UNIVERSITY OF CAPE COAST

DESIGN AND FABRICATION OF VOLTAGE STABILIZER USING 8051 MICROCONTROLLER

BANS BANDOH FREMPONG

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BY

BANS BANDOH FREMPONG

Thesis submitted to the Department of Physics, School of Physical Sciences, College of Agriculture and Natural Sciences, University of Cape Coast, in partial fulfilment of the requirements for the award of Master of Philosophy degree in Physics

JUNE 2016

DECLARATION

Candidate's Declaration

I hereby declare that this thesis is the result of my own original research and that no part of it has been presented for another degree in this university or elsewhere.

Candidate's Signature: .... Date: ....

Name: Bans Bandoh Frempong

Supervisors' Declaration

We hereby declare that the preparation and presentation of the thesis were supervised in accordance with the guidelines on supervision of thesis laid down by the University of Cape Coast.

Principal Supervisor's Signature: .... Date: ....

Name: Dr. Paul Kwabena Obeng

Co-Supervisor's Signature: .... Date: ....

Name: Dr. Alfred Owusu

ABSTRACT

This study deals with the design and fabrication of a single-phase voltage stabilizer using 8051 microcontroller. The basic building blocks for this design include an AT89S51 microcontroller, a solid-state relay (SSR), a stabilizer transformer, a diode-based bridge rectifier, a 7805 regulator, an ADC 0804 and LEDs to display the digital value of the input voltage. This design is based on the principle of varying the input voltage to obtain an output voltage that is considerably constant. Any time there is a change in the input mains supply voltage, a corresponding voltage is digitised and fed into the microcontroller which then switches on an appropriate SSR to add or subtract a winding to or from the transformer, so as to maintain the output voltage. Apart from the voltage stabilisation, the device also provides voltage protection against transient voltages that are harmful to industrial, laboratory and domestic appliances. The voltage differences from red, yellow and green windings were however higher. The sudden change in AC voltage was due to only two additional windings. As a result, three relays were used to select the output voltages as the input voltage changes. This situation can be avoided when a transformer with more windings (tappings) are used. A variable transformer was used to vary the AC input voltage from 270 V AC and the corresponding voltages on the ADC output and the AC outputs from the Red, Yellow and Green tappings of the transformer were recorded.

ACKNOWLEDGEMENTS

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Lastly, I thank my family for the continual support I enjoyed from them during the course of my study, especially my wife, Jemima and my little girl, Nhyira.

DEDICATION

To my late father, Mr. Kodjo Ampozah-Frempong for his vision and exemplary life. May his soul rest in perfect peace.

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LIST OF ABREVIATIONS

AC	Alternating Current
ADC	Analog - to - Digital Converter
AE	Address Enable
ALE	Address Latch Enable
AMD	Advanced Micro Devices
ATSC	Advanced Television Systems Committee
AVR	Automatic Voltage Regulator
BDC	Binary Coded Decimal
BJT	Bipolar Junction Transistor
CLR	Clear
CMOS	Complementary Metal-Oxide Semiconductor
CPL	Complement
CPU	Central Processing Unit
CSIR	Centre for Scientific and Industrial Research
DAC	Digital - to - Analog Converter
DAQ	Data Acquisition
DPTR	Data Pointer Register
D-STATCOM	Distribution Static Synchronous Compensator
DVD	Digital Versatile Disc
DVR	Dynamic Voltage Restorer
EA	External Access
EOC	End-of Conversion
EPROM	Electrically Erasable Programmable Read-Only Memory

FACT	Flexible Alternating Current Transmission
FET	Field Effect Transistor
FF	Fundamental Frequency
F.S.	Full-scale
GND	Ground
GPIB	General Purpose Interface Bus
HDTV	High Definition Television
IC	Integrated Circuit
IEEE	Institute of Electrical and Electronics Engineers
I/O	Input Output
LAN	Local Area Network
LCD	Liquid Crystal Display
LED	Light Emitting Diode
LSI	Large scale integration
MCU	Microcontroller Unit
MOSFET	Metal-Oxide Semiconductor Field-Effect Transistor
MSI	Medium Scale Integration
NEMA	National Electrical Manufacturers Association
NGT	Negative
OE	Output Enable
PC	Personal Computer
PQ	Power Quality
PSEN	Program Store Enable
PWM	Pulse-Width-Modulated
RAM	Random Access Memory

RMS	Root Mean Square
ROM	Read Only Memory
RST	Reset
RXD	Receive Data
SAC	Successive Approximation Converter
SEPIC	Single Ended Primary Inductor Converter
SETB	Set Bit
SMPS	Switched-Mode Power Supply
SMPS	Switched-Mode Power Supply
SSI	Small Scale Integration
SSR	Solid-State Relay
TTL	Transistor-to-Transistor Logic
TXD	Transmit Data
UART	Universal Asynchronous Receiver/Transmitter
UPS	Uninterruptible Power Supply
VLSI	Very Large Scale Integration

CHAPTER ONE

INTRODUCTION

Overview

Chapter one of this research work entails the background of the study, statement of the problem, purpose of the study and research objectives. Also included in this chapter is a brief introduction on the need for a voltage stabilizer, power quality problems and their solutions.

Background to the Study

Power fluctuations and interruptions are the major causes of scientific equipment breakdown in developing countries like Ghana, due to unstable power supplies. Systems such as patient monitors, imaging equipment, and various computer systems used in hospitals also encounter such problems. Domestic appliances like the television set, radio receivers, refrigerators and other household appliances are not left out.

Voltage stabilizers imported from the developed countries do not meet the requirements that are prevalent to the developing countries like Ghana. For example, the voltage stabilizers that are imported into Ghana normally have voltage limit between 165 V alternating current (AC) to 250 V AC, but the supply voltage can sometimes go as low as 140 V AC or as high as 300 V AC. At such a supply voltage, the voltage stabilizer no longer performs its desired function.

A voltage stabilizer (also known as a line conditioner or power line conditioner) is a device intended to improve the quality of the power that is delivered to electrical load equipment (Meier, 2006). It can also be said to be an electrical device that provides 'clean' AC power to sensitive electrical equipment. Voltage stabilizer often refers to a device that acts in one or more ways to deliver a voltage of the proper level and characteristics to enable load equipment to function properly.

However, Institute of Electrical and Electronics Engineers (IEEE), National Electrical Manufacturers Association (NEMA), and other standards organizations, a new actual engineering definition has now been developed and accepted to provide an accurate depiction of this definition. Voltage conditioning is the ability to filter the AC line signal provided by the power company (Bollen, 2000).

Voltage Stabilizers

Voltage stabilizers can vary greatly in specific functionality and size, with both parameters generally determined by the application. They provide only minimal voltage regulation while others provide protection from half a dozen or more power quality problems. A typical block diagram of voltage stabilizer system is shown in Figure 1.

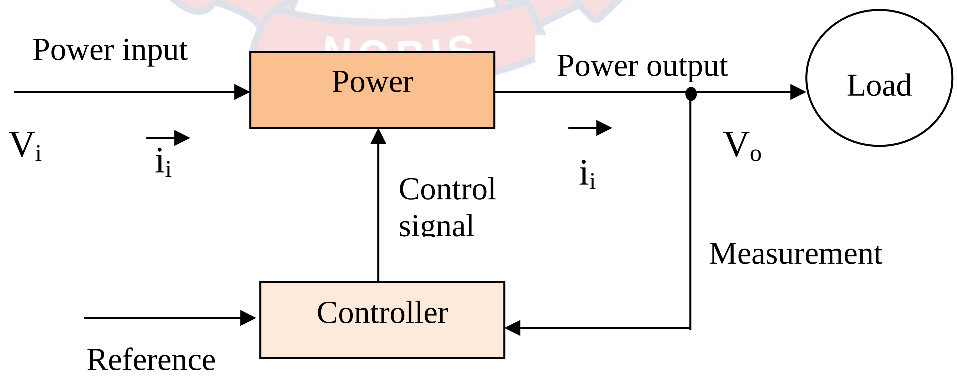


Figure 1: Block diagram of voltage stabilizer system (Mohan et al., 2003)

Voltage stabilizers regulate, filter, and suppress noise in AC power for sensitive computer and other solid state equipment. The main purpose of a voltage stabilizer is to make the voltage supplied by the line or network equal to the voltage supply needed by the electrical devices or load.

Luo et al. (2005) defined voltage stabilizer as the technology of processing and controlling the flow of electric energy by supplying voltages and currents in a form that is optimally suited to the end-user's requirements. A typical block diagram of voltage stabilizer system is given in Figure 1. The input power can be either AC or DC source. The output power to the load can either be AC or DC voltage.

Voltage stabilizers (Figure 2) are used as series connection unit with mains with deviating voltage. At the output of the device is a constant voltage which is available for the consumer load. This constant voltage ensures a constant performance of the machine, independent from the mains deviations.

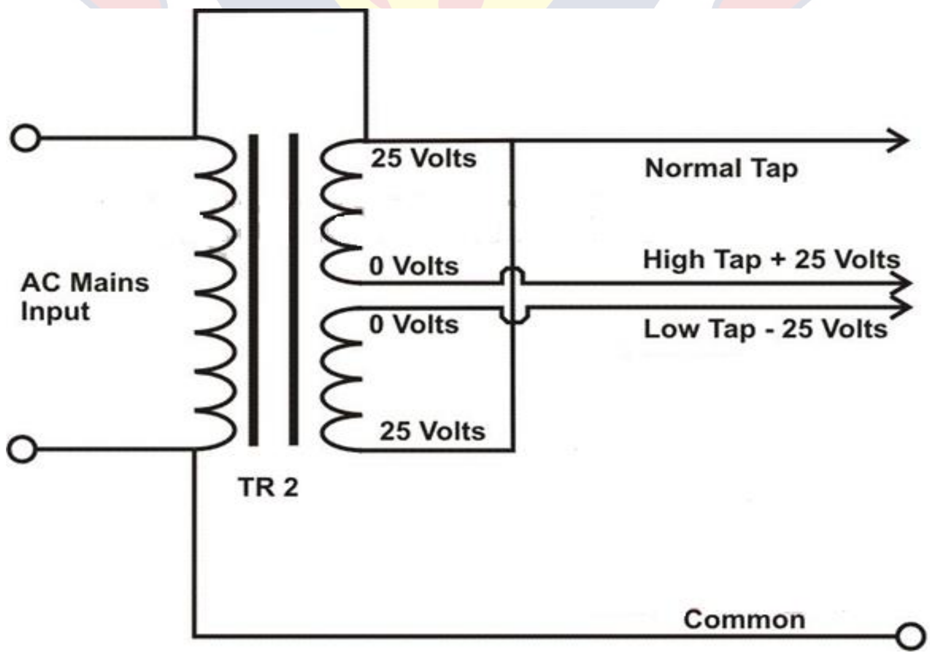


Figure 2: Circuit diagram of a typical Voltage Stabilizer

There are a variety of specific types of voltage stabilizers based on the particular method they use to control the voltage in a circuit. In general, a voltage stabilizer functions by comparing its output voltage to a fixed reference and minimizing this difference with a negative feedback loop. Its function is to make sure that electrical appliances do not feel the voltage fluctuations on the main line, thus, protecting them from being damaged.

Patchett (2010) also defined voltage stabilizer as a device designed to reduce the variations in voltage of the supply to some other apparatus. He further explained that voltage stabilizer works on the principle of a transformer, where the input current is connected to primary windings and output is received from secondary windings. When there is a drop in incoming voltage, it activates electromagnetic relays which add to more number of turns in the secondary winding, thus, giving higher voltage which compensates for loss in output voltage. When there is rise in the incoming voltage, the reverse happens, and thus, the voltage at the output side remains almost unchanged.

Voltage Conditioner

A Voltage Conditioner is any device that ‘conditions’ the voltage. Voltage Conditioning may include voltage regulation, isolation, filtering, harmonic cancellation, transient suppression, or any combination of these (TEAL, 1999).

A voltage conditioner typically consists of voltage stabilizers in combination with output isolation transformers and transient voltage suppression circuitry, line filters, and surge suppressors. They provide electrical isolation and noise and spike attenuation to ensure the quality and consistency of voltage to sensitive medical, laboratory, computer, and other high technology equipment.

A distinction has been made by Glynne-Jones (2000) between a voltage stabilizer and a voltage regulator. The former correcting for input voltage changes but not for changes in load, whereas the latter will correct for both (Patchett, 2010). This does not appear to be a recognized distinction, and accordingly voltage stabilizers have been classified by the author into three main types. Type A voltage stabilizers maintain constant voltage independent of changes in the supply but not independent of load changes. A Type B stabilizer maintains constant voltage independent of changes of load but not independent of supply changes. Type C also maintains constant voltage independent of supply and load changes. A type C stabilizer may obviously be formed by the combination of types A and B, but this is not essential.

AC Voltage Regulator

A voltage regulator (Figure 3) can regulate AC and DC voltages. Most voltage regulators compare the output voltage against an internal reference voltage. If there is any difference between the two voltages, the voltage regulator will automatically compensate to provide the right output. The regulation element in a voltage regulator will start producing more or less voltage depending on either low or high output voltage reading. The task of the voltage regulator is to make sure the voltage stays as close to the prefixed level as possible. This induces two variables, the speed of response of the voltage regulator and its stability.

A voltage stabilizer is basically a voltage regulator that is used in homes to output a constant voltage even if the backend power supply fluctuates for any reason. A voltage stabilizer uses a negative feedback that helps to control the tap position. The tap moves in the opposite direction of the voltage value. A lowering in voltage will cause it to step up voltage and vice versa. The only other way to maintain constant voltage is the use of a type of transformer known as the ferro-resonant transformer. This type of transformer uses a tank circuit and a capacitor that slowly drains out voltage at a constant value. Ferro-resonant transformers are designed to achieve regulation with non-linear operation. They provide line regulation, reduce harmonics, and are current limiting.

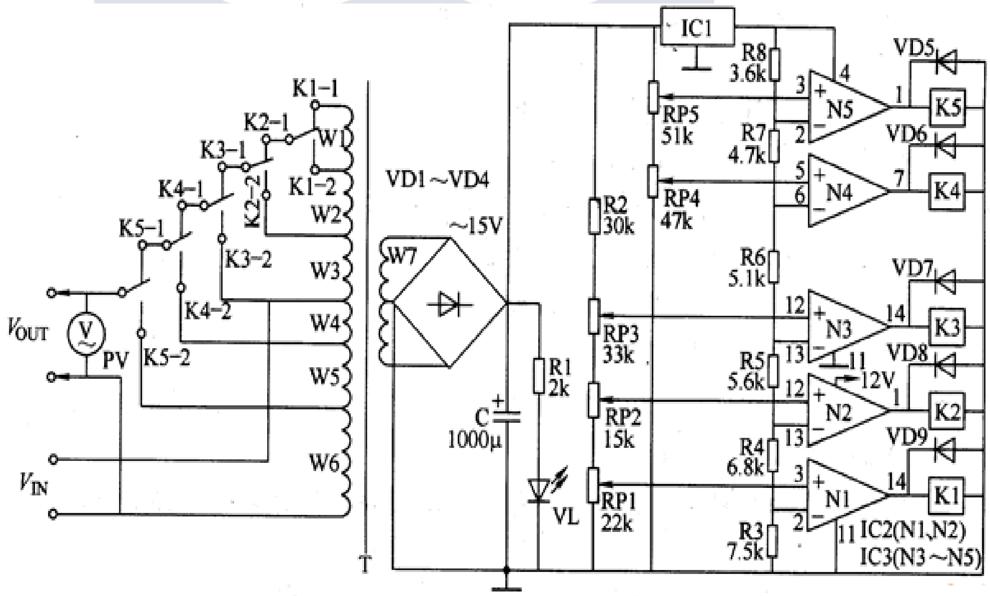


Figure 3: Circuit diagram for AC voltage regulator (http://www.seekic.com)

The input and output voltage range and output power range AC voltage regulator introduced in Figure 3 are 160-270 V, 220 (1±5 %) V and 600-800 W respectively, which can meet the need of general household appliances. The AC voltage regulator circuit is composed of lifting and reduction voltage commutation circuits and automatic control circuit and it is shown in Figure 3. The lifting and reduction commutation circuits consists of power supply transformer's (T) Wl-W6 winding relay's normally closed contact Kl-l-K5-1, normally open contact Kl-2-K5-2 and voltmeter.

Important specifications to consider when designing for power conditioners include power rating, input voltage, output voltage, voltage regulation accuracy, phase, and frequency (Dugan et al., 2003). The power rating is usually expressed in volt-amps, which is the product of the maximum root mean square (RMS) voltage and the RMS current that the conditioner can handle. Input voltage is the nominal line voltage to which the conditioner is connected. The output voltage is regulated or the conditioned voltage. The voltage regulation accuracy is the accuracy with which the output voltage is controlled.

Automatic Voltage Regulator

The automatic voltage regulator (AVR), as the name implies, is a device intended to regulate voltage automatically: that is to take a varying voltage level and turn it into a constant voltage level (Sharma, 1987). Automatic voltage regulators are widely used in electrical power field to obtain the stability and good regulation of the electric system.

In typical AVRs, switching is done by electromagnetic relays, or servomotor, or electronic device, which automatically selects taps in the transformer to get the required voltage to boost (add) or buck (subtract) the input voltage. Relay tap changers have problems such as power lost momentarily during relay change over, unstable output and relay contact damages. Servo motor types gave the disadvantages that they have low life of the contact points of the relays (Sen, 1987).

Solid state electronic device that uses AVRs can overcome most of the above problems as they do not use any moving part and the output voltage can vary from cycle to cycle (Ahmed, 1999; Jacob, 2002). Microcontrollers have proven their abilities to perform well in a wide range of applications (Peatman, 1998; Penfold, 1997).

The Need for Voltage Stabilizers

Industrial electrical environments are plagued with voltage disturbances due to the interaction of high-powered equipment. The interaction of motors, variable speed drives, solenoids, welders, and hand tools result in voltage disturbances. Over 2000 transients per hour and re-occurring voltage fluctuations are the resulting power anomalies caused by high-powered equipment. Calls for perpetual attention, adjustment, high maintenance, constant restarts and calibration, abnormal rejection rates, system upsets, nuisance alarms, erroneous data and premature failures are all incidences caused by voltage fluctuation anomalies.

The Power Purifier is the solution to 99.95 % of all power problems. The Power Purifier protects sensitive electronic equipment from voltage spikes, oscillatory ring waves, noise, impulses, over voltages, under-voltages, distorted sine-waves and even short duration power outages. In addition, the power purifier protects building electrical system from the effects of damaging harmonic currents and also corrects for poor power factor conditions. In short, the triple value-add of the power purifier's double magnetic conversion, lineinteractive design, enhances control equipment performance, extends equipment life and improves the building's overall electrical system.

Voltage Quality

Voltage quality as defined by Dugan et al., (2003) is the set of limits of electrical properties that allows electrical systems to function in their intended manner without significant loss of performance or life. The term is used to describe electrical voltage that drives an electrical load and the load's ability to function properly with that electric voltage (Bollen, 2000). Without the proper voltage, an electrical device (or load) may malfunction, fail prematurely or not operate at all. There are many ways in which electrical voltage can be of poor quality and many more causes of such poor quality voltage.

The electric power industry comprises electricity generation (AC power), electric voltage transmission and ultimately electricity distribution to an electricity meter located at the premises of the end user of the electric power. The electricity then moves through the wiring system of the end user until it reaches the load. The complexity of the system to move electric energy from the point of production to the point of consumption combined with variations in weather, generation, demand and other factors provide many opportunities for the quality of supply to be compromised.

While 'power quality' is a convenient term for many, it is the quality of the voltage rather than power or electric current that is actually described by the term (Dugan et al., 2003). The quality of electrical voltage may be described as a set of values of parameters, such as Continuity of service, Variation in voltage magnitude, Transient voltages and currents and Harmonic content in the waveforms, etc.

Voltage quality is the measurement of how close to perfection an electrical voltage is, at any given time or point. High quality electrical voltage is a sine wave that measures exactly what is expected in both voltage and frequency (Stones & Collinsion, 2001).

Historically, most voltage quality problems were considered to be those things that affected the distribution of the voltage. Line or transformer failures and/or very high electrical demands (brown outs) on electrical network are just a few. Today, however, most voltage quality problems are due to technology changes and the way electricity is used.

One of the many aspects of voltage quality that can affect electricity users is voltage fluctuation that causes lights to flicker. Whenever the electrical load changes, the supply voltage is affected proportionately. Most people have seen this occur in their house; when the refrigerator or the cooker starts, some of the lights may dim. If a large enough change occurs, such as the start-up of a large industrial motor, lights can dim or brighten, not only for that customer, but all over town. Normally the customer whose load is changing is the most affected, but other customers are all affected to some degree, depending on how large the load change is and how close they are to the changing load. If large voltage changes occur in rapid succession, light levels will vary, and when the variation becomes large enough to be noticeable or annoying, the effect is called light flicker (Bollen, 2000).

Voltage Quality Problems

Voltage Quality Problems include all possible situations in which the waveforms of the supply voltage or load current deviate from the sinusoidal waveform at rated frequency with amplitude corresponding to the rated RMS value for all three phases of a three-phase system. Voltage quality disturbance covers sudden, short duration deviation impulsive and oscillatory transients, voltage dips (or sags), short interruptions, as well as steady- state deviations, such as harmonics and flicker. Other voltage quality problems include voltage swell, under/ over voltage, harmonic distortion, voltage notching, transient disturbance and outage and frequency variation

Voltage Sag

Voltage sag is a reduction in the RMS voltage in the range of 0.1 to 0.9 p.u. (retained) for duration greater than a mains cycle and less than 1 minute. It is often referred to as a ‘dip‘. It is caused by faults, increased load demand and transitional events such as large motor starting.

Voltage Swell

A voltage swell is an increase in the RMS voltage in the range of 1.1 to 1.8 p.u. for a duration greater than half a main cycle and less than 1 minute. It is caused by system faults, load switching and capacitor switching.

Voltage Interruption

A voltage interruption is the complete loss of electric voltage (Figure 4). Interruptions can be short duration (lasting less than 2 minutes) or long duration. A disconnection of electricity causes an interruption usually by the opening of a circuit breaker, line re-closure, or a fuse.

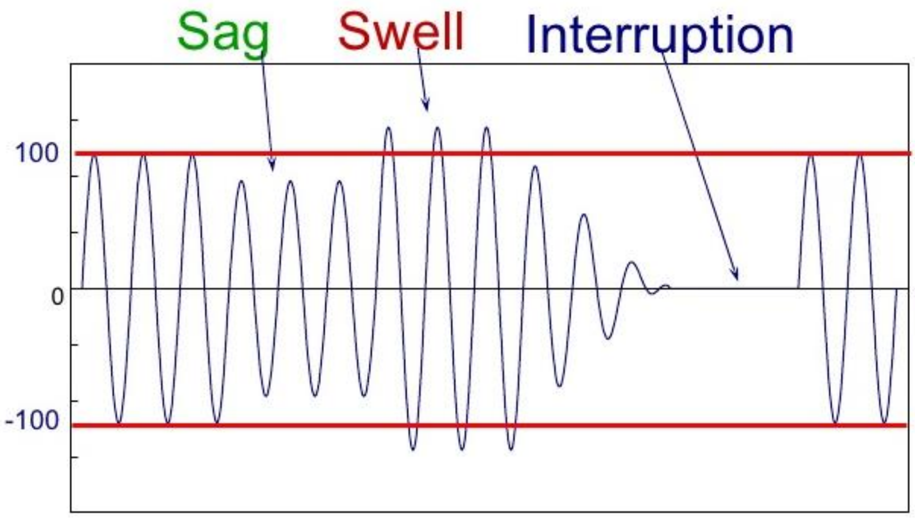


Figure 4: Voltage Sag, Swell and Interruption (Gupta, 2012)

Over Voltage and Under Voltage

Long-duration voltage variations that are outside the normal limits (that is, too high or too low) are most often caused by unusual conditions on the power system. For example, out-of-service lines or transformers sometimes cause under voltage conditions. These types of RMS voltage variations are normally short term, lasting less than one or two days. In addition, voltage can be reduced intentionally in response to a shortage of electric supply.

Voltage Flicker

A waveform may exhibit voltage flicker if its waveform amplitude is modulated at frequencies less than 25 Hz, which the human eye can detect as a variation in the lamp intensity of a standard bulb (Gupta, 2012). Voltage flicker (Figure 5) is caused by an arcing condition on the power system. Flicker problems can be corrected with the installation of filters, static VAR systems, or distribution static compensators.

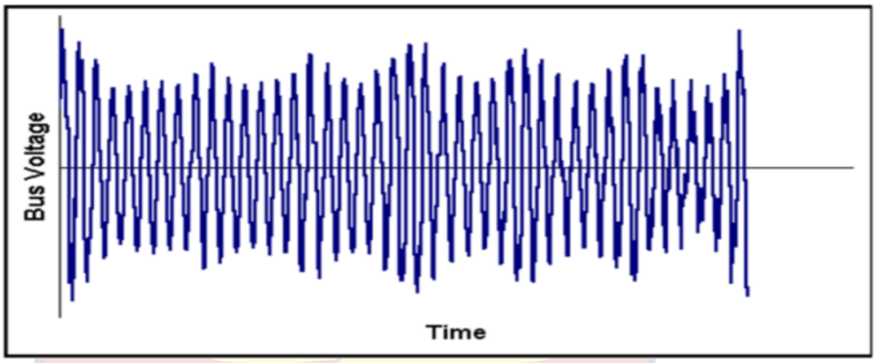


Figure 5: Voltage Flicker (Gupta, 2012)

Harmonics

A pure sinusoidal voltage is conceptual quantity produced by an ideal AC generator build with finely distributed stator and field windings that operate in a uniform magnetic field. Since neither the winding distribution nor the magnetic field is uniform in a working AC machine, voltage waveform distortion is created, and the voltage time relation-ship deviates from the pure sine function. The distortion at the point of generation is very small (about 1 % to 2 %), but nonetheless it exists. Because this is a deviation from a pure sine wave, the deviation is in the form of a periodic function and by definition, the voltage distortion contains harmonics.

When a sinusoidal voltage is applied to a certain type of load, the current drawn by the load is proportional to the voltage and impedance and follows the envelope of the voltage waveform. These loads are referred to as linear loads (loads where the voltage and current follow one another without any distortion to their pure sine waves) such as resistive heaters, incandescent lamps and constant speed induction and synchronous motors. In contrast, some loads cause the current to vary disproportionately with the voltage during each half cycle. These loads are classified as nonlinear loads and the current and voltage have waveforms that are non-sinusoidal containing distortions whereby 50 Hz waveform has numerous additional waveforms superimposed upon it creating multiple frequencies within the normal 50 Hz sine wave. The multiple frequencies are harmonics of the fundamental frequency.

Power systems designed to function at the fundamental frequency which is 50 Hz in Ghana are prone to unsatisfactory operation and at times failure when subjected to voltages and currents that contains substantial harmonic frequency elements. Very often the operation of electrical equipment may seem normal but under a certain combination of conditions the impact of harmonics is enhanced with damaging results.

Voltage Notching

Voltage notching (Figure 6) is caused by the commutation of power electronic rectifiers. It is an effect that can raise PQ issues in any facility where solid-state rectifiers (for example, variable-speed drives) are used (Arnold, 2001). When the drive DC link current is commutated from one rectifier thyristor to the next, an instant exists during which a line-to-line short circuit occurs at the input terminals to the rectifier. With this disturbance, any given phase voltage waveform will typically contain four notches per cycle as caused by a six-pulse electronic rectifier (de Almeida et al., 2003).

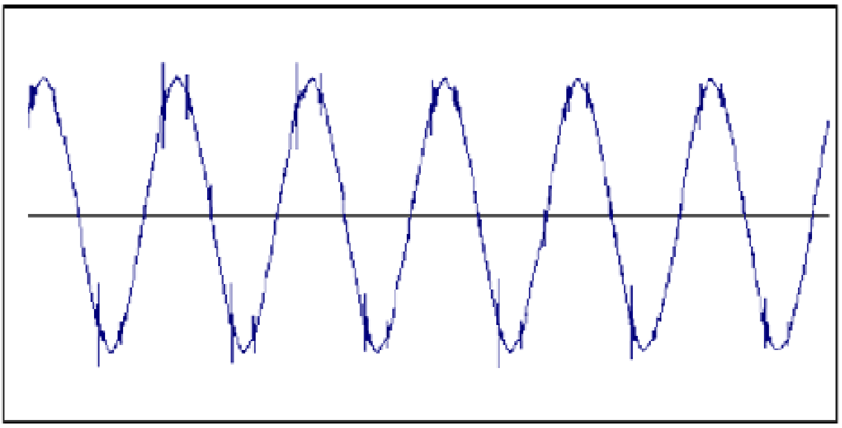


Figure 6: Voltage Notching Waveform (Arnold, 2001)

Transient Disturbance

Transient disturbances are undesirable momentary deviation of the supply voltage or load current and caused by the injection of energy by switching or by lightning. Transients are classified in two categories; Impulsive and oscillatory (Figure 7 and Figure 8).

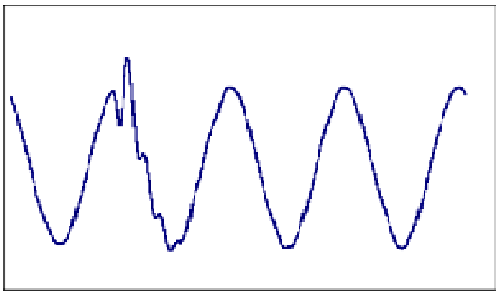


Figure 7: Oscillatory transient waveform (Stones & Collinsion, 2001)

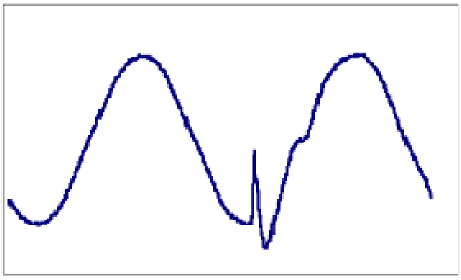


Figure 8: Impulsive transient waveform (Stones & Collinsion, 2001)

Causes of Voltage Fluctuations

Voltage fluctuation, or variation in the voltage at the electrical outlet, can be caused by events at many different points in the voltage distribution system. For most consumers, voltage generated by many large generators comes to them through a high-voltage electrical transmission network, or grid. Voltage flows through this grid at voltages around 100 or 200 kV to a substation, where the voltage is reduced by a transformer to a lower voltage, typically 12 to 25 kV. It then flows through an underground or overhead distribution system until it reaches a distribution transformer, where it is reduced further to the consumer voltage. The voltage then flows through a service conductor to the customer's meter and distribution panel and through the building electrical system to the outlet or light fixture.

The voltage at the outlet is determined by two factors: the generator output voltage and the voltage drop, or loss in the transmission and distribution system. It is only when a major event, such as a transmission line outage due to a lightning strike or mechanical failure occurs, or when system demand is greater than the combined available generation capacity, that the regulators are unable to maintain the voltage. Under these conditions there may be a temporary under-voltage or overvoltage until the condition is corrected, or in the worst case, the system may become unstable, causing some areas to lose power completely and other areas to separate from the grid.

Most voltage variations are caused by changes in the voltage drop in the distribution system. Each component of the system has losses associated with it, and produces a voltage drop that is approximately proportional to the current flowing through it. The ratio of voltage drop to current flow is called the impedance, and can conveniently be expressed as the percentage drop in voltage at rated current.

Increasing demands for electric power have caused existing voltage grids to become overloaded. Overloading is a common cause of line voltage fluctuations. Inadequate power generation and inadequate distribution systems are also causes of line voltage problems. Improper or poorly designed voltage regulating devices may create voltage fluctuations.

Voltage fluctuations can also be caused by loose or corroded connections at either the house or on the power lines, and are often noticed by flickering lights (Baggini, 2008). Dim lights can be a symptom of the voltage being too low. This can be caused by overloading on the network, loose connections or the conductor wire carrying voltage to your house being too small. In extreme cases, a loose connection can cause electric shocks from metal appliances and surfaces in your house. Such occurrences are prevalent on the coastal areas.

Throughout the areas where voltage fluctuation is common, lightning is a frequent cause of changes in line voltage. Lightning causes voltage fluctuations through direct strikes on power lines or indirect strikes that are close to voltage lines. The effect of lightning on voltage lines is magnified by poor grounding of the voltage line system (Kusko & Marc, 2007).

Thermal fluctuations (thermal noise) are caused by the random movement of thermally excited charge carriers in a conductor, which results in a fluctuating difference in potential between the conductor’s terminals. Because of the large concentration of conduction electrons in metals and the shortness of the mean free path, the velocities of thermally excited electrons are many times greater than the velocity of the directed motion in an electric field. Consequently, the electrical fluctuations in metals vary with temperature, but they are not a function of the applied voltage (the Nyquist formula).

Solutions of Voltage Quality Problems

Voltage Quality Problems can be solved with the use of Flicker Mitigation which consist of Static VAR Compensator and D-STATCOM (Hingorani, 1995), Harmonic Mitigation Passive Filter, Active Filter and Multi-pulse Configuration (Bollen, 2000) and Mitigation of Voltage Dips and Short Interruption Motor-generator set, Static series compensator, Dynamic Voltage Restorer (DVR) and Static transfer switch. Other possible techniques that can be employed to solve the problem are proper earthling practices, online UPS/Hybrid UPS, Energy storage system, Ferro-resonant transformer and Network equipment and design (Gupta, 2012).

Voltage Transformers

A Transformer does not generate electrical power, it transfers electrical power. A transformer is a voltage changer. The transformer works on the principle that energy can be efficiently transferred by magnetic induction from one winding to another winding by a varying magnetic field produced by alternating current.

According to Floyd (1991), transformers are sometimes used to couple AC voltage from one point in a circuit to another, or to increase or decrease the AC voltage. When two coils are placed close together and a sinusoidal current is applied to one coil, the changing magnetic field produced by the current causes an induced voltage in the other coil, in accordance with Faraday's law. This situation basically describes how a transformer operates. Thus, two coils that are magnetically linked to each other make up a transformer. There is no electrical connection between the coils; therefore, they are electrically isolated.

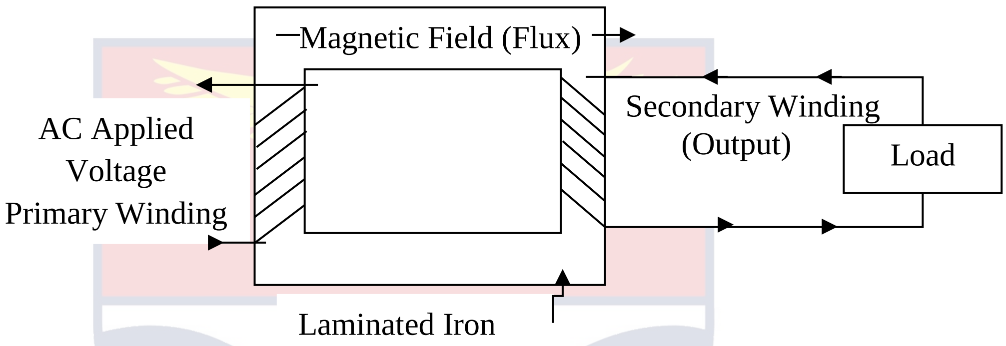


Figure 9: A Transformer with Load

A transformer has no moving parts and is a completely static solid state device, which ensures under normal conditions, a long and trouble-free life. It consists, in its simplest form, of two or more coils of insulated wire wound on a laminated steel core (Figure 9). When an alternating voltage is introduced to one coil, called the primary, it creates a fluctuating magnetic field in the iron core. This fluctuating field then induces an alternating voltage in the other coil, called the secondary or output coil. The change of voltage (or voltage ratio) between the primary and secondary depends on the turns ratio of the two coils.

Types of Transformers

Most transformers are designed to either step voltage up or to step it down, although some are used only to isolate one voltage from another. Hiley et al. (2005) asserted that a transformer in which the secondary voltage is less than the primary voltage is called a step – down transformer. The amount that the voltage is step–up depends on the turns ratio which is always less than 1.

A transformer in which the secondary voltage is greater than the primary voltage is called a step–up transformer. The amount that the voltage is step–up depends on the turns ratio. From Winders (2002), for any transformer, the ratio of the secondary voltage (V_s) to primary voltage (V_p) is equal to the ratio of the number of secondary (N_s) turns to the number of primary turns (N_p). Thus;

$$\frac{V_s}{V_p} = \frac{N_s}{N_p} \qquad 1$$

From this relationship, we get

$$V_s = \left(\frac{N_s}{N_p}\right) V_p \qquad 2$$

This equation shows that the secondary voltage is equal to the turns ratio (N_s/N_p) multiplied by the primary voltage. This conclusion assumes that all the magnetic flux lines produced in the primary pass through the secondary. The turns ratio for a step-up transformer is always greater than 1.

Voltage Regulation of a Transformer

Kelly & Nicholas (1998) defined voltage regulation of a transformer as the secondary voltage between no load and full load, expressed as either a percentage-unit or a percentage of the no–load voltage, the primary voltage being assumed as constant. That is,

$$\text{Voltage Regulation} = \frac{\text{No load voltage} - \text{Full load voltage}}{\text{No load voltage}} \times 100\% \qquad 3$$

If V_1 is the primary applied voltage then secondary voltage on no load, V_2 is

$$V_2 = V_1 \times \frac{N_2}{N_1} \qquad 4$$

since the voltage drop in the primary winding due to the no–load current is negligible. If V_2 is the secondary terminal voltage on full scale,

$$\text{Voltage Regulation} = \frac{V_1 - V_2 \frac{N_1}{N_2}}{V_1} \times 100\% \qquad 5$$

Electronic Voltage Regulators

A simple voltage regulator can be made from a resistor in series with a diode (or series of diodes). Due to the logarithmic shape of diode V - I curves, the voltage across the diode changes only slightly due to changes in current drawn. When precise voltage control is not important, this design may work fine.

Feedback voltage regulators operate by comparing the actual output voltage to some fixed reference voltage. Any difference is amplified and used to control the regulation element in such a way as to reduce the voltage error. This forms a negative feedback control; increasing the open-loop gain tends to increase regulation accuracy but reduce stability. There will also be a trade-off between stability and the speed of the response to changes. If the output voltage is too low, the regulation element is commanded, up to a point, to produce a higher output voltage by dropping less of the input voltage, or to draw input current for longer periods. If the output voltage is too high, the regulation element will normally be commanded to produce a lower voltage.

However, many regulators have over-current protection, so that they will entirely stop sourcing current or limit the current if the output current is too high, and some regulators may also shut down if the input voltage is outside a given range.

Electromechanical Regulators

In electromechanical regulators, voltage regulation is easily accomplished by coiling the sensing wire to make an electromagnet. The magnetic field produced by the current attracts a moving ferrous core held back under spring tension or gravitational pull. As voltage increases, so does the current, strengthening the magnetic field produced by the coil and pulling the core towards the field. The magnet is physically connected to a mechanical power switch, which opens as the magnet moves into the field. As voltage decreases, so does the current, releasing spring tension or the weight of the core and causing it to retract. This closes the switch and allows the power to flow once more. If the mechanical regulator design is sensitive to small voltage fluctuations, the motion of the solenoid core can be used to move a selector switch across a range of resistances or transformer windings to gradually step the output voltage up or down, or to rotate the position of a moving-coil AC regulator.

Early automobile generators and alternators had a mechanical voltage regulator using one, two, or three relays and various resistors to stabilize the generator's output at slightly more than 6 or 12 V, independent of the engine's rpm or the varying load on the vehicle's electrical system. Essentially, the relay(s) employed pulses width modulation to regulate the output of the generator, controlling the field current reaching the generator (or alternator) and in this way controlling the output voltage produced. The circuit diagram of an electromechanical voltage regulator is shown in Figure 10.

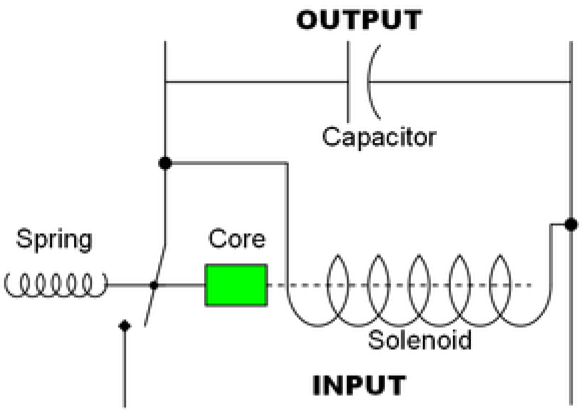


Figure 10: Circuit design of a simple electromechanical voltage regulator (https://en.wikipedia.org)

The regulators used for DC generators also disconnect the generator when it is not producing electricity, thereby preventing the battery from discharging back into the generator and attempting to run it as a motor. The rectifier diodes in an alternator automatically perform this function so that a specific relay is not required; this appreciably simplifies the regulator design.

Autotransformer

An autotransformer is an electrical transformer with only one winding (Horowitz & Hill, 1989). Autotransformer (Figure 11) consists of a single copper wire common to both the primary and secondary circuit. The copper wire is wound over a silicon steel core. At least three taps are provided over the windings which provide three levels of output voltage. By providing a smooth sliding brush over the winding, a variable turns ratio can be obtained. Even a small incremental voltage can be made possible by using the sliding contact.

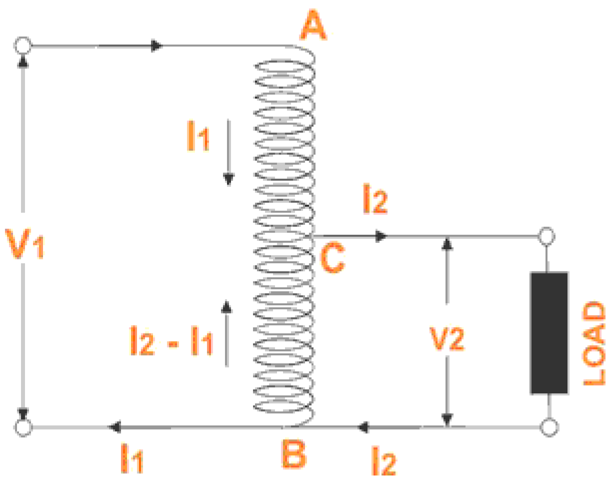


Figure 11: Autotransformer circuit configuration

(http://www.electrical4u.com)

The primary and the secondary windings of autotransformer are connected electrically as well as coupled magnetically. This makes the autotransformers much cheaper, smaller and more efficient for voltage ratings less than 3 than ordinary transformers. Also, an autotransformer has lower reactance, lower losses, smaller excitation voltage and better regulation compared to its two winding counterpart.

In an autotransformer, energy transfer is mainly through conduction process and only a small part is transferred inductively. Since the voltage per turn is same in both primary and secondary, the voltage can be varied by simply varying the number of turns. So the load is connected in such a way that one terminal is connected to any one of the tapping and the other is connected to the neutral.

Theory of Autotransformer

In Autotransformer, one single winding is used as primary winding as well as secondary winding. But in two windings transformer two different windings are used for primary and secondary purpose. A diagram of auto transformer is shown in Figure 11. The winding AB of total turns N_1 is considered as primary winding. This winding is tapped from point C and the portion BC is considered as secondary. Assuming that, the number of turns in between points B and C is N_2. If V_1 voltage is applied across the winding i.e. in between A and C

$$\text{voltage per turn in this winding} = \frac{V_1}{N_1} \qquad 6$$

Hence, the voltage across the portion BC of the winding, will be

$$\frac{V_1}{N_1} \times N_2 \qquad 7$$

And from equation 4, this is V_2. Hence

$$V_2 = \frac{V_1}{N_1} \times N_2 \qquad 8$$

That is

$$\frac{V_2}{V_1} = \frac{N_2}{N_1} = k \qquad 9$$

As BC portion of the winding is considered as secondary, it can easily be understood that value of constant k is the turns ratio or voltage ratio of that Autotransformer. When a load is connected between the secondary terminals i.e. between B and C, the load current I_2 starts flowing. The current in the secondary winding or common winding is the difference of I_2 and I_1.

Advantages of Autotransformers

The autotransformer has a smooth variation of voltage as per the requirement is possible. It is more efficient than the conventional transformer. It requires less conductive material (copper) than two winding transformer. It is handy, smaller and less expensive than two winding transformer.

The resistance and leakage reactance of autotransformers are less compared to two winding transformer. They have less copper loss and superior voltage regulation than two winding transformer.

Limitations of Autotransformers

The main limitation of the auto -transformer is that the primary and secondary are not electrically isolated. Any undesirable condition at the primary will affect the equipment connected to the secondary. Due the lack of isolation harmonics generated by the equipment connected to supply will be passed to the supply.

Autotransformers have low impendence hence high short circuit currents on the secondary side. If the section common to both primary and secondary is opened, whole primary voltage will occur across the secondary which may lead to severe accidents.

Statement of the Problem

Electronic and electrical devices are designed to operate at a certain maximum supply voltage, and considerable damage can be caused by voltage that is higher than that for which the devices are rated. For example, an electric filament bulb has a wire in it that at the given rated voltage will carry a current just large enough for the wire to get very hot (giving off light and heat), but not hot enough for it to melt.

However, if the voltage is too high, then the wire may melt and the bulb would have "burned out". Similarly, other electrical devices may stop working, or may even burst into flames if an overvoltage is delivered to the circuit of which these devices are part. This situation may cause an entire building or a place to burst into flames. Ghana has experienced rampart market fires in recent times of which overvoltage cannot be ruled out completely.

Breakdown of scientific equipment and devices are partly due to unstable voltage supplies. Hospitals, and most importantly research centres, have to purchase new equipment when the old ones break down. This is hard to come by as they may have to wait for years before these equipment can be replaced. As a developing country, the few resources available should not always be used to buy new equipment if there is a way of protecting them from damage. There is therefore the need to design a device that can protect these sensitive equipment from damage as a result of unstable voltage supply.

Purpose of the Study

The main function of a voltage stabilizer is to make the output voltage that feeds the equipment connected to it, as much as possible, equivalent to the ideal electrical voltage supply to the appliance or equipment. This is to ensure that, the oscillations in the electrical power are offset, and its output maintain a stable value, preventing them from being experienced by equipment and thereby avoiding their damage. Most stabilizers also have electronic filters whose purpose is to suppress noise and peak voltage.

The purpose of the study is to design a voltage stabilizer that will automatically maintain a constant voltage level, to protect electrical equipment against voltage surges, over voltage, under voltage and smoothing impulsive noise.

Research Objectives

For various reasons the voltage of the energy distribution does not remain constant, showing considerable fluctuations in the nominal value, which leads to the apparatus, not only a loss of efficiency, but also a significant increase in failure rate. Voltage stabilizers are devices used to regularize and control the variation and fluctuations in supply voltage within a desired range. This device when designed will be used in voltage stabilizing in a twin manner, i.e. controls voltage supply and prevents the peak voltage to go beyond a fixed limit.

The objectives of this study is to design and construct a device that can be used to regulate the amount of voltage supplied to electrical devices. The device will also be responsible for correcting the voltage of an electrical power supply to provide a stable and secure power supply to equipment, allowing for a stable voltage and protecting the equipment from most of the problems emanating from the mains. The aim is to provide clean power to the load equipment to protect it from damage as a result of unstable voltage supply.

The device when designed will produce an output voltage which will stay in the range of 210 V AC – 230 V AC with an input voltage of 180 V AC

– 260 V AC. It will particularly guard them against the dangerous high voltages and also from the possible brownouts (low voltages).

CHAPTER TWO

LITERATURE REVIEW

Overview

This chapter is devoted to the review of literature related to power protection devices and their functions. It is imperative that several issues relating to the study of semiconductor theory, integrated circuits (ICs), microcontrollers and microprocessors and their applications are discussed.

Semiconductor Theory

Atoms are closely packed in a solid crystal structure and their energy levels are broadened into bands of closely spaced levels. The crystal structure has three distinct parts, namely, the conduction band, the forbidden gap and the valence band. The electrons in the conduction band are free to move in the crystal lattice of the solid. Below the conduction band is the forbidden gap (energy gap), which does not contain electrons but electrons may travel back and forth through the forbidden gap. The valence band lies just below the forbidden gap, and contains electrons which give off energies in the ground state. However in conductors, the conduction band and the valence band overlap so the forbidden gap does not exist in conductors.

The electrons in semiconductors can have energies only within certain bands (such as ranges of levels of energy) between the energy of the ground state, corresponding to tightly bound atomic nuclei of a material, and the free electron energy, which is required for an electron to escape entirely from the material. The energy bands correspond to a large number of discrete quanta of the electrons, and most of the states with low energy (closer to the nucleus) are full, up to a particular band called the valence band.

Semiconductors and insulators are distinguished from metals because the valence band in semiconductor materials are nearly filled under usual operating conditions, thus causing more electrons to be available in the 'conduction band', which is the band immediately above the valence band. The ease with which electrons in a semiconductor can be excited from the valence band to the conduction band depends on the band gap between the bands, and it is the size of this band that serves as an arbitrary dividing line (approximately 4 eV) between semiconductors and insulators.

In semiconductors, the valence band and the conduction band (Figure 12) are separated by a narrow band gap. The conduction band is empty at low temperature, but the valence band is completely filled. The energy gap is so narrow that electrons in the valence band may gain enough energy due to thermal randomness at room temperature. Thus, semiconductors have a negative temperature coefficient of resistance. However, the thermal agitation at room temperature does not give most of the valence electrons enough energy to move into the conduction band.

Semiconductors are generally classified by their electrical resistivity at room temperature with values of the range 0.010 to hundreds of mega ohms-cm, and strongly dependent on temperature. At absolute zero, pure, perfect crystal of most semiconductors will be an insulator, if we define an insulator as having a resistivity of above 10^{14} ohm-cm.

In other to increase the conductivity of the semiconductor material an impurity is introduced into the pure crystal in a process called doping. If the impurity introduces extra electrons into the pure crystal, the semiconductor is known as n-type semiconductor. However if an extra hole is created, then it is known as p-type semiconductor. The fusion of the n-type and n-type semiconductors in different forms, form the p-n junction. Phosphorus is a pentavalent electron that can be used to create an n-type semiconductor whereas lithium is a trivalent electron that can be used to make a p-type semiconductor. Devices based on semiconductors include transistors, switches and integrated circuits.

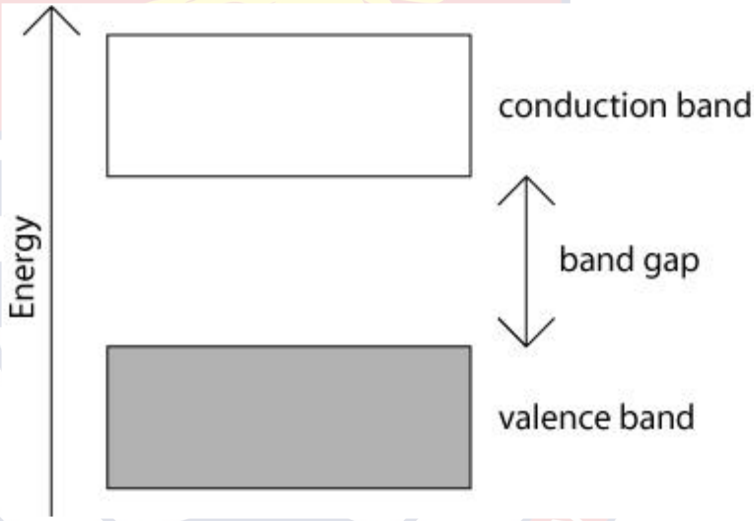


Figure 12: Energy Band for a Solid Crystal

Integrated Circuits

In electronics, an integrated circuit (IC) is a miniaturized electronic unit consisting mainly of semiconductor devices as well as passive components such as resistors, capacitors and inductors that has been manufactured in the surface of a thin substrate material. An IC is also known as microcircuit, microchip, silicon chip and chip. There are different scales of integration found among IC devices.

The ordinary Small Scale Integration (SSI) device consists of single gates, small amplifiers and other small circuits. The number of components on each chip is on the order of 20 or less. The Medium Scale Integration (MSI) devices have a slightly higher degree of complexity, and may have about 100 or so components on the chip. Devices such as operational amplifiers, shift registers, counters and EPROMs are usually classified as MSI devices.

Large scale integration (LSI) devices are mostly digital ICs and include functions such as calculators and microprocessors. Typically, LSI contain about 100 to 1000 components. Some newer devices are called Very Large Scale Integration (VLSI) and include some of the latest computer chips. The number and descriptions listed for SSI, MSI and LSI devices are approximates only, but serves to provide guidelines. Most linear IC devices are either SSI or MSI, with the latter predominating. ICs are used in almost all electronic equipment in use today and have revolutionized the world of electronics. The advent of ICs has produced a trend whereby the engineer tends to design more from a system viewpoint, rather than being involved in detailed circuit design. This is because an integrated circuit is a subsystem, which can be considered to be a device characterized by appropriate parameters that define its performance. Figure 13 shows an EPROM, MSI IC.

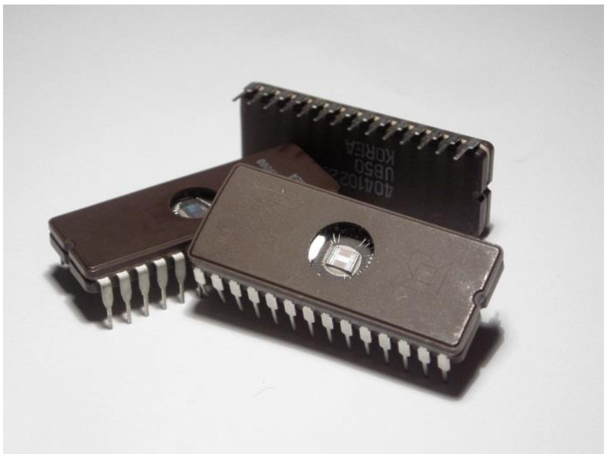


Figure 13: EPROM, MSI Integrated Circuit

Integrated circuit fabrication takes many forms, but it is convenient to divide the fabrication methods into two general categories, hybrid and monolithic. A monolithic device is one in which a complete circuit, including active and passive elements and all interconnections (except those going to external leads), are formed upon and within a single of crystalline silicon material.

A hybrid IC is a miniaturized electronic circuit constructed of individual semiconductor devices, as well as passive components, bonded to a substrate or circuit board. Hybrid ICs are made by a variety of techniques, but generally involve mounting separate parts on an insulating substrate with interconnections made by wires or a metallization pattern. A hybrid IC may contain one or more monolithic ICs and may use a combination of film and monolithic techniques.

Multichip hybrid ICs are, as the name indicates, made by connecting several chips together. The chips may be resistors, capacitors, transistors or even fairly complicated monolithic ICs. The chips are mounted on an insulating substrate and interconnected by wire bonding. Integrated circuits were made possible by experimental discoveries which showed that semiconductor devices could perform the functions of vacuum tubes and by mid-20th century technology advancements in semiconductor device fabrication. The integration of large numbers of tiny transistors into a small chip was an enormous improvement over the manual assembly of circuits using electronic components. The IC's production capability, reliability, and building-block approach to circuit design ensured the rapid adoption of standardized ICs in place of designs using discrete transistors.

Microcontrollers and Microprocessors

Microprocessors and microcontrollers are electronic semiconductor devices. The microcontroller is a by-product of the microprocessor (Ayala, 1991). They are both based on the same fabrication techniques and programming concepts and hence can perform the same function. A microprocessor incorporates the functions of a computer's central processing unit (CPU) on a single IC, or at most a few ICs. It is a multipurpose, programmable device that accepts digital data as input, processes it according to instructions stored in its memory, and provides results as output. It is an example of sequential digital logic, as it has internal memory. Microprocessors operate on numbers and symbols represented in the binary numeral system (Ayala, 1991).

This is not usually the case with microcontrollers. A microcontroller has a CPU (a microprocessor) in addition to a fixed amount of RAM, ROM, I/O ports, and a timer all embedded onto a single chip. The fixed amount of

RAM, ROM and a number of I/O ports makes it ideal for many applications where cost and space are critical. In many applications, for example a washing machine, there is no need for the computing power of a high speed processor such as 80486 or Pentium processors. In numerous applications, the space it takes, the power it consumes, and the price per unit are much more critical considerations than the computing power. These applications most often require some I/O operations to read signals and turn on and off certain bits. The block diagram of a microprocessor is illustrated in Figure 14.

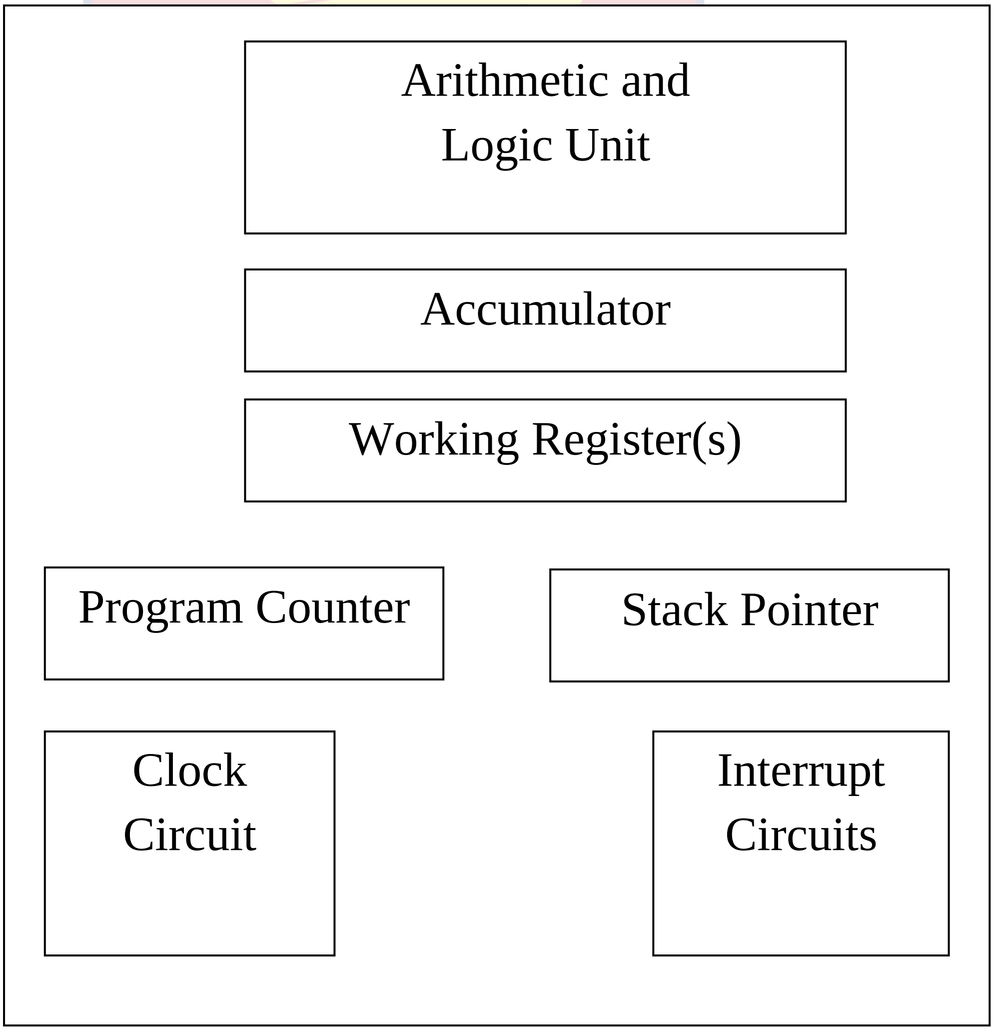


Figure 14: Block Diagram of a Microprocessor

The advent of low-cost computers on ICs has transformed modern society. General-purpose microprocessors in personal computers are used for computation, text editing, multimedia display, and communication over the internet. Many more microprocessors are part of embedded systems, providing digital control of a myriad of objects from appliances to automobiles to cellular phones and industrial process control.

For this reason, some call these microcontrollers 'kitty-bitty-processors'. Some microcontroller manufacturers have gone as far as integrating Analogue-to-Digital Converters and other peripherals into the micro controller (Masidi & Masidi, 2002).

Application of Microprocessors

Thousands of items that were traditionally not computer-related now include microprocessors. These include large and small household appliances, cars (and their accessories), car keys, tools and test instruments, toys, light switches/dimmers and electrical circuit breakers, smoke alarms, battery packs, and hi-fi audio/visual components. Such products as cellular telephones, Digital Versatile Disc or Digital Versatile Disc (DVD) video system and Advanced Television Systems Committee (ATSC) High Definition Television (HDTV) broadcast system fundamentally require consumer devices with powerful, low-cost, microprocessors. Increasingly, stringent pollution control standards effectively require automobile manufacturers to use microprocessor engine management systems, to allow optimal control of emissions over widely varying operating conditions of an automobile. Non-programmable controls would require complex, bulky, or costly implementation to achieve the results possible with a microprocessor.

A microprocessor control program can be easily tailored to different needs of a product line, allowing upgrades in performance with minimal redesign of the product. Different features can be implemented in different models of a product line at negligible production cost.

Microprocessor control of a system can provide control strategies that would be impractical to implement using electromechanical controls or purpose-built electronic controls. For example, an engine control system in an automobile can adjust ignition timing based on engine speed, load on the engine, ambient temperature, and any observed tendency for knocking; allowing an automobile to operate on a range of fuel grades.

Structure of the Microcontroller

A microcontroller is a small and low–cost computer built for the purpose of dealing with specific tasks, such as displaying information in a microwave LED or receiving information from a television's remote control. In short, a microcontroller is a true computer on a chip. Microcontrollers are mainly used in products that require a degree of control to be exerted by the user. The block diagram of the microcontroller is shown in Figure 15.

The microcontroller is a general-purpose device meant to read data, perform limited calculations on that data and control its environment based on those calculations. The prime use of a microcontroller is to control the operations of a machine using a fixed program that is stored in ROM and does not change over the lifetime of the system. The microcontroller is concerned with getting data from and to its own pins; the architecture and instruction set are optimized to handle data in bit and byte size.

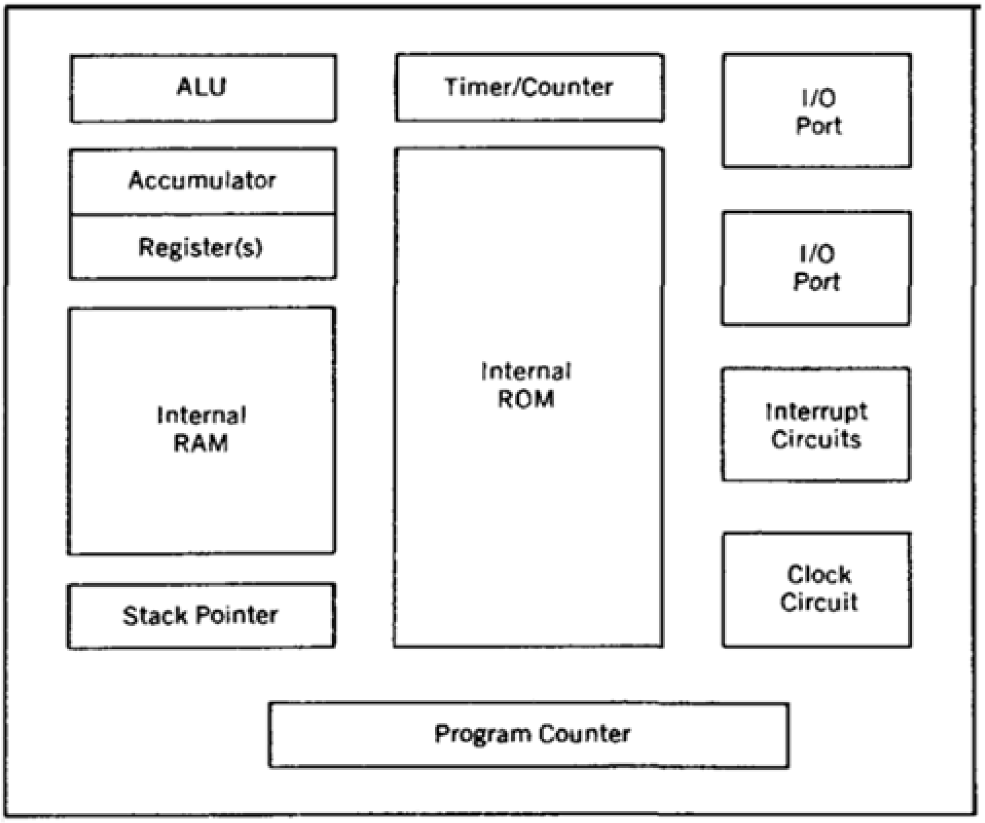


Figure 15: Block diagram of a microcontroller

The microcontroller takes a unique personality by the software program instructions given by the designer. Its capacity to perform arithmetic, make comparisons, and update memory makes it a very powerful digital problem solver. Changing a few program instructions, unlike the hard-wired system that may have to be totally redesigned and reconstructed, can usually make changes to an application. External support chips are incorporated into most of these applications leading to too much circuitry and cost (Houpis & Lamount, 1992). Despite all these, microprocessor–based system applications have a number of disadvantages.

Microcontrollers for Embedded Systems

Microcontrollers are used in numerous embedded system products. An embedded system uses a microcontroller or a microprocessor to do a single task only. A good example of an embedded system is a printer. It fetches data and prints it.

This kind of single tasking can be contrasted with a multi-tasking microprocessor such as a Pentium based personal computer (PC). A PC can be used for a myriad of applications such as word processors, network servers, multimedia applications and so on. The main reason a PC can run numerous applications is that it has RAM and an operating system that loads the application software into RAM and lets the CPU run it. In an embedded system, there is only one application software that is typically stored or 'burned' in ROM. A PC consists of embedded system peripherals such the keyboard, hard-disk controllers, printer, modem, and so on (Predko, 2000).

The 8051 Microcontroller

Microcontrollers were introduced when the skills of the semiconductor industry allowed several functions such as CPU, Memory and I/O to be integrated onto one piece of silicon. This in turn reduced the size (and the power consumption) of any microprocessor–based solution.

Because of the low cost and ease of integration within an application, they are used wherever possible to reduce the chip count of a piece of electronics. The word 'intelligent' tends to be applied to any device that contains some sort of processing or memory capability.

The intelligence of course belongs to the hardware and software designers who program the devices. Intel introduced the 8051 family in 1980, and from a simple microcontroller, it has grown into at least 30 different versions and have been second-sourced by numerous manufacturers. The 8051 was introduced to replace the older 8048 which was originally used as a keyboard handler for IBM PC's. The original product line-up includes a ROM-Based 8051, an EPROM-Based 8751 and a ROMless 8031.

ROM-Based 8051

The program memory is on-chip and is specified by the user. The manufacturer mask-programs the silicon disc so that the CPU can only execute the one program.

EPROM-Based 8751

This variant is used mostly for development or very small production runs. The advantage is that the memory may be erased and 'burned' again.

ROMless 8031

This chip needs an external memory (EPROM) to hold the program. To access the memory, the 8031 has to use some of its input/output (I/O) ports. This means that an 8031-Based Microcontroller has only 14 I/O lines left to directly interface to the outside world. When referring to the family, most engineers simply refer to the 8051. It was introduced at a time when a single +5V supply was a pleasant relief to digital system engineers. The original 40-pin DIL package was easily configured and the availability of 4x8 ports was pure luxury.

The basic device has a 128 bytes of on-chip RAM (expandable to 64 kB externally), 32 I/O lines, two 16-bit timers, six sources of program interrupt and full duplex Serial port (UART). Of the leading 8-bit microcontrollers, the 8051 family has the largest number of diversified (multiple source) suppliers. Nowadays, there are quite a number of companies that manufacture the MCS-51 based family of microcontrollers. These include Atmel, Philips/Signetics, Advanced Micro Devices (AMD), Siemens and Dallas Semiconductor.

General Architecture of 8051 Microcontroller

The 8051 microcontroller is an 8–bit, low–power microcontroller. The architecture of 8051 microcontroller depends on the application it is built for. For example, some designs include usage of more than one RAM, ROM and I/O functionality integrated into the package (Ibrahim, 2003).

The architecture of a typical microcontroller is complex and may include 4kB ROM, 128 bytes RAM, four 8-Bit I/O ports, two 16-Bit timers, full duplex serial interface, 64kB external code memory Space, 64kB external data, memory space, Boolean processor which is one bit, 210 bit addressable locations, and 4 μs multiply/divide for a 12-MHz crystal. Figure 16 shows a block diagram of the internal hardware architecture of the 8051.

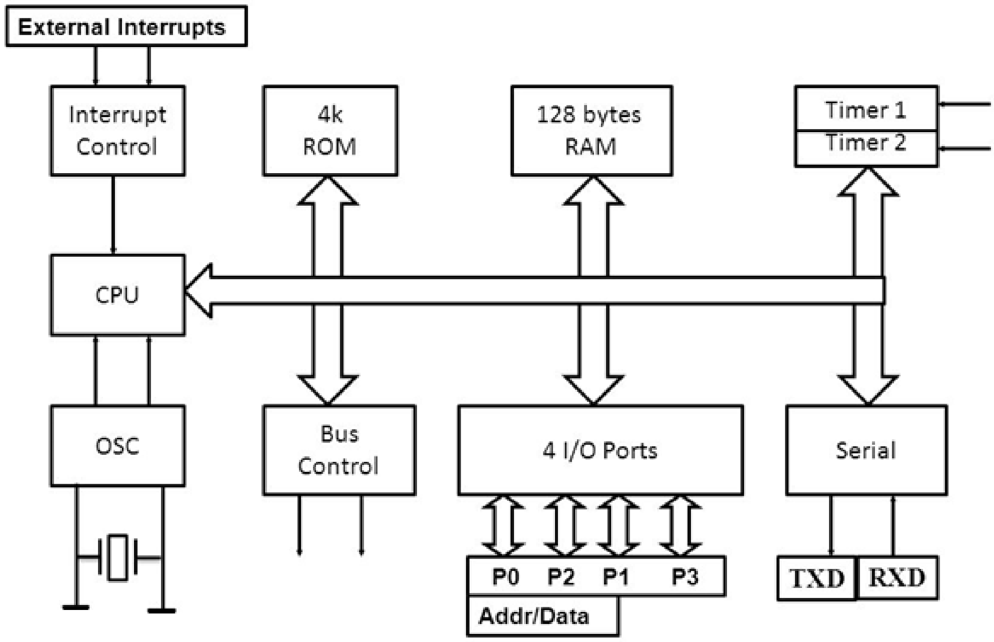


Figure 16: Block Diagram of 8051 Microcontroller

(https://www.google.com.gh)

Hardware Summary of 8051 Microcontroller (Around the Pins)

The Intel 8051 (Figure 17) is a 40-pin integrated circuit (IC) chip. The four I/O ports require a total of thirty-two pins. In order to provide for the other microcontroller control signals, most of those pins have alternate functions. The 8051 is able to handle the overlapping address spaces used by internal memory, external memory, and the special function registers.

Port 0 is dual-purpose, serving as either an 8-bit bidirectional I/O port on P0.0-P0.7 or the low-order multiplexed address/data bus (AD_0-AD_7). When used as I/O port, it sink up to 8 LS TTL loads in the LOW condition and is a float for the HIGH condition. The alternate port designations, AD_0-AD_7, are used to access external memory. The AD lines are demultiplexed into A_0-A_7 and D_0 -D_7 by using the Address Latch Enable (ALE) signal.

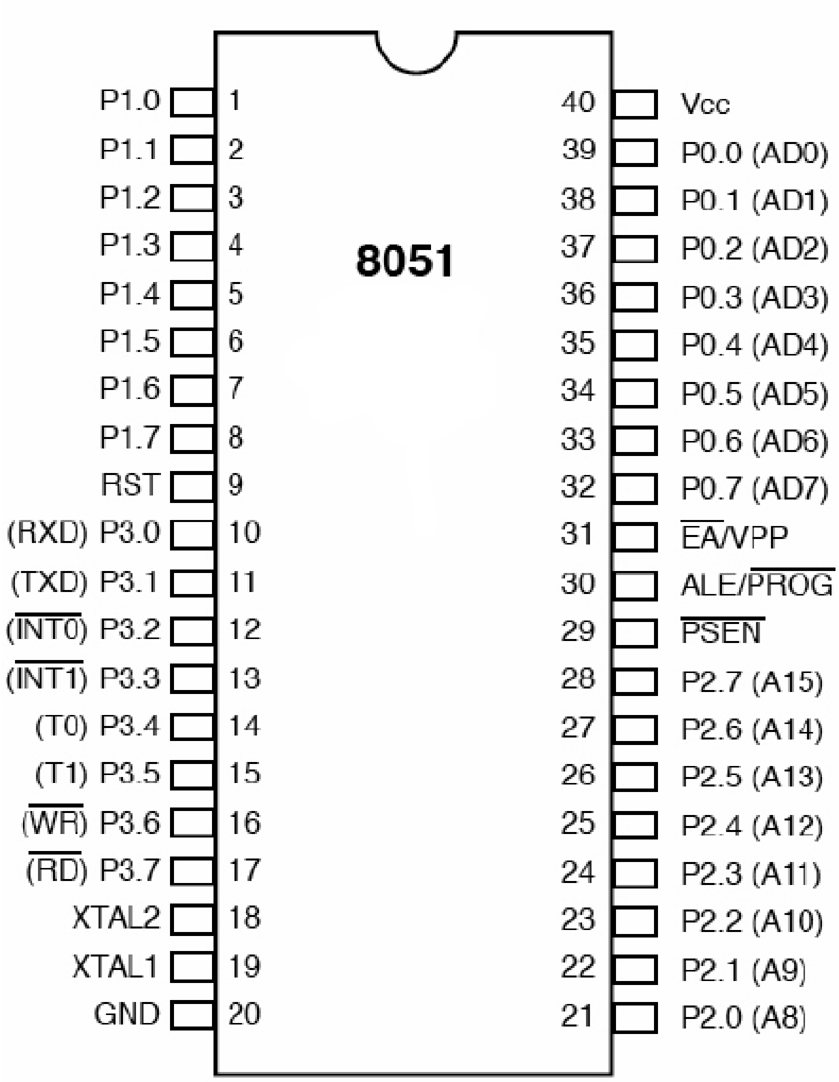


Figure 17: The 8051 Microcontroller Pin-Outs (Mackenzie, 1999)

Port 1 is an 8-bit bidirectional I/O port on P1.0-P1.7 and can sink or source up to 4 LS TTL loads. No alternate functions are assigned for Port 1 pins; thus they are used solely for interfacing to external devices.

Port 2 is a dual purpose port serving as either an 8-bit bidirectional I/O port P2.0-P2.7), or as the high-order address bus A8-A15 for access to external code memory. As an I/O port it can sink or source up to 4 LS TTL loads.

Port 3 is a dual purpose port (P3.0-P3.7), serving as an 8-bit bidirectional I/O port that can sink or source up to 4 LS TTL loads or as special-purpose I/O to provide the functions listed in Table 1.

Table 1: The Alternative Functions of Port 3

BIT	NAME	BIT ADDRESS	ALTERNATE FUNCTION
P3.0	RXD	B0H	Receive Data for serial Port
P3.1	TXD	B1H	Transmit Data for Serial Port
P3.2	/INTO	B2H	External Interrupt 0
P3.3	/INT1	B3H	External Interrupt 1
P3.4	T0	B4H	Timer/Counter 0 External Input
P3.5	T1	B5H	Timer/Counter 1 External Input
P3.6	/WR	B6H	External data memory WR strobe
P3.7	/RD	B7H	External data memory RD strobe

The Program Store Enable (PSEN) is read strobe for external program memory which is connected to the Output Enable (OE) of the external ROM or EPROM. Address Latch Enable (ALE) output pulse for latching the low-order byte of the address during accesses to external memory. It is also the program pulse input (PROG)’ during programming of the EPROM versions of the 8051 and the FLASH based microcontrollers e.g. The Atmel AT89C51.

The External Access (EA) is tied LOW to enable the microcontroller to fetch its program code from an external memory IC. It also receives the 21 V programming supply voltage for programming the EPROM parts. The Reset

(RST) input on pin 9 resets the microcontroller when active HIGH. For normal operation, RST is low.

XTAL1, XTAL2

XTAL1 is the input part of internal oscillator. It is used for synchronizing the MCU with another circuit. Input of the internal oscillator connects to XTAL2. When an external oscillator is used, XTAL2 is without a function.

Supply Voltage (Vcc) and Ground (GND)

These are the +5V supply (Vcc = Pin 40) and Ground pin (GND = Pin 20) respectively. ICs using bipolar transistors have V_{CC} (positive) power supply pins. In many single supply digital and analog circuits the negative power supply is also called 'GND'.

I/O Port Structure

Data is loaded into a port latch when a port pin is written to. The latch drives a field-effect transistor connected to the port pin. The drive capabilities are low-power Skottky loads for ports 1, 2 and 3, and eight LS loads for port 0. When port 0 is functioning as the external address/data bus, the pull-up resistor is present, otherwise it is absent. Depending on the input characteristics of the device being driven by the port, an external pull-up resistor may be needed. There is both a "read latch" and "read pin" capability. A read-modify-write operation instruction (e.g. CPL P1.3) reads the latch to avoid misinterpreting the voltage level. This happens when the pin is heavily loaded like when driving the base of a transistor. Instructions that input a port bit (e.g., MOV C, P1.3) read the pin. The port latch must contain a 1; in this case, otherwise the FET driver is ON and pulls the output low.

A system reset sets all port latches, so port pins may be used as inputs without explicitly setting the port latches. However, if a port latch is cleared (e.g., CLR P1.3), then it cannot function as an input unless the latch is set first (i.e., SETB P1.3).

Memory Organization of the 8051 Microcontroller

All 80C51 devices have separate address spaces for program and data memory. The logical separation of program and data memory allows the data memory to be accessed by 8-bit addresses, which can be quickly stored and manipulated by an 8-bit CPU. Nevertheless, 16-bit data memory addresses can also be generated through the DPTR register. Program memory (ROM, EPROM) can only be read, not written to. There are 64 k bytes of program memory. In the 89S51, the lowest 4K bytes of program are on-chip. In the ROMless, versions, all program memory is external. Data Memory (RAM) occupies a separate address space from Program Memory. In the 80C51, the lowest 128 bytes of data memory are on-chip. Up to 64K bytes of external RAM can be addressed in the external Data Memory. In the ROMless version, the lowest 128 bytes are on-chip.

The on-chip RAM contains a rich arrangement of general-purpose storage, bit-addressable storage, register banks, and special function registers. Two notable features are the registers and I/O ports are memory mapped and accessible like any other memory location, and the stack resides within the internal RAM, rather than in external RAM as typical with microprocessors.

Central Processor Unit (CPU)

Central Processor Unit or CPU is the mind of any processing machine. It scrutinizes and manages all processes that are carried out in the Microcontroller. User has no power over the functioning of CPU. It interprets program printed in storage space (ROM) and carries out all of them and do the projected duty.

Interrupts

An Interrupt is a sub-routine call that reads the Microcontroller's key function or job and helps it to perform some other program which is extra important at that point of time. The characteristic of Interrupt is extremely constructive as it aids in emergency cases. Interrupts provides us a method to postpone or delay the current process, carry out a sub-routine task and then all over again restart standard program implementation.

The Microcontroller 8051 can be assembled in such a manner that it momentarily stops or break the core program at the happening of interrupt. When sub-routine task is finished then the implementation of core program initiates automatically as usual. There are 5 interrupt supplies in 8051 Microcontroller, two out of five are peripheral interrupts, two are timer interrupts and one is serial port interrupt.

Bus

Fundamentally, bus is a group of wires which functions as a communication canal or means for the transfer of data. These buses comprise of 8, 16 or more cables. As a result, a bus can bear 8 bits or 16 bits all together. There are two types of buses. These are Address Bus and Data Bus. An address bus of the 8051 Microcontroller consists of 16 bit address bus. It is brought into play to address memory positions. It is also utilized to transmit the address from the CPU to memory. The data bus of 8051 Microcontroller on the other hand comprises of 8 bits data bus. It is employed to cart data.

Oscillator

The Microcontroller is a digital circuit piece of equipment. Thus it needs a timer for it to function. For this function, Microcontroller 8051 consists of an on-chip oscillator which toils as a time source for CPU. As the productivity thumps of oscillator are steady as a result, it facilitates harmonized employment of all pieces of 8051 Microcontroller.

Input/output Port

The Microcontroller is employed in embedded systems to manage the functions of devices. Thus to gather it to other machinery, gadgets or peripherals we need I/O (input/output) interfacing ports in Micro-controller. For this function Microcontroller 8051 consists of 4 input/output ports to unite it to other peripherals. Timers/Counters: Microcontroller 8051 is incorporated with two 16 bit counters & timers. The counters are separated into 8 bit registers. The timers are utilized for measuring the intervals, to find out pulse width etc.

8051 Microcontroller Applications

According to Ayala (1991), the 8051 microcontroller has been in application in a large amount of machines, principally because it is simple to incorporate in a project or to assemble a machine around it. The key spots of spotlight are energy management, touch screens, automobiles and medical devices.

Energy Management

Competent measuring device systems aid in calculating energy consumption in domestic and industrialized applications. These meter systems are prepared competent by integrating microcontrollers.

Touch screens

A high degree of microcontroller suppliers integrate touch sensing abilities in their designs. Transportable devices such as media players, gaming devices & cell phones are some illustrations of microcontroller integrated with touch sensing screens.

Automobiles

The microcontroller 8051 discovers broad recognition in supplying automobile solutions. They are extensively utilized in hybrid motor vehicles to control engine variations. In addition, works such as cruise power and antibrake mechanism has created it more capable with the amalgamation of microcontrollers. The advancement in transportation technology is developing the efficient robotic vehicles which can be used for transportation without driver.

Medical Devices

Handy medicinal gadgets such as glucose and blood pressure monitors bring into play microcontrollers, to put on view the measurements. As a result, offering higher dependability in giving correct medical results.

The application of microcontroller 8051 in medical applications made revolutionary changes in the medical field. The patient health monitoring system with location details by GPS over GSM is an electronic project based on the application of microcontroller. This project is designed for tracking the patient's location such that it enables the facility to reach patient location quickly in case of emergency.

Interfacing with the Analog World

A digital quantity has a value that is specified as one of two possibilities, such as 0 or 1, LOW or HIGH, true or false, and so on. In practice, a digital quantity such as a voltage may actually have a value that is anywhere within specified ranges, and we define values within a given range to have the same digital value. For example, TTL, we know that 0 V to 0.8 V = logic 0 and 2 V to 5 V = logic 1.

Any voltage falling in the range of 0 to 0.8 V is given the digital value 0, and any voltage in the range 2 to 5 V is assigned the digital value 1. The exact voltage values are not significant because the digital circuits respond in the same way to all voltage values within a given range. By contrast, an analog quantity can take on any value over a continuous range of values and, most important, its exact value is significant. For example, the output of an analog temperature-to-voltage converter might be measured as 2.76 V, which may represent a specific temperature of 27.6 ^{o}C. If the voltage was measured as something different, such as 2.34 V or 3.78 V, this would represent a completely different temperature.

In other words, each possible value of an analog quantity has a different meaning. Another example of this is the output voltage from an audio amplifier into a speaker. This voltage is an analog quantity because each of its possible values produces a different response in the speaker. Most physical variables are analog in nature and can take on any value within a continuous range of values. Examples include temperature, pressure, light intensity, audio signals, position, rotational speed, and flow rate. Digital systems perform all of their internal operations using digital circuitry and digital operations. Any information that must be input to a digital system must first be put into digital form. Similarly, the outputs from a digital system are always in digital form. When a digital system such as a computer is to be used to monitor and/or control a physical process, we must deal with the difference between the digital nature of the computer and the analog nature of the process variables.

Figure 18 illustrates the five elements that are involved when a computer is monitoring and controlling a physical variable that is assumed to be analog. The five elements are a transducer, an ADC, a digital system, a DAC and an actuator.

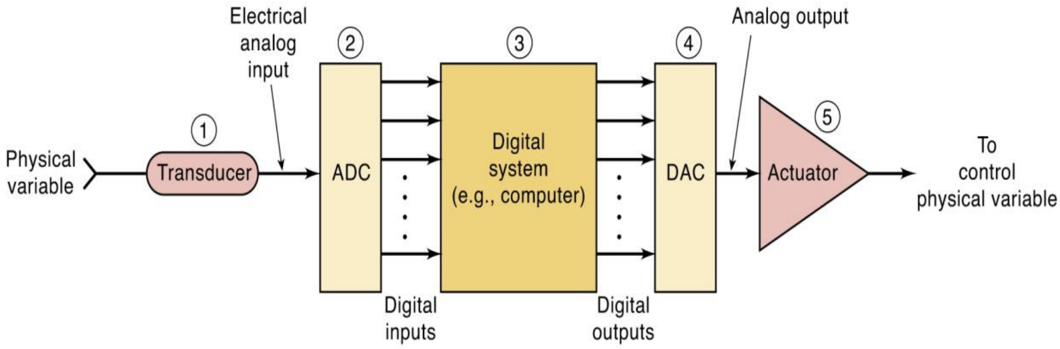


Figure 18: Analog-to-Digital Converter (ADC) and Digital-to-Analog Converter (DAC) (Tocci et al., 2011)

Transducer

The physical variable is normally a nonelectrical quantity. A transducer is a device that converts the physical variable to an electrical variable. Some common transducers include thermistors, photocells, photodiodes, flow meters, pressure transducers, and tachometers. The electrical output of the transducer is an analog current or voltage that is proportional to the physical variable that it is monitoring. For example, the physical variable could be the temperature of water in a large tank that is being filled from cold and hot water pipes. Let's say that the water temperature varies from 80 to 150 °C and that a thermistor and its associated circuitry convert this water temperature to a voltage ranging from 800 to 1500 mV. Note that the transducer's output is directly proportional to temperature such that each 1 °C produces a 10 mV output. This proportionality factor was chosen for convenience.

Analog-to-digital converter (ADC)

The transducer's electrical analog output serves as the analog input to the ADC. The ADC converts this analog input to a digital output. This digital output consists of a number of bits that represent the value of the analog input. For example, the ADC might convert the transducer's 800 to 1500 mV analog values to binary values ranging from 01010000 (80) to 10010110 (150). Note that the binary output from the ADC is proportional to the analog input voltage so that each unit of the digital output represents 10 mV.

Computer

The digital representation of the process variable is transmitted from the ADC to the digital computer, which stores the digital value and processes it according to a program of instructions that it is executing. The program might perform calculations or other operations on this digital representation of temperature to come up with a digital output that will eventually be used to control the temperature.

Digital-to-Analog Converter (DAC)

This digital output from the computer is connected to a DAC, which converts it to a proportional analog voltage or current. For example, the computer might produce a digital output ranging from 00000000 to 11111111, which the DAC converts to a voltage ranging from 0 to 10 V.

Actuator

The analog signal from the DAC is often connected to some device or circuit that serves as an actuator to control the physical variable. For our water temperature example, the actuator might be an electrically controlled valve that regulates the flow of hot water into the tank in accordance with the analog voltage from the DAC. The flow rate would vary in proportion to this analog voltage, with 0 V producing no flow and 10 V producing the maximum flow. Thus, we see that ADCs and DACs function as interfaces between a completely digital system, such as a computer, and the analog world. This function has become increasingly more important as inexpensive microcomputers have moved into areas of process control where computer control was previously not feasible.

Analog-to-Digital Conversion

Signals in the real world are analog: light, sound, and photographs, etc. So, real-world signals must be converted into digital, using ADC, before they can be manipulated by digital equipment. When you scan a picture with a scanner what the scanner, is doing is an analog-to-digital conversion. It is taking the analog information provided by the picture (light) and converting into digital.

An ADC (Figure 19) is a device that converts a continuous physical quantity (usually voltage) to a digital number that represents the quantity's amplitude. The conversion involves quantization of the input, so it necessarily introduces a small amount of error.

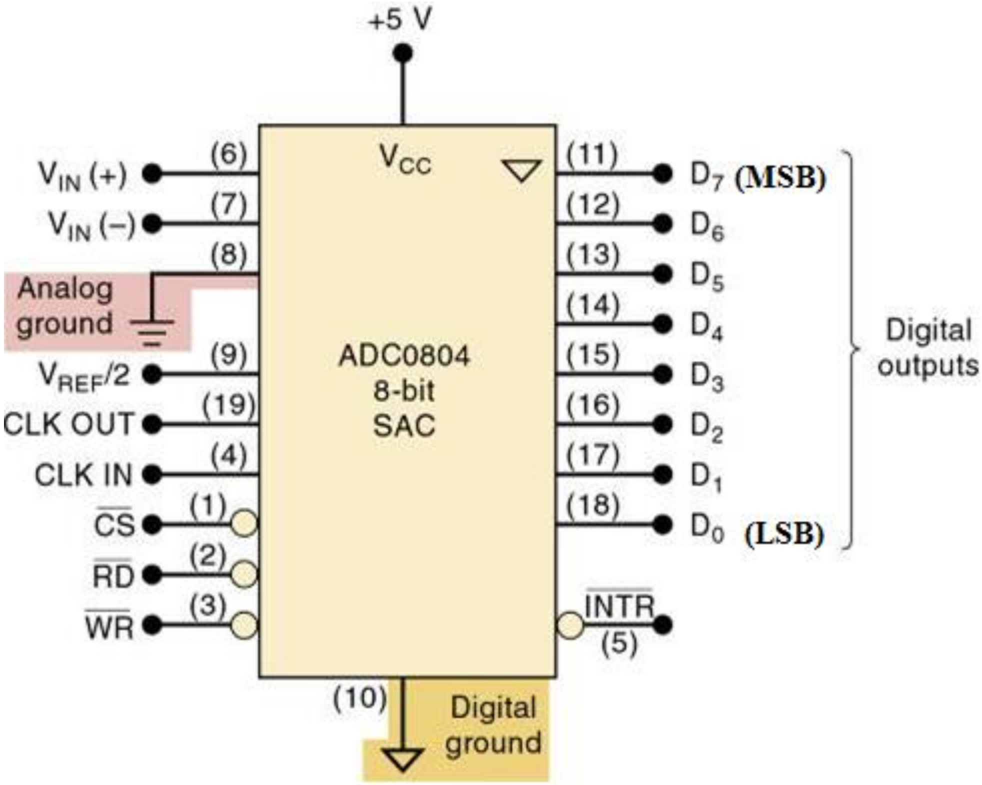


Figure 19: Analog to Digital Converter (Tocci, et al, 2011)

Instead of doing a single conversion, an ADC often performs the conversions periodically. The result is a sequence of digital values that have converted a continuous-time and continuous-amplitude analog signal to a discrete-time and discrete-amplitude digital signal.

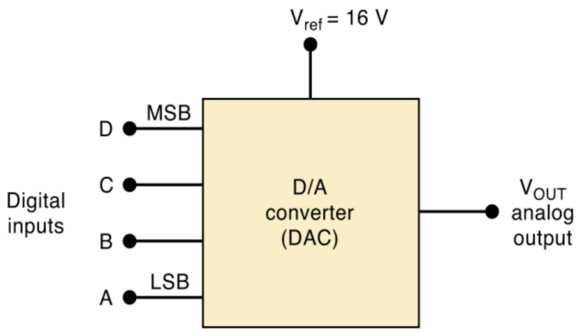
Digital-to-Analog Converter

Many voltages and currents in electronics vary continuously over some range of values. In digital circuitry the signals are at either one of two levels, representing the binary values of 1 or zero. An ADC obtains a digital value representing an input analog voltage, while a DAC changes a digital value back into an analog voltage (Boylestad & Nashelsky, 2009).

To Tocci & Widmer (2001), a DAC is a device that converts a digital (usually binary) code to an analog signal which may be current, voltage or electric charge. Signals are easily stored and transmitted in digital form, but a DAC is needed for the signal to be recognized by human senses or other non-digital systems.

A common use of digital-to-analog converters is generation of audio signals from digital information in a music player. Digital video signals are converted to analog in television and mobile phones to display colours and shades. Digital-to-analog conversion can degrade a signal, so conversion details are normally chosen so that the errors are negligible.

Basically, D/A conversion is the process of taking a value represented in digital code (such as straight binary or BCD) and converting it to a voltage or current that is proportional to the digital value. Figure 20 (a) shows the symbol for a typical four bit D/A converter.



a

b

D	C	B	A	V_{OUT}	
0	0	0	0	0	Volts
0	0	0	1	1	
0	0	1	0	2	
0	0	1	1	3	
0	1	0	0	4	
0	1	0	1	5	
0	1	1	0	6	
0	1	1	1	7	
1	0	0	0	8	
1	0	0	1	9	
1	0	1	0	10	
1	0	1	1	11	
1	1	0	0	12	
1	1	0	1	13	
1	1	1	0	14	
1	1	1	1	15	Volts

Figure 20: A four bit Digital-to-Analog Converter with voltage output (Tocci, & Widmer, 2001)

Notice that there is an input for a voltage reference, V_{ref}. This input is used to determine the full-scale output or maximum value that the DAC can produce. The digital inputs *D*, *C*, *B*, and *A* are usually derived from the output register of a digital system. The $2^4 = 16$ different binary numbers represented by these four bits are listed in Figure 20 (b). For each input number, the DAC output voltage is a unique value.

In fact, for this case, the analog output voltage V_{OUT} is equal in volts to the binary number. It could also have been twice the binary number or some other proportionality factor. The same idea would hold true if the DAC output were a current I_{OUT}. In general,

$$\text{Analog output} = K \times \text{Digital input} \qquad 10$$

where K is the proportionality factor and is a constant value for a given DAC connected to a fixed reference voltage. The analog output can, of course, be a voltage or a current. When it is a voltage, K will be in voltage units, and when the output is a current, K will be in current units. For the DAC of Figure 20, K = 1 V, so that

$$V_{OUT} = (1\ V) \times \text{Digital input} \qquad 11$$

Equation 11 can be used to calculate V_{OUT} for any value of digital input.

Analog Output

The output of a DAC is technically not an analog quantity because it can take on only specific values, such as the 16 possible voltage levels for V_{OUT} in Figure 20, as long as V_{ref} is constant. Thus, in that sense, it is actually digital. The number of different possible output values can be increased and the difference between successive values decreased by increasing the number of input bits. This will allow us to produce an output that is more and more like an analog quantity that varies continuously over a range of values. In other words, the DAC output is a "pseudo-analog" quantity. We will continue to refer to it as analog, keeping in mind that it is an approximation to a pure analog quantity.

Input Weights

For the DAC of Figure 20, each digital input contributes a different amount to the analog output. This is easily seen if we examine the cases where only one input is HIGH (Table 2). The contributions of each digital input are weighted according to their position in the binary number. Thus, A, which is the LSB, has a weight of 1 V; B has a weight of 2 V; C has a weight of 4 V; and D, the MSB, has the largest weight, 8 V. The weights are successively doubled for each bit, beginning with the LSB. Thus, we can consider V_{OUT}, to be the weighted sum of the digital inputs. For instance, to find V_{OUT} for the digital input 0111, we can add the weights of the C, B, and A bits to obtain 4 V + 2 V + 1 V = 7 V.

Table 2: Voltage output of a four bit DAC

D	C	B	A	V_{OUT}
0	0	0	1	1
0	0	1	0	2
0	1	0	0	4
1	0	0	0	8

Resolution (Step Size)

Resolution of a DAC is defined as the smallest change that can occur in the analog output as a result of a change in the digital input. Referring to the table in Figure 20 (b), we can see that the resolution is 1 V because V_{OUT} can change by no less than 1 V when the digital input value is changed. The resolution is always equal to the weight of the LSB and is also referred to as the step size because it is the amount that V_{OUT}, will change as the digital input value is changed from one step to the next. This is illustrated better in Figure 21, where the outputs from a four-bit binary counter provide the inputs to our DAC. As the counter is being continually cycled through its 16 states by the clock signal, the DAC output is a staircase waveform that goes up 1 V per step. When the counter is at 1111, the DAC output is at its maximum value of 15V; this is its full-scale output. When the counter recycles to 0000, the DAC output returns to 0 V.

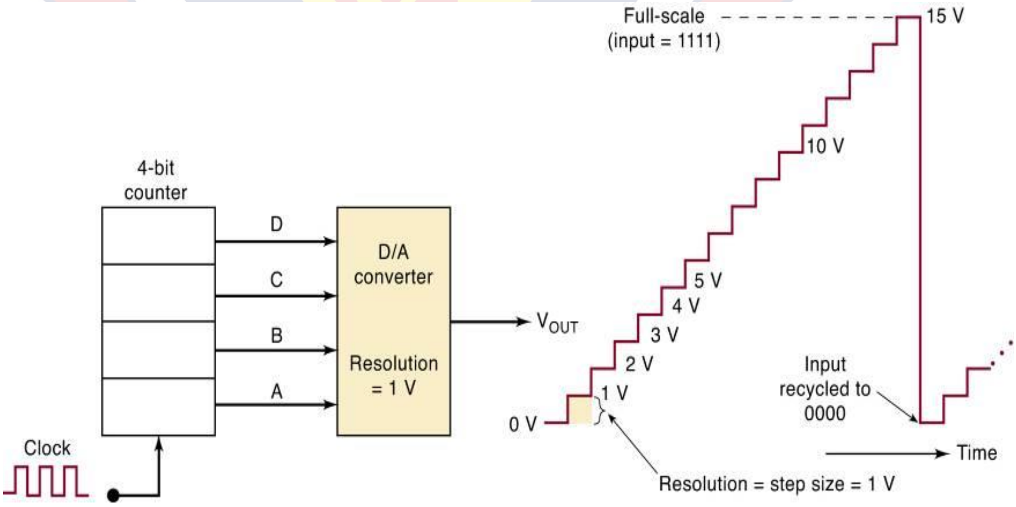


Figure 21: Output waveforms of a DAC as inputs are provided by a binary counter (Tocci et al, 2011)

The resolution (or step size) is the size of the jumps in the staircase waveform; in this case, each step is 1 V. Note that the staircase has 16 levels corresponding to the 16 input states, but there are only 15 steps or jumps between the 0 V level and full-scale. In general, for an N-bit DAC, the number of different levels will be 2^N, and the number of steps will be $2^N - 1$. It is essential to note that resolution (step size) is the same as the proportionality factor in the DAC input/output relationship in equation 10.

A new interpretation of this expression would be that the digital input is equal to the number of steps, K is the amount of voltage (or current) per step, and the analog output is the product of the two. We now have a convenient way of calculating the value of K for the D/A:

$$\text{Resolution} = \text{K} = \frac{A_{fs}}{(2^n - 1)} \qquad 12$$

where A_{fs} is the analog full-scale output and n is the number of bits.

Percentage Resolution

Although resolution can be expressed as the amount of voltage or current per step, it is also useful to express it as a percentage of the full-scale output. To illustrate, the DAC of Figure 21 has a maximum full-scale output of 15 V. The step size is l V, which gives a percentage resolution of

$$\%\ \text{Resolution} = \frac{\text{step size}}{\text{full scale (F.S.)}} \times 100\% \qquad 13$$

$$= \frac{1\ \text{V}}{15\ \text{V}} \times 100\% = 6.67\%$$

This means that it is only the number of bits that determines the percentage resolution. Increasing the number of bits increases the number of steps to reach full scale, so that each step is a smaller part of the full-scale voltage.

Most DAC manufacturers specify resolution as the number of bits. Percentage resolution can also be expressed in terms of the number of bits (N) or t total number of steps. That is;

$$\%\ \text{Resolution} = \frac{1}{\text{total number of steps}} \times 100\% \qquad 14$$

$$\%\ \text{Resolution} = \frac{1}{2^{N} - 1} \times 100\% \qquad 15$$

Meaning of Resolution

A DAC cannot produce a continuous range of output values and so, strictly speaking, its output is not truly analog. A DAC produces a finite set of output values. For example, a computer generates a digital output to provide an analog voltage between 0 and 10 V to an electrically controlled valve. The DAC's resolution (number of bits) determines how many possible voltage values the computer can send to the valve. If a six-bit DAC is used, there will be 63 possible steps of 0.159 V between 0 and 10 V. When an eight-bit DAC is used, there will be 255 possible steps of 0.039 V between 0 and 10 V. The greater the number of bits, the finer the resolution (the smaller the step size).

The system designer must decide what resolution is needed on the basis of the required system performance. The resolution limits how close the DAC output can come to a given analog value. Generally, the cost of DACs increases with the number of bits, and so the designer will use only as many bits as necessary.

Accuracy

DAC manufacturers have several ways of specifying accuracy. The two most common are called full-scale error and linearity error, which are normally expressed as a percentage of the converter's full-scale output (% F.S.). Full-scale error is the maximum deviation of the DAC's output from its expected (ideal) value, expressed as a percentage of full scale. Linearity error is the maximum deviation in step size from the ideal step size.

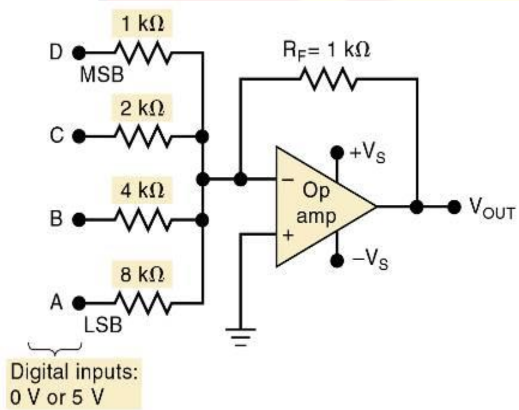
It is important to understand that accuracy and resolution of a DAC must be compatible. It is illogical to have a resolution of, say, 1 percent and accuracy of 0.1 percent, or vice versa. To illustrate, a DAC with a resolution of 1 percent and an F.S. output of 10 V can produce an output analog voltage within 0.1 V of any desired value, assuming perfect accuracy. It makes no sense to have a costly accuracy of 0.01% F.S. (or 1 mV) if the resolution already limits the closeness of the desired value to 0.1 V. The same can be said for having a resolution that is very small (many bits) while the accuracy is poor; it is a waste of input bits.

Offset Error

Ideally, the output of a DAC will be zero volts when the binary input is all 0s. In practice, however, there will be a very small output voltage for this situation; this is called offset error. This offset error, if not corrected, will be added to the expected DAC output for all input cases. Many DACs have an external offset adjustment that allows you to zero the offset. This is usually accomplished by applying all 0s to the DAC input and monitoring the output while an offset adjustment potentiometer is adjusted until the output is as close to 0 V as required.

DA Converter Circuitry

Figure 22 (a) shows the basic circuit for one type of four-bit DAC. The inputs ***A*,** B, C, and D are binary inputs that are assumed to have values of either 0 or 5 V. The operational amplifier is employed as a summing amplifier, which produces the weighted sum of these input voltages.



a

b

Input code					
D	C	B	A	V_{OUT} (volts)	
0	0	0	0	0	
0	0	0	1	−0.625	← LSB
0	0	1	0	−1.250	
0	0	1	1	−1.875	
0	1	0	0	−2.500	
0	1	0	1	−3.125	
0	1	1	0	−3.750	
0	1	1	1	−4.375	
1	0	0	0	−5.000	
1	0	0	1	−5.625	
1	0	1	0	−6.250	
1	0	1	1	−6.875	
1	1	0	0	−7.500	
1	1	0	1	−8.125	
1	1	1	0	−8.750	
1	1	1	1	−9.375	← Full-scale

Figure 22: Simple DAC using an op-amp summing amplifier with binary weighted resistors (Tocci et al., 2011)

The summing amplifier multiplies each input voltage by the ratio of the feedback resistor R_F to the corresponding input resistor R_{IN}**.** In this circuit R_F = 1 kΩ, and the input resistors range from 1 to 8 kΩ. The D input has R_{IN} = 1 kΩ, so the summing amplifier passes the voltage at D with no attenuation. The C input has R_{IN} = 2 kΩ, so that it will be attenuated by ½. Similarly, the B input will be attenuated by ¼ and the A input by $^{1}/_{8}$. The amplifier output can thus be expressed as

$$V_{OUT} = -\left(V_D + \frac{1}{2}V_C + \frac{1}{4}V_B + \frac{1}{8}V_A\right) \qquad 16$$

The negative sign is present because the summing amplifier is a polarity–inverting amplifier, but it will not concern us here.

Clearly, the summing amplifier output is an analog voltage that represents a weighted sum of the digital inputs, as shown by the table in Figure 22 (b). This table lists all of the possible input conditions and the resultant amplifier output voltage. The output is evaluated for any input condition by setting the appropriate inputs to either 0 or 5 V.

Digital-to-analog conversion can also be achieved using a network of resistors, called a ladder network (Boylestad & Nashelsky, 2009). A ladder network accepts inputs of binary values at, typically, 0 V or V_{ref} and provides an output voltage proportional to the binary input value. Figure 23 shows a ladder network with four input voltages, representing 4 bits of digital data and a dc voltage output. The output voltage is proportional to the digital input value as given by the relation

$$V_0 = \frac{(B_0 \times 2^0) + (B_1 \times 2^1) + (B_2 \times 2^2) + (B_3 \times 2^3)}{2^4} V_{ref} \qquad 17$$

A basic R-2R resistor ladder network is shown in Figure 23. Bit a_{n-1} (most significant bit, MSB) through bit a_0 (least significant bit, LSB) are driven from digital logic gates. Ideally, the bit inputs are switched between $V = 0$ (logic 0) and $V = V_{ref}$ (logic 1). The R-2R network causes these digital bits to be weighted in their contribution to the output voltage V_{out}. Depending on which bits are set to 1 and which to 0, the output voltage (V_{out}) will have a corresponding stepped value between 0 and V_{ref} minus the value of the minimal step, corresponding to bit 0. The actual value of V_{ref} (and the voltage of logic 0) will depend on the type of technology used to generate the digital signals.

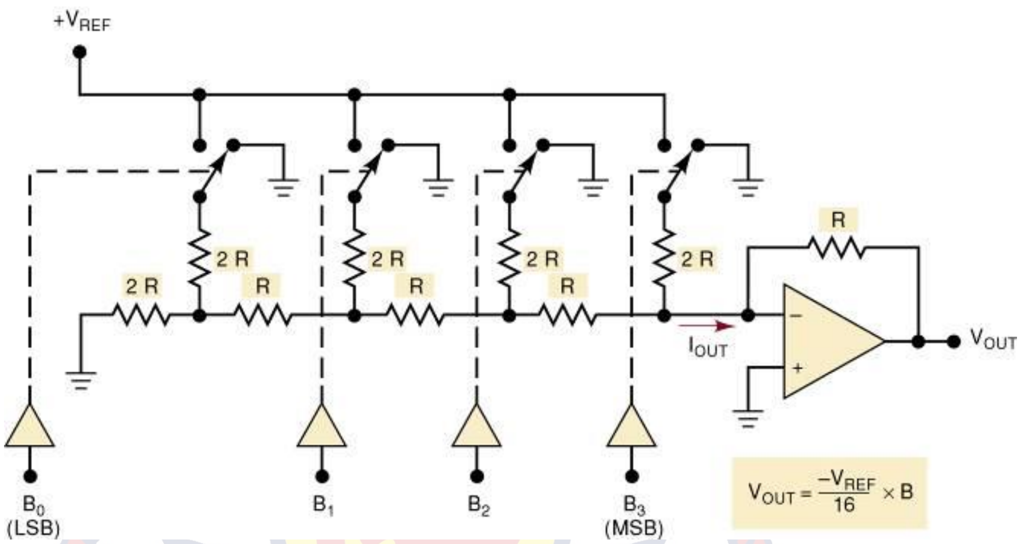


Figure 23: 4-Bit R-2R Resistor Ladder

The function of the ladder network is to convert the 16 possible binary values from 0000 to 1111 into one of 16 voltage levels in steps of $V_{ref}/16$. Using more sections of ladder allows having more binary inputs and greater quantization for each step. For example, a 10-stage ladder network could extend the number of voltage steps or the voltage resolution to $V_{ref}/2^{10}$ or $V_{ref}/1024$. A reference voltage of V_{ref} = 10 V would then provide output voltage steps of 10 V/1024 or approximately 10 mV. More ladder stages provide greater voltage resolution. In general, the voltage resolution for n ladder stages is

$$\frac{V_{ref}}{2^n} \quad (18)$$

The R-2R ladder is inexpensive and relatively easy to manufacture, since only two resistor values are required (or even one, if R is made by placing a pair of 2R in parallel, or if 2R is made by placing a pair of R in series). It is fast and has fixed output impedance R. The R-2R ladder operates as a string of current dividers, whose output accuracy is solely dependent on how well each resistor is matched to the others.

Depending on the type of logic gates used and design of the logic circuits, there may be transitional voltage spikes at such major crossings even with perfect resistor values. These can be filtered with capacitance at the output node (the consequent reduction in bandwidth may be significant in some applications).

Finally, the 2R resistance is in series with the digital-output impedance. High-output-impedance gates may be unsuitable in some cases. For all of the above reasons this type of DAC tends to be restricted to a relatively small number of bits; although integrated circuits may push the number of bits to 14 or even more, 8 bits or fewer is more typical.

Accuracy of R-2R Resistor Ladders

Resistors used with the more significant bits must be proportionally more accurate than those used with the less significant bits; for example, in the R-2R network discussed above, inaccuracies in the bit-4 (MSB) resistors must be insignificant compared to R/32 (i.e., much better than 3 %). Further, to avoid problems at the 10000_2-to-01111_2 transition, the sum of the inaccuracies in the lower bits must be significantly less than R/32. The required accuracy doubles with each additional bit: for 8 bits, the accuracy required will be better than 1/256 (0.4 %).

Within integrated circuits, high-accuracy R-2R networks may be printed directly onto a single substrate using thin-film technology, ensuring the resistors share similar electrical characteristics. Even so, they must often be laser-trimmed to achieve the required precision. Such on-chip resistor ladders for digital-to-analog converters achieving 16-bit accuracy have been demonstrated. On a printed circuit board, using discrete components, resistors of 1 % accuracy would suffice for a 5-bit circuit, however with bit counts beyond this the cost of ever increasing precision resistors becomes prohibitive. For a 10-bit converter, even using 0.1 % precision resistors would not guarantee monotonicity of output. This being said, high resolution R-2R ladders formed from discrete components are sometimes used, the nonlinearity being corrected in software.

Conversion Accuracy

The table in Figure 20 (b) gives the ideal values of V_{OUT} for the various input cases. How close the circuit comes to producing these values depends primarily on two factors: (1) the precision of the input and feedback resistors and (2) the precision of the input voltage levels.

The resistors can be made very accurate (within 0.01 percent of the desired values) by trimming, but the input voltage levels must be handled differently. It should be clear that the digital inputs cannot be taken directly from the outputs of FFs or logic gates because the output logic levels of these devices are not precise values like 0 V and 5 V but vary within given ranges.

For this reason, it is necessary to add some more circuitry between each digital input and its input resistor to the summing amplifier, as shown in Figure 24.

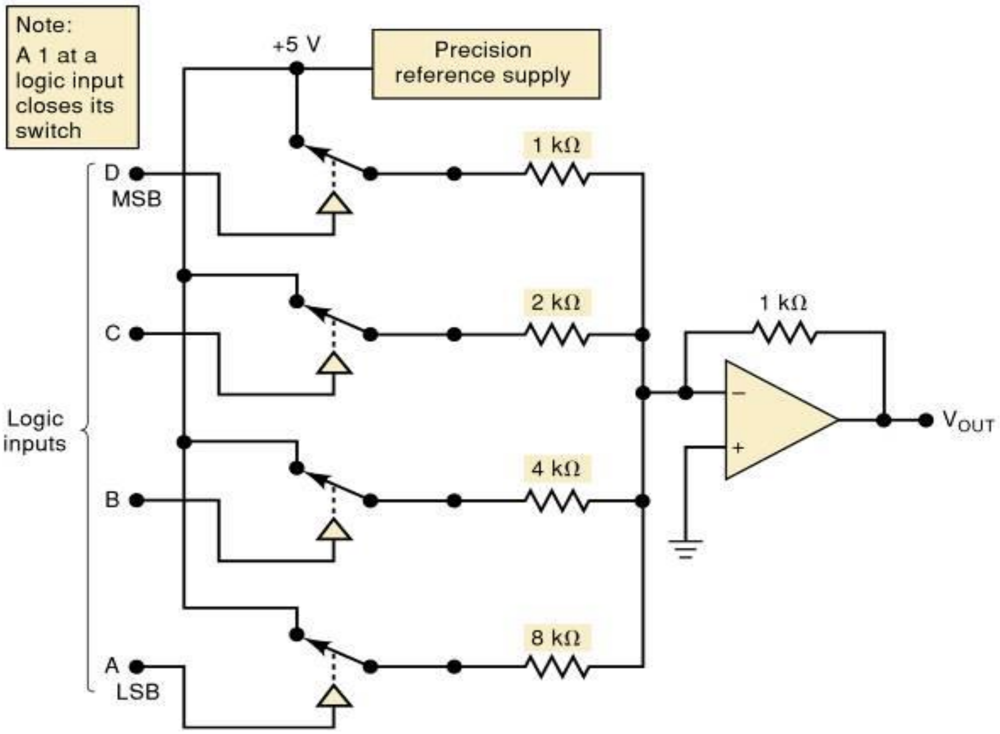


Figure 24: Complete four-bit DAC including a precision reference supply (Tocci, Widmer, & Moss, 2011)

Each digital input controls a semiconductor switch such as the CMOS transmission gate. When the input is HIGH, the switch closes and connects a precision reference supply to the input resistor; when the input is LOW, the switch is open. The reference supply produces a very stable, precise voltage needed to generate an accurate analog output.

Data Acquisition (DAS or DAQ)

There are many applications in which analog data must be digitized and transferred into a computer's memory. The process by which the computer acquires these digitized analog data is referred to as data acquisition.

Acquiring a single data point's value is referred to as sampling the analog signal, and that data point is often called a sample. The computer can do several different things with the data, depending on the application. In a storage application, such as digital audio recording, video recording, or a digital oscilloscope, the internal microcomputer will store the data and then transfer them to a DAC at a later time to reproduce the original analog signal. In a process control application, the computer can examine the data or perform computations on them to determine what control outputs to generate.

DAQ typically convert analog waveforms into digital values for processing. The components of data acquisition systems include sensors, to convert physical parameters to electrical signals; a signal conditioning circuitry, to convert sensor signals into a form that can be converted to digital values; and analog-to-digital converters, to convert conditioned sensor signals to digital values.

Data acquisition applications are usually controlled by software programs developed using various general purpose programming languages such as Assembly, Basic, C, C++, C#, FORTRAN, Java, Pascal, etc. Stand-alone data acquisition systems are often called data loggers.

There are also open-source software packages providing all the necessary tools to acquire data from different hardware equipment. These tools come from the scientific community where complex experiment requires fast, flexible and adaptable software. Those packages are usually custom fit but more general DAQ package like the Maximum Integrated Data Acquisition System can be easily tailored and is used in several physics experiments worldwide.

History of Data Acquisition System

In 1963, IBM produced computers which specialized in data acquisition. These include the IBM 7700 Data Acquisition System, and its successor, the IBM 1800 Data Acquisition and Control System. These expensive specialized systems were surpassed in 1974 by general purpose S-100 computers and data acquisitions cards produced by Tecmar/Scientific Solutions Inc. In 1981 IBM introduced the IBM Personal Computer and Scientific Solutions introduced the first PC data acquisition products.

Sources and Systems Data Acquisition

Data acquisition begins with the physical phenomenon or physical property to be measured. Examples of this include temperature, light intensity, gas pressure, fluid flow, and force. Regardless of the type of physical property to be measured, the physical state that is to be measured must first be transformed into a unified form that can be sampled by a data acquisition system. The task of performing such transformations falls on devices called *sensors*. A data acquisition system is a collection of software and hardware that lets you measure or control physical characteristics of something in the real world. A complete data acquisition system consists of DAQ hardware, sensors and actuators, signal conditioning hardware, and a computer running DAQ software.

Figure 25 (a) shows how a microcomputer is connected to a digital ramp ADC for the purpose of data acquisition. The computer generates the START pulses that initiate each new A/D conversion. The EOC (end-of conversion) signal from the ADC is fed to the computer. The computer monitors EOC to find out when the current A/D conversion is complete; then it transfers the digital data from the ADC output into its memory.

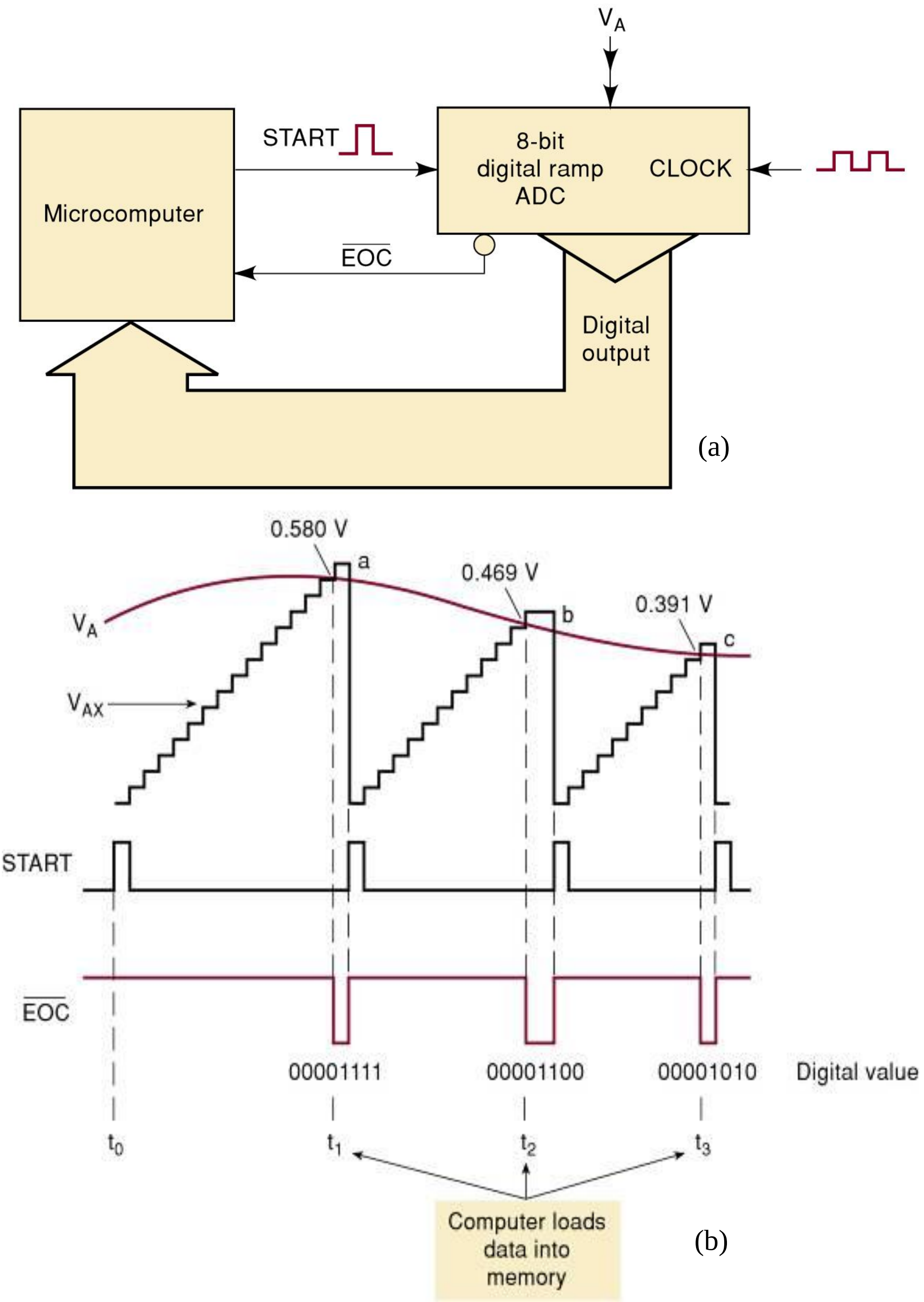


Figure 25: (a) Optical computer data acquisition system; (b) waveforms showing how the computer initiates each new conversion cycle

The waveforms in Figure 25 (b) illustrate how the computer acquires a digital version of the analog signal, V_A. The V_{AX} staircase waveform that is generated internal to the ADC is shown superimposed on the V_A waveform for purposes of illustration. The process begins at t_o, when the computer generates a START pulse to start an A/D conversion cycle. The conversion is completed at t_1, when the staircase first exceeds V_A, and EOC goes LOW. This NGT at EOC signals the computer that the ADC has a digital output that now represents the value of V_A at point a, and the computer will load these data into its memory.

The computer generates a new START pulse shortly after t_1 to initial second conversion cycle. Note that this resets the staircase to 0 and EOC back HIGH because the START pulse resets the counter in the ADC. The second conversion ends at t_2 when the staircase again exceeds V_A. The computer then loads the digital data corresponding to point b into its memory. These steps are repeated at t_3, t_4, and so on.

The process whereby the computer generates a START pulse, monitors EOC, and loads ADC data into memory is done under the control of a program that the computer is executing. This data acquisition program will determine how many data points from the analog signal will be stored in the computer memory. Figure 26 illustrates how a data acquisition system works.

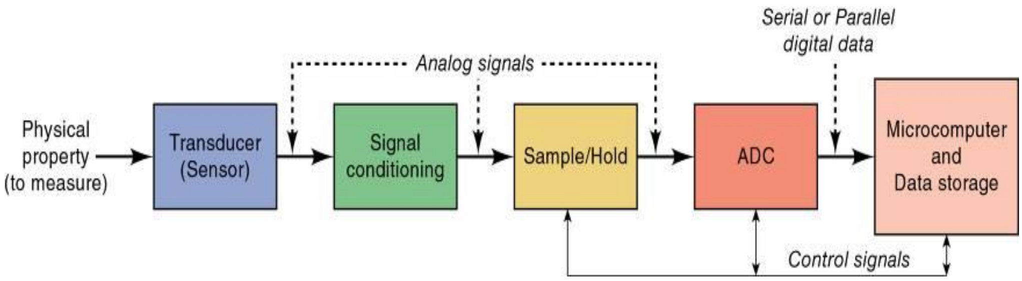


Figure 26: Block Diagram of a data Acquisition System (Fornetti, 2013)

Reconstructing a Digitized Signal

Figure 27 (a), shows how the ADC continually performs conversions to digitize the analog signal at points a, *b, c, d***,** and so on. If these digital data are used to reconstruct the signal, the result will look like that in Figure 27 (b). The black line represents the voltage waveform that would actually come out of the D/A converter. The red line would be the result of passing the signal through a simple low-pass RC filter.

In Figure 27 (b), the ADC is operating at its maximum speed because a new START pulse is generated immediately after the computer acquires the ADC output data from the previous conversion. The problem with this method of storing a waveform is that in order to reconstruct the waveform, we would need to know the point in time that each data value is to be plotted. Normally, when storing a digitized waveform, the samples are taken at fixed intervals at a rate that is at least two times greater than the highest frequency in the analog signal. The digital system will store the waveform a, a list of sample data values.

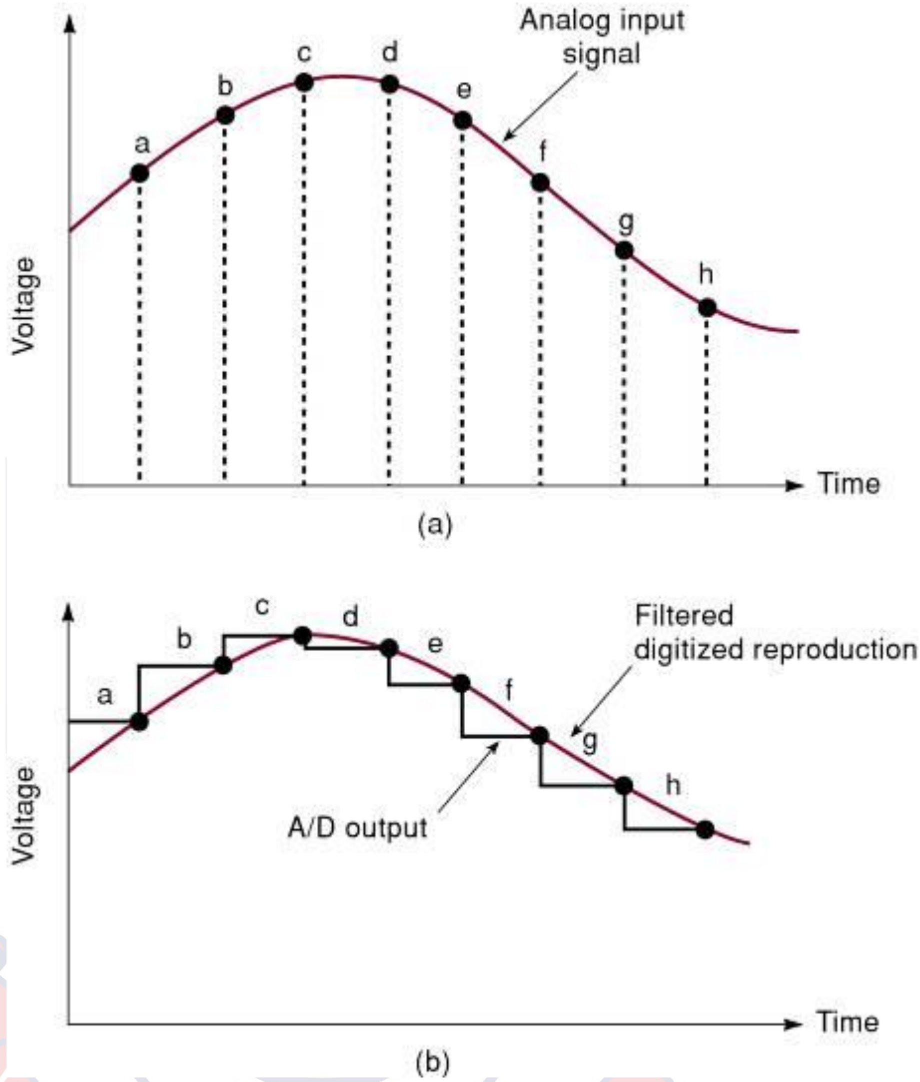


Figure 27: (a) Digitizing an analog signal; (b) Reconstructing the signal from the digital data (Tocci, Widmer, & Moss, 2011)

It can be seen that, it is a fairly good reproduction of the original analog signal because the analog signal does not make any rapid changes between digitized points. If the analog signal contained higher frequency variations, the ADC would not be able to follow the variations, and the reproduced version would be much less accurate.

Successive-Approximation ADC

The successive-approximation converter (SAC) is one of the most widely used types of ADC. It has more complex circuitry than the digital-ramp ADC but a much shorter conversion time. In addition, SACs have a fixed value of conversion time that is not dependent on the value of the analog input. The basic arrangement, shown in Figure 28 (a), is similar to that of the digital-ramp ADC.

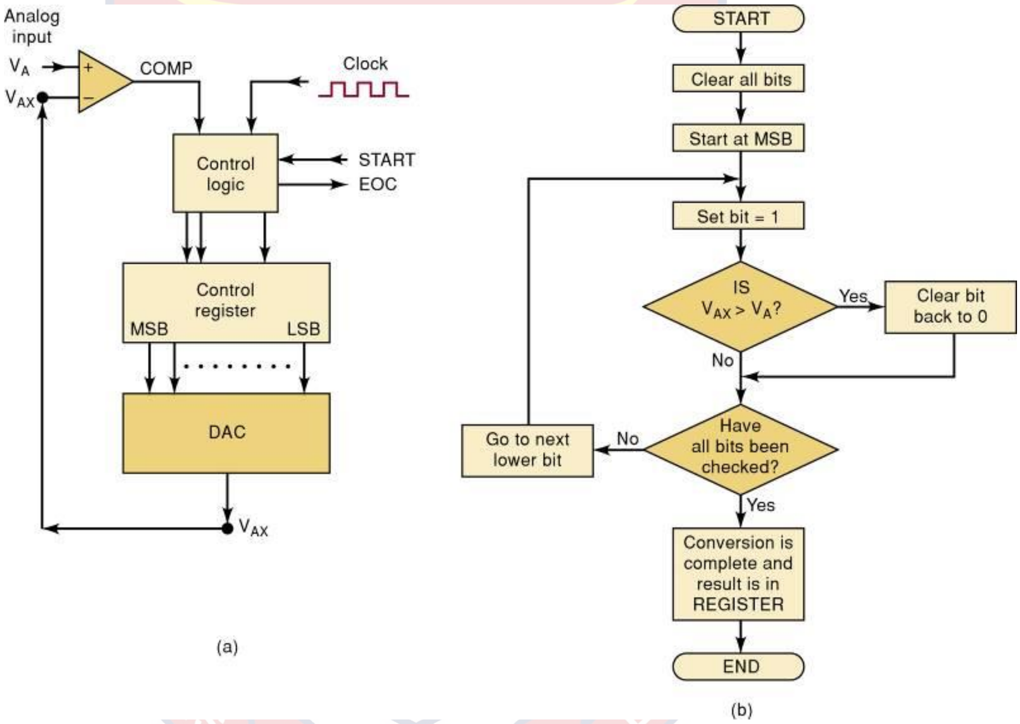


Figure 28: Successive-approximation ADC: (a) simplified block diagram; (b) flowchart of operation (Tocci, Widmer, & Moss, 2011)

The SAC, however, does not use a counter to provide the input to the DAC block but uses a register. The control logic modifies the contents of the register bit by bit until the register data are the digital equivalent of the analog input V_A within the resolution of the converter. The basic sequence of operation is given by the flowchart in Figure 29 (b).

Operation of the Data Acquisition Circuit

The computerized acquisition of analog quantities is becoming more important than ever in today's automated world. Computer systems are capable of scanning several analog inputs on a particular schedule to monitor critical quantities and acquire data for future recall. A typical eight channel computerized DAQ is shown in Figure 29.

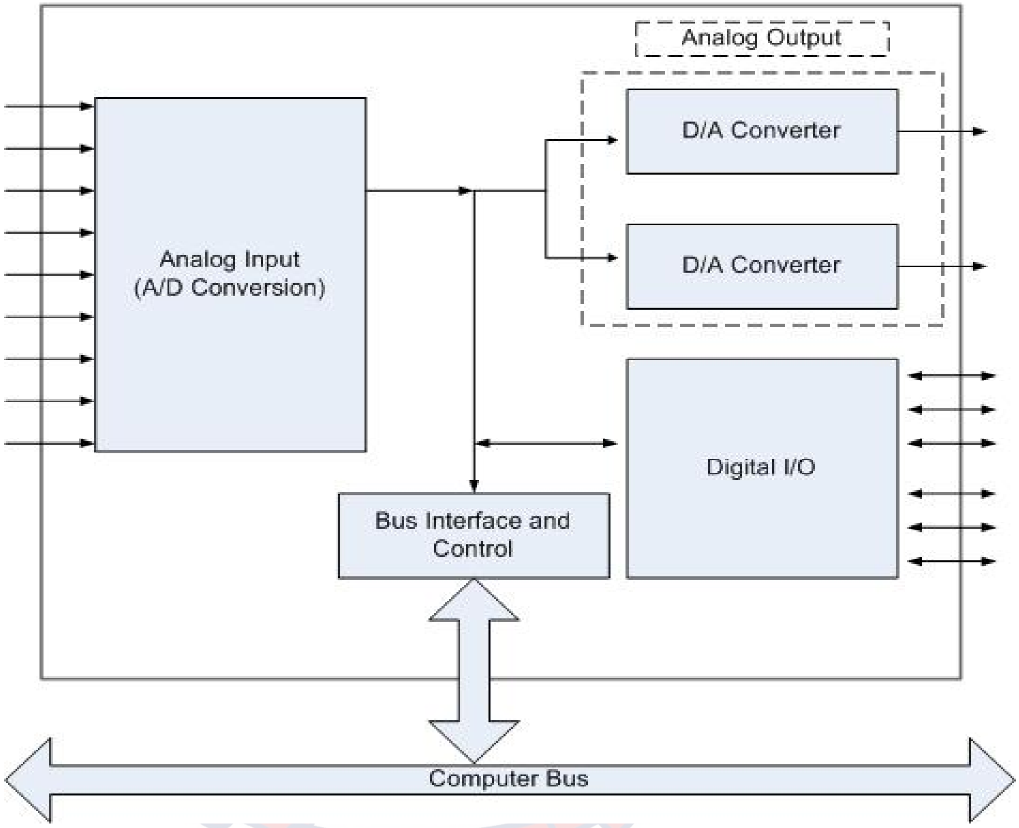


Figure 29: Data Acquisition System

The entire system communicates via two common buses, the data bus and the control bus. The data bus determines the information carrying capability of a particular processor or microprocessor based system. In this case, there are three devices on the data bus: the ADC, microcontroller, and memory.

The control bus passes control signals to and from the various devices for such things as chip select (CS), output enables (RD), system clock, triggers, and selects. Each of the eight transducers is set up to output a voltage that is proportional to the analog quantity being measured.

The task of the microcontroller is to scan all the quantities at some precise interval and store the digital results in memory for future use. To do this, the microprocessor must enable and send the proper control signals to each of the devices, in order, starting with the multiplexer and ending with the ADC.

Analog-to-Digital Converter (ADC0801)

The ADC receives the adjusted analog voltage and converts it to an equivalent 8-bit binary string. To do that, the microprocessor/microcontroller issues chip select (CS)' and start conversion ((WR)' or STC) pulses. When the end-of-conversion (INTR or EOC) lines go LOW, the microprocessor/micro controller issues an output enable (RD or OE) to read the data (D0 to D7) that pass, via the data bus, into the microprocessor/microcontroller and then the random-access-memory (RAM) chip.

This cycle repeats for all eight transducers whenever the microprocessor determines that it is time for the next scan. Other software routines executed by the microcontroller will act on the data that have been gathered. Some possible responses to the measured results might be to sound an alarm, speed up a fan, reduce energy consumption, increase a fluid level, or simply produce a tabular report on the measured quantities.

Work on microcontroller based applications is vast. This includes: 8051 microcontroller based: digital centigrade thermometer, temperature-dependent pulse-width-modulated (PWM) speed control application, integrating solar radiometer and portable adapter for barcode scanners (Kleitz, 2003).

Programming Languages

Computer software is generally divided into two broad categories, i.e., operating system software and application (user) software. Operating system software is the collection of programs, which are needed in the creation, preparation, and execution of other programs. Application software consists of those programs generated by the various users of the system in their attempt to apply the computer to solving their problems. There are three levels of programming, namely; Machine Language, Assembly Language and High Level Language.

Machine Language

Machine language is the final step in creating an executable program for the microcontroller. In this step, we must determine the actual binary codes that will be stored in memory to be read by the microcontroller. First, we have to determine what memory locations will be used for our program. This depends on the memory map assignments made in the system hardware design. The first step in a hand assembly is to determine the code for MVI A in the case of the 8085 microprocessor or, MOV A in case of the 8051

Microcontroller. This is known as the opcode (Operation Code) and is found in the microcontroller Assembly Language Reference chart.

Instructions for storing the program into memory are given by the manufacturer of the microprocessor/micro controller. Programming in machine language is very tedious and hence the introduction of assembly language described in the next section.

Assembly Language

Assembly language is written using mnemonics: MOV, JNZ, ADD, DIV, etc. The term mnemonics is defined as 'abbreviations used to assist the memory'. The mnemonics, MOV, stands for "move". The instruction MOV A, 20H moves the contents of RAM location 20H to the accumulator. If an assembler software package is used, instead of hand assembly, then the machine code that is generated is usually saved on a computer disk or used to program an EPROM. The EPROM is placed in a custom microcontroller hardware design.

The mnemonic source program prepared by the programmer using the symbolic instruction set appropriate to a given microcontroller is translated by its assembler into a corresponding machine language object program which is subsequently executed. Practical assemblers provide error messages, which are very helpful to the programmer in preparing new routines. This level of programming is very efficient in the use of computer memory space and in the total time required to execute the program.

In a 'structured programming' technique, the program, written in assembly language, is broken into modules, or subroutines. Each module has a specific function and can be written and tested on its own. This is very helpful for program development and debugging. Each program is entered in a different block of memory.

High-Level Language

Because each detailed step in the program must be included, programming in assembly language is also tedious. Higher-level languages have been developed in which single statements can be translated into large groups of machine language instructions. In this case, the translating program is called a compiler because, in effect, the computer compiles its own program following quite general instructions. It is much simpler to program in High-level Language than either in assembly language or machine language.

It often turns out, however, that a machine language program compiled in this fashion is inefficient in the use of computer memory space or in the total time required to execute the program. This results from the generalities inherent in a compiler. Thus while FORTRAN, BASIC, Pascal and other high-level languages are widely used, assembly languages are necessary to realize the maximum capabilities of any computer (Brophy, 1990).

Electric Power

Electric power, like mechanical power, is the rate of doing work, measured in watts (W), and represented by the letter *P*. The term *wattage* is used colloquially to mean 'electric power in watts'. The electric power in watts produced by an electric current *I* consisting of a charge of *Q* coulombs every t seconds passing through an electric potential (voltage) difference of V is

$$P = \text{workdone per unit time} = \frac{QV}{t} = IV \qquad 19$$

where

Q is electric charge in coulombs,

t is time in seconds,

I is electric current in amperes,

V is electric potential or voltage in volts.

Electric power is usually produced by electric generators, but can also be supplied by chemical sources such as electric batteries. Electric power is generally supplied to businesses and homes by the electrical power industry. Electric power is usually sold by the kilowatt hour (3.6 MJ) which is the product of power in kilowatts multiplied by running time in hours. Electric utilities measure power using an electricity meter, which keeps a running total of the electric energy delivered to a customer.

Electric power is transformed to other forms of power when electric charges move through an electric potential (voltage) difference, which occurs in electrical components in electric circuits. When electric charges move through a potential difference from a high voltage to a low voltage, the energy in the potential is converted to kinetic energy of the charges, which perform work on the device. Devices in which this occurs are called passive devices or loads; they consume electric power, converting it to other forms such as mechanical work, heat, light, etc. Examples are electrical appliances, such as light bulbs, electric motors, and electric heaters.

If the charges are forced to move by an outside force in the direction from a lower potential to a higher, work is being done on the charges, so power is transferred to the electric current from some other type of energy, such as mechanical energy or chemical energy. Devices in which this occurs are called active devices or power sources; sources of electric current, such as electric generators and batteries.

Efficiency of Electric Power

The term 'efficiency' is typically associated with how energy is consumed at the point of end use, but the concept of efficiency can also be applied to how energy is produced and distributed. The efficiency of an entity (a device, or system) in electronics and electrical engineering is defined as useful power output divided by the total electrical power consumed. That is

$$\text{Efficiency} = \frac{\text{useful power output}}{\text{total power input}} \times 100\ \% \qquad 20$$

Efficiency should not be confused with effectiveness: a system that wastes most of its input power but produces exactly what it is meant to is effective but not efficient. The term "efficiency" makes sense only in reference to the wanted effect. A light bulb, for example, might have 2 % efficiency at emitting light yet still be 98 % efficient at heating a room (In practice it is nearly 100 % efficient at heating a room because the light energy will also be converted to heat eventually, apart from the small fraction that leaves through the windows). An electronic amplifier that delivers 10 watts of power to its load (e.g. a loudspeaker), while drawing 20 watts of power from a power source is 50 % efficient.

Power Protection Devices

According to a white paper on power conditioner (1999) by Powervar, puts power protection devices into one of two main categories; those that alter, change, or otherwise control the character of electricity and those that provide an alternate or secondary source of power in the event of the failure of the primary source.

Products in the first group include surge protectors, filters, voltage regulator, power conditioners, and others. The amount of protection varies from device to device. The operational requirements of local area network (LAN) systems along with an emphasis on protecting data, software, and processes have created a significant level of interest in the uninterruptible power supply (UPS) products that comprise the second group. While it is possible for a UPS to also function as a power conditioner, such capabilities cannot automatically be assumed.

Power Supplies

A power supply is a device that supplies electric power to an electrical load. The term is most commonly applied to electric power converters that convert one form of electrical energy to another, though it may also refer to devices that convert another form of energy (mechanical, chemical, solar) to electrical energy. A regulated power supply is one that controls the output voltage or current to a specific value; the controlled value is held nearly constant despite variations in either load current or the voltage supplied by the power supply's energy source.

Power supplies for electronic devices can be broadly divided into line-frequency (or 'conventional') and switching power supplies. The line-frequency supply is usually a relatively simple design, but it becomes increasingly bulky and heavy for high-current equipment due to the need for large mains-frequency transformers and heat-sinked electronic regulation circuitry. Conventional line-frequency power supplies are sometimes called 'linear', but that is a misnomer because the conversion from AC voltage to DC is inherently non-linear when the rectifiers feed into capacitive reservoirs. Linear voltage regulators produce regulated output voltage by means of an active voltage divider that consumes energy, thus making efficiency low. A switched-mode supply of the same rating as a line-frequency supply will be smaller, is usually more efficient, but would be more complex.

Types of Power Supplies

DC Power Supply

An AC powered unregulated power supply usually uses a transformer to convert the voltage from the wall outlet (mains) to a different, nowadays usually lower, voltage. If it is used to produce DC, a rectifier is used to convert alternating voltage to a pulsating direct voltage, followed by a filter, comprising one or more capacitor, resistors, and sometimes inductors, to filter out (smooth) most of the pulsation. A small remaining unwanted alternating voltage component at mains or twice mains power frequency (depending upon whether half- or full-wave rectification is used) ripple is unavoidably superimposed on the direct output voltage. For purposes such as charging batteries the ripple is not a problem, and the simplest unregulated mains-powered DC power supply circuit consists of a transformer driving a single diode in series with a resistor.

Before the introduction of solid-state electronics, equipment used valves (vacuum tubes) which required high voltages; power supplies used step-up transformers, rectifiers, and filters to generate one or more direct voltages of some hundreds of volts, and a low alternating voltage for filaments. Only the most advanced equipment used expensive and bulky regulated power supplies.

AC Power Supply

An AC power supply typically takes the voltage from a wall outlet (main supply) and lowers it to the desired voltage. Some filtering may take place as that of the DC power supply.

AC/DC Supply

In the past, mains electricity was supplied as DC in some regions, AC in others. Transformers cannot be used for DC, but a simple, cheap unregulated power supply could run directly from either AC or DC mains without using a transformer. The power supply consisted of a rectifier and a filter capacitor. When operating from DC, the rectifier was essentially a conductor, having no effect; it was included to allow operation from AC or DC without modification.

Linear Regulated Power Supply

The voltage produced by an unregulated power supply will vary depending on the load and on variations in the AC supply voltage. For critical electronics applications, a linear regulator may be used to set the voltage to a precise value, stabilized against fluctuations in input voltage and load. The regulator also greatly reduces the ripple and noise in the output direct current. Linear regulators often provide current limiting, protecting the power supply and attached circuit from overcurrent.

Adjustable linear power supplies are common laboratory and service shop test equipment, allowing the output voltage to be adjusted over a range. For example, a bench power supply used by circuit designers may be adjustable up to 30 volts and up to 5 amperes output. Some can be driven by an external signal, for example, for applications requiring a pulsed output.

Switched-Mode Power Supply

In a switched-mode power supply (SMPS), the AC mains input is directly rectified and then filtered to obtain a DC voltage. The resulting DC voltage is then switched on and off at a high frequency by electronic switching circuitry, thus producing an AC current that will pass through a high-frequency transformer or inductor. Switching occurs at a very high frequency (typically 10 kHz - 1 MHz), thereby enabling the use of transformers and filter capacitors that are much smaller, lighter, and less expensive than those found in linear power supplies operating at mains frequency. After the inductor or transformer secondary, the high frequency AC is rectified and filtered to produce the DC output voltage. If the SMPS uses an adequately insulated high-frequency transformer, the output will be electrically isolated from the mains; this feature is often essential for safety.

Switched-mode power supplies are usually regulated, and to keep the output voltage constant, the power supply employs a feedback controller that monitors current drawn by the load. The switching duty cycle increases as power output requirements increase.

Switched-mode power supplies often include safety features such as current limiting or a crowbar circuit to help protect the device and the user from harm. In the event that an abnormal high-current power draw is detected, the switched-mode supply can assume this is a direct short and will shut itself down before damage is done.

Switched-mode power supplies have an absolute limit on their minimum current output. They are only able to output above a certain power level and cannot function below that point. In a no-load condition the frequency of the power slicing circuit increases to great speed, causing the isolated transformer to act as a Tesla coil, causing damage due to the resulting very high voltage power spikes. Switched-mode supplies with protection circuits may briefly turn on but then shut down when no load has been detected. A very small low-power dummy load such as a ceramic power resistor or 10 watts light bulb can be attached to the supply to allow it to run with no primary load attached.

Switched-mode power supplies have traditionally been a source of power line harmonics and have a very poor power factor. The rectifier input stage distorts the wave shape of current drawn from the supply; this can produce adverse effects on other loads. The distorted current causes extra heating in the wires and distribution equipment. Switched mode power supplies in a building can result in poor power quality for other utility customers. Customers may face higher electric bills for a low power factor load. Some switch-mode power supplies use filters or additional switching stages in the incoming rectifier circuit to improve the waveform of the current taken from the AC line. This adds to the circuit complexity.

Programmable Power Supply

Programmable power supplies allow for remote control of the output voltage through an analog input signal or a computer interface such as RS232 or GPIB. Variable properties include voltage, current, and frequency (for AC output units). These supplies are composed of a processor, voltage/current programming circuits, current shunt, and voltage/current read-back circuits. Additional features can include over current, overvoltage, and short circuit protection, and temperature compensation. Programmable power supplies also come in a variety of forms including modular, board-mounted, wall-mounted, floor-mounted or bench top.

Programmable power supplies can furnish DC, AC, or AC with a DC offset. The AC output can be either single-phase or three-phase. Single-phase is generally used for low-voltage, while three-phase is more common for high-voltage power supplies. Programmable power supplies are now used in many applications. Some examples include automated equipment testing, crystal growth monitoring, and differential thermal analysis.

Uninterruptible Power Supply

An uninterruptible power supply (UPS) takes its power from two or more sources simultaneously. It is usually powered directly from the AC mains, while simultaneously charging a storage battery. Should there be a dropout or failure of the mains, the battery instantly takes over so that the load never experiences an interruption. In a computer installation, this gives the operators time to shut down the system in an orderly way.

Other UPS schemes may use an internal combustion engine or turbine to continuously supply power to a system in parallel with power coming from the AC. The engine-driven generators would normally be idling, but could come to full power in a matter of a few seconds in order to keep vital equipment running without interruption. Such a scheme might be found in hospitals or telephone central offices.

High-Voltage Power Supply

High voltage refers to an output on the order of hundreds or thousands of volts. High-voltage supplies use a linear setup to produce an output voltage in this range. Additional features available on high-voltage supplies can include the ability to reverse the output polarity along with the use of circuit breakers and special connectors intended to minimize arcing and accidental contact with human hands. Some supplies provide analog inputs that can be used to control the output voltage, effectively turning them into high-voltage amplifiers albeit with very limited bandwidth.

Kuffel et al., (2000) explained that high voltage D.C. power supply is widely used in research work (especially in field of applied physics) and in industry level the main application of high voltage D.C., Power supply is in proof design of high voltage cables with relatively large capacitive load, which draws high current if it is tested with A.C. high voltage power frequency of sinusoidal waveform instead of D.C. voltage.

Naidu & Kamaraju (2004) also suggested that high voltages are generated for testing high voltage dielectric equipment using power frequency A.C./D.C. switching surge voltage and lightning impulse voltages. For dielectric testing of high voltage equipment, voltages are increased up to several million volts but currents are decreased to few milliamps and maximum of one ampere for A.C./D.C. high voltage test sets. There are several application of D.C. high voltage, in the field of electrical engineering and applied physics such as electron microscope, X-rays, electrostatic precipitators, particles accelerator in nuclear physics, dielectric testing and so on.

Voltage Regulator

A voltage regulator generates a fixed output voltage of a pre-set magnitude that remains constant regardless of changes to its input voltage or load conditions. There are two types of voltage regulators: linear and switching.

A linear regulator employs an active (BJT or MOSFET) pass device (series or shunt) controlled by a high gain differential amplifier. It compares the output voltage with a precise reference voltage and adjusts the pass device to maintain a constant output voltage (Ferracci, 2000). A switching regulator converts the dc input voltage to a switched voltage applied to a power

MOSFET or BJT switch. The filtered power switch output voltage is fed back to a circuit that controls the power switch on and off times so that the output voltage remains constant regardless of input voltage or load current changes. Switching regulator has three common topologies: buck (step-down), boost (step-up) and buck-boost (step-up/step-down). Other topologies include the flyback, SEPIC, Cuk, push-pull, forward, full-bridge, and half-bridge topologies.

Switching regulators require a means to vary their output voltage in response to input and output voltage changes. One approach is to use PWM that controls the input to the associated power switch, which controls its' on and off time (duty cycle). In operation, the regulators' filtered output voltage is fed back to the PWM controller to control the duty cycle. If the filtered output tends to change, the feedback applied to the PWM controller varies the duty cycle to maintain a constant output voltage.

Electric Power Conversion

In electrical engineering, power engineering and the electric power industry, power conversion is converting electric energy from one form to another, converting between AC and DC, or just changing the voltage or frequency, or some combination of these. A power converter is an electrical device for converting electrical energy. This could be as simple as a transformer to change the voltage of AC power, but also includes far more complex systems. The term can also refer to a class of electrical machinery that is used to convert one frequency of alternating current into another frequency.

One way of classifying power conversion systems is according to whether the input and output are alternating current (AC) or direct current (DC), thus we may have DC to DC, DC to AC, AC to DC, and AC to AC.

Direct Current to Direct Current Converter

DC power is simply the application of a steady constant voltage across a circuit resulting in a constant current (Doucet et al., 2007). A battery is the most common source of DC transmission as current flows from one end of a circuit to the other. Most digital circuitry today is run off of DC power as it carries the ability to provide either a constant high or constant low voltage, enabling digital logic to process code executions.

A DC to DC converter is an electronic circuit which converts a source of DC from one voltage level to another. DC/DC converters consist of one capacitor and one inductor; therefore, the modelling is simple (Luo et al., 2005).

DC to DC converters are important in portable electronic devices such as cellular phones and laptop computers, which are supplied with power from batteries primarily. Such electronic devices often contain several sub-circuits, each with its own voltage level requirement different from that supplied by the battery or an external supply (sometimes higher or lower than the supply voltage). Additionally, the battery voltage declines as its stored power is drained. Switched DC to DC converters offer a method to increase voltage from a partially lowered battery voltage thereby saving space instead of using multiple batteries to accomplish the same thing.

Direct Current to Alternating Current Inverter

DC/AC inverters are used for inverting DC power source into AC power applications (Luo et al., 2005). They are generally used in applications such as variable voltage or frequency AC supplies in adjustable speed drives (ASDs), such as induction motor drives; constant regulated voltage AC power supplies, such as uninterruptible power supplies (UPSs); Static VAR compensations, Active filters, flexible AC transmission systems (FACTSs), and voltage compensations.

Alternating Current to Direct Current Converter

Alternating current (AC) is the most efficient way to deliver electrical power. However, most electronic devices need direct current (DC) to function. For this reason, AC to DC converters is either a part of devices themselves or as part of their power cords. An AC to DC converter is an integral part of any power supply unit used in all electronic equipment. Also, it is used as an interface between utility and most of the power electronic equipment. These electronic equipment form a major part of load on the utility. Jha et al. (2006) suggested that, to convert line frequency AC to DC, a line frequency diode bridge rectifier (Figure 30) is used. They further explained that, to reduce the ripple in the DC output voltage, a large filter capacitor is used at the rectifier output.

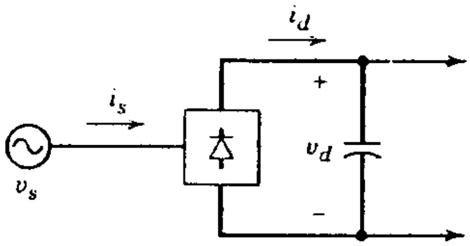


Figure 30: Block Diagram of a Rectifier

Alternating Current to Direct Current

A solid-state AC-AC converter converts an AC waveform to another AC waveform, where the output voltage and frequency can be set arbitrarily. The solid state units are power converters, converting incoming AC power into DC power (rectifier stage) and then converting the DC power into the required AC frequency and voltage.

An AC-AC converter with approximately sinusoidal input currents and bidirectional power flow can be realized by coupling a PWM rectifier and a PWM inverter to the DC-link. The DC-link quantity is then impressed by an energy storage element that is common to both stages, which is a capacitor *C* for the voltage DC-link or an inductor L for the current DC-link. The PWM rectifier is controlled in a way that a sinusoidal AC line current is drawn, which is in phase or anti-phase (for energy feedback) with the corresponding AC line phase voltage.

Due to the DC-link storage element, there is the advantage that both converter stages are to a large extent decoupled for control purposes. Furthermore, a constant, AC line independent input quantity exists for the PWM inverter stage, which results in high utilization of the converter's power capability. On the other hand, the DC-link energy storage element has a relatively large physical volume, and when electrolytic capacitors are used, in the case of a voltage DC-link, there is potentially a reduced system lifetime (Petry et al., 2005).

Summary of Literature Review

The Literature highlighted on the design and fabrication of voltage stabilizer using 8051 microcontroller. Areas of much concern were voltage stabilization, the need for power conditioning, power quality, autotransformers, their advantages and limitations, semiconductor theory, the microcontroller 8051 and its architecture. Also considered under the review of related literature are interfacing with the analog world, analog-to-digital conversion and vice versa.

CHAPTER THREE

EXPERIMENTAL SETUP AND DATA ACQUISITION

Overview

Experimental setup of the work is presented in this section. The setup consists of a Tecktronix oscilloscope that was used to view the digital output of the ADC. The oscilloscope (Plate 1B) was also used to monitor the waveforms of the AC inputs on the autotransformer. A Fluke multimeter (Plate 1A) was used to measure AC and DC voltages. Variable transformer (Plate 2) was used to apply various AC voltages to the autotransformer. Figure 31 illustrates the circuit diagram of this research work whilst Plate 3 shows the constructed circuit of this research showing some of the components used.

Plate 1: Measuring Instruments used for measuring voltages and waveforms during the Data acquisition stage of this work; A) Digital Multimeter; B) Tektronix Oscilloscope.

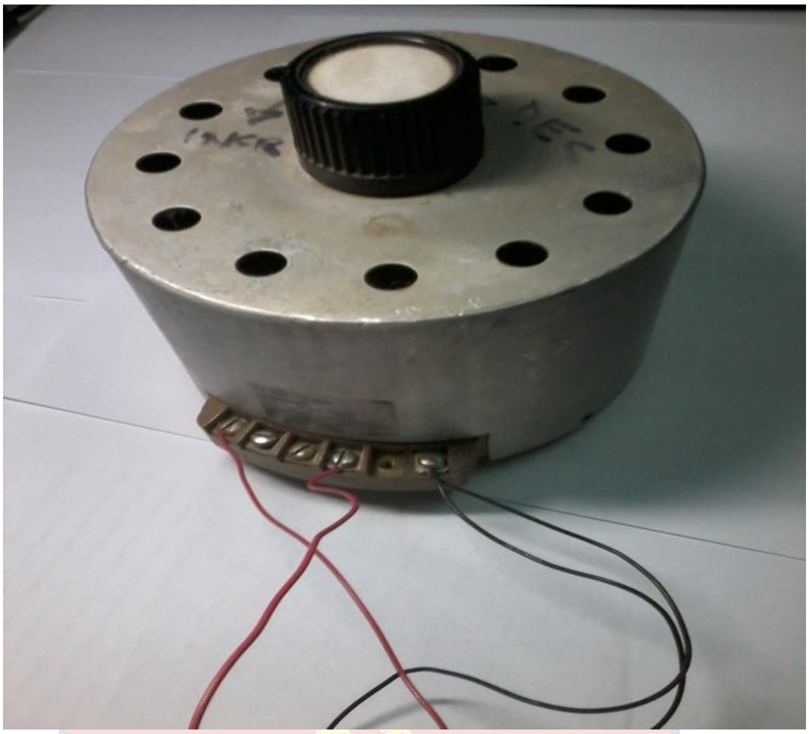


Plate 2: Variable Transformer used to vary the 230 V AC for this research

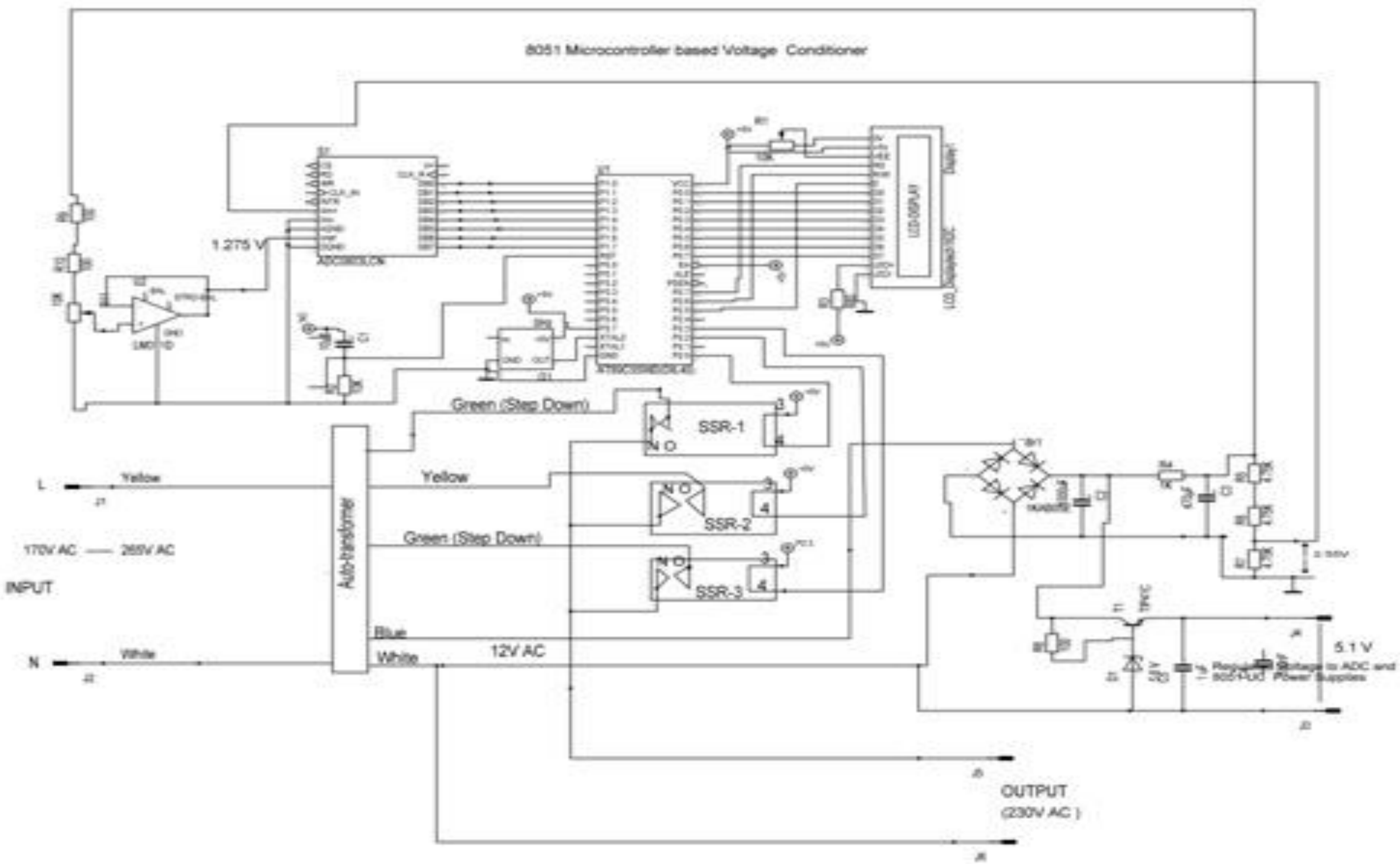


Figure 31: Circuit diagram of this Research Work

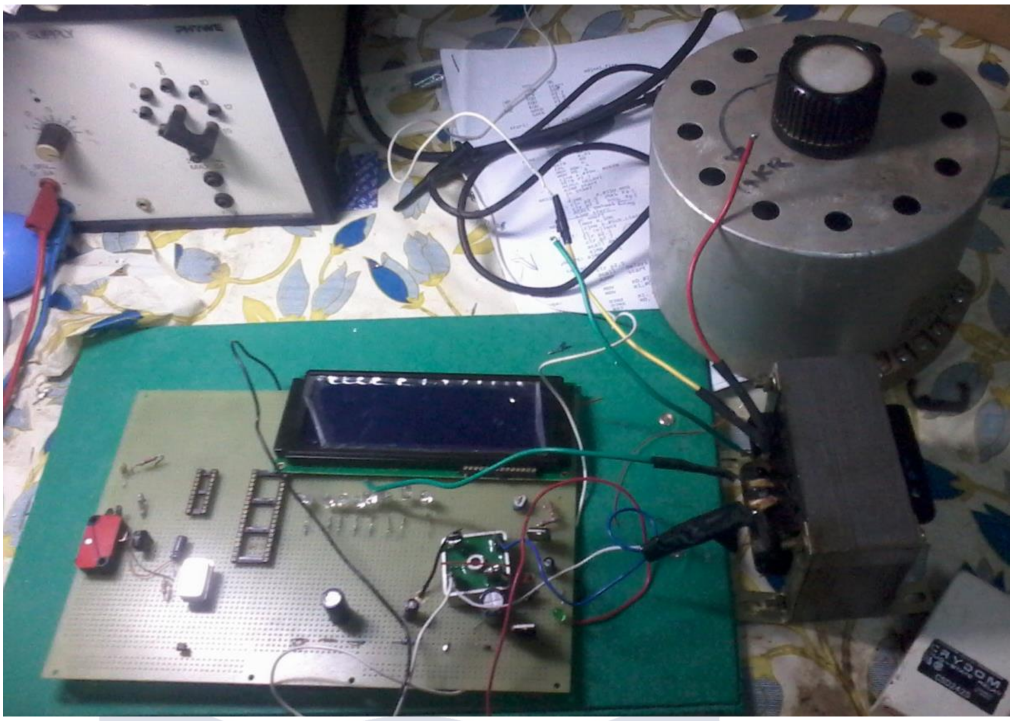


Plate 3: The constructed circuit of this research showing some of the components

Measurement and Data Collection with the Data Acquisition Board

Components and Functions of the Acquisition Board

Figure 32 shows the block diagram of the Data Acquisition Board. The components are variable transformer, stabilizer transformer, and bridge rectifier diode, a 7805 regulator, an ADC 0804, an 89C55 microcontroller and output LEDs to display the digital value of the input voltage.

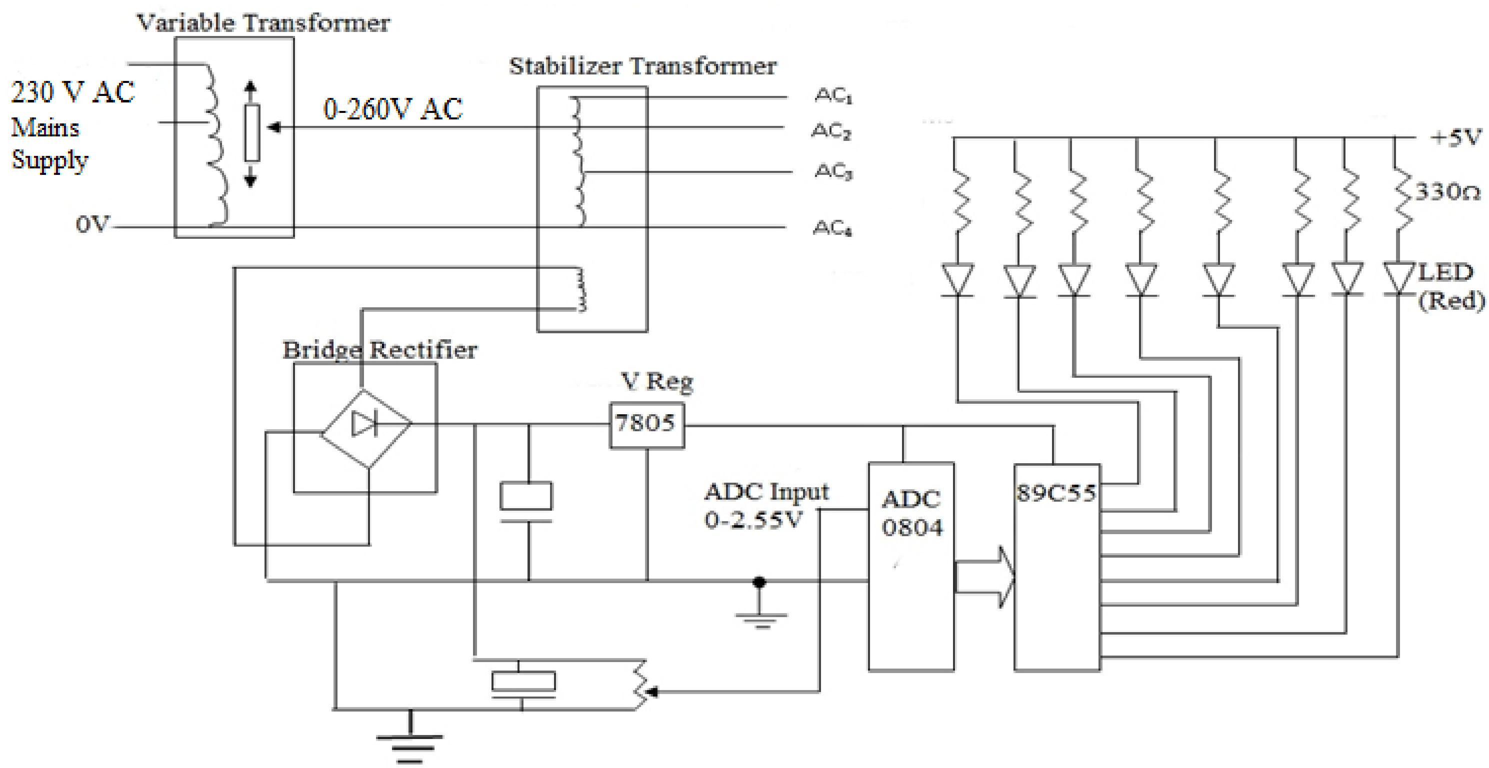


Figure 32: Block diagram of the data acquisition of this research

Signal Flow in the Block Diagram of the Data Acquisition

Figure 32 shows the block diagram of the data acquisition part of this work. The variable transformer was used to change the constant input 230 V AC from the mains between 0-300 V AC. The voltage was then fed to the stabilizer transformer with the output tappings. The stabilizer transformer has additional low voltage winding of zero to twenty volts AC (0-20 V AC) at the stabilizer input. The voltage was rectified and regulated to produce a 5 V DC that was used to supply the Integrated Circuits namely the ADC and the microcontroller and the operational amplifier used to design the Data Acquisition. Another variable input was fed to the ADC input which converted the Analogue Voltage to digital to switch on the eight LEDs that was connected to the 89C55 microcontroller.

As shown in Figure 33, the extra windup of the stabilizer transformer was rectified and then used a 7805 voltage regulator integrated circuit (IC) to regulate input to +5 V to the supply ICs. Another variable input was reduced to 0-2.55 V and was fed into the input of the 0804 ADC input. The reason why such an input range was selected is based on the fact that the 0804 ADC is eight bit. That means that the quantization error for such an ADC is

$$K = \frac{V_{ref}}{2^N - 1} \tag{21}$$

where V_{ref} is full scale voltage and N is the number of bits; which for 8 bits N=8. Therefore, for the above reference voltage of 5 V,

$$K = \frac{5V}{2^8 - 1} = \frac{5V}{256 - 1} = \frac{5V}{255} = 0.019V = 19\ mV$$

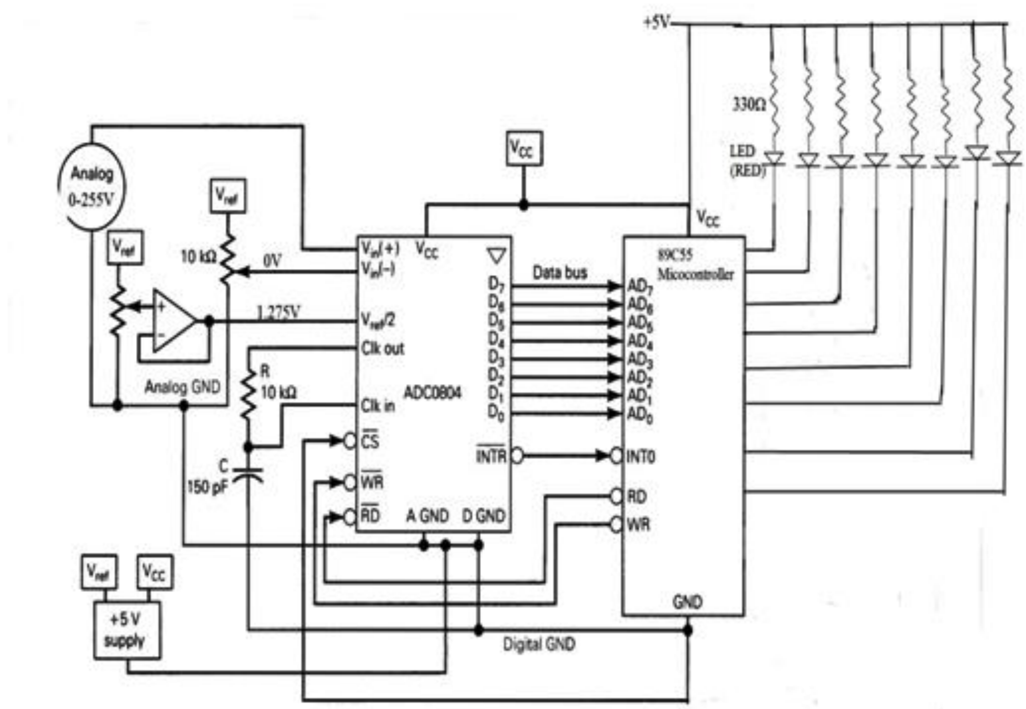


Figure 33: Detailed circuit diagram of the data acquisition circuit showing the 0804 ADC and the 89C55 Microcontroller

The quantization error is the same as the step size or the least significant bit (LSB), which means that the input voltage of the ADC is lower than this step size. There would not be any change in the ADC output. The voltage that is applied to pin 9 $(V_{ref} / 2)$ input thus determine the V_{ref} (full scale voltage).

A voltage of 1.275 V was set at pin 9 $(V_{ref} / 2)$ of the 0804 ADC to make the full scale voltage (V_{ref}) 2.55 V. Thus, making the resolution or the step size equal

$$K = \frac{2.55\ V}{2^8 - 1} = \frac{2.55\ V}{255} = 10\ mV$$

as compared to K= 19.6 mV, when the V $_{full\ scale}$ was 5 V. The input voltage was varied from 0 – 2.55 V which corresponded to the digital equivalent of

$$V_{anal} = K \times D, \qquad 22$$

where K is the resolution, and D is the digital value and

$$D = \frac{V_{anal}}{K}, \qquad 23$$

where V_{anal} is analogue voltage and K is the resolution of the ADC. The digital output was the one showed on the eight LEDs that were connected to the 89C55 microcontroller output which ranged from 00 - FF H (hexadecimal) or 0 - 265 decimal. The constructed data acquisition board showing the LEDs reading 8E Hex (Plate 4) and 0FF Hex (Plate 5) at the output of the 89C55 Microcontroller.

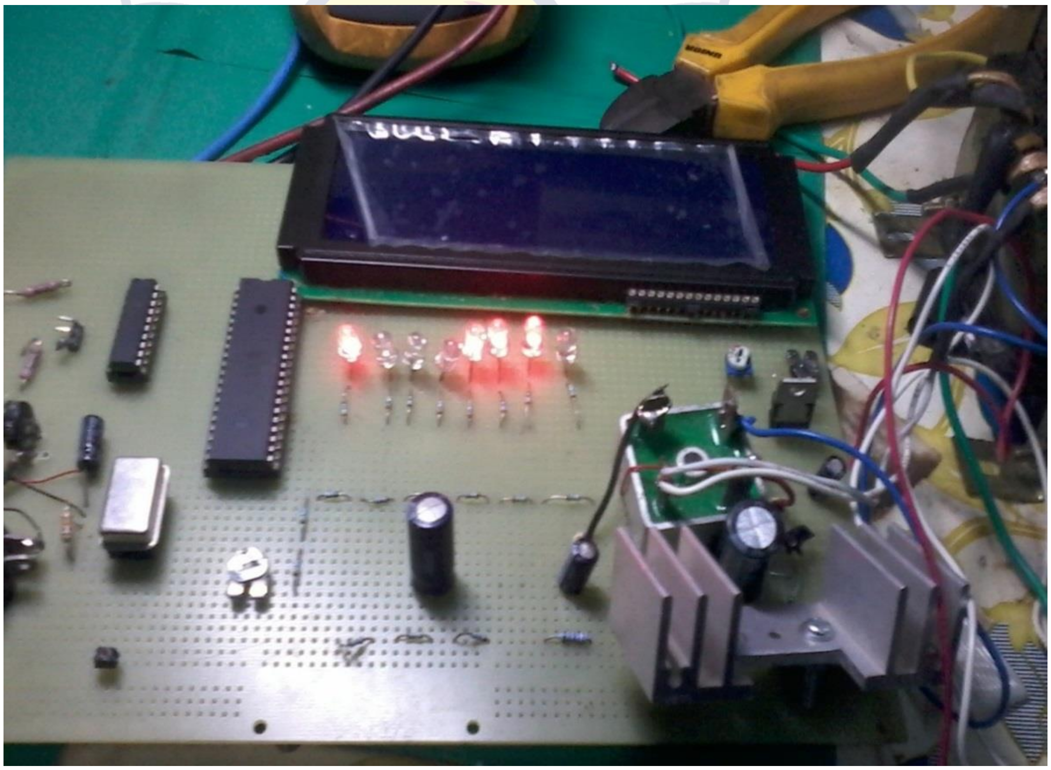


Plate 4: The constructed data acquisition board showing the LEDs reading 8E Hex, at the output of the 89C55 Microcontroller

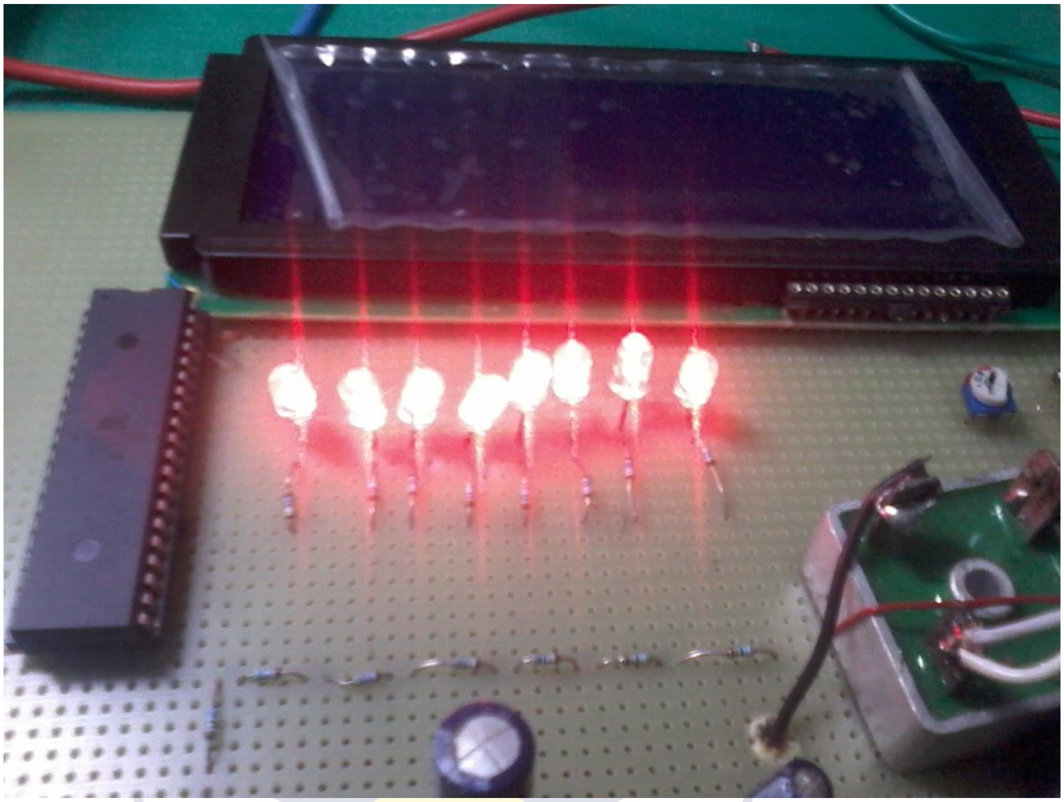


Plate 5: The constructed data acquisition board showing the LEDs reading 0FFH, at the output of the 89C55 Microcontroller

Data Acquisition Measurements

The variable transformer was used to get a variable AC voltage between 0 - 300 V AC from the mains supply voltage (230 V AC). Since the mains voltage was not changing very fast as required by this work, it would have been very difficult to conduct the research without the variable transformer. The output of the variable transformer was fed into the input of the stabilizer transformer.

The stabilizer transformer has three (3) tappings. These tappings were coloured red, green and yellow for easy identification. The red tap has the highest number of turns ratio (step-up) followed by the yellow tap, which doubles as input and output and the green tap which has the lowest turns ratio (step – down) and so any voltage at the input from between 170 V AC - 260 V AC. One of these three tappings will be selected as an output at a time.

The stabilizer winding has an auxiliary winding (between 0 - 20 V AC). This voltage was rectified by the bridge rectifier diode (Figure 32), and then a reservoir capacitor (4,700 μF) which then passed through a voltage regulator (7805) to produce a constant five volts (+5 V) to supply the digital IC. This voltage (+5 V) is to power the internal components of the device.

As seen from the circuit diagram of this work (Figure 31), another output of the rectified voltage was sent to the input of the 0804 ADC, whose operation is provided after Figure 32 under 'Operation of the Data Acquisition Circuit'.

Data Collection

Arrangement of the components for the measurement is as shown in Figure 34. The measurements start by turning on the mains switch of the variable transformer. This in turn turns on the variable transformer. The nob of the variable transformer is varied until the multimeter reads a voltage of 265 V AC. This is achieved within the variable transformer configuration whereby one tap is fixed and the other tap is connected to a brush that slides along an uninsulated section of the coil. The coil used by the variable transformer for this work is a toroidal-shaped core.

This voltage (265 V AC) was applied to the stabilizer transformer's yellow tappings which serve as input/output. The voltage is the maximum voltage that the stabilizer (finished product) is supposed to regulate. Any voltage that is more than this voltage will cut off the output load from the power supply and the liquid crystal display (LCD) will display (INPUT VOLTAGE EXCEEDED).

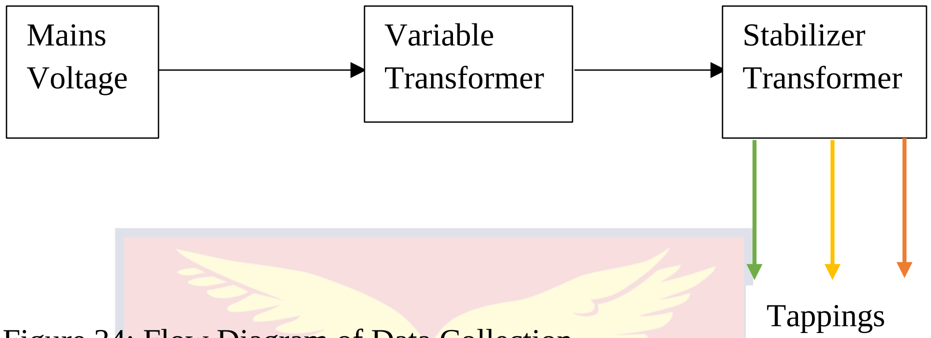


Figure 34: Flow Diagram of Data Collection

The voltage on pin 9 ($V_{ref}/2$) of the ADC (Figure 34) was adjusted to read 1.275 V DC. Since the full scale voltage depends on the voltage at pin 9, i.e. $V_{ref}/2$ = 1.275 V and V_{ref} = (2x1.275) V = 2.55 V DC. At this point, all the eight (8) LEDs connected to Port 0 of the 89C55 microcontroller came on, which represented (0FF) Hexadecimal (Hex), or 255 decimal (Plate 5). The Red and Green tappings of the stabilizer transformer read 303 V AC and 235 V AC respectively. The variable transformer was set to 260 V AC, the ADC input produced 2.511 V, and the output digital produced (FB) Hex. The process continued for all values that the input was allowed to operate from (170 - 264 V AC). A table of all the data acquired during this measurement is shown in Table 1 (Data acquisition results).

Software Program for the Data Acquisition

In order for the 89C55 Microcontroller to display the digital output data from the 0804 ADC, there was the need to write an assembly language program to initiate analog to digital conversion, and display the data on the 8 LEDS connected to port 0 of the 89C55 microcontroller. The Assembly Language Program used to Convert Analog voltage into digital is shown in Appendix A. The flow chart of how the Assembly Language Program works to Convert Analog voltage into digital voltage is illustrated in Figure 35. This code was programmed into the 89C55 Microcontroller with Galep-5 Programmer (Plate 6).

Plate 6: Galep-5 Programmer used to write the program unto the microcontroller and the IC

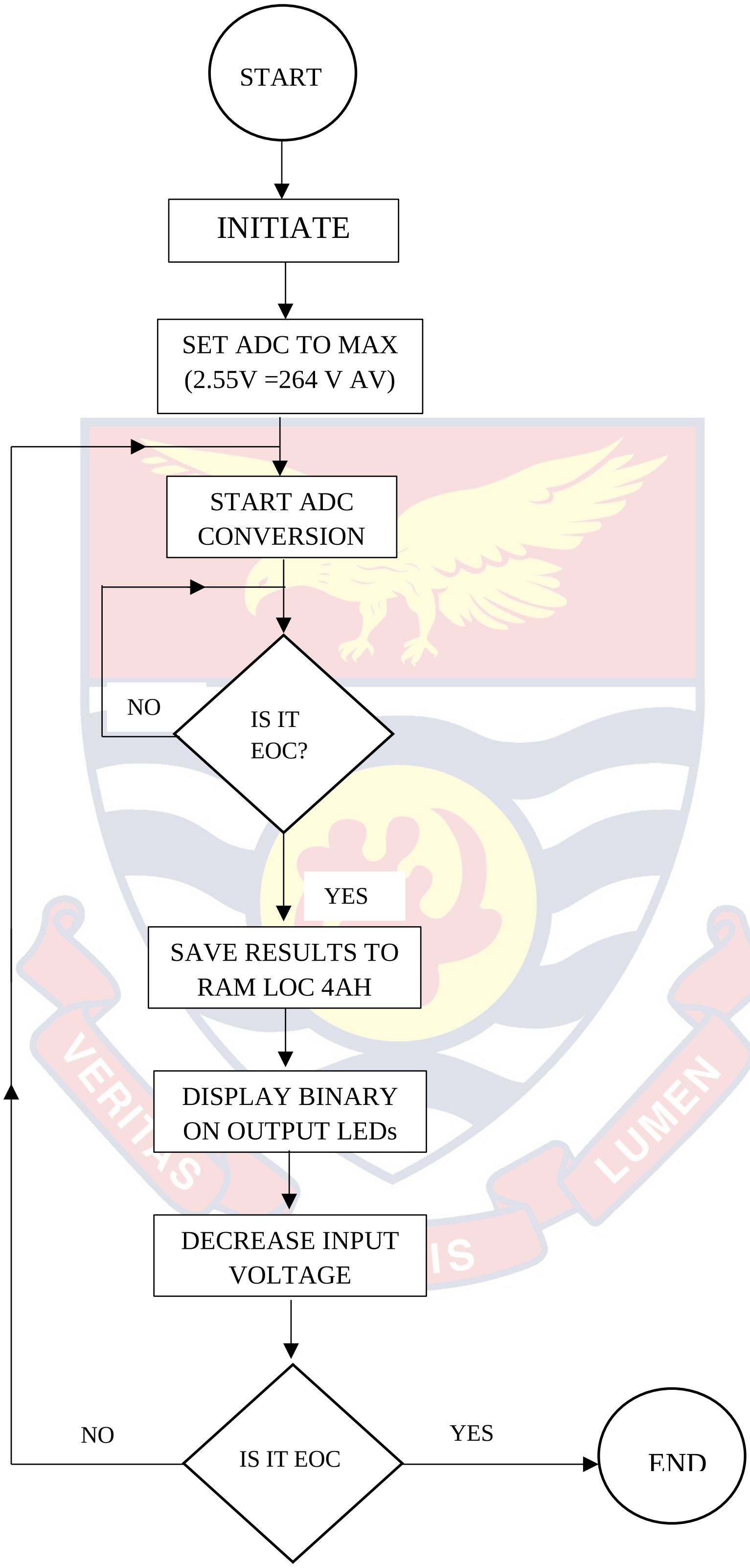


Figure 35: Flowchart of the ADC Program

After programing the ADC to obtain the digital values, it was used to write another program onto the microcontroller that will determine the selection of an SSR to switch a particular winding or tapping on. Figure 36 shows the block diagram of the completed voltage stabilizer device showing the unregulated and regulated (input and output) AC voltages with the SSR connected.

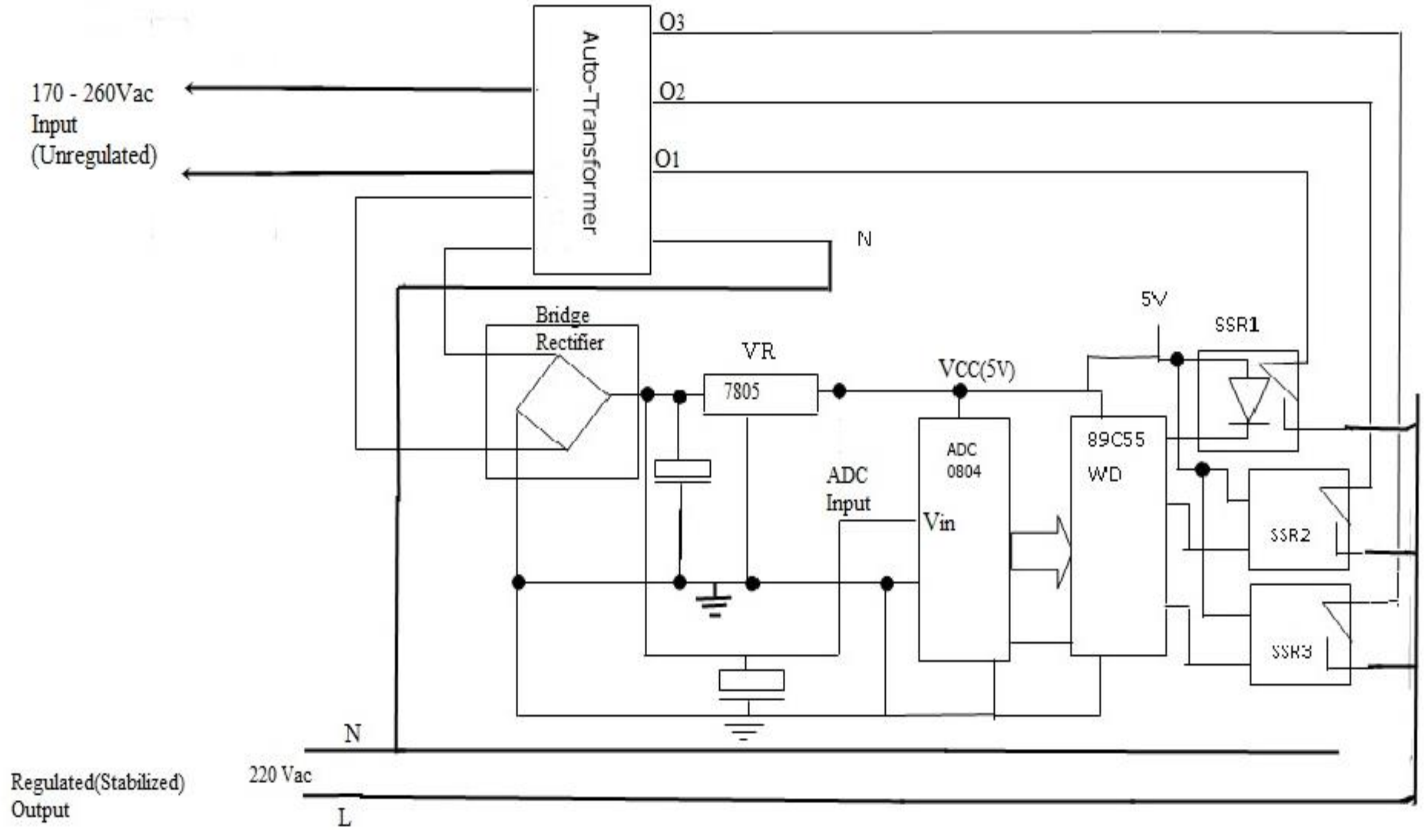


Figure 36: The block diagram of the completed Voltage Stabilizer device showing the unregulated and regulated (input and output) AC Voltages

CHAPTER FOUR

RESULTS AND DISCUSSION

Introduction

Data acquisition measurements were conducted with the setup shown in Figures 31 - 36; and Plates 1-3. The data acquisition was designed and built purposely for the construction of a voltage stabilizer that is controlled by a microprocessor (microcontroller).

Results

The results obtained during the measurements are shown in Table 3.

Table 3: Results of Measured Voltages

	OUTPUTS (AC)					
INPUT /OUTPUT (Yellow)	240 (High) (Red)	210 (Low) (Green)	ADC REF	ADC INPUT	DIGITAL OUTPUT (HEX)	DIGITAL OUTPUT (BIN)
170	195	151	1.275	1.642	A4	10100100
171	196	152	1.275	1.650	A5	10100101
172	197	153	1.275	1.658	A6	10100110
173	198	154	1.275	1.666	A7	10100111
174	199	155	1.275	1.674	A8	10101000
175	200	156	1.275	1.682	A9	10101001
176	201	157	1.275	1.690	AA	10101010
177	202	158	1.275	1.698	AB	10101011
178	203	159	1.275	1.720	AC	10101100
179	205	159	1.275	1.730	AD	10101101
180	206	160	1.275	1.740	AE	10101110
181	207	161	1.275	1.750	AF	10101111
182	208	161	1.275	1.760	B0	10110000
183	209	162	1.275	1.770	B1	10110001
184	210	162	1.275	1.780	B2	10110010
185	211	163	1.275	1.790	B3	10110011
186	212	164	1.275	1.800	B4	10110100
187	214	165	1.275	1.810	B5	10110101
188	215	166	1.275	1.820	B6	10110110
189	216	167	1.275	1.830	B7	10110111

Table 3 Continued

190	217	168	1.275	1.835	B8	10111000
191	219	169	1.275	1.850	B9	10111001
192	220	170	1.275	1.865	BA	10111010
193	222	171	1.275	1.880	BB	10111011
194	224	172	1.275	1.895	BC	10111100
195	225	173	1.275	1.910	BD	10111101
196	226	174	1.275	1.925	BE	10111110
198	227	175	1.275	1.940	BF	10111111
199	228	176	1.275	1.920	C0	11000000
200	229	177	1.275	1.932	C1	11000001
201	230	178	1.275	1.940	C2	11000010
202	231	179	1.275	1.948	C3	11000011
203	232	180	1.275	1.956	C4	11000100
204	233	181	1.275	1.964	C5	11000101
205	234	182	1.275	1.972	C6	11000110
206	236	183	1.275	1.980	C7	11000111
207	237	184	1.275	1.988	C8	11001000
208	238	185	1.275	2.010	C9	11001001
209	239	186	1.275	2.020	CA	11001010
210	240	186	1.275	2.028	CB	11001011
211	241	187	1.275	2.040	CC	11001100
212	242	188	1.275	2.050	CD	11001101
213	243	189	1.275	2.060	CE	11001110
214	244	190	1.275	2.070	CF	11001111
215	246	191	1.275	2.080	D0	11010000
216	248	192	1.275	2.090	D1	11010001
217	249	193	1.275	2.100	D2	11010010
218	250	194	1.275	2.110	D3	11010011
219	251	194	1.275	2.120	D4	11010100
220	252	195	1.275	2.130	D5	11010101
221	253	196	1.275	2.140	D6	11010110
222	255	197	1.275	2.150	D7	11010111
223	256	198	1.275	2.160	D8	11011000
224	257	199	1.275	2.170	D9	11011001
225	259	200	1.275	2.180	DA	11011010
226	260	201	1.275	2.190	DB	11011011
227	261	202	1.275	2.200	DC	11011100
229	262	203	1.275	2.210	DD	11011101
230	263	204	1.275	2.221	DE	11011110
231	264	204	1.275	2.230	DF	11011111
232	265	205	1.275	2.239	E0	11100000
233	266	206	1.275	2.248	E1	11100001

Table 3 Continued

234	268	207	1.275	2.257	E2	11100010
235	269	208	1.275	2.266	E3	11100011
236	270	209	1.275	2.275	E4	11100100
237	272	210	1.275	2.284	E5	11100101
238	273	211	1.275	2.293	E6	11100110
239	274	212	1.275	2.310	E7	11100111
240	275	213	1.275	2.318	E8	11101000
241	276	214	1.275	2.320	E9	11101001
242	278	215	1.275	2.322	EA	11101010
243	279	216	1.275	2.324	EB	11101011
245	280	217	1.275	2.326	EC	11101100
246	282	218	1.275	2.328	ED	11101101
247	283	219	1.275	2.330	EE	11101110
248	284	220	1.275	2.390	EF	11101111
249	285	221	1.275	2.400	F0	11110000
250	286	222	1.275	2.415	F1	11110001
251	288	223	1.275	2.420	F2	11110010
252	289	224	1.275	2.430	F3	11110011
253	290	225	1.275	2.440	F4	11110100
254	291	226	1.275	2.450	F5	11110101
255	292	226	1.275	2.460	F6	11110110
256	293	227	1.275	2.470	F7	11110111
257	285	228	1.275	2.480	F8	11111000
258	296	229	1.275	2.490	F9	11111001
259	297	230	1.275	2.500	FA	11111010
260	298	231	1.275	2.511	FB	11111011
261	299	231	1.275	2.520	FC	11111100
262	301	233	1.275	2.530	FD	11111101
263	302	234	1.275	2.540	FE	11111110
264	303	235	1.275	2.550	FF	11111111

The data obtained from the measurements as recorded in Table 3 was used to plot graphs of Transformer Output AC Voltage (Red, Yellow, and Green) Verses Binary outputs (Figure 37a and Figure 37b). This was to know the window within which the designed stabilizer can operate on.

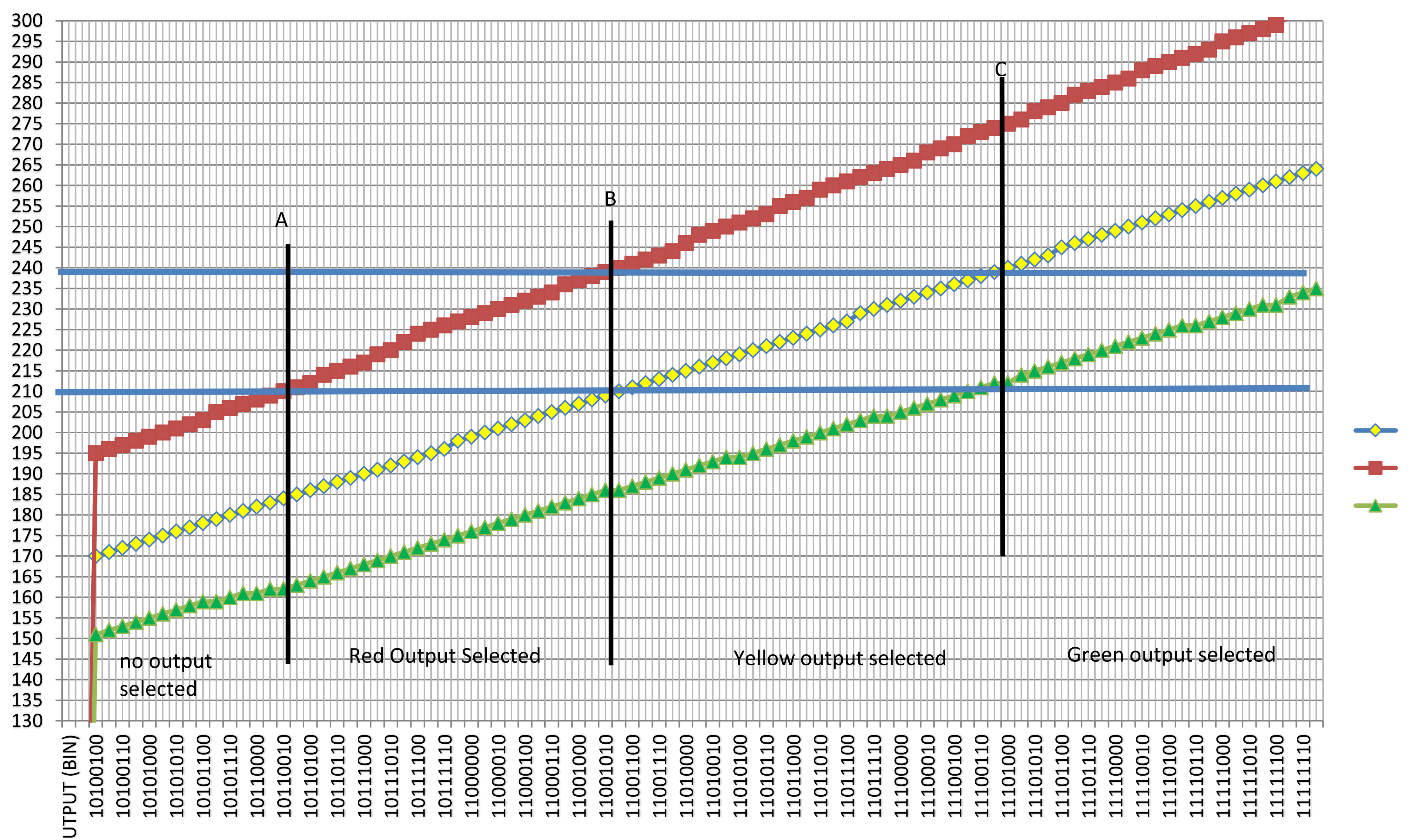


Figure 37a: Plot of Transformer Output AC Voltage (Red, Yellow, and Green) Verses Binary outputs showing the selected voltages

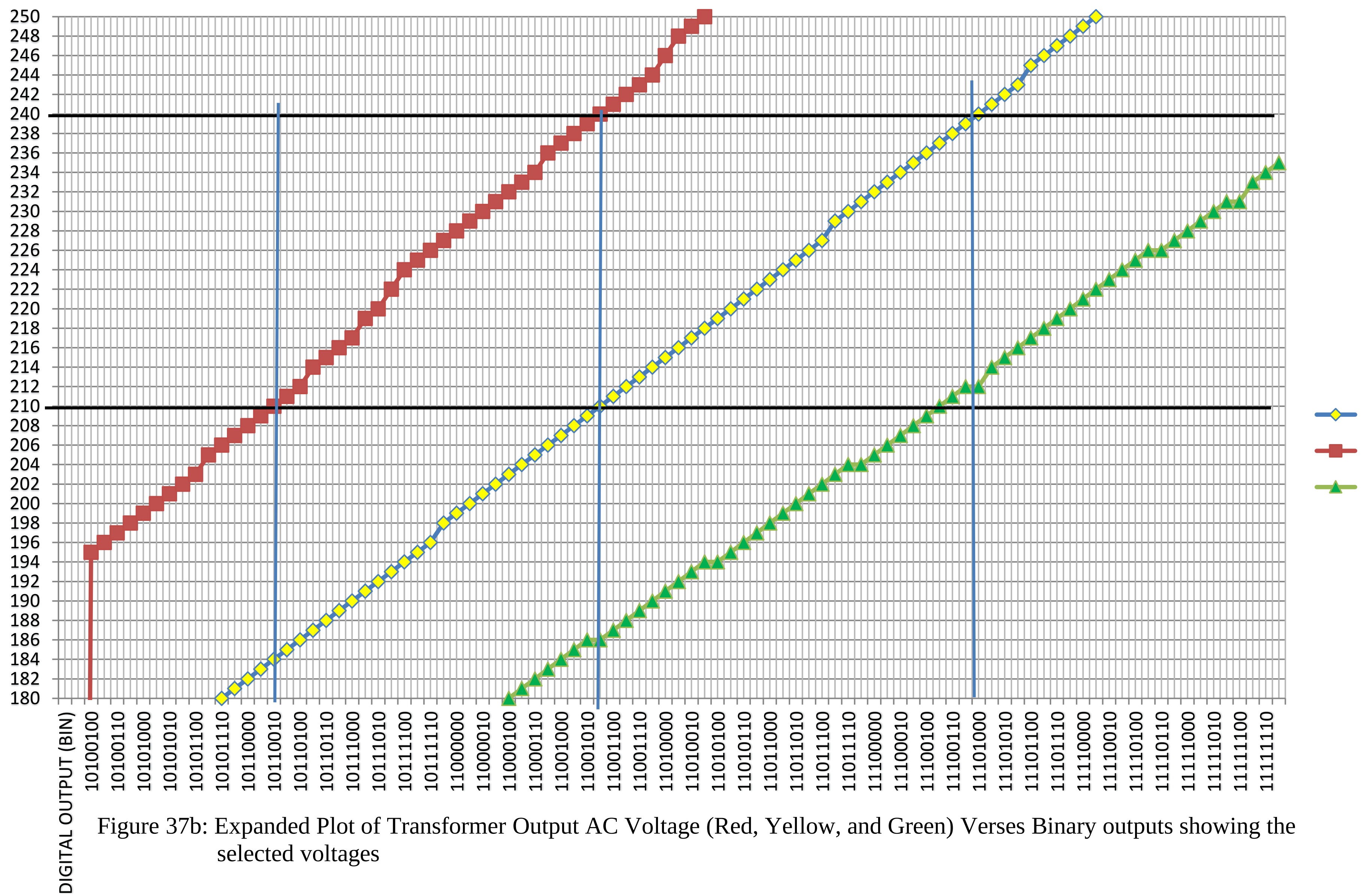


Figure 37b: Expanded Plot of Transformer Output AC Voltage (Red, Yellow, and Green) Verses Binary outputs showing the selected voltages

Figure 37 shows the graph of the Auto transformer's output voltage (AC voltage) for all the tapings (red, yellow and green) verses binary output which is the yellow tapping converted by the ADC. The yellow taping was used as both input and output taping and it has 1:1 ratio. The figure shows a study rise of output voltage for all the tappings as against the input voltage which is the yellow tapping. The red winding is a step up, and green taping is a step down.

From Figure 37b, it shows that at low voltages the red winding of the Autotransformer output was selected. For example, when the input voltage (yellow tapping) was 184 V AC the red output was 210 V AC and green output voltage was 162 V AC, and the ADC converted this voltage (0B2H) and 10110010B hexadecimal and binary formats respectively.

The program was written to select the output voltage to be between 220 – 230 V AC. As the input voltage increases, the output voltage from the red taping became so big that the yellow taping was selected to the output voltage as seen from Figure 37b. As the input voltage was increased to 210 V AC, the red output voltage was over 240 V AC so the yellow taping was selected as the output. When the input voltage was further increased to 240 V AC and beyond, the microcontroller selected the green (step down) taping or winding was selected on the output (212 V AC).

When the input voltage reached 256 V AC, the green output tapping produced an output voltage of 227 V AC whilst the red tapping produced an output voltage of 293 V AC with the ADC output being (0F7H) and 11110111B (Table 3). The software to select the various tappings of the autotransformer to ensure the output voltage was closed to 210 V AC to 240 V AC is show in Appendix A. The selection range is shown in Table 4.

Table 4: Transformer Tapping Selection by the 8051 Microcontroller

Input	Selected Output		
Yellow Tapping	Red Tapping	Yellow Tapping	Green Tapping
184	210		
185	211		
186	212		
187	214		
188	215		
189	216		
190	217		
191	219		
192	220		
193	222		
194	224		
195	225		
196	226		
198	227		
199	228		
200	229		
201	230		
202	231		
203	232		
204	233		
205	234		
206	236		
207	237		
208	238		
209	239		
210	240	210	
211		211	
212		212	
213		213	
214		214	
215		215	
216		216	
217		217	
218		218	
219		219	
220		220	
221		221	

Table 4 Continued

222	222	
223	223	
224	224	
225	225	
226	226	
227	227	
229	229	
230	230	
231	231	
232	232	
233	233	
234	234	
235	235	
236	236	
237	237	
238	238	
239	239	
240	240	
241		214
242		215
243		216
245		217
246		218
247		219
248		220
249		221
250		222
251		223
252		224
253		225
254		226
255		226
256		227
257		228
258		229
259		230
260		231
261		231
262		233
263		234
264		235

Analysis of Data

The data received from the ADC output was used to program the microcontroller to select the relay that connected the corresponding winding (tapping) of the autotransformer. There were three windings which was terminated with red, yellow and green wires to respective relays. The solid state relays input was directly controlled by the microcontroller Port 0, bit 2 (P0.2), Port 2, bit 2 (P2.2) and Port 2, bit 3 (P2.3).

Discussion of Results

The results produced from Analog to Digital Converter output as compared to the ADC output data Hexadecimal and voltage is found in Table 3. The AC voltage from the variable transformer (Figure 32 and Figure 34). The windings of the Transformer were three and were terminated at the end with red, yellow and green wire.

The output voltage from the various windings and the selected output at one particular time is produced in Table 4. For input voltages between 184 V AC to 210 V AC, the tapping which was the step – up winding was selected, and produced the voltage between 210 V AC to 240 V AC. As the input voltage increased, the red tapping output become so big that the output was switched to the yellow tapping. The turns ratio of the yellow tapping was (1:1) ratio, and so the yellow tapping become input/output tapping and selected output as seen from Table 4. Input and output voltages were the same (210 V AC to 240 V AC).

As the input continued to increase, at above 240 V AC, the output voltage of the yellow tapping output, become so high that the output was switched to the green transformer winding which started at (210 V AC to 235 V AC) as compared to the input voltage of (240 V AC to 264 V AC).

Output Load

The output connected to the solid state relays for the red, yellow and green tappings were connected to an AC load, namely an electric lamp, radio and a pressing iron. The final programme was written (Appendix B) and the assembly's language generated (Appendix C). The necessary bugs were fixed and then compiled to produce a hex file (Appendix D). It was then programmed onto the AT89S51 Microcontroller. The final project was tested and worked to satisfaction.

Voltage Stabilizer Using AT89S51 Microcontroller

Voltage stabilizers are used for many appliances in home, offices and industries. The mains supply suffers from large voltage drops due to losses on the distribution lines. A voltage stabilizer maintains the voltage to the appliances at the nominal value of around 230 V even if the inputs main fluctuates over a wide range.

The circuit of an automatic voltage stabilizer can be adapted to any power rating. Its intelligence lays in the program on AT89S51–a low cost microcontroller that is readily available. The circuit, when used with any appliances, will maintain the voltage at around 230 V even if the input mains voltage varies between 180 V and 260 V.

Result in Terms of Voltage Regulation

The Voltage Regulator using AT89S51 microcontroller is smart voltage regulator good for domestic appliances. Theoretically, it can give an output voltage of 230V in the range of voltage variation of 170 V to 364 V mains.

However it is accompanied by some harmonic content as seen from the waveform. When the fabricated circuit was tested in the laboratory, it gave an output voltage of 210 V for an input of 184 V mains. Thus it can be said to provide a voltage regulation of 87.62% which is satisfactory.

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Overview

This chapter deals with the summary of the study. Also, it takes care of the findings that resulted from data collected for the study. Other components of the chapter are the conclusions drawn from the study; recommendations made from the findings and suggested areas for further research.

Summary

The purpose of the study was to design and construct an electronic device that can be used to regulate the amount of voltage supplied to electrical devices for domestic use, in hospitals or research centres. The aim is to provide clean power to the load equipment to protect it from damage as a result of unstable voltage supply. The objective of this work was to design and construction a device that produces an output voltage which will stay in the range of 200 VAC - 240 V AC with an input voltage of 175 V AC - 265 V AC. It will particularly guard electronic gadgets against the dangerous high voltages and also from the possible brownouts (low voltages) and transient voltages.

Literature was reviewed on the design and fabrication of voltage stabilizer using 8051 microcontroller. Areas of much concern were voltage stabilization, the need for power conditioning, power quality, autotransformers, their advantages and limitations, semiconductor theory, the microcontroller 8051 and its architecture. Also considered under the review of related literature were interfacing with the analog world, analog-to-digital conversion and vice versa.

Summary of Key Points

1. The Target 300! schematic design software was used to design the schematic diagram of the project
2. The circuit was then captured on a PCB
3. Power supply unit was also designed, built and calibrated
4. The stabilizer circuit was then built on a prototype board
5. The whole circuit was then powered to check whether there was a short circuit or open circuit some where
6. The completed setup of the oscilloscope, Digital voltmeter, the variable transformer as shown in plate 5 was then arranged
7. An assembly language programme was written to collect data from the ADC's output to the microcontroller
8. The variable transformer was then varied from 170 V to 265 V AC and at each set point, the digital equivalent was displayed on the Eight bit LED were recorded.
9. The Hex file was then programmed into the 89C55 microcontroller with GALEP – 5 programmer
10. The completed setup was then arranged where with, energy saving lambs, radio and television set on the output of the voltage stabilizer, and it worked satisfactorily.

Conclusions

The voltage stabilizer was successfully designed and fabricated. Three output devices namely energy saving bulbs, a radio and a TV set were used as output loads at different times to the stabilizer. These appliances worked perfectly whilst using the designed voltage stabilizer.

The voltage differences from red, yellow and the yellow to green were however higher. For example, there was a change of 240 V output (red) to 210 V (yellow) output when the input voltage of the transformer was 210 V AC. Again, there was a change from 240 V AC (yellow) output to 214 V AC (green) output when the input voltage was 240 V AC.

Recommendations

The tappings of the transformer used for this study was three (3) tappings. Due to the fewer number of tappings used, there were sharp changes in the voltage from one tapping to another in the designed voltage stabilizer. Because of this it is recommended that, any student or researcher who would like to continue on this project is encouraged to use a transformer with five or six tappings so that the sudden change of voltage from 240 V AC to 210 V AC will not occur.

For very stable output and also ensuring that the output voltage remained constant at approximately 230 V ±2V AC, it is recommended that the designer uses a stabilizer with about five or six output tappings. The ADC resolution can be increased to 12 bits instead of the 8 bits ADC that was used in this project. The output of the stabilizer transformer tappings should include a 110 V AC to accommodate loads that have lower AC voltage.

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APPENDICES

APPENDIX A

Assembly Language Program to Convert Analog voltage into Digital voltage

;BANS BANDOH FREMPONG ASSEMBLY PROGRAM

; The Assembly Language Program to Convert Analog voltage at input of 0804 ; ADC to Digital and display it at port 0 LEDs of 89C55 Microcontroller

```
                org     0000h
                ajmp    30h
                org     30h
repeat:         acall   start_ADC
                ;cpl    a
                mov     a,40h
                mov     p2,a
                acall   delay
                ajmp    repeat
delay:
        ;setb   rs0
        ;setb   rs1
        Mov r0,#0a5h
in2:    mov r1,#05h
in1:    mov r2,#00h
again:  djnz r2,again
        djnz r1,in1
        djnz r0,in2
        ;clr    rs0
        ;clr    rs1
        ret

start_ADC:
ADC_RD                  equu    p3.7
ADC_WR                  equ     p3.6
EOC             equ     p3.5
                ;setb   ie0
                ;setb   ex0
                ;setb   ea
begin:          setb    ADC_RD
                setb    ADC_WR
;Start conversion
                clr     ADC_WR
                nop
                setb    ADC_WR
here:           jb      EOC,here
                clr     ADC_RD
                mov     a,p1
```

```
cpl     a
mov     40h,a
setb    ADC_RD
;mov  r0,#TEMP_RAM
;movx @r0,a
;lcall ramdelay
;setb    ADC_RD
;lcall   DEL
ret
end
```

The hex file produced when the above software was compiled is as shown below.

```
:020000000130CD
:100030001147E540F5A0113A013078A579057A001D
:10004000DAFED9FAD8F622D2B7D2B6C2B600D2B604
:0D00500020B5FDC2B7E590F4F540D2B7220F
:00000001FF
```

APPENDIX B

Main Program

```
        ORG   0000H

        AJMP  START


        SETB  P2.0; Relay for Red
        SETB  P2.2; Relay for Yellow
        SETB  P2.3; Relay for Green

;Voltage Range for change over
;is 210-240v for red winding
;       210v to 240v for yellow winding
;       212V and above for green winding
START:
        Mov A, P1
        CJNE A, #0FFH, loop
        CLR P2.3
loop:   CJNE A, #0FEH, loop1
        CLR P2.3
loop1:  CJNE A, #0FDH, loop2
        CLR P2.3
loop2:  CJNE A, #0FCH, loop3
        CLR P2.3
loop3:  CJNE A, #0FBH, loop4
        CLR P2.3
loop4:  CJNE A, #0FAH, loop5
        CLR P2.3
loop5:  CJNE A, #0F9H, loop6
        CLR P2.3
loop6:  CJNE A, #0F8H, loop7
        CLR P2.3
loop7:  CJNE A, #0F7H, loop8
        CLR P2.3
loop8:  CJNE A, #0F6H, loop9
        CLR P2.3
loop9:  CJNE A, #0F5H, loop10
        CLR P2.3
loop10: CJNE A, #0F4H, loop11
        CLR P2.3
loop11: CJNE A, #0F3H, loop12
        CLR P2.3
loop12: CJNE A, #0F2H, loop13
        CLR P2.3
loop13: CJNE A, #0F1H, loop14
        CLR P2.3
loop14: CJNE A, #0F0H, loop15
```

```
        CLR P2.3
loop15: CJNE A, #0EFH, loop16
        CLR P2.3
loop16: CJNE A, #0EEH, loop17
        CLR P2.3
loop17: CJNE A, #0EDH, loop18
        CLR P2.3
loop18: CJNE A, #0ECH, loop19
        CLR P2.3
loop19: CJNE A, #0EBH, loop20
        CLR P2.3
loop20: CJNE A, #0EAH, loop21
        CLR P2.3
loop21: CJNE A, #0E9H, loop22
        CLR P2.3
loop22: CJNE A, #0E8H, loop23
        CLR P2.2
loop23: CJNE A, #0E7H, loop24
        CLR P2.2
loop24: CJNE A, #0E6H, loop25
        CLR P2.2
loop25: CJNE A, #0E5H, loop26
        CLR P2.2
loop26: CJNE A, #0E4H, loop27
        CLR P2.2
loop27: CJNE A, #0E3H, loop28
        CLR P2.2
loop28: CJNE A, #0E2H, loop29
        CLR P2.2
loop29: CJNE A, #0E1H, loop30
        CLR P2.2
loop30: CJNE A, #0E0H, loop31
        CLR P2.2
loop31: CJNE A, #0DFH, loop32
        CLR P2.2
loop32: CJNE A, #0DEH, loop33
        CLR P2.2
loop33: CJNE A, #0DDH, loop34
        CLR P2.2
loop34: CJNE A, #0DCH, loop35
        CLR P2.2
loop35: CJNE A, #0DBH, loop36
        CLR P2.2
loop36: CJNE A, #0DAH, loop37
        CLR P2.2
loop37: CJNE A, #0D9H, loop38
        CLR P2.2
loop38: CJNE A, #0D8H, loop39
        CLR P2.2
loop39: CJNE A, #0D7H, loop40
```

```
        CLR P2.2
loop40: CJNE A, #0D6H, loop41
        CLR P2.2
loop41: CJNE A, #0D5H, loop42
        CLR P2.2
loop42: CJNE A, #0D4H, loop43
        CLR P2.2
loop43: CJNE A, #0D3H, loop44
        CLR P2.2
loop44: CJNE A, #0D2H, loop45
        CLR P2.2
loop45: CJNE A, #0D1H, loop46
        CLR P2.2
loop46: CJNE A, #0D0H, loop47
        CLR P2.2
loop47: CJNE A, #0CFH, loop48
        CLR P2.2
loop48: CJNE A, #0CEH, loop49
        CLR P2.2
loop49: CJNE A, #0CDH, loop50
        CLR P2.2
loop50: CJNE A, #0CCH, loop51
        CLR P2.0
loop51: CJNE A, #0CBH, loop52
        CLR P2.0
loop52: CJNE A, #0CBH, loop53
        CLR P2.0
loop53: CJNE A, #0CAH, loop54
        CLR P2.0
loop54: CJNE A, #0C9H, loop55
        CLR P2.0
loop55: CJNE A, #0C8H, loop56
        CLR P2.0
loop56: CJNE A, #0C7H, loop57
        CLR P2.0
loop57: CJNE A, #0C6H, loop58
        CLR P2.0
loop58: CJNE A, #0C5H, loop59
        CLR P2.0
loop59: CJNE A, #0C4H, loop60
        CLR P2.0
loop60: CJNE A, #0C3H, loop61
        CLR P2.0
loop61: CJNE A, #0C2H, loop62
        CLR P2.0
loop62: CJNE A, #0C1H, loop63
        CLR P2.0
loop63: CJNE A, #0C0H, loop64
        CLR P2.0
loop64: CJNE A, #0BFH, loop65
```

```
        CLR P2.0
loop65: CJNE A, #0BEH, loop66
        CLR P2.0
loop66: CJNE A, #0BDH, loop67
        CLR P2.0
loop67: CJNE A, #0BCH, loop68
        CLR P2.0
loop68: CJNE A, #0BBH, loop69
        CLR P2.0
loop69: CJNE A, #0BAH, loop70
        CLR P2.0
loop70: CJNE A, #0B9H, loop71
        CLR P2.0
loop71: CJNE A, #0B8H, loop72
        CLR P2.0
loop72: CJNE A, #0B7H, loop73
        CLR P2.0
loop73: CJNE A, #0B6H, loop74
        CLR P2.0
loop74: CJNE A, #0B5H, loop75
        CLR P2.0
loop75: CJNE A, #0B4H, loop76
        CLR P2.0
loop76: CJNE A, #0B3H, loop77
        CLR P2.0
loop77: CJNE A, #0B2H, loop78
        CLR P2.0
        LJMP START
loop78:         LJMP START
        END
```

APPENDIX C

Assembly Language for the Program

```
ASEM-51 V1.3                              Copyright (c) 2002 by W.W. Heinz
PAGE 1

     MCS-51 Family Macro Assembler   A S E M - 5 1   V 1.3

=====================================================
          Source File:    C:\Users\SIET
DEAN\Documents\BANS_PROJECT.ASM
          Object File:    C:\Users\SIET
DEAN\Documents\BANS_PROJECT.hex
          List File:      C:\Users\SIET DEAN\Documents\BANS_PROJECT.lst



 Line  I  Addr  Code            Source

    1:            N      0000           ORG   0000H
    2:      0000  01 08                 AJMP  START
    3:
    4:      0002  D2 A0                 SETB  P2.0; Relay for Red
    5:      0004  D2 A2                 SETB  P2.2; Relay for Yellow
    6:      0006  D2 A3                 SETB  P2.3; Relay for Green
    7:
    8:                          ;Voltage Range for change over
    9:                          ;is 210-240v for red winding
   10:                          ;       210v to 240v for yellow winding
   11:                          ;       212V and above for green winding
   12:      0008                START:
   13:      0008  E5 90                 Mov A, P1
   14:      000A  B4 FF 02              CJNE A, #0FFH, loop
   15:      000D  C2 A3                 CLR P2.3
   16:      000F  B4 FE 02      loop:   CJNE A, #0FEH, loop1
   17:      0012  C2 A3                 CLR P2.3
   18:      0014  B4 FD 02      loop1:  CJNE A, #0FDH, loop2
   19:      0017  C2 A3                 CLR P2.3
   20:      0019  B4 FC 02      loop2:  CJNE A, #0FCH, loop3
   21:      001C  C2 A3                 CLR P2.3
   22:      001E  B4 FB 02      loop3:  CJNE A, #0FBH, loop4
```

```
0021  C2 A3                 CLR P2.3
0023  B4 FA 02      loop4:  CJNE A, #0FAH, loop5
0026  C2 A3                 CLR P2.3
0028  B4 F9 02      loop5:  CJNE A, #0F9H, loop6
002B  C2 A3                 CLR P2.3
002D  B4 F8 02      loop6:  CJNE A, #0F8H, loop7
0030  C2 A3                 CLR P2.3
0032  B4 F7 02      loop7:  CJNE A, #0F7H, loop8
0035  C2 A3                 CLR P2.3
0037  B4 F6 02      loop8:  CJNE A, #0F6H, loop9
003A  C2 A3                 CLR P2.3
003C  B4 F5 02      loop9:  CJNE A, #0F5H, loop10
003F  C2 A3                 CLR P2.3
0041  B4 F4 02      loop10: CJNE A, #0F4H, loop11
0044  C2 A3                 CLR P2.3
0046  B4 F3 02      loop11: CJNE A, #0F3H, loop12
0049  C2 A3                 CLR P2.3
004B  B4 F2 02      loop12: CJNE A, #0F2H, loop13
004E  C2 A3                 CLR P2.3
0050  B4 F1 02      loop13: CJNE A, #0F1H, loop14
0053  C2 A3                 CLR P2.3
```

```
 Line  I  Addr  Code          Source

  44:     0055  B4 F0 02      loop14: CJNE A, #0F0H, loop15
  45:     0058  C2 A3                 CLR P2.3
  46:     005A  B4 EF 02      loop15: CJNE A, #0EFH, loop16
  47:     005D  C2 A3                 CLR P2.3
  48:     005F  B4 EE 02      loop16: CJNE A, #0EEH, loop17
  49:     0062  C2 A3                 CLR P2.3
  50:     0064  B4 ED 02      loop17: CJNE A, #0EDH, loop18
  51:     0067  C2 A3                 CLR P2.3
  52:     0069  B4 EC 02      loop18: CJNE A, #0ECH, loop19
  53:     006C  C2 A3                 CLR P2.3
  54:     006E  B4 EB 02      loop19: CJNE A, #0EBH, loop20
  55:     0071  C2 A3                 CLR P2.3
  56:     0073  B4 EA 02      loop20: CJNE A, #0EAH, loop21
  57:     0076  C2 A3                 CLR P2.3
  58:     0078  B4 E9 02      loop21: CJNE A, #0E9H, loop22
  59:     007B  C2 A3                 CLR P2.3
  60:     007D  B4 E8 02      loop22:CJNE A, #0E8H, loop23
  61:     0080  C2 A2                 CLR P2.2
  62:     0082  B4 E7 02      loop23: CJNE A, #0E7H, loop24
  63:     0085  C2 A2                 CLR P2.2
  64:     0087  B4 E6 02      loop24: CJNE A, #0E6H, loop25
  65:     008A  C2 A2                 CLR P2.2
  66:     008C  B4 E5 02      loop25: CJNE A, #0E5H, loop26
  67:     008F  C2 A2                 CLR P2.2
  68:     0091  B4 E4 02      loop26: CJNE A, #0E4H, loop27
  69:     0094  C2 A2                 CLR P2.2
  70:     0096  B4 E3 02      loop27: CJNE A, #0E3H, loop28
  71:     0099  C2 A2                 CLR P2.2
  72:     009B  B4 E2 02      loop28: CJNE A, #0E2H, loop29
  73:     009E  C2 A2                 CLR P2.2
  74:     00A0  B4 E1 02      loop29: CJNE A, #0E1H, loop30
  75:     00A3  C2 A2                 CLR P2.2
  76:     00A5  B4 E0 02      loop30: CJNE A, #0E0H, loop31
  77:     00A8  C2 A2                 CLR P2.2
  78:     00AA  B4 DF 02      loop31: CJNE A, #0DFH, loop32
  79:     00AD  C2 A2                 CLR P2.2
  80:     00AF  B4 DE 02      loop32: CJNE A, #0DEH, loop33
  81:     00B2  C2 A2                 CLR P2.2
  82:     00B4  B4 DD 02      loop33: CJNE A, #0DDH, loop34
```

```
00B7 C2 A2              CLR P2.2
00B9 B4 DC 02    loop34: CJNE A, #0DCH, loop35
00BC C2 A2              CLR P2.2
00BE B4 DB 02    loop35: CJNE A, #0DBH, loop36
00C1 C2 A2              CLR P2.2
00C3 B4 DA 02    loop36: CJNE A, #0DAH, loop37
00C6 C2 A2              CLR P2.2
00C8 B4 D9 02    loop37: CJNE A, #0D9H, loop38
00CB C2 A2              CLR P2.2
00CD B4 D8 02    loop38: CJNE A, #0D8H, loop39
00D0 C2 A2              CLR P2.2
00D2 B4 D7 02    loop39: CJNE A, #0D7H, loop40
00D5 C2 A2              CLR P2.2
00D7 B4 D6 02    loop40: CJNE A, #0D6H, loop41
00DA C2 A2              CLR P2.2
00DC B4 D5 02    loop41: CJNE A, #0D5H, loop42
00DF C2 A2              CLR P2.2
```

```
 Line  I  Addr  Code           Source

 100:     00E1  B4 D4 02       loop42: CJNE A, #0D4H, loop43
 101:     00E4  C2 A2                  CLR P2.2
 102:     00E6  B4 D3 02       loop43: CJNE A, #0D3H, loop44
 103:     00E9  C2 A2                  CLR P2.2
 104:     00EB  B4 D2 02       loop44: CJNE A, #0D2H, loop45
 105:     00EE  C2 A2                  CLR P2.2
 106:     00F0  B4 D1 02       loop45: CJNE A, #0D1H, loop46
 107:     00F3  C2 A2                  CLR P2.2
 108:     00F5  B4 D0 02       loop46: CJNE A, #0D0H, loop47
 109:     00F8  C2 A2                  CLR P2.2
 110:     00FA  B4 CF 02       loop47: CJNE A, #0CFH, loop48
 111:     00FD  C2 A2                  CLR P2.2
 112:     00FF  B4 CE 02       loop48: CJNE A, #0CEH, loop49
 113:     0102  C2 A2                  CLR P2.2
 114:     0104  B4 CD 02       loop49: CJNE A, #0CDH, loop50
 115:     0107  C2 A2                  CLR P2.2
 116:     0109  B4 CC 02       loop50: CJNE A, #0CCH, loop51
 117:     010C  C2 A0                  CLR P2.0
 118:     010E  B4 CB 02       loop51:         CJNE A, #0CBH, loop52
 119:     0111  C2 A0                  CLR P2.0
 120:     0113  B4 CB 02       loop52: CJNE A, #0CBH, loop53
 121:     0116  C2 A0                  CLR P2.0
 122:     0118  B4 CA 02       loop53: CJNE A, #0CAH, loop54
 123:     011B  C2 A0                  CLR P2.0
 124:     011D  B4 C9 02       loop54: CJNE A, #0C9H, loop55
 125:     0120  C2 A0                  CLR P2.0
 126:     0122  B4 C8 02       loop55: CJNE A, #0C8H, loop56
 127:     0125  C2 A0                  CLR P2.0
 128:     0127  B4 C7 02       loop56: CJNE A, #0C7H, loop57
 129:     012A  C2 A0                  CLR P2.0
 130:     012C  B4 C6 02       loop57: CJNE A, #0C6H, loop58
 131:     012F  C2 A0                  CLR P2.0
 132:     0131  B4 C5 02       loop58: CJNE A, #0C5H, loop59
 133:     0134  C2 A0                  CLR P2.0
 134:     0136  B4 C4 02       loop59: CJNE A, #0C4H, loop60
 135:     0139  C2 A0                  CLR P2.0
 136:     013B  B4 C3 02       loop60: CJNE A, #0C3H, loop61
 137:     013E  C2 A0                  CLR P2.0
 138:     0140  B4 C2 02       loop61: CJNE A, #0C2H, loop62
```

```
0143  C2 A0                   CLR P2.0
0145  B4 C1 02      loop62: CJNE A, #0C1H, loop63
0148  C2 A0                   CLR P2.0
014A  B4 C0 02      loop63: CJNE A, #0C0H, loop64
014D  C2 A0                   CLR P2.0
014F  B4 BF 02      loop64: CJNE A, #0BFH, loop65
0152  C2 A0                   CLR P2.0
0154  B4 BE 02      loop65: CJNE A, #0BEH, loop66
0157  C2 A0                   CLR P2.0
0159  B4 BD 02      loop66: CJNE A, #0BDH, loop67
015C  C2 A0                   CLR P2.0
015E  B4 BC 02      loop67: CJNE A, #0BCH, loop68
0161  C2 A0                   CLR P2.0
0163  B4 BB 02      loop68: CJNE A, #0BBH, loop69
0166  C2 A0                   CLR P2.0
0168  B4 BA 02      loop69: CJNE A, #0BAH, loop70
016B  C2 A0                   CLR P2.0
```

```
ASEM-51 V1.3                         Copyright (c) 2002 by W.W. Heinz
PAGE 4

 Line  I  Addr  Code           Source

 156:     016D B4 B9 02        loop70: CJNE A, #0B9H, loop71
 157:     0170  C2 A0                  CLR P2.0
 158:     0172  B4 B8 02       loop71: CJNE A, #0B8H, loop72
 159:     0175  C2 A0                  CLR P2.0
 160:     0177  B4 B7 02       loop72: CJNE A, #0B7H, loop73
 161:     017A C2 A0                   CLR P2.0
 162:     017C B4 B6 02        loop73: CJNE A, #0B6H, loop74
 163:     017F  C2 A0                  CLR P2.0
 164:     0181  B4 B5 02       loop74: CJNE A, #0B5H, loop75
 165:     0184  C2 A0                  CLR P2.0
 166:     0186  B4 B4 02       loop75: CJNE A, #0B4H, loop76
 167:     0189  C2 A0                  CLR P2.0
 168:     018B B4 B3 02        loop76: CJNE A, #0B3H, loop77
 169:     018E C2 A0                   CLR P2.0
 170:     0190  B4 B2 05       loop77: CJNE A, #0B2H, loop78
 171:     0193  C2 A0                  CLR P2.0
 172:     0195  02 00 08               LJMP START
 173:     0198  02 00 08       loop78:         LJMP START
 174:                                  END


           register banks used:  ---


           no errors
```

L I S T O F S Y M B O L S

==

SYMBOL	TYPE	VALUE	LINE
??ASEM_51	NUMBER	8051	
??VERSION	NUMBER	0130	
AC	BIT	D6	
ACC	DATA	E0	
B	DATA	F0	
CY	BIT	D7	
DPH	DATA	83	
DPL	DATA	82	
EA	BIT	AF	
ES	BIT	AC	
ET0	BIT	A9	
ET1	BIT	AB	
EX0	BIT	A8	
EX1	BIT	AA	
EXTI0	CODE	0003	
EXTI1	CODE	0013	
F0	BIT	D5	
IE	DATA	A8	
IE0	BIT	89	
IE1	BIT	8B	
INT0	BIT	B2	
INT1	BIT	B3	
IP	DATA	B8	
IT0	BIT	88	
IT1	BIT	8A	
LOOP	CODE	000F	16
LOOP1	CODE	0014	18
LOOP10	CODE	0041	36
LOOP11	CODE	0046	38
LOOP12	CODE	004B	40
LOOP13	CODE	0050	42
LOOP14	CODE	0055	44
LOOP15	CODE	005A	46
LOOP16	CODE	005F	48
LOOP17	CODE	0064	50
LOOP18	CODE	0069	52

LOOP19	CODE	006E	54
LOOP2	CODE	0019	20
LOOP20	CODE	0073	56
LOOP21	CODE	0078	58
LOOP22	CODE	007D	60
LOOP23	CODE	0082	62
LOOP24	CODE	0087	64
LOOP25	CODE	008C	66
LOOP26	CODE	0091	68
LOOP27	CODE	0096	70
LOOP28	CODE	009B	72
LOOP29	CODE	00A0	74
LOOP3	CODE	001E	22
LOOP30	CODE	00A5	76

SYMBOL	TYPE	VALUE	LINE
LOOP31	CODE	00AA	78
LOOP32	CODE	00AF	80
LOOP33	CODE	00B4	82
LOOP34	CODE	00B9	84
LOOP35	CODE	00BE	86
LOOP36	CODE	00C3	88
LOOP37	CODE	00C8	90
LOOP38	CODE	00CD	92
LOOP39	CODE	00D2	94
LOOP4	CODE	0023	24
LOOP40	CODE	00D7	96
LOOP41	CODE	00DC	98
LOOP42	CODE	00E1	100
LOOP43	CODE	00E6	102
LOOP44	CODE	00EB	104
LOOP45	CODE	00F0	106
LOOP46	CODE	00F5	108
LOOP47	CODE	00FA	110
LOOP48	CODE	00FF	112
LOOP49	CODE	0104	114
LOOP5	CODE	0028	26
LOOP50	CODE	0109	116
LOOP51	CODE	010E	118
LOOP52	CODE	0113	120
LOOP53	CODE	0118	122
LOOP54	CODE	011D	124
LOOP55	CODE	0122	126
LOOP56	CODE	0127	128
LOOP57	CODE	012C	130
LOOP58	CODE	0131	132
LOOP59	CODE	0136	134
LOOP6	CODE	002D	28
LOOP60	CODE	013B	136
LOOP61	CODE	0140	138
LOOP62	CODE	0145	140
LOOP63	CODE	014A	142
LOOP64	CODE	014F	144
LOOP65	CODE	0154	146
LOOP66	CODE	0159	148

LOOP67		CODE	015E	150
LOOP68		CODE	0163	152
LOOP69		CODE	0168	154
LOOP7		CODE	0032	30
LOOP70		CODE	016D	156
LOOP71		CODE	0172	158
LOOP72		CODE	0177	160
LOOP73		CODE	017C	162
LOOP74		CODE	0181	164
LOOP75		CODE	0186	166
LOOP76		CODE	018B	168
LOOP77		CODE	0190	170
LOOP78		CODE	0198	173
LOOP8		CODE	0037	32
LOOP9		CODE	003C	34
OV	BIT	D2		
P	BIT	D0		

SYMBOL	TYPE	VALUE	LINE
P0	DATA	80	
P1	DATA	90	
P2	DATA	A0	
P3	DATA	B0	
PCON	DATA	87	
PS	BIT	BC	
PSW	DATA	D0	
PT0	BIT	B9	
PT1	BIT	BB	
PX0	BIT	B8	
PX1	BIT	BA	
RB8	BIT	9A	
RD	BIT	B7	
REN	BIT	9C	
RESET	CODE	0000	
RI	BIT	98	
RS0	BIT	D3	
RS1	BIT	D4	
RXD	BIT	B0	
SBUF	DATA	99	
SCON	DATA	98	
SINT	CODE	0023	
SM0	BIT	9F	
SM1	BIT	9E	
SM2	BIT	9D	
SP	DATA	81	
START	CODE	0008	12
T0	BIT	B4	
T1	BIT	B5	
TB8	BIT	9B	
TCON	DATA	88	
TF0	BIT	8D	
TF1	BIT	8F	
TH0	DATA	8C	
TH1	DATA	8D	
TI	BIT	99	
TIMER0	CODE	000B	
TIMER1	CODE	001B	
TL0	DATA	8A	

TL1	DATA		8B
TMOD	DATA		89
TR0	BIT	8C	
TR1	BIT	8E	
TXD	BIT	B1	
WR	BIT	B6	

APPENDIX D

Hex Code from the Compiled Program

```
:100000000108D2A0D2A2D2A3E590B4FF02C2A3B449
:10001000FE02C2A3B4FD02C2A3B4FC02C2A3B4FB9D
:1000200002C2A3B4FA02C2A3B4F902C2A3B4F80292
:10003000C2A3B4F702C2A3B4F602C2A3B4F502C2CB
:10004000A3B4F402C2A3B4F302C2A3B4F202C2A3E3
:10005000B4F102C2A3B4F002C2A3B4EF02C2A3B4CB
:10006000EE02C2A3B4ED02C2A3B4EC02C2A3B4EB8D
:1000700002C2A3B4EA02C2A3B4E902C2A3B4E80272
:10008000C2A2B4E702C2A2B4E602C2A2B4E502C2AE
:10009000A2B4E402C2A2B4E302C2A2B4E202C2A2C7
:1000A000B4E102C2A2B4E002C2A2B4DF02C2A2B4AE
:1000B000DE02C2A2B4DD02C2A2B4DC02C2A2B4DB80
:1000C00002C2A2B4DA02C2A2B4D902C2A2B4D80255
:1000D000C2A2B4D702C2A2B4D602C2A2B4D502C28E
:1000E000A2B4D402C2A2B4D302C2A2B4D202C2A2A7
:1000F000B4D102C2A2B4D002C2A2B4CF02C2A2B48E
:10010000CE02C2A2B4CD02C2A2B4CC02C2A0B4CB71
:1001100002C2A0B4CB02C2A0B4CA02C2A0B4C90237
:10012000C2A0B4C802C2A0B4C702C2A0B4C602C270
:10013000A0B4C502C2A0B4C402C2A0B4C302C2A08B
:10014000B4C202C2A0B4C102C2A0B4C002C2A0B470
:10015000BF02C2A0B4BE02C2A0B4BD02C2A0B4BC61
:1001600002C2A0B4BB02C2A0B4BA02C2A0B4B90217
:10017000C2A0B4B802C2A0B4B702C2A0B4B602C250
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