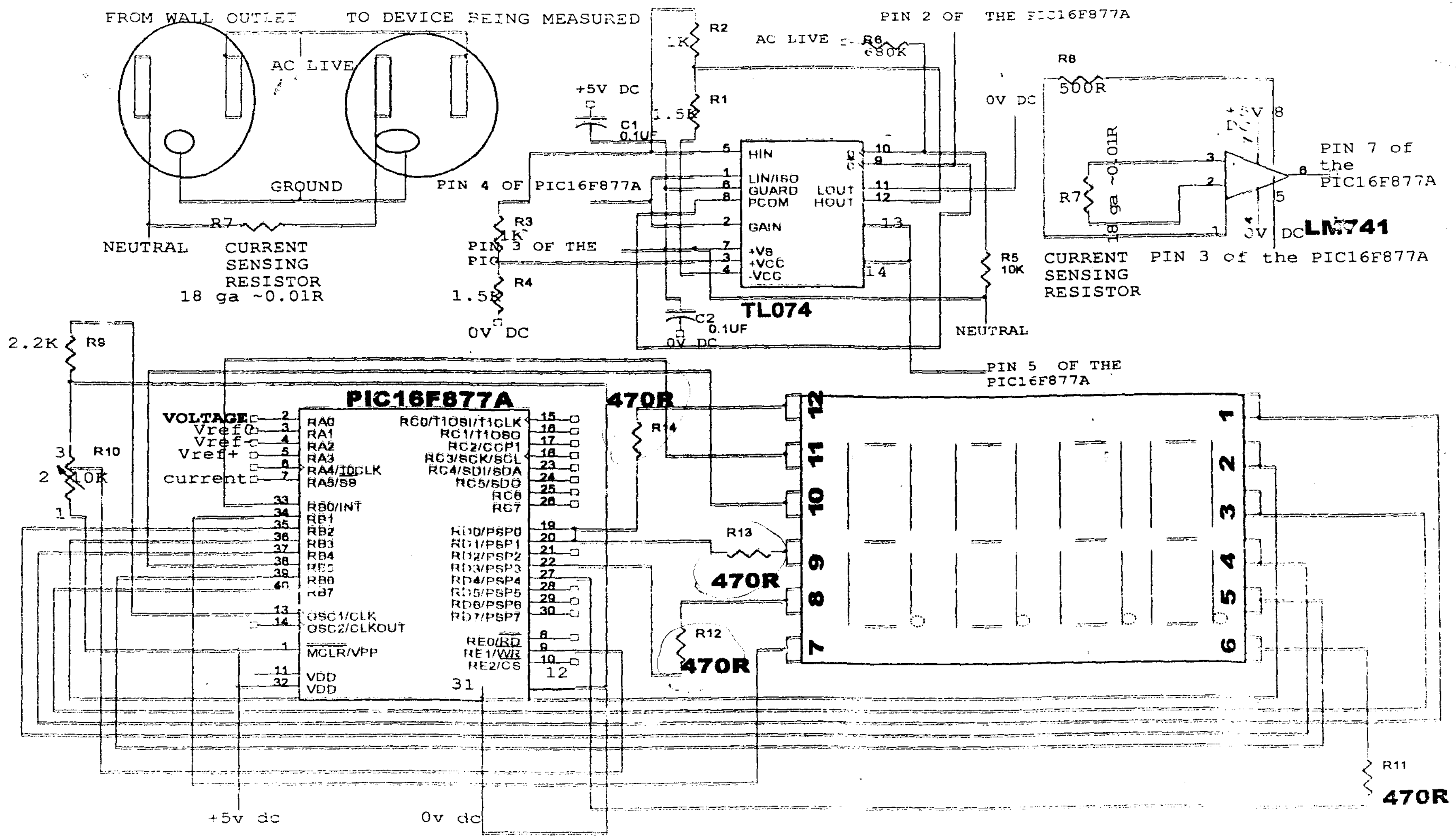

Figure 3.13 Circuit diagram of the portable power meter

CHAPTER FOUR

TESTS, RESULTS AND DISCUSSION

4.1 TESTS

After construction, tests were carried out at various points and joints of the circuit to ensure the gadget operates as designed. The main tests that were carried out are as follows:

- The power supply was properly tested to ensure that it produced the correct voltage output, as power supply is a crucial component for the proper operation and functionality of the system.
- The entire board was examined to ensure that no short circuiting on any of the joints and tracks of the board.
- The A/D converter was examined to make sure the frequency of operation does not exceed the maximum sampling frequency of the microcontroller, so as to conform to the Nyquist criterion of sampling.
- A laptop was connected with the device so as to try and measure the power consumed by it.

4.2 RESULTS / DISCUSSION

The results obtained during prototyping and testing were satisfactory. In the final testing of the portable power meter device, some test loads were used such as a laptop, DVD machine, TV set so as to ascertain the power consumed by them over a period of at least 30 minutes.

The results were good without much deviation from the normally expected results. The project was hence a success.

4.3 CONSTRAINTS

There was a little challenge in some components sourcing towards this project realization because of the scarcity. As regards the soldering of the work that was no problem, since I had knowledge of soldering prior to embarking on this project.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

The design and construction of a portable energy meter was the aim of this project. The principle aim of the project earlier stated has been actualized. The device computes satisfactory the amount of electrical power flowing through a particular electrical appliance.

The project has brought a simple technique of building a cheap, reliable and flexible means of metering or measuring electrical power, thus a considerable success.

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-
- Handbook for Electricity Metering from EEI
- How to use your meter to calculate money saved by replacing old appliances

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APPENDIX

```
/* ----------------------------------------------------------------------------------------- */
/* Template source file generated by piklab */
#include <pic16f877a.h>

/* ----------------------------------------------------------------------------------------- */
/* Configuration bits: adapt to your setup and needs */
typedef unsigned int word;
word at 0x2007 CONFIG = _RC_OSC & _WDT_OFF & _PWRTE_ON & _BODEN_OFF &
_LVP_OFF & _CPD_OFF & _WRT_OFF & _DEBUG_OFF & _CP_OFF;

// how do you officially define binary data in sdcc?
// this should work in any compiler
#define BIN(x) \
( ((0x##x##L & 0x00000001L) ? 0x01 : 0) \
| ((0x##x##L & 0x00000010L) ? 0x02 : 0) \
| ((0x##x##L & 0x00000100L) ? 0x04 : 0) \
| ((0x##x##L & 0x00001000L) ? 0x08 : 0) \
| ((0x##x##L & 0x00010000L) ? 0x10 : 0) \
| ((0x##x##L & 0x00100000L) ? 0x20 : 0) \
| ((0x##x##L & 0x01000000L) ? 0x40 : 0) \
| ((0x##x##L & 0x10000000L) ? 0x80 : 0))

#define set_bit(REGISTER, BIT) REGISTER |= (1 << BIT)

void disp_set_num(unsigned long val);
void disp_set_num_raw(int val);
void disp_set_decimal_places(unsigned char decimals);
void disp_kilo();
void disp_dig(unsigned char d);
void disp_disp();

// holds the magic numbers required to spell out each digit
// on the LED display.
char sseg[10] = {
//          .gfedcba
        BIN(00111111),      // 0
        BIN(00000110),      // 1
        BIN(01011011),      // 2
        BIN(01001111),      // 3
        BIN(01100110),      // 4
        BIN(01101101),      // 5
        BIN(01111101),      // 6
        BIN(00000111),      // 7
        BIN(01111111),      // 8
        BIN(01101111)       // 9
};

// I haven't tried changing this yet.
#define DISP_SIZE (4)

// set these to calibrate the final output power reading
```

```
// CALIBRATION_OFFSET will be added to the final after dividing the
// unscaled raw value by 1000 and then multiplying by
// CALIBRATION_SCALE. This is to allow some fractional constants
// without going back and forth between floating point and int
// types. This will work as long as the power doesn't exceed
// 2^32/1000000 = 4294 watts. Otherwise change it to a scale of
// 100 or the way this is done.
#define CALIBRATION_OFFSET ( -35 )
// #define CALIBRATION_SCALE ( 0.598476f )
// #define CALIBRATION_SCALE ( 598 )
#define CALIBRATION_SCALE ( 1671 )

unsigned char dispsize = 0;
unsigned char dispdig[5];
unsigned char dot_after = 0;
unsigned char kilo = 0;

unsigned int reference = 1;
unsigned int current = 2;
unsigned int current_diff = 12;
unsigned long current_max = 0;
unsigned int voltage = 4;
unsigned int voltage_diff = 13;
unsigned long voltage_max = 0;

// each of these correspond to one of the modes the mode knob
// could be in. If mode1 is selected, the value in mode1 is
// displayed on the LED display.
unsigned long mode1 = 1;
unsigned long mode2 = 2;
unsigned long mode3 = 3;
unsigned long mode4 = 4;
unsigned long mode5 = 5;
unsigned long mode6 = 6;
unsigned long mode7 = 7;
unsigned long mode8 = 8;

// data to keep moving averages of watts. Input values are the
// result data from an analyze call
#define MOVING_AVG_SIZE (5)
unsigned long moving_avg[MOVING_AVG_SIZE];
unsigned long moving_avg_total = 0;
unsigned char moving_avg_i = 0;

// totals used to sum per sample values
unsigned long total1 = 0;
unsigned long total_cnt = 0;

// the primary display function. sets the number to display
// use disp_disp() to actually light up the display
// displays val / 1000, or thousandths.
// displayed number can be in the range of [0.001, 99999999.9999]
// WARNING: doesn't obey DISP_SIZE
void disp_set_num(unsigned long val)
{
```

```
		if(val < 10000L) {
			disp_set_num_raw(val);
			disp_set_decimal_places(3);
			kilo = 0;
		} else if(val < 100000L) {
			disp_set_num_raw(val/10L);
			disp_set_decimal_places(2);
			kilo = 0;
		} else if(val < 1000000L) {
			disp_set_num_raw(val/100L);
			disp_set_decimal_places(1);
			kilo = 0;
		} else if(val < 10000000L) {
			disp_set_num_raw(val/1000L);
			disp_set_decimal_places(0);
			kilo = 0;
		} else if(val < 100000000L) {
			disp_set_num_raw(val/10000L);
			disp_set_decimal_places(2);
			kilo = 1;
		} else if(val < 1000000000L) {
			disp_set_num_raw(val/100000L);
			disp_set_decimal_places(1);
			kilo = 1;
		} else if(val < 0xFFFFFFFF) {
			disp_set_num_raw(val/1000000L);
			disp_set_decimal_places(0);
			kilo = 1;
		}
}

// dispalys the int val. No scaling is performed.
void disp_set_num_raw(int val)
{
	char i = DISP_SIZE;

	while(val != 0)
	{
		dispdig[i--] = val % 10;
		val = val / 10;
	}
	while(i != 0)
	{
		dispdig[i--] = 0;
	}

	dispsize = i;
}

// set the number of decimal places visible.
// decimals can be in the range of [0, DISP_SIZE]
void disp_set_decimal_places(unsigned char decimals) {
		dot_after = DISP_SIZE - decimals;
}
```

```
// update the kilo LED
// TODO: use defines or constants to set which PORT/pin is used
void disp_kilo() {
	if(kilo) {
		PORTC = 0x01;
	} else {
		PORTC = 0x00;
	}
}

// display a single digit
//  valid digits are from [1, DISP_SIZE+1]
//  use this if you would like to display numbers while doing other
//  computations.
// dig_pins sets the pins used to select each digit.  See LED display in docs
unsigned char dig_pins[4] = {0x01, 0x02, 0x08, 0x10};
void disp_dig(unsigned char d) {
	unsigned int i;
	PORTB = 0xFF;
	i = d - 1;
	PORTD = dig_pins[i];
	PORTB = ~sseg[dispdig[d]];
	if(d == dot_after) {
		PORTB &= 0x7F;
	}
}

// display the entire number.
// TODO: allow an optional delay to be inserted between each digit to decrease
// the PWM frequency.
void disp_disp() {
	// d = dispsize;
	unsigned char d = 0;
	unsigned int i = 0;

	disp_kilo();

	for(i = 1; i <= DISP_SIZE; ++i) {
		disp_dig(i);
	}
}

/////////////////////////////////////////////////////////////////////////
//
//  ADC
//
/////////////////////////////////////////////////////////////////////////

// wait for a conversion to complete
void adc_wait(){
	while(ADCON0 & 0x04) { }
}

// count to n
void delay(unsigned int n) {
```

```
	unsigned int i;
	for(i = 0; i < n; ++i) {}
}

// turn on the adc module
void adc_on() {
	_asm
	BSF ADCON0, 0;
	_endasm;
}

// turn off the adc module
void adc_off() {
	_asm
	BCF ADCON0, 0;
	_endasm;
}

// set the adc clock.
//
void adc_set_clock(unsigned char clk) {
	if(clk & 0x01) {
		_asm BSF ADCON0, 6 _endasm;
	} else {
		_asm BCF ADCON0, 6 _endasm;
	}

	if(clk & 0x02) {
		_asm BSF ADCON0, 7 _endasm;
	} else {
		_asm BCF ADCON0, 7 _endasm;
	}

	if(clk & 0x04) {
		_asm BSF ADCON1, 6 _endasm;
	} else {
		_asm BCF ADCON1, 6 _endasm;
	}
}

// please no channel > 7
void adc_set_channel(unsigned char channel) {
//	ADCON0 = (ADCON0 & BIN(11000111)) | (channel << 3);
	unsigned char tmp;
	channel <<= 3;
	tmp = ADCON0;
	tmp &= BIN(11000111);
	tmp |= channel;
	ADCON0 = tmp;
}

// start a conversion
void adc_start() {
	_asm
	BSF ADCON0, 0x2;
```

```
        _endasm;
}

// control which pins are analog, which are digital and if voltage
//  reference are pins on port a or Vdd, Vss?
void adc_set_port_config(unsigned char PCFG) {
        ADCON1 = (ADCON1 & 0xF0) | PCFG;
}

// TODO: create function to select between left and right justified data

// read an integer from the adc.  currently assumes right justified data
unsigned int adc_read_int() {
        unsigned int ret, tmp;
        ret = ADRESH;
        ret <<= 2;
        tmp = ADRESL;
        tmp >>= 6;
        return ret | tmp;
}

// computation, loops, the brains

// initialize data (per reading)
void init_data() {
        total_cnt = 0;
        total1 = 0;
        voltage_max = 0;
        current_max = 0;
}

// where is the sweep pot at?
unsigned char read_sweep() {
        int ret;

        adc_set_port_config(BIN(0000));
//      ADCON1 = BIN(01000000);

        adc_set_channel(5);
        delay(20);

        adc_start();
        adc_wait();

        ret = adc_read_int();
        ret >>= 3;

        return ret;
}

// read the position of the mode knob
unsigned char read_mode() {
        unsigned char mode;

        adc_set_port_config(BIN(0000));
```

```
//      ADCON1 = BIN(01000000);

        adc_set_channel(6);
//      ADCON0 = BIN(10110001);
        delay(20);

        adc_start();
//      ADCON0 = BIN(10110101);
        adc_wait();

        mode = ADRESH >> 5;

        return mode;
}

// retreive a single sample.
void get_data() {
        unsigned char neg;

        adc_set_port_config(BIN(1000));
//      ADCON1 = BIN(01001000);

        adc_set_channel(0);
//      ADCON0 = BIN(10000001);
        // wait for the channel to aquire the voltage
        delay(10);

        adc_start();
//      ADCON0 = BIN(10000101);
        adc_wait();

        adc_set_channel(1);
//      ADCON0 = BIN(10001001);

        // read channel 0
        voltage = adc_read_int();

//      TODO: why do these do different things?
//      adc_start();
        ADCON0 = BIN(10001101);
        adc_wait();

        adc_set_channel(4);

        // read channel 1
        reference = adc_read_int();

        ADCON0 = BIN(10100101);
        //adc_start();
        adc_wait();

        current = adc_read_int();

        // neg is used to keep track of the sign bit. I've had problems
        // with the compiler and this was the easiest way to ensure that
```

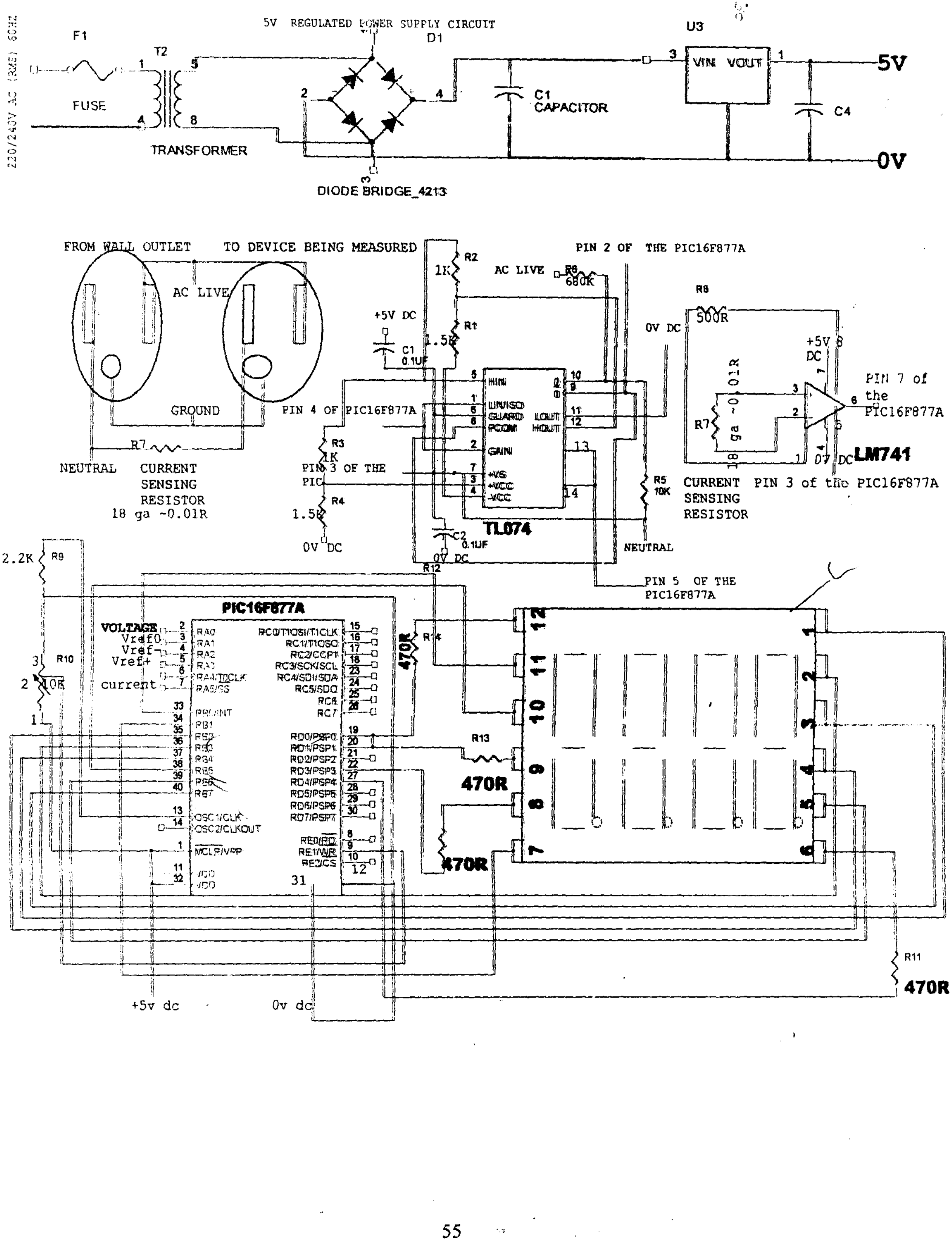
```
        // everything worked.
        // 0 is positive
        // 1 is negative
        neg = 0;

        // TODO: why do I have to work around the problem like this?
        // these two commented out lines show what the next two if blocks
        // do.  For some reason, these aren't the same.  I think it has
        // something to do with how different data types are handled.
        // especially when two different data types are used in an
        // arithmatic operation.
//      current_diff = current - reference;
//      voltage_diff = voltage - reference;
        if(current > reference) {
                current_diff = current - reference;
        } else {
                current_diff = reference - current;
                neg = 1;
        }

        if(voltage > reference) {
                voltage_diff = voltage - reference;
        } else {
                voltage_diff = reference - voltage;
                neg ^= 1;
        }

        // using the mode output values for temp variables
        // useful for debuging
        // total1 = total1 + current_diff*current_diff;
        mode1 = current_diff;
        mode2 = voltage_diff;
        mode4 = mode1 * mode2;
        mode6 = current_diff * voltage_diff;
        if(neg) {
                total1 = total1 - mode4;
        } else {
                total1 = total1 + mode4;
        }

        ++total_cnt;
}

// this is run once every reading, currently 256 samples
void analysis() {
        mode8 = total1/total_cnt;
        if(mode8 > 10000000) {
                mode8 = 0;
        }
        mode7 = mode8;
        // update moving average
        // moving_avg[i] is the most recent sample, moving_avg[i+1] is the oldest;
        //  unless i+1 == MOVING_AVG_SIZE at which point moving_avg[0] is the oldest
        // after each sample:
        //   subtract out the oldest from the total
```

```
	//  add in the newest
	//  remember the newest so it can be subtracted when it is the oldest
	//  calculate new average
	++moving_avg_i;
	if(moving_avg_i >= MOVING_AVG_SIZE) {
		moving_avg_i = 0;
	}
	moving_avg_total -= moving_avg[moving_avg_i];
	moving_avg_total += mode8;
	moving_avg[moving_avg_i] = mode8;
	mode8 = moving_avg_total / MOVING_AVG_SIZE;
	// calibrate
	mode8 *= 1000;
	mode8 /= CALIBRATION_SCALE;
	mode8 += CALIBRATION_OFFSET;
}

void main() {
	int i = 0;
	unsigned char neg = 0;			// true/1 when the last sample was negative
(voltage < reference)
	unsigned char sweep = 0;
	unsigned char mode;

	// no interupts
	INTCON = 0;

	// setup in/out ports
	TRISA = 255;
	TRISB = 0;
	TRISC = 0;
	TRISD = 0;

	// turn on and configure adc
//	ADCON0 = BIN(10000000);
	adc_set_clock(0x2);
	adc_on();

	// initialize the moving average data
	for(i = 0; i < MOVING_AVG_SIZE; ++i) {
		moving_avg[i] = 0;
	}

	// each iteration of the while loop is a single reading of data:
	//  256 samples
	//  analysis
	//  update display
	while(1) {
		init_data();
		mode = read_mode();
		sweep = read_sweep();

		// wait for a zero crossing on the voltage line.  Helps stabalize results
		// and makes debugging easier
		neg = 0;
```

```
		while(1) {
			// Count the next get_data if we break this time
			init_data();
			get_data();
			if(voltage < reference) {
				neg = 1;
			} else if (neg) {
				break;
			}
		}

		// read in 256 samples of data
		for(i = 1; i < 256; ++i) {
			get_data();
			if(sweep == i) {
//				mode5 = sweep;
//				mode6 = voltage_diff;
//				mode7 = current_diff;
			}
			// every 4 samples, turn on the next digit in the display
			// we must interleave this because the display needs to refresh
			// often and we want it to happen at the same point in the cycle
			// every time to keep results consistent.
			if(i & 4) {
				neg = i;
				neg >>= 3;
				neg = neg & 0x03;
				neg += 1;
				disp_dig(neg);
			}
		}

		// analyse the past 256 samples
		analysis();

		// depending on what mode we are in, display one of the values created in the
		// analysis.
		// TODO: rework this framework so that the analysis simply only generates the
data
		// required to output the selected information.
		// might still leave some from of this in here for debuging.  Was extremely
useful!
		switch (mode) {
			case 0 :
				disp_set_num(mode1);
				break;
			case 1 :
				disp_set_num(mode2);
				break;
			case 2 :
				disp_set_num(mode3);
				break;
			case 3 :
				disp_set_num(mode4);
				break;
```

```
                    case 4 :
                            disp_set_num(mode5);
                            break;
                    case 5 :
                            disp_set_num(mode6);
                            break;
                    case 6 :
                            disp_set_num(mode7);
                            break;
                    default :
                            disp_set_num(mode8);
                            break;
            }

            // update the kilo-LED
            disp_kilo();
        }
}
```

APPENDIX B


5V REGULATED POWER SUPPLY CIRCUIT
220/240V AC (RMS) 60HZ
F1
FUSE
T2
TRANSFORMER
D1
DIODE BRIDGE_4213
C1
CAPACITOR
U3
VIN VOUT
C4
5V
0V
FROM WALL OUTLET
TO DEVICE BEING MEASURED
AC LIVE
GROUND
NEUTRAL
R7
CURRENT SENSING RESISTOR
18 ga ~0.01R
PIN 4 OF PIC16F877A
PIN 3 OF THE PIC
PIN 2 OF THE PIC16F877A
PIN 5 OF THE PIC16F877A
R2
1K
R1
1.5K
R3
1K
R4
1.5K
+5V DC
0V DC
C2
0.1UF
R6
680K
R5
10K
NEUTRAL
TL074
R8
500R
LM741
PIN 7 of the PIC16F877A
PIN 3 of the PIC16F877A
R9
2.2K
R10
10K
PIC16F877A
VOLTAGE
Vref0
Vref-
Vref+
current
R14
470R
R13
470R
470R
R11
470R
+5v dc
0v dc