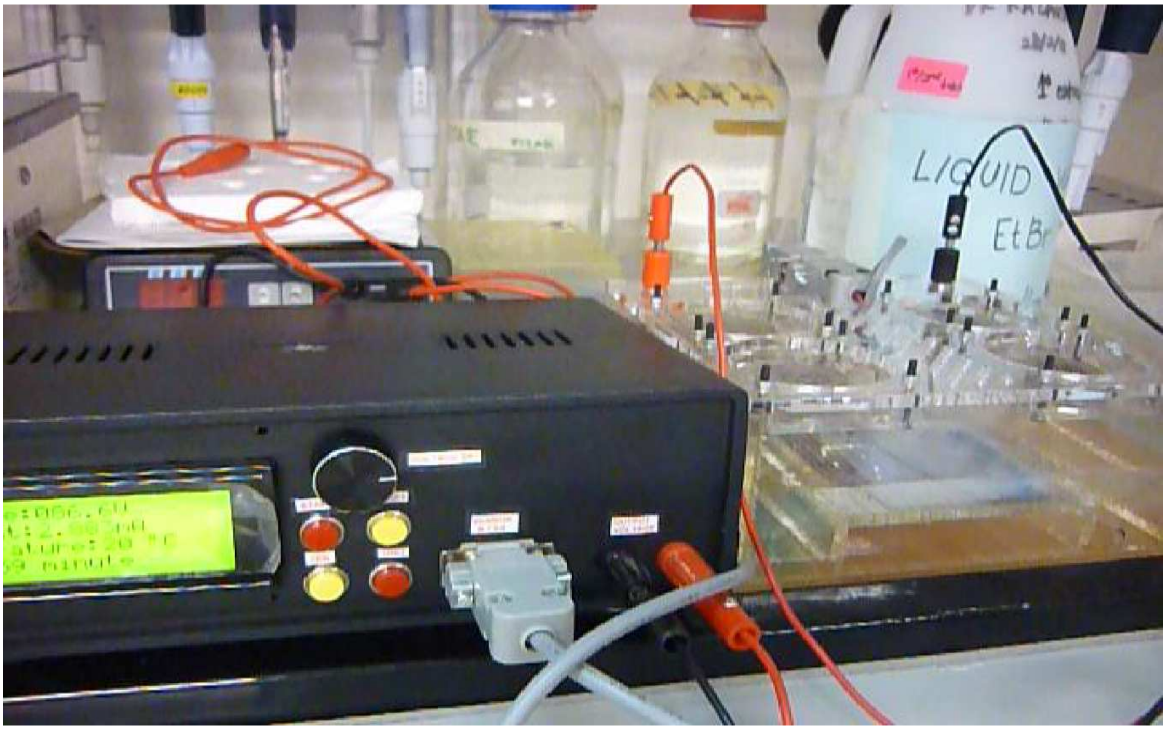
PROJECT PROFILE

Vote: 77273



THEORETICAL FORMULATION FOR REDUCE DNA SEPARATION TIME USING HIGH EFFICIENCY SWITCH MODE POWER SUPPLY (SMPS) OF A GEL ELECTROPHORESIS UNIT

Muhammad Arif bin Abdul rahim
Infocomm
Universiti Teknologi Malaysia
(arif@fke.utm.my)

ABSTRACT

The project work based on theoretical analysis and experimentation of the deoxyribonucleic acid (DNA) separation process using the Gel Electrophoresis unit with temperature control in order to reduce the cost and time. Gel Electrophoresis is a technique use for the separation of deoxyribonucleic acid (DNA), ribonucleic acid (RNA), or protein molecules using an electric current applied to a gel matrix. The term gel in this instance refer to the matrix used contain and then separate the target molecules while electrophoresis is defined as a movement of particle though solvent under external electric field influence. The project uses PIC 18F452 microcontroller as the main brain of the system. This microcontroller exchanges the analog and digital data between master controller and temperature sensor so that the temperatures for every two seconds are known. Besides that, this microcontroller is also use to read the voltage output from the power supply and measure the current flow. A countdown timer is applied to calculate time of Electrophoresis process. All the parameter is displayed on Liquid crystal display (LCD). After computing the DNA separation process, a sound beep through buzzer is produce. The significant of this project is to show that the newly designed electrophoresis apparatus will sustain the temperature raise and optimize the electrophoresis process. The temperature controller circuit is expected to control the temperature and proportionally control the fan speed to accommodate the thermal distributed within the DNA separation process.

1. INTRODUCTION

Nowadays, Switch Mode Power Supply (SMPS) is used widely in electronics systems. Many electrical appliances such as televisions and computer use SMPS to provide constant internal supply, SMPS also used to achieve higher voltage supply compared to powering battery voltage such as tape recorders, compact disc players, notebooks, mobile phones and cameras. Most critically, SMPS now is being used widely in biomedical research field since their efficiency and reliability to provide stable and constant configurable voltage range is required. Theoretically, SMPS provides 100% efficiency or lossless. However, in practical, SMPS has efficiency of 70% to 95% and this result to operation in low temperature and high reliability. Appreciating the contribution of SMPS in medical and science research environment, this thesis had focused on designing a new gel electrophoresis unit which consists of Flyback converter SMPS and gel container. In this case, electric field for separation DNA process of gel electrophoresis was achieved by the SMPS with characteristics such as wide range in output voltage (70-130v), output current reaching 300mA, and good voltage regulation. The significant of this project is to show that the newly designed of Gel Electrophoresis DNA container will sustain the temperature raise and optimize the electrophoresis process. The Gel Electrophoresis is a technique used for the separation of deoxyribonucleic acid (DNA), ribonucleic acid (RNA) or protein molecules using and electric current applied to a gel matrix. By placing the molecules in the gel and applying an electric current, the molecules will move through the matrix at different rates, determined largely by their mass when the charge to mass ratio (Z) of all species in uniform, toward the anode if negatively charged or toward the cathode if positively charged. Furthermore, this project is to convert of analog voltage display to digital voltage display which affix countdown timer to calculate the time of the electrophoresis process and current measure using printed circuit board (PCB). After the process is completed, the buzzer produces the beep sound.

2. RESEARCH METHODOLOGY

Research methodology of the project is conducted as follows;

a) Design and develop SMPS
b) Design and develop new gel electrophoresis container/tank
c) Experimenting the new gel electrophoresis unit

Figure 1 shows a general concept of the new gel electrophoresis unit. The first block refers to the power pack or SMPS and the second block shows the container/tank.

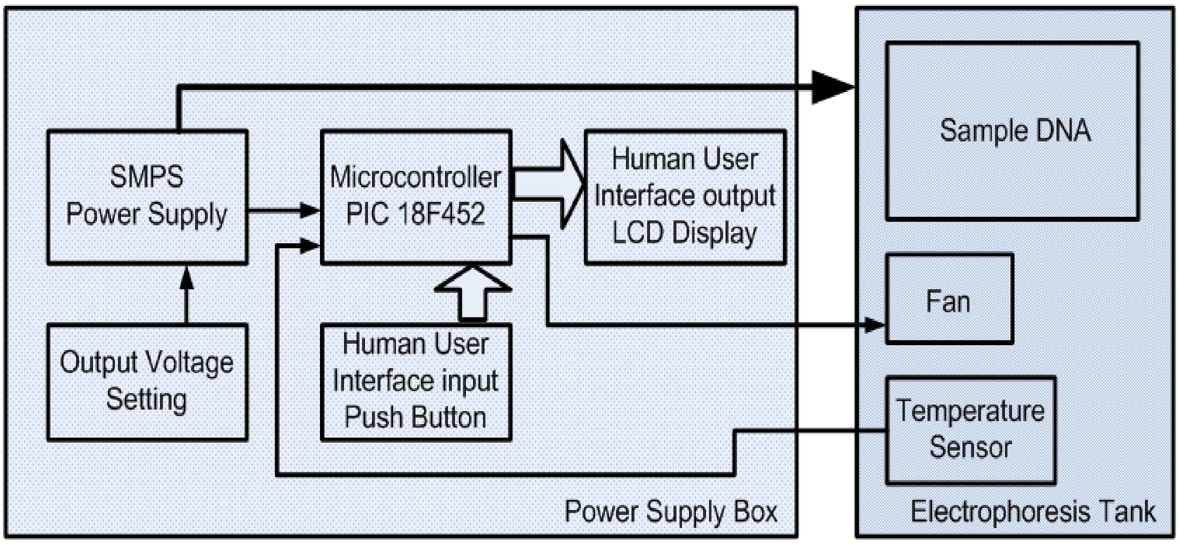


Figure 1. Bolck diagram of new gel electrophoresis unit

2.1 Design and develop SMPS

Part of the project focuses on designing and implementing a high efficient and safe flyback topology SMPS for electrophoresis process. The Flyback SMPS will be built specially for AC input voltage of 230V. This design will used PWM as the controller module with switching range of 40KHz. Schematic of Flyback SMPS will be designed, tested and fabricated into a printed circuit board (PCB) with all the required testing to be done to check the performance of the SMPS prior to implementation in electrophoresis process. The Flyback is configured with a voltage range from as minimum as 70V up to a maximum of 130V. The maximum current to be tested shall be 400mA. As a final outcome, the implementation is validated and verified for functionality through electrophoresis process.

2.2 Design and develop new gel electrophoresis container/tank

The other part of the project is to design a new container Gel Electrophoresis DNA separation with temperature control by using single chip microcontroller to control the temperature during the DNA separation process. The new container is designed by fixing the fans and temperature sensor in order to maintain the Gel Electrophoresis DNA separation temperature. Besides that, single chip microcontroller is used to convert the analog voltage meter display on existing power supply to digital display on liquid crystal display (LCD) screen with current measure. Additionally, it is also fitted with countdown timer to calculate the time of the electrophoresis process. All parameters display will be programmed onto single chip microcontroller. Finally, DNA separation time will be reduced with the increase of voltage power supply. An algorithm is formulated (pseudo code base) to interact between the temperature sensor and the SMPS so that the increase in voltage will turn on the fan for cooling purpose.

2.3 Experimenting the new gel electrophoresis unit

Experiment and data collection are performed at standard procedure with several voltages level to observe the capability of the system.

3. LITERATURE REVIEW

3.1 Electrophoresis

The history of electrophoresis begins in earnest with the work of Arne Tiselius in the 1930s, and new separation processes and chemical analysis techniques based on electrophoresis continue to be developed into the 21st century. Tiselius, with support from the Rockefeller

Foundation, developed the "Tiselius apparatus" for moving boundary electrophoresis, which was described in 1937 in the well-known paper "A New Apparatus for Electrophoretic Analysis of Colloidal Mixtures"[1]. The method spread slowly until the advent of effective zone electrophoresis methods in the 1940s and 1950s, which used filter paper or gels as supporting media. By the 1960s, increasingly sophisticated Gel Electrophoresis methods made it possible to separate biological based on minute physical and chemical differences, helping to drive the rise of molecular biology. Gel Electrophoresis and related techniques became the basis for a wide range of biochemical methods, such as protein fingerprinting, Southern blot and similar blotting procedures, DNA sequencing, and many more.

3.1.1 Electrophoresis Process

Gel electrophoresis is a technique used for the separation of *deoxyribonucleic acid* (DNA), *ribonucleic acid* (RNA), or protein molecules using an electric current applied to a gel matrix. DNA Gel electrophoresis is generally only used after amplification of DNA via Polymerase Chain Reaction (PCR). It is usually performed for analytical purposes, but may be used as a preparative technique prior to use of other methods such as mass spectrometry, Restriction Fragment Length Polymorphism (RFLP), PCR, cloning, DNA sequencing, or Southern blotting for further characterization [2].

The term gel in this instance refers to the matrix used to contain, then separate the target molecules. In most cases, the gel is a crosslinked polymer whose composition and porosity is chosen based on the specific weight and composition of the target to be analyzed. When separating proteins or small nucleic acids (DNA, RNA, or oligonucleotides) the gel is usually composed of different concentrations of acrylamide and a cross-linker, producing different sized mesh networks of polyacrylamide. When separating larger nucleic acids (greater than a few hundred bases), the preferred matrix is purified agarose. In both cases, the gel forms a solid, yet porous matrix. Acrylamide, in contrast to polyacrylamide, is a neurotoxin and must be handled using appropriate safety precautions to avoid poisoning. Agarose is composed of long unbranched chains of uncharged carbohydrate without cross links resulting in a gel with large pores allowing for the separation of macromolecules and macromolecular complexes.

Electrophoresis refers to the electromotive force (EMF) that is used to move the molecules through the gel matrix. By placing the molecules in wells in the gel and applying an electric current, the molecules will move through the matrix at different rates, determined largely by their mass when the charge to mass ratio (Z) of all species is uniform, toward the anode if negatively charged or toward the cathode if positively charged. Electrophoresis process can be explained with Figure 3.1 where particles of sample will move according its polarity and the distance traveled will depend directly on the time and voltage

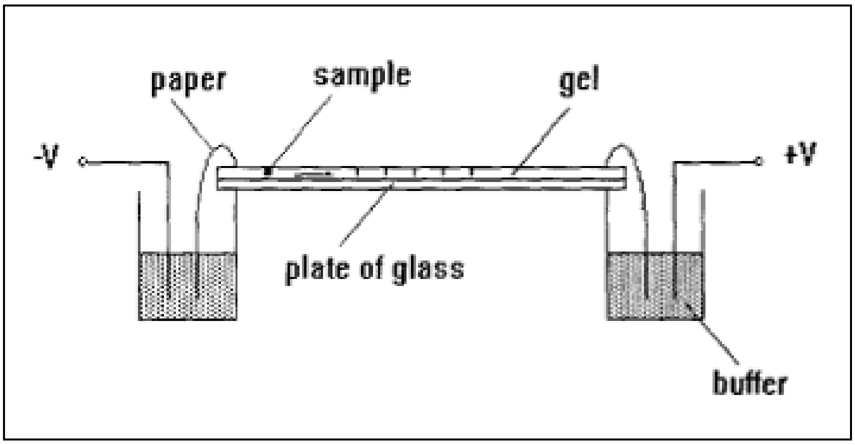


Figure 3.1 Electrophoresis process

Most kind of electrophoresis tests employ gel as the solvent in which particles will move when electric field is applied, some examples of that are shown in Table 3.1 as below.

Table 3.1: Electrophoresis test data for various types

Electrophoresis tests	Test Plan
Simple immunoelectrophoresis	Test voltage: IO V/cm gel length Test time: 60 to 180 minutes
Immunoelectrophoresis for rockets	Test voltage: 10 V/cm gel length Test time: 3 minutes
Crossed immunoelectrophoresis	Test voltage: 10-15 V/cm gel length Test time: 60 minutes
Inverse immunoelectrophoresis	Test voltage: 5-10 V/cm gel length Test time: 60 to 300 minutes
Bidimentional electrophoresis	Test voltage: 300 V Test time: 960 minutes

3.1.2 Effects of Voltage and Temperature on Electrophoresis Process

Electrophoresis velocities are directly proportional to the field strength, so the use of the highest voltages possible will result in the shortest times for the separation. Theory predicts that short separation times will give the highest efficiencies since diffusion is the most important feature contributing to band broadening. The limiting factor here is Joule heating. The electrophoresis mobility shown in equation (1) and the electro osmotic flow shown in equation (2) expressions both contain a viscosity term in the denominator. Viscosity is a function of temperature; therefore, precise temperature control is important. As the temperature increases, the viscosity decreases thus, the electrophoresis mobility increases as well. This will results in change of characteristic of the separation process [3].

$$\mu_{ep} = \frac{q}{6\pi\eta R}$$

Equation (1)

where *q* is the net charge, *R* is the apparatus radius, and η is the viscosity

$$v_{eo} = \frac{\varepsilon\zeta E}{4\pi\eta}$$

Equation (2)

where ε is the dielectric constant, η is the viscosity of the buffer, and ζ is the zeta potential measured at the plane of shear close to the liquid-solid interface. Most separations are performed at 25^0C (*i.e.*, near room temperature)[3]. For the process to have a table temperature, new modification had been implemented in changing the off the shelf electrophoresis apparatus to a temperature controllable universal tank.

3.2 Microcontroller

A microcontroller is a microprocessor system which contains data and program memory, serial and parallel I/O, timers, and external and internal interrupts all integrated into a single chip that can be purchased for as little as two dollars. About 40 per cent of all microcontroller applications are found in office equipment, such as PCs, laser printers, fax machines, and intelligent telephones. About one third of all microcontrollers are found in consumer electronic goods. Products like CD players, hi-fi equipment, video games, washing machines, and cookers fall into this category. The communications market, the automotive market, and the military share the rest of the applications [4].

It emphasizes high integration, in contrast to a microprocessor which only contains a CPU (the kind used in a PC). In addition to the usual arithmetic and logic elements of a general purpose microprocessor, the microcontroller integrates additional elements such as read-write memory for data storage, read-only memory for program storage, Flash memory for permanent data storage, peripherals, and input/output interfaces. At clock speeds of as little as 32 KHz, microcontrollers often operate at very low speed compared to microprocessors, but this is adequate for typical applications. They consume relatively little power (milliwatts or even microwatts), and will generally have the ability to retain functionality while waiting for an event such as a button press or interrupt. Power consumption while sleeping (CPU clock and peripherals disabled) may be just nanowatts, making them ideal for low power and long lasting battery applications.

Microcontrollers are used in automatically controlled products and devices, such as automobile engine control systems, remote controls, office machines, appliances, power tools, and toys. By reducing the size, cost, and power consumption compared to a design using a separate microprocessor, memory, and input/output devices, microcontrollers make it economical to electronically control many more processes.

3.3 Temperature Sensor LM 35DZ

The LM35DZ series are precision integrated-circuit temperature sensors, whose output voltage is linearly proportional to the Celsius (Centigrade) temperature. The LM35 does not require any external calibration or trimming to provide typical accuracies of (+1/4^{0}C at room temperature and +1/4^0) over a full -55 to +150^{0}C temperature range. Low cost is assured by trimming and calibration at the wafer level. The LM35's low output impedance, linear output, and precise inherent calibration make interfacing to readout or control circuitry especially easy. It can be used with single power supplies, or with plus and minus supplies. As it draws only 60mA from its supply, it has very low self-heating, less than 0.1^{0}C in still air. The LM35DZ is rated to operate over a -55 to a150^{0}C temperature range. The LM35 series is available packaged in hermetic TO-46 transistor packages. Features of LM 35:

- Calibrated directly in degree Celsius (Centigrade)
- Linear a 10.0 mV/^{0}C scale factor
- 0.5^{0}C accuracy guarantee (at a 25^{0}C)
- Rated for full -55 to a150^{0}C range
- Suitable for remote applications
- Low cost due to wafer-level trimming
- Operates from 4 to 30 volts
- Less than 60mA current drain
- Low self-heating, 0.08^{0}C in still air
- Nonlinearity only +1/4^{0}C typical
- Low impedance output, 0.1Ω for 1mA load

Figure 3.2 shows the physical dimension of LM35DZ. It can be glued or cemented to a surface and its temperature will be within about $0.01^{o}C$ of the surface temperature. In this project, the rainbow wire is used to connect the temperature sensor with PIC MCU on DB9 to connect on the PCB circuit as shown in Figure 3.3. The pins of LM35DZ must not be connected to each other by covering each of them with insulated tape to avoid short-circuited.

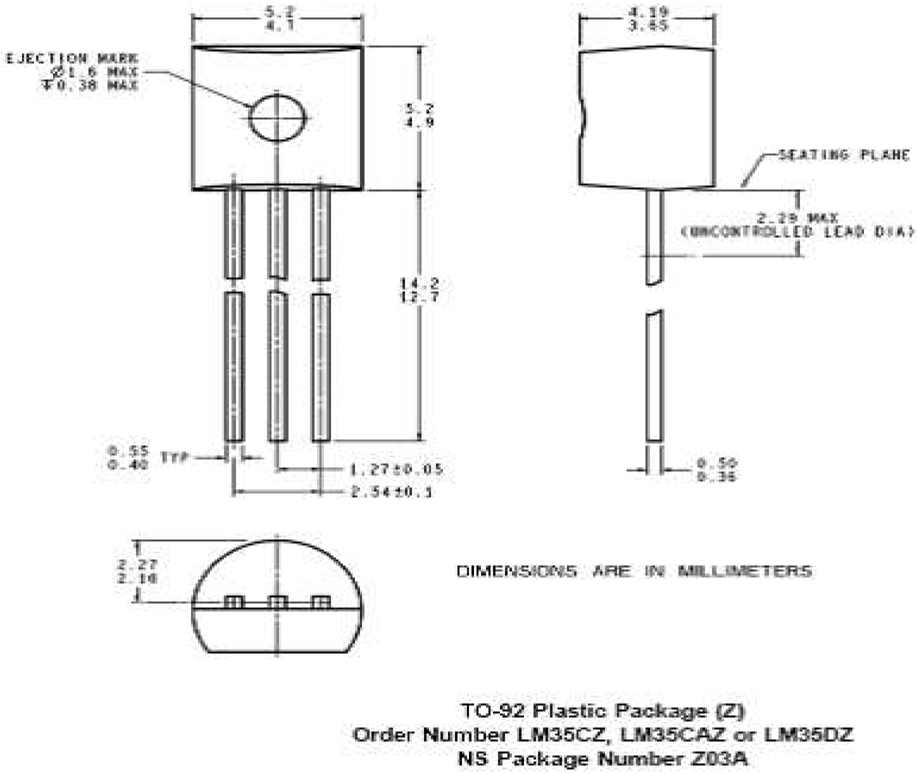


Figure 3.2 Physical dimension of LM35DZ

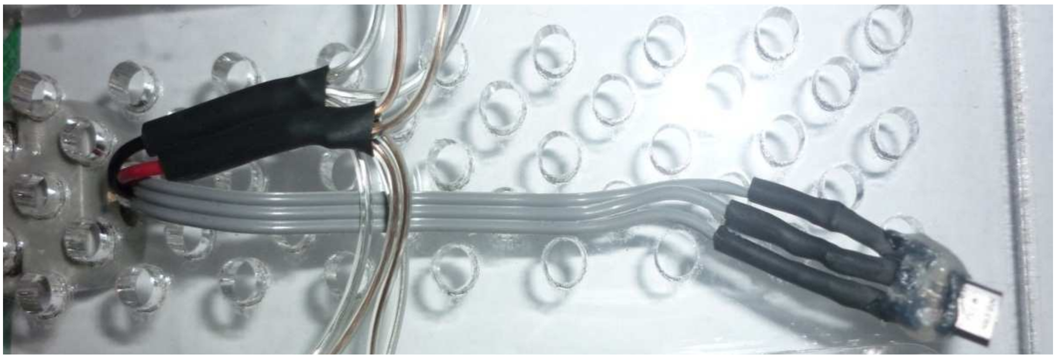


Figure 3.3 Rainbow wire used to connect LM35DZ with connects DB9 to connect on the PCB board.

To immerse this temperature sensor in a fluid, it must be wrapped with a silicon and rubber tubes to avoid short on circuit. Alternatively, there are many ways to make LM35DZ water proof and one of them is to use an empty modified pen tube. As with any IC, the LM35DZ and accompanying wiring and circuits must be kept insulated and dry to avoid leakage and corrosion.

3.4 Introduction to SMPS

A switch mode power supply can be classified as either an AC to DC or DC to DC converter in which the AC to DC input voltage is converted to the required DC output voltage. Both converters operate in very similar ways except that the AC input voltage of AC and DC converter has to be rectified to a DC voltage first. After which, the two converters operate very much the same way. Figure 3.4 below shows an open case of SMPS unit.

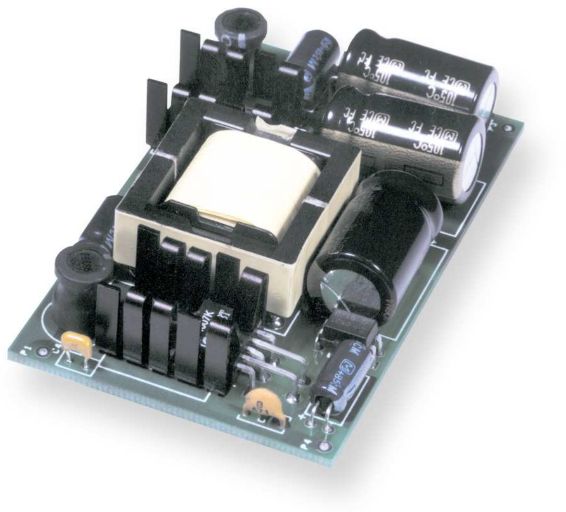


Figure 3.4 SMPS unit

SMPS designs have several topologies but they are common in the fact that a DC current is turned on and off producing a pulse waveform through an inductor or transformer. The fundamental principle for the inductor topology is that inductor current cannot change instantaneously based on Lenz's law. In most design, the DC current passed through the primary side of transformer when the switch is turned ON and the current has no path to continue when the switch is turned OFF. However, due to its inductive property, the current cannot instantaneously change so the energy that is previously built up in the transformer is transferred to the secondary side of the transformer. By introducing necessary circuitries (rectification, clamp, feedback …etc) to the design, the converter is able to transform the input voltage from the mains to the desired output voltage on the secondary side of the transformer [5].

3.5 Principle of SMPS

Many appliances and circuits as well as the electrophoresis process will not be able to operate properly if they do not receive a constant supply voltage. Such devices need a reliable supply that provides a highly stable DC voltage despite the variation from input voltage of the power source. With the ever increasing demand for power supplies, SMPS must be capable to carrying out of following task [6,7]:

- Converting input voltage from the mains to a suitable voltage for the electrical devices
- Rectifying the AC input voltage to DC output voltage
- Filtering by smoothing the ripple of the rectified voltage
- The DC voltage must be stable and independent of line and load variation
- Providing isolation between the main line and the output of the power supply
- The power supply must be high efficiency.
- Small in size
- Low in cost
- Must be able to handle wide range of input voltage.

3.5.1 Drawback of SMPSs

There are several benefits when using SMPSs which made them really attractive. However, their greatest weakness is the generation of Electromagnetic Interference (EMI). Due to the fact that SMPSs are switching its current constantly, they produced a great amount of EMI compared to linear power supplies [8]. Proper design must be practiced to the circuit in order eliminate or reduce noises so that it will not interfere with the performance of the power supply. In additional SMPSs have more complicated circuitries to analyze and slower transient reaction compared to LPSs [9].

3.5.2 SMPS Topologies

The word *topology* refers to the “science of place’. Two systems are considered as topologically similar if they are different only in the circuit elements that put together their branches. An SMPS comprises of a number of storage components and switches which are arranged in a topology such that the switches cyclically controls the transfer of power from the mains input to the generate required DC level at the output. In general, the storage element arranged in such a way that they form a filter to achieve a low output ripple voltage. The two basic topologies of SMPS are the buck converter and the boost converter. Many of the other topologies are derived from these two converters as they are considered topologically similar to either of the two converters [10]. Additionally, converters can be classified as non-isolated or isolated, depending on whether a transformer is used in the design [11]. In the following section, the principle operations of a few popular topologies are presented, including brief introduction of rectifiers.

3.5.3 Rectifiers

If the SMPS has an AC input, then the first stage is to convert the input to DC. This is called rectification. The rectifier circuit can be configured as a voltage doublers by the addition of a switch operated either manually or automatically. This is a feature of larger supplies to permit operation from 120 volt or 240 volt supplies. The rectifier produces an unregulated DC voltage which is then sent to a large filter capacitor. The current drawn from the mains supply by this rectifier circuit occurs in short pulses around the AC voltage peaks. These pulses have significant high frequency energy which reduces the power factor. [12]

Special control techniques can be employed by the following SMPS to force the average input current to follow the sinusoidal shape of the AC input voltage thus the designer should try correcting the power factor. A SMPS with a DC input does not require this stage. An SMPS designed for AC input can often be run from a DC supply (for 230V AC this would be 330V DC), as the DC passes through the rectifier stage unchanged. However, this type of use may be harmful to the rectifier stage as it will only utilize half of diodes in the rectifier for the full load. This may result in overheating of these components, and make them fail as short circuits. Choosing the best rectifiers for any switching power supply design is an important process. The rectifiers are the largest source of loss within switching power supplies. To choose the best rectifier, one must understand the parameters that affect their efficiency. The most important rectifier parameters are the forward voltage drop (Vf) and the reverse recovery time (trr). The forward voltage drop creates a loss just by having a voltage across the device while high currents are flowing through it.

The reverse recovery loss is where the rectifier becomes reverse biased, and current appears to actually flow backwards through the rectifier. It is actually the minority carriers being swept from the P-N junction. Nonetheless, it is a significant loss. This loss is minimized by selecting the rectifier with the shortest reverse recovery time (trr). Table 3.2 shows a summary of the various rectifier technologies that are appropriate in switching power supplies.

Table 3.2: Comparative information on rectifies [12].

Rectifier Technology	Forward Voltage (Volts)	Reverse Recovery Time (nS)	Forward Recovery Time (nS)	Relative Cost
Fast Recovery	1.0	150	1050	1.0
UltraFast Recovery	0.9	75	50	1.5
Megahertz	1.6	28	-	2.0
Schottky	0.5	<1.0	-	1.6

For low voltage outputs, Schottky rectifiers are recommended because of their low forward voltage drop and their negligible reverse recovery time. For higher output voltages, the ultrafast recovery rectifiers are recommended because of their very fast reverse recovery times.

3.5.4 The Buck Converter

The most elementary forward-mode converter is the Buck or Step-down Converter which can be seen in Figure 2.6. Its operation can be seen as having two distinct time periods which occur when the series power switch is on and off.

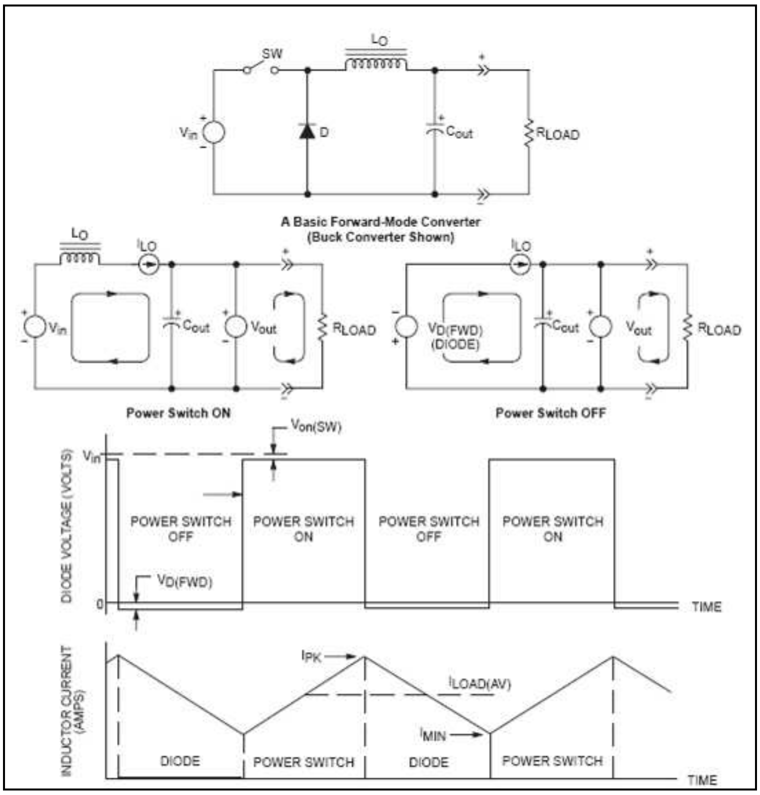


Figure 3.5 Schematic and waveform of Buck converter topology

When the power switch is on, the input voltage is connected to the input of the inductor. The output of the inductor is the output voltage, and the rectifier is back-biased. During this period, since there is a constant voltage source connected across the inductor, the inductor current begins to linearly ramp upward which is described by:

$$i_{L(on)} = \frac{(V_{in} - V_{out})\, t_{on}}{L}$$

Equation (3)

During the "on" period, energy is being stored within the core material of the inductor in the form of flux. There is sufficient energy stored to carry the requirements of the load during the next off period. The next period is the "off" period of the power switch. When the power switch turns off, the input voltage of the inductor flies below ground and is clamped at one diode drop below ground by the *catch diode*. Current now begins to flow through the catch diode thus maintaining the load current loop. This removes the stored energy from the inductor. The inductor current during this time is:

$$i_{L(off)} = \frac{(V_{in} - V_D)\, t_{off}}{L}$$

Equation (4)

This period ends when the power switch is once again turned on. Regulation is accomplished by varying the on-to-off duty cycle of the power switch. The relationship which approximately describes its operation is:

$$V_{out} \sim D \,.\, V_{in}$$

Equation (5)

where d is the duty cycle ($D = t_{on}/(t_{on} + t_{off})$).

The buck converter is capable of kilowatts of output power, but suffers from one serious shortcoming which would occur if the power switch were to fail short-circuited, the input power source is connected directly to the load circuitry with usually produces catastrophic results. To avoid this situation, a *crowbar* is placed across the output. A crowbar is a latching SCR which is fired when the output is sensed as entering an overvoltage condition. The buck converter should only be used for board-level regulation.

3.5.5 The Boost Converter

The most elementary flyback-mode converter is the Boost or Step-up Converter. Its schematic can be seen in Figure 3.6. Its operation can also be broken into two distinct periods where the power switch is on and off. When the power switch turns on, the input voltage source is placed directly across the inductor. This causes the current to begin linearly ramping upwards from zero and is described by:

$$i_{L(on)} = \frac{(V_{in})\, t_{on}}{L}$$

Equation (6)

The amount of energy stored during each cycle times the frequency of operation must be higher than the power demands of the load. The power switch then turns off and the inductor voltage flyback above the input voltage and is clamped by the rectifier at the output voltage. The current then begins to linearly ramp downward until the energy within the core is completely depleted. Its waveform which is shown in Figure 3.7 is determined by:

$$i_{L(off)} = \frac{(V_{out} - V_{in})\, t_{off}}{L}$$

Equation (7)

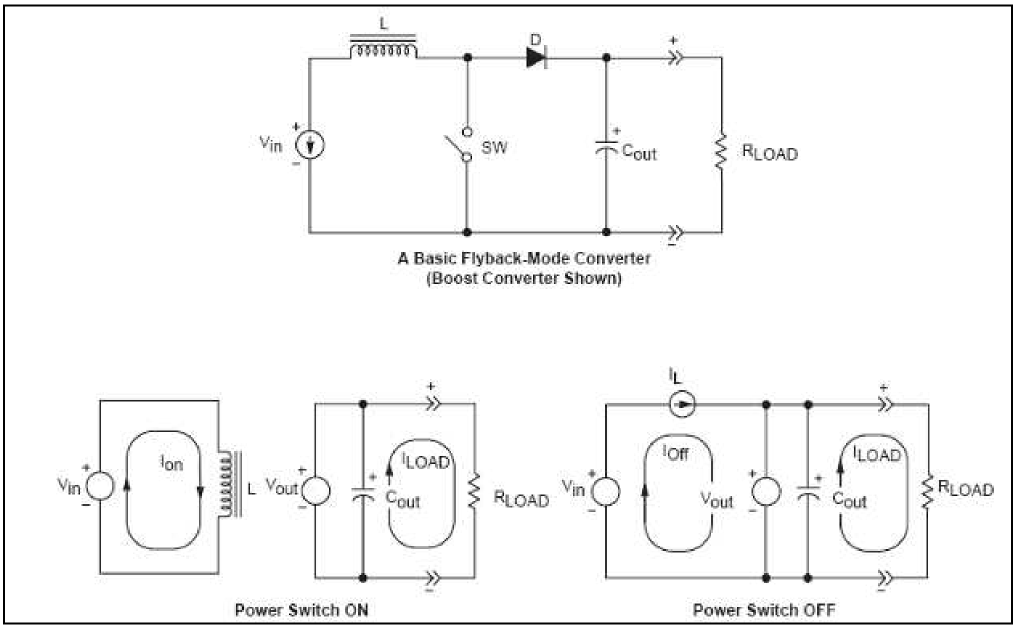


Figure 3.6 Schematic of a Boost Converter

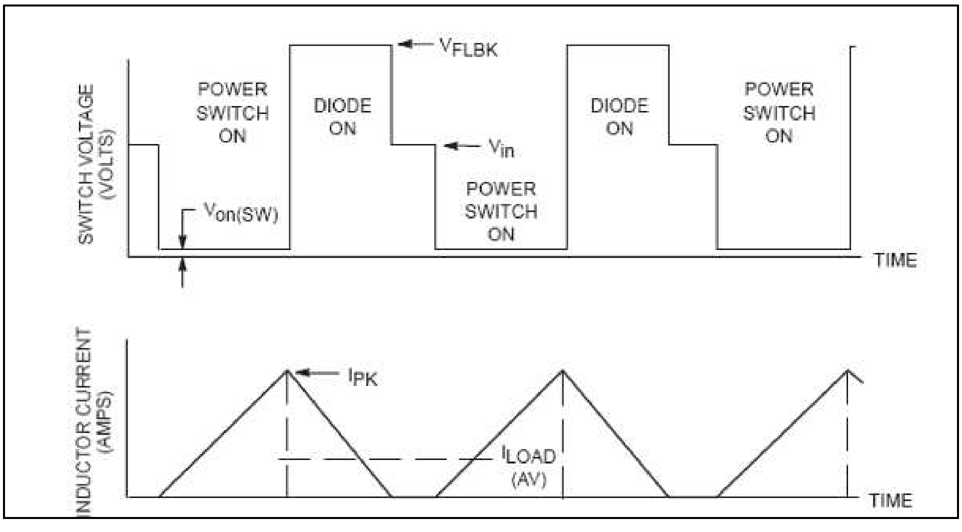


Figure 3.7 Waveforms of a Boost Converter

3.5.6 The Flyback Converter

Filter inductor, boost inductors and the Flyback Transformer are all members of the "Power Inductor" family [13]. They all function by taking energy from the electrical circuit, storing it in a magnetic field, and subsequently returning this energy (minus losses) to the circuit [13]. A Flyback Transformer is actually a multi winding coupled inductors that have an air gap in the core in order to stored energy. The basic topology of the Flyback Converter is almost similar to Buck Boost converter [14].

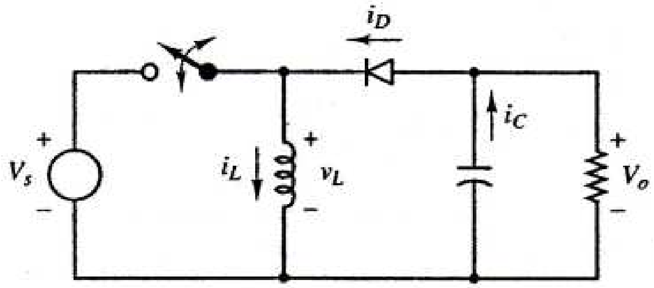


Figure 3.8 Topology circuit of The Buck Boost Converter [14]

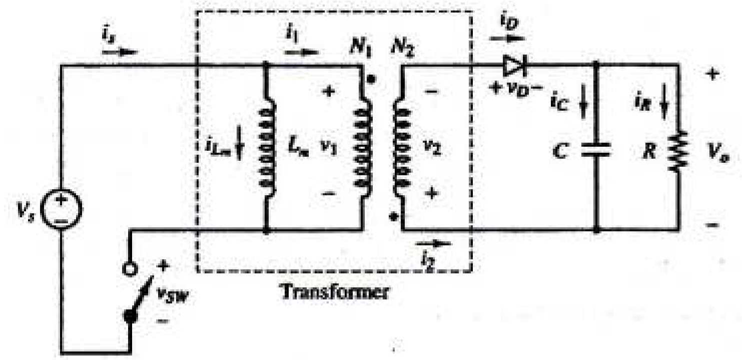


Figure 3.9 Topology circuit of The Flyback Converter [14]

Figure 3.8 is the basic Buck converter with diode and mosfet act as switch. The inductor is replaced by a set of coupled inductor without changing operation. If the coupled inductors are separated and rearranged, the Flyback Converter is created as shown in figure 3.9. The operation of the Flyback Converter is similar to the Buck-Boost except for the differences related to using a transformer instead of inductors as the intermediate energy storage stage. For examples, the Flyback Converter is able to regulate the output voltage at either negative or positive polarity with respect to the input voltage depending on the phasing of the output winding with respect to the primary [15]. In the Flyback Converter, primary winding is conducting while the mosfet ON and the secondary winding is conducting when the diode ON. Unlike the ideal transformer, current does not flow simultaneously in both winding of the

Flyback Transformers [16]. Figure 3.9 shows that, the polarities of the transformer are reversed, to obtain a positive output voltage [16].

In the Buck Boost topology the output voltage must have a polarity opposite to the input voltage to ensure volt-second balance across the inductors. The input output voltages of the two converters are shown below

For Buck Boost converter,

$$\frac{V_{out}}{V_{in}} = \frac{-D}{1-D}$$

Equation (8)

For Flyback converter,

$$\frac{V_{out}}{V_{in}} = \frac{N.D}{1-D}$$

Equation (9)

3.5.7 The Flyback Converter Implementation

From the circuit topology, flyback converter consists of four main components diode, MOSFET, capacitor and transformer. In this chapter, function and effects of every component will be discussed. From the principles operation of diode, we know that diode will be forward biased and reverse biased depends on the voltage across it. Due to forward biased and reverse biased, diode will be in short circuit and open circuit respectively [14]. Since MOSFET can operate in high frequency, this makes its suitable used in flyback converter [14]. PWM (Pulse Width Modulated) is used to turn ON and turn OFF the switch by generating pulse signal to the gate of transistor. At the output of circuit, the capacitor is used to regulate the output voltage and reduce the voltage ripple [14]. Transformer in the flyback converter is very unique; the air gap of the transformer is used to store the energy when switch ON and transfer the energy to the load when switch is OFF.

Before we go through to the analysis of the Flyback Converter when switch is ON and OFF, additional assumptions for the analysis are added:

- The value of output capacitor is very large to obtain constant output voltage.

- The circuit must be operating in steady state to implying all the currents and voltages are periodic which is starting and ending at the same point over the switching period.
- The switch and diode are ideal in other word there is no voltage drop across each component.

When the switch (MOSFET) is operating (ON) only the primary path of the transformer winding is working. This is because the secondary path of the transformer winding is open circuit due to the reverse biased on the diode. Figure 3.10 illustrates the Flyback Converter circuit when switch is ON.

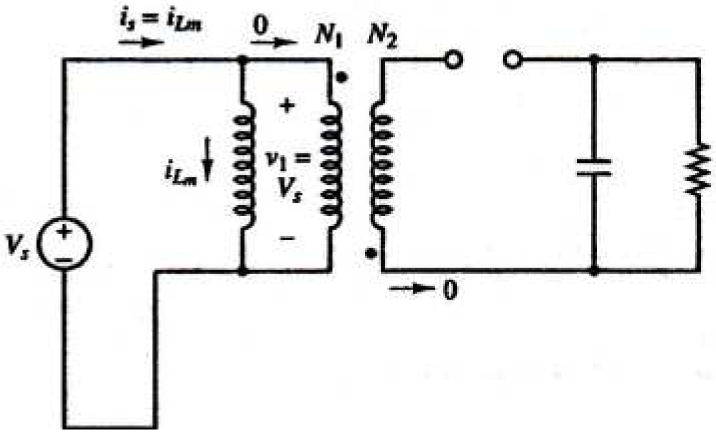


Figure 3.10 Flyback Converter circuit when switch is ON [14]

On the primary side of the transformer as shown in figure 3.10,

$$V_1 = V_S = L_M \cdot \frac{di_{lm}}{dt}$$

Equation (10)

$$\frac{di_{lm}}{dt} = \frac{\Delta i_{lm}}{\Delta t} = \frac{\Delta i_{lm}}{DT} = \frac{V_s}{L_m}$$

Equation (11)

Hence the change of current in the transformer magnetizing inductance,

$$(\Delta i_{lm})_{closed} = \frac{V_s DT}{L_m}$$

Equation (12)

The secondary sides of the transformer become,

$$V_2 = V_1 \frac{N_2}{N_1} = V_S \frac{N_2}{N_1}$$

Equation (13)

$$V_d = -V_0 - V_S \frac{N_2}{N_1} < 0$$

Equation (14)

$$i_2 = 0$$

Equation (15)

$$i_1 = 0$$

Equation (16)

This means that, there are no currents flows in the windings and current from source, I_s is charge linearly in the magnetizing inductance, L_m. In other words, current is increasing linearly in the primary winding and no current exists in the secondary winding. When the switch (MOSFET) is OFF the current cannot change instantaneously in the inductance Lm, so the conduction path must be through the primary turns of the transformer. The current i_{lm} enters the undotted terminal of the primary and must exit the undotted terminal of the secondary since the diode current is positive. Figure 3.11 illustrated the Flyback Converter circuit when switch is OFF.

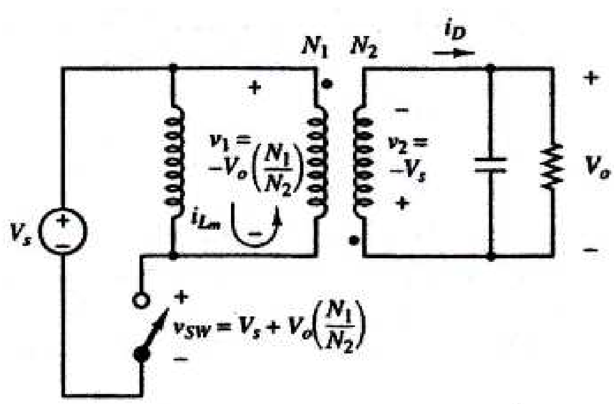


Figure 3.11: Flyback Converter circuit when switch is off [14]

The secondary voltages of the transformer V_2 become $-V_0$ since the current flow in opposite direction,

$$V_1 = -V_0 \frac{N_1}{N_2}$$

Equation (17)

Voltages and current for a open switch ,

$$V_2 = -V_0$$

Equation (18)

$$V_1 = V_2 \frac{N_1}{N_2} = -V_0 \frac{N_1}{N_2}$$

Equation (19)

$$L_m \frac{di_{Lm}}{dt} = V_1 = -V_0 \frac{N_1}{N_2}$$

Equation (20)

Hence the change of current in the transformer magnetizing inductance,

$$(\Delta i_{lm})_{open} = \frac{-V_0 (1-D)T}{L_m} \frac{N_1}{N_2}$$

Equation (21)

For steady state operation, the net change of inductor current must be zero over one period,

$$\Delta i_{lm(closed)} + \Delta i_{lm(open)} = 0$$

Equation (22)

$$\frac{V_S DT}{L_m} - \frac{V_0(1-D)T}{L_m} \frac{N_1}{N_2} = 0$$

Equation (23)

Hence the output voltage equation becomes:

$$V_0 = \frac{V_S D}{1-D} \frac{N_1}{N_2} = 0$$

Equation (24)

From the formula above the others current and voltages can be obtained:

$$i_d = -i_1\left(\frac{N_1}{N_2}\right) = i_{lm}\left(\frac{N_1}{N_2}\right)$$

Equation (25)

$$V_{SW} = V_S - V_1 = V_S + V_0\left(\frac{N_1}{N_2}\right)$$

Equation (26)

$$i_R = \frac{V_0}{R}$$

Equation (27)

$$i_c = id - iR = i_{lm}\left(\frac{N_1}{N_2}\right) - \frac{V_0}{R}$$

Equation (28)

For ideal case, the power absorbed by the load resistors must be the same as input power,

$$P_S = P_O$$

Equation (29)

$$V_S I_S = \frac{V_0^2}{R}$$

Equation (30)

The average source current is related to the average magnetizing current,

$$i_S = \frac{(i_{lm})DT}{T} (i_{lm})\, D$$

Equation (31)

Hence the magnetizing current becomes,

$$V_S i_{lm} D = \frac{V_0^2}{R}$$

Equation (32)

$$il_{m(max)} = \frac{V_0^2}{V_S D R}$$

Equation (33)

The maximum and minimum magnetizing inductors current also can be obtained,

$$i_{lm(max)} = i_{lm} + \frac{\Delta i_{lm}}{2}$$

Equation (34)

$$i_{lm(max)} = \frac{V_S D}{(1-D)^2 R} \left(\frac{N_2}{N_1}\right)^2 + \frac{V_S D T}{2L_m}$$

Equation (35)

$$i_{lm(min)} = i_{lm} - \frac{\Delta i_{lm}}{2}$$

Equation (36)

$$i_{lm(min)} = \frac{V_S D}{(1-D)^2 R} \left(\frac{N_2}{N_1}\right)^2 - \frac{V_S D T}{2L_m}$$

Equation (37)

For the continuous current mode operation $I_{lm\ min} > 0$,

$$i_{lm(min)} = 0$$

Equation (38)

$$\frac{V_S D}{(1-D)^2 R}\left(\frac{N_2}{N_1}\right)^2 = \frac{V_S DT}{2L_m}$$

Equation (39)

Hence the minimum value of Lm is,

$$(L_m)_{min} = \frac{(1-D)^2 R}{2f}\left(\frac{N_1}{N_2}\right)^2$$

Equation (40)

And the output ripple voltages become,

$$\frac{\Delta V0}{V0} = \frac{D}{RCf}$$

Equation (41)

3.5.8 The Flyback Operation Mode

The Flyback Converter can operate in various operational models which are Continuous Conduction Mode (CCM), Boundary Conduction Mode (BCM) and Discontinuous Conduction Mode (DCM).

3.5.9 Continuous Conduction Mode (CCM)

In the CCM mode the magnetizing inductance of the transformer starts from a nonzero current condition when the switch turns ON. The CCM Flyback Converter is typically implemented in fixed frequency application. The secondary current does not return to zero. Also when the load current is varied in a CCM Flyback, the DC energy stored in the transformer respond accordingly. For example, if a higher amount of load current is drawn from the output, the controller will ensure that the transformer move to a higher current level from which is starts and ends during each cycle. The amount of energy transferred to the load increases since the inductors stored energy according to $1/2Li^2$.

3.5.10 Boundary Conduction Mode (BCM)

In the BCM mode, the controller operates rights on the boundary between CCM and DCM [15]. The switch turns ON and stores just enough charge to replenish the load during the time the switch opened [15]. Thus the switch turns ON again as soon as all the energy is transferred to the output [15]. The controller ensures that there is very little time when the transformer has no energy stored as flux, known as dead time.

3.5.11 Discontinuous Conduction Mode (DCM)

In the DCM mode, the stored energy and current starts and return to zero in each cycle [15]. The energy stored in the primary when switch is ON is completely transferred to the output through the secondary after the switch opens [15]. The time when the switch is open and energy is not transferred to the load is known as dead time.

4. SMPS DESIGN AND IMPLEMENTATION

4.1 Selection of Magnetic Material

First of all we need to choose the magnetic core that we use to build the Flyback Transformer. The Flyback Transformer plays an important role on the Switch Mode Power Supply converter and will influence the design specification. In this project we used E core type of magnetic core (ETD34) as illustrated in Figure 4.1. Table 4.1 describes the parameter of the ETD 34. From table 4.1, E or EC shapes of type 3C90 ferrite core are chosen for flyback transformer designing because it has low core cost, excellent winding flexibility, simple assembly, good mounting flexibility, and excellent heat dissipation if compared with other shapes of ferrite cores.

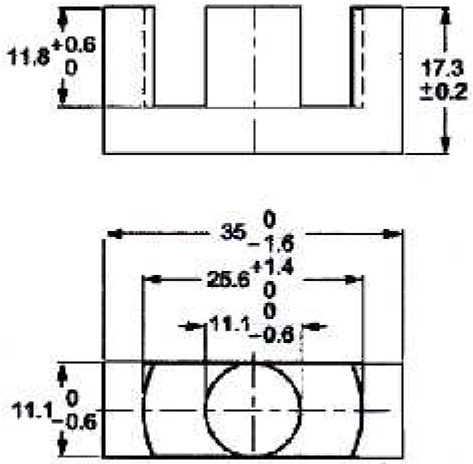


Figure 4.1: ETD34 core half [16]

Table 4.1: Effective core parameters

Symbol	Parameter	Value	Unit
$\sum (I/A)$	Core factor (C1)	0.810	mm^{-1}
V_e	Effective volume	7640	mm^3
I_e	Effective length	78.6	mm
A_e	Effective area	97.1	mm^2
A_{min}	Minimum area	91.6	mm^2
m	Mass of core half	≈20	g

Table 4.2: Comparison of different type of core shapes

Consideration/shapes	Pot Core	E Core	EC,ETD Core	PQ Core	EP Core	Toroid
Core Cost	High	Low	Medium	High	Medium	Very low
Winding Cost	Low	Low	Low	Low	Low	High
Winding Flexibility	Good	Excellent	Excellent	Good	Good	Fair
Assembly	Simple	Simple	Medium	Simple	Simple	None
Mounting Flexibility	Good	Good	Fair	Fair	Good	Poor
Heat Dissipation	Poor	Excellent	Good	Good	Poor	Good
Shielding	Excellent	Poor	Poor	Fair	Excellent	Good

There are many types of core that can be used to build a flyback transformer because every core materials has its own unique properties. Basically there are two types of transformer core which are ferromagnetic and ferrimagnetic. Ferromagnetic is the normal type of magnetic and always exhibit as horseshoe magnet and refrigerator magnet. Ferromagnetism is defined as the phenomenon by which materials such as iron, in an external magnetic field become magnetized and remain magnetized for a period after the material is no longer in the field.

Ferromagnetic metal alloy by very rapid cooling has the advantage that their properties are nearly isotropic. The advantages are low hysteresis loss, high permeability and high electrical resistivity.

A ferrimagnetic material is one in which the magnetic moment of the atoms on different sublattices (anti-ferromagnetism). Ferrimagnetic materials have high resistivity and anisotropic property. The anisotropy is actually induced by an external applied field. Ferrimagnetism is exhibited by ferrites and magnetic garnets. Some ferromagnetic materials are YIG (Yttrium Iron Garnet) and ferrites composed of iron oxides and other elements such as aluminum, cobalt, nickel, manganese and zinc. Manufactured of ferrite core is different from the previous materials. The raw materials are oxides of various metals such as manganese, iron and zinc. The oxides normally act as an insulators and therefore ferrite core have higher resistivity than magnetic alloys and permitting the ferrite core to operate in higher frequency up to Mega Hertz. As a conclusion, ferrite core type 3C90 will be chosen as a material to build the flyback transformer due to the low core losses in high frequency (>20 kHz) and available in variety of shapes.

4.2 Rectifier Circuit

Figure 4.2 illustrates the rectifier circuit that is used to convert AC to DC. Main component that need to be taken into consideration is the DC link apacitor which is circled in Figure 4.2. The key rule is to decide the value of DC link capacitor which in this circuit will be 3 micro farad per watt of input 230V. The voltage rating for the capacitor is 400V due to rectifier device multiplication with factor of 1.41.

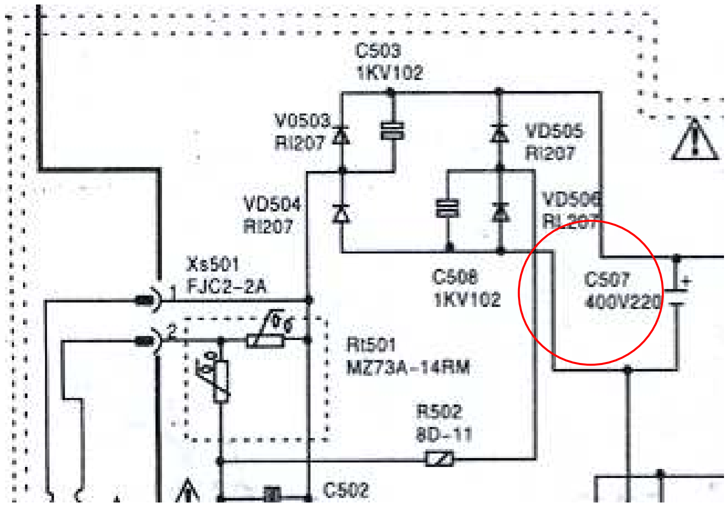


Figure 4.2 AC to DC Rectifier

4.3 Flyback Converter

After the main voltage is rectified by a bridge rectifier, smoothen by a DC link capacitor and a main DC bus voltage is obtained. The DC bus concerned is switched across P1 winding of the ferrite core Switch Mode Transformer (SMT) which is designed to operate at high switching frequency with high efficiency. According to the system requirements, a number of winding could be added to both sides of SMT to obtain multiple-output AC-DC isolated SMPS. When the switching element is ON, the energy is stored in P1, called energy storage phase. When the switching element is OFF, the stored energy in P1 is transferred to the secondary side, called energy transfer phase. The desired DC supply voltages required are generated at the secondary side of SMT with additional rectifications. One of the rectified outputs which is the most critical one for the system operation is normally considered as the main output and by means of a potential meter for adjustable main output voltage from 70V to 130V is generated. The block at the control pin of the switching element in Fig. 4.3 (commonly a MOSFET or BJT) contains a driver circuitry and accomplishes the current and/or voltage control. The duty cycle (D) of the driving signal is adjusted based on the feedback signals coming from the main output via an optocoupler.

The regulation on the main output determines the other voltage output levels of the system. In practical applications, in order to transfer all the energy stored under the worst-case conditions, which is assumed as minimum mains voltage and maximum load, D is kept below fifty percent (0.5). In some applications, there is a mechanism to prevent starting a new energy storage phase before transferring all the energy stored in the previous cycle. When this technique is not applied, primary winding current would have a DC level that leads to the temperature increase of the SMT.

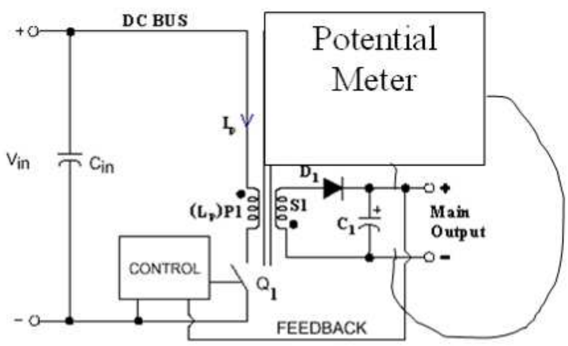


Figure 4.3: Multiple Output Flyback SMPS Circuitry Using Potential Meter

4.4 Control Circuit – Pulse Width Modulation (PWM)

Pulse Width Modulation (PWM) control works by switching the power supplied to the flyback converter. In this project the AN 6753 was chosen as a PWM integrated circuit. The

AN 6753 was designed to offer improved performance and lowered external part count when used in designing all type of switching power supplies. The main function of the PWM circuit is to provide pulse signal to the gate terminal of the mosfet. This will lead the mosfet ON or OFF depending on the duty cycle and the switching frequency. Figure 4.4 illustrates PWM circuitry in Flyback SMPS.

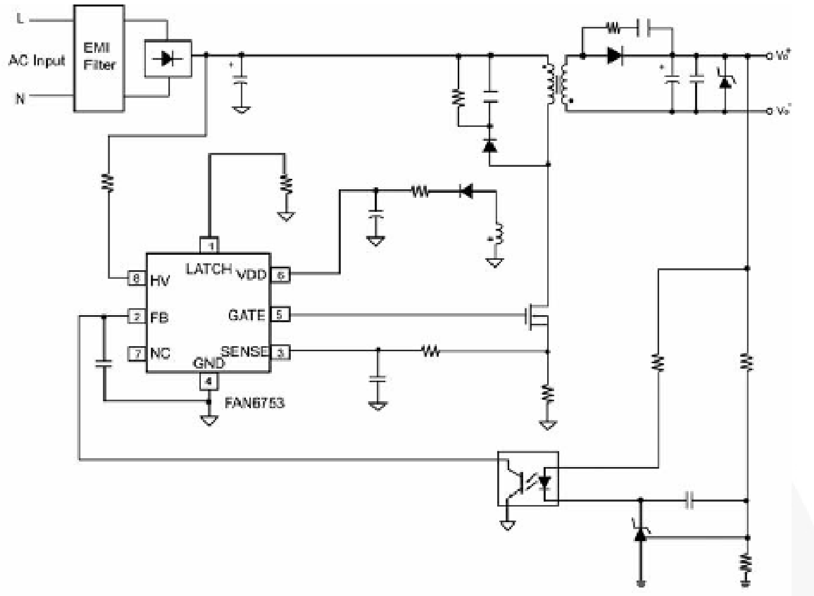


Figure 4.4 PWM in Flyback SMPS

4.5 Hardware Implementation of Flyback SMPS

Figure 4.5 shows the realization of Flyback PCB fabrication.

Figure 4.5 Flyback SMPS PCB

The following figure 4.6 shows the snap shot of the real Fylback SMPS ready to be used for electrophoresis process.

Figure 4.6: Flyback SMPS

4.6 SMPS Verification and Validation

Table 4.1 states the standard power supply data sheet parameter which describes the Flyback electrical characteristic

Table 4.1 Flyback SMPS Electrical Characteristic

Rated Specifications	Value	Unit
Input Voltage	230	V
Input Current	N/A	Amps
Input Frequency	60	Hz
Rated Output Power	52	Watts

As a result of verification, the next figure shows the performance of the power supply. Figure 4.7 illustrates the percentage of errors calculated due to the variance between entered voltage value against displayed value.

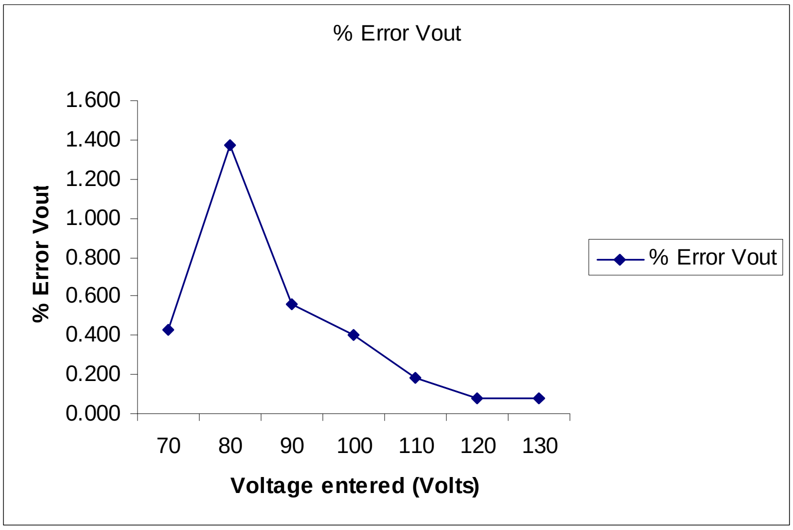


Figure 4.7 Relationship between Vout (%error) and Voltage data entered

From the obtained result of Flyback performance validation, the percentage of error is likely to decrease with the increase of the Voltage entered. Figure 4.8 below illustrates the voltage deviation during Electrophoresis process.

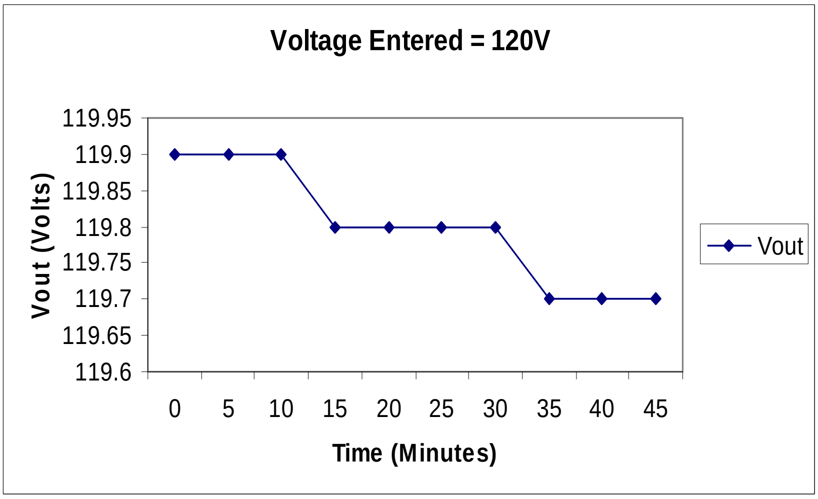


Figure 4.8: Voltage variation during Electrophoresis process

The voltage deviated with error of less than 0.2% and provided stable voltage at 119.7V. To validate further and the most important part of this thesis is to get the Flyback to operate efficiently for the electrophoresis process. Figure 4.9 gives a brief snap shot of the test setup that will be validated and figure 4.10 shows the real Flyback in active mode during electrophoresis process.

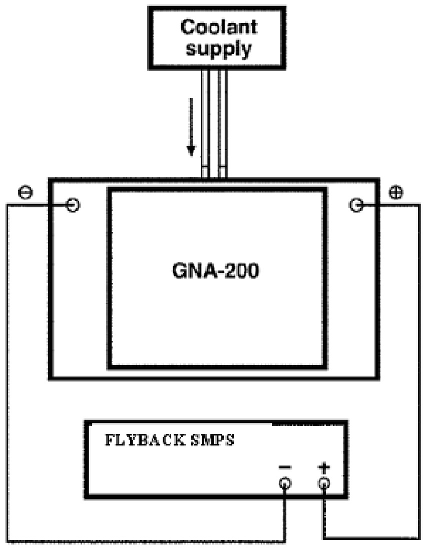


Figure 4.9 Electrophoresis process setup

Figure 4.10 Electrophoresis process in lab environment

4.7 Design and Development of Gel Electrophoresis Container

Figure 4.11 shows a sketch of the Gel Electrophoresis DNA separation container, which it can be seen from the four angles of container that are front view, back view, top view and the

3D view with the actual size. This sketch is important together actual view size before drawing in AutoCAD software.

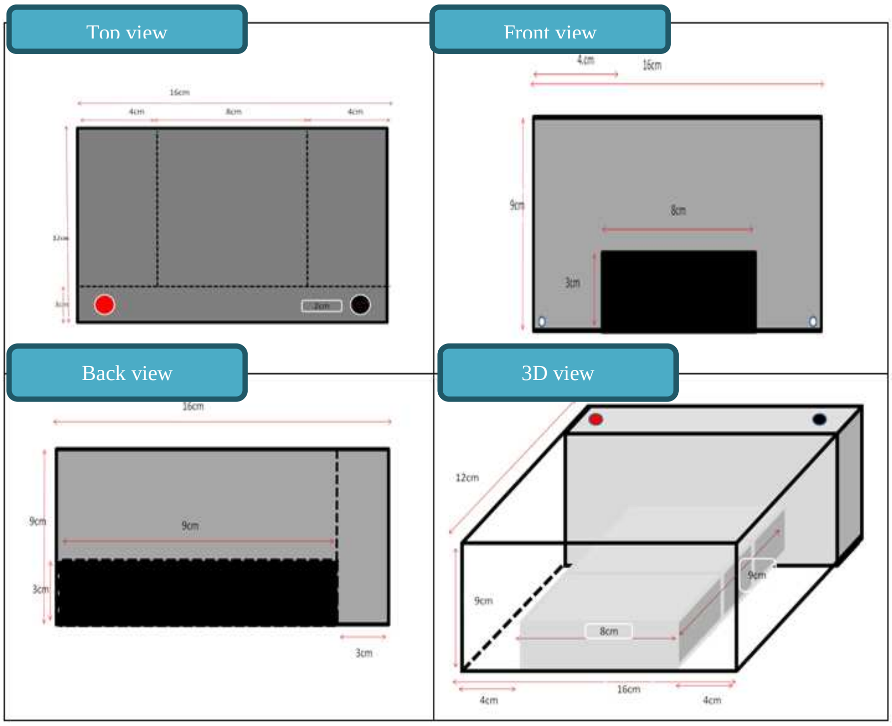


Figure 4.11 Design sketch of a new Gel Electrophoresis DNA separation container

Figure 4.12 shows of the first sketches of new design DNA Gel Electrophoresis separation cover with temperature control, where the cooler fan used to cool the temperature inside the container exceeds the prescribed limit and there are temperature sensors to send signals to the microcontroller.

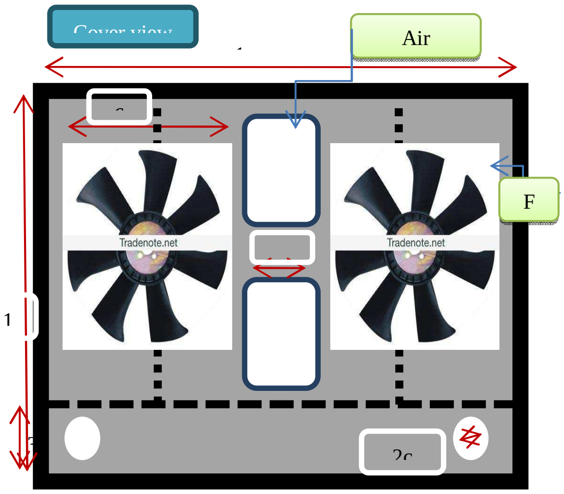


Figure 4.12 sketch of cover Gel Electrophoresis container

After sketching the electrophoresis container, transfer it to AutoCAD software and to be cut using laser cutting machine. Figure 4.13 below shows the lines that were drawn by using AutoCAD software.

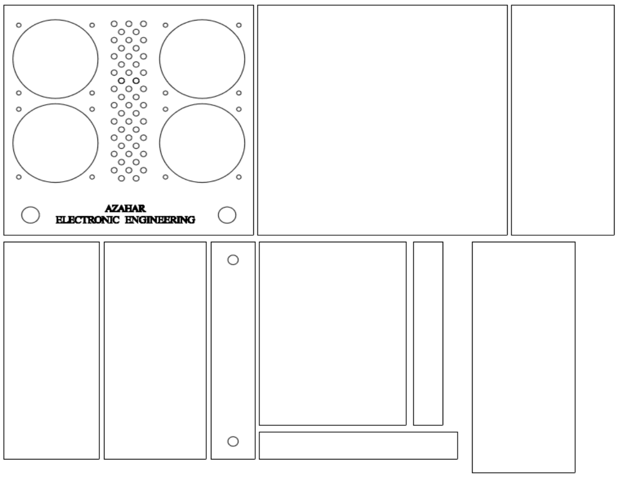


Figure 4.13 The view of drawing using AutoCAD software

Upon cutting process is completed, all part shown in Figure 4.14 are combined with liquid clorofon to complete a new DNA Gel Electrophoresis separation container as in Figure 4.15.

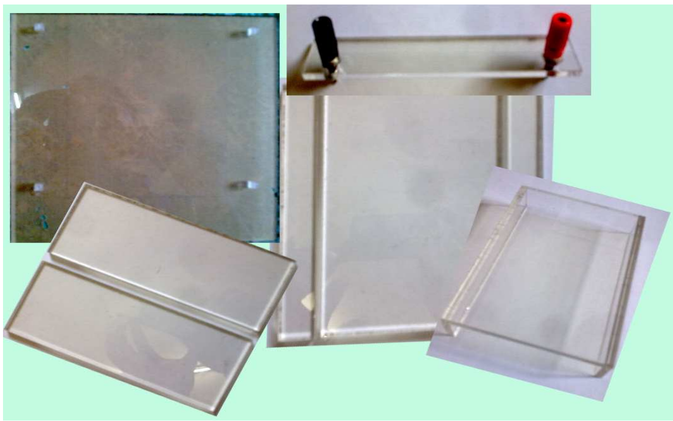


Figure 4.14 Parts of container

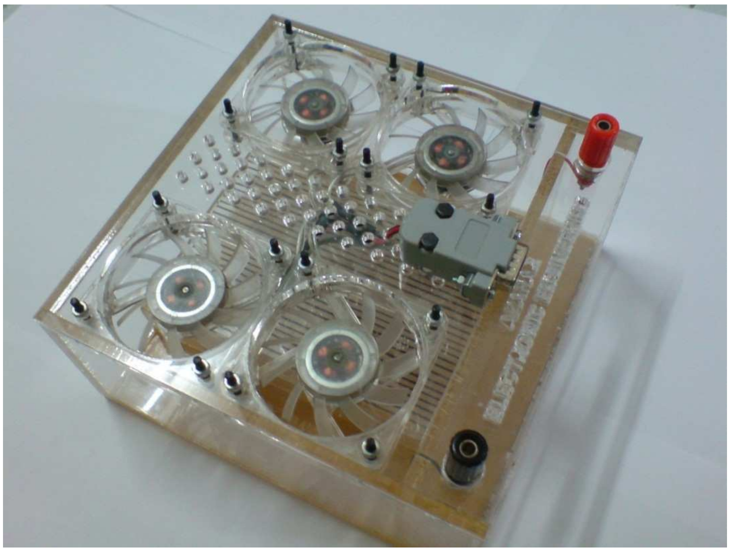


Figure 4.15 The complete new Gel Electrophoresis DNA separation container

4.7 Pseudo Code and Program Algorithm

Microcontroller acts as a brain of the whole temperature sensor, current and voltage measurement and also for timer to control the electrophoresis process system. It will sense the temperature from LM35DZ through RA0 pin of PIC 18F452. The temperature sensor will be measure the temperature of TAE buffer which is in between 20^{o} to 25^{o}C. If the temperature is out of this range, the microcontroller will instruct the cooler fan to switch on through RC1 pin of PIC 18F452. An algorithm has to be developed to make the microcontroller to read the input and respond accordingly. Therefore, the algorithm is established and represented by the flow chart and pseudo code in Figure 4.16 and Figure 4.17 respectively. These flow charts are then translated into C language and compiled using mikroC for PIC, the PIC 18F452 software development tool.

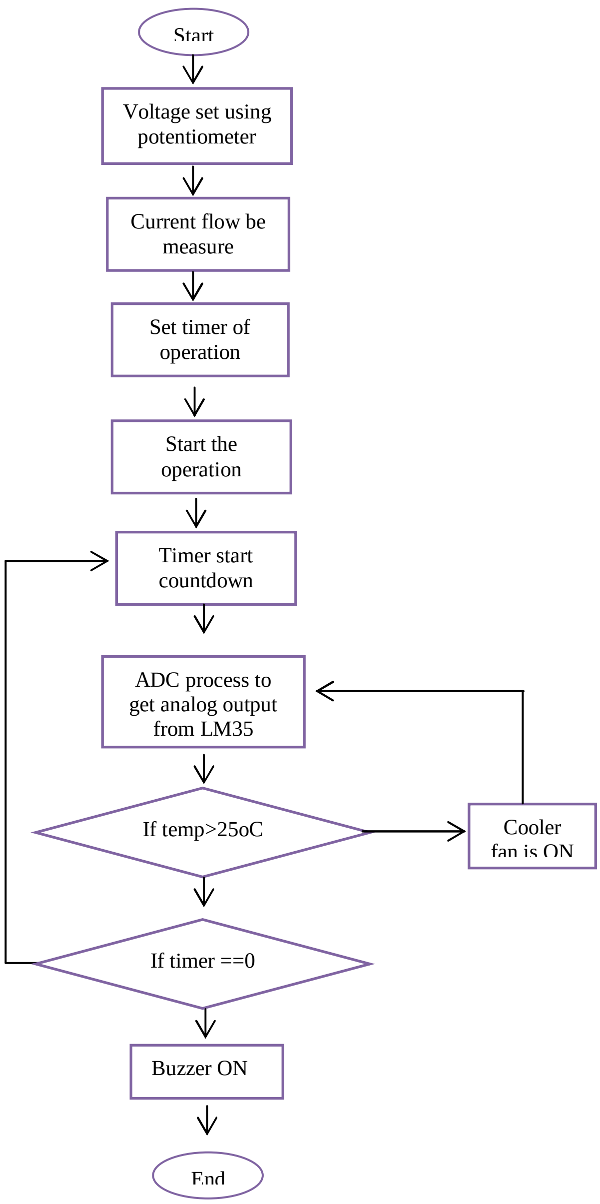


Figure 4.16: The flowchart of the program

```
//program//
Start
Main ();
Display character at first row: Voltage:    V
Display character at second row: Current:    mA
Display character at third row: Temperature:    °C
Display character at fourth row: Time:    minutes

Do {
read voltage output;
display voltage measure;
read current output;
display current measure;

read temperature value;
convert in Celsius;
if(temperature>25°C)
{
fan = ON;
}
else{
Fan = OFF;
}
Display value of temperature;

Input unit time;
Display value time"unit";
Input tens time;
Display value time"tens";
Select start button;
for (i=0; i< tmin; i++){

  tme1 = (tmin-i)%10 ;
  teme2 = (tmin-i)/10 ;
  display time left;

  do {
read temperature, voltage, current;
display current value all parameter;
  j++;
  } while(((j<=60) && (Clear ==0)));
  if (Clear) {
buzzer on
}
}
}
While(1);
}
End.
```

Figure 4.16: Pseudo code algorithm

4.8 Result Analysis

Some experiment and data collection are performed at standard procedure and difference voltage level in order to observe the cability of the system. The figure below show that the electrophoresis process setup had been defined to go across 120V with minimum current through is 20mA within 40 minutes. The DNA moved from the negatively charged pole towards the positively charged pole. Below are the figures illustrating the DNA separation process taking place every 5 minutes.

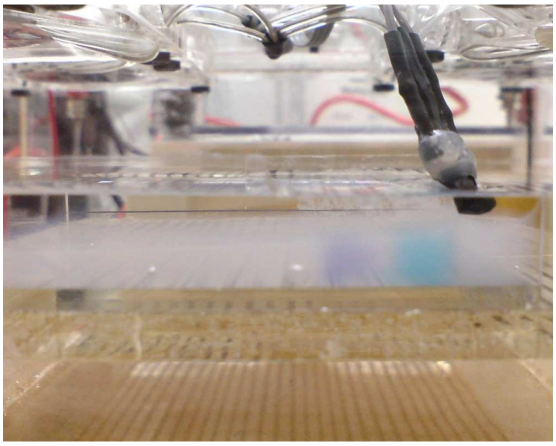


Figure 4.17 DNA separation after 5 minutes

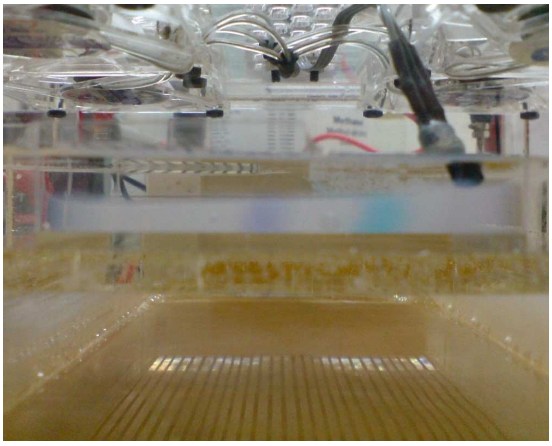


Figure 4.18 DNA separation after 10 minutes

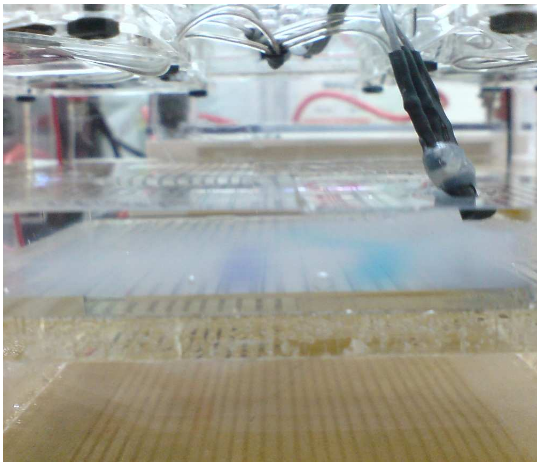


Figure 4.19 DNA separation after 15 minutes

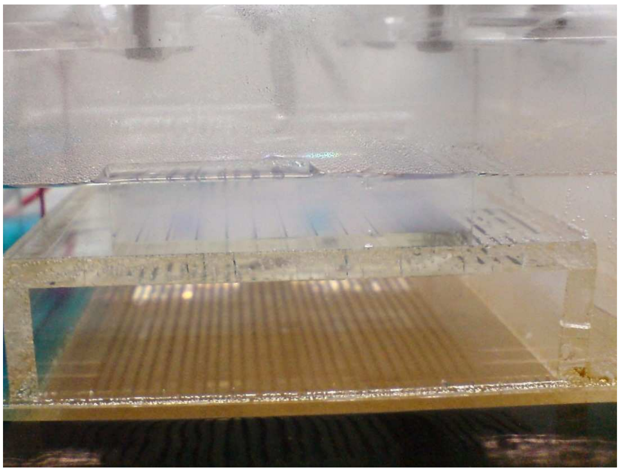


Figure 4.20 DNA separation after 20 minutes

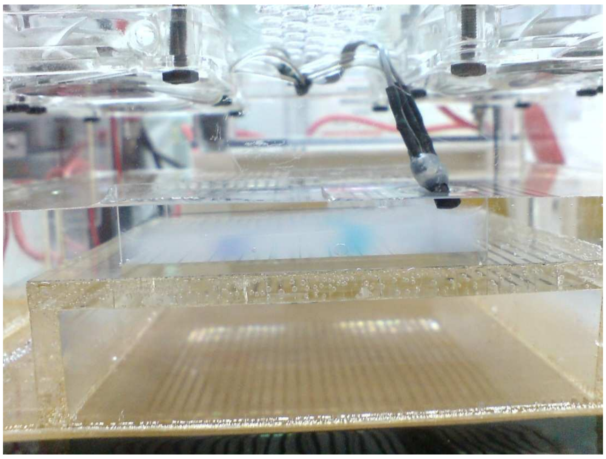


Figure 4.21 DNA separation after 25 minutes

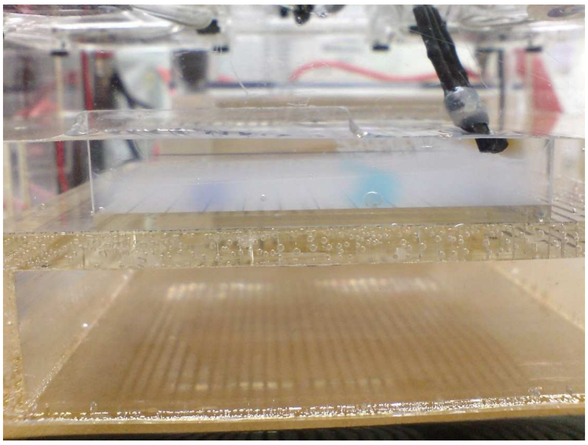


Figure 4.22 DNA separation after 30 minutes

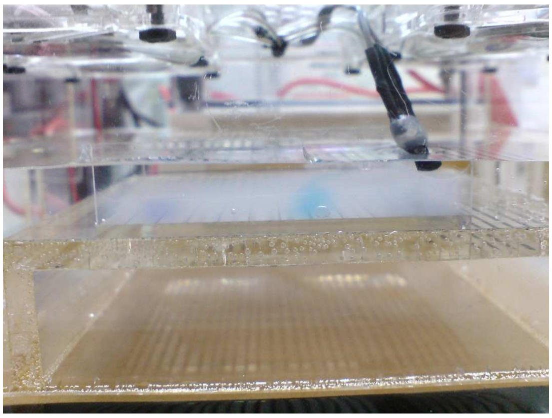


Figure 4.23 DNA separation after 35 minutes

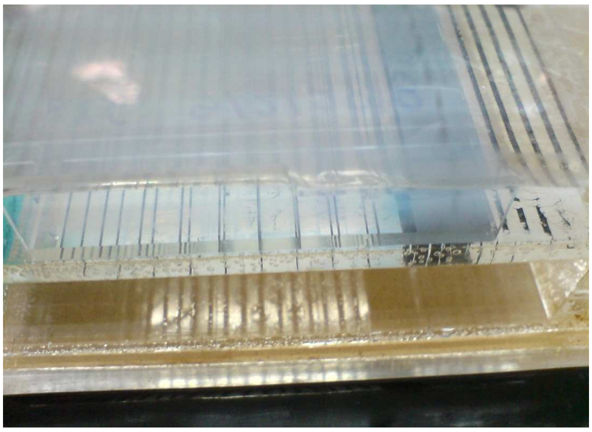


Figure 4.24 DNA separation after 40 minutes

After the DNA had been moved until the end of the well/container, the samples were sent into an UV machine to validate the electrophoresis process. Figure 4.25 reveals the DNA under UV light.

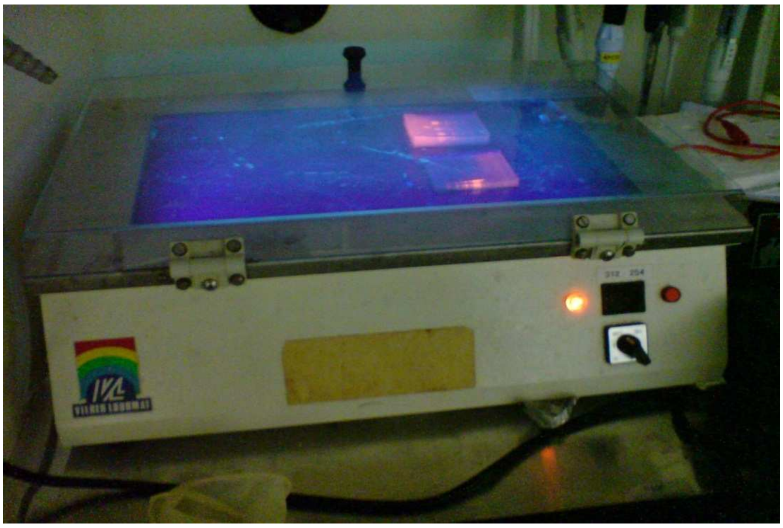


Figure 4.25 DNA sample under UV machine

4.8 Experimental result analysis

4.8.1 Gel Electrophoresis experiment with 80VDC (standard procedure) using standard container

Figure 4.26 shows the result of Gel Electrophoresis DNA separation with 80VDC using original container. This experiment was conducted by standard procedure. The process of this experiment takes 60 minute to complete the DNA separation. From the figure, a bigger and a smaller molecule DNA move from negative to positive current. However, the DNA movement is blur due to improper gel preparation.

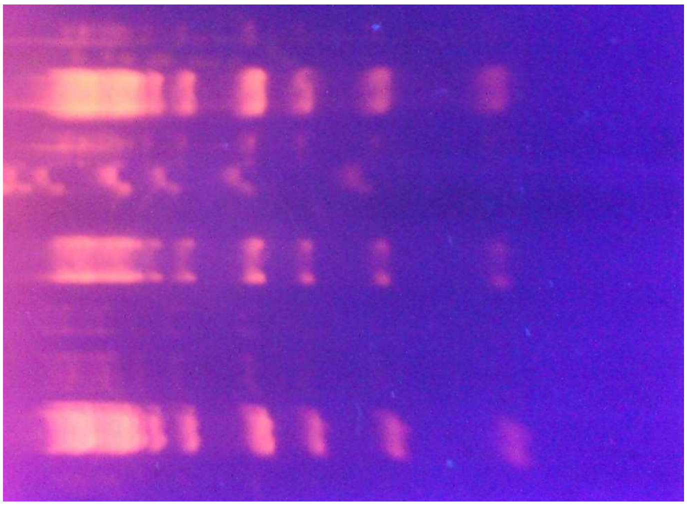


Figure 4.26 DNA result for standard procedure using standard container

4.8.2 Gel Electrophoresis experiment with 80VDC (standard procedure) using new container

Figure 4.27 shows the result of Gel Electrophoresis DNA separation with 80VDC using new container. This experiment was conducted by standard procedure. The process of this experiment takes 60 minute to complete the DNA separation. From the figure, a bigger and a smaller molecule DNA move from negative to positive current similarly as stated in theory.

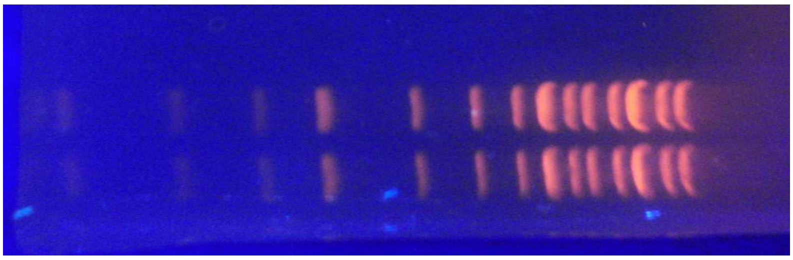


Figure 4.27: DNA result for standard procedure using new container

4.8.3 Gel Electrophoresis experiment with 100VDC using new container

Figure 4.28 shows the result of Gel Electrophoresis DNA separation with 100VDC using new container. The process of this experiment takes 50 minutes to complete the DNA separation.

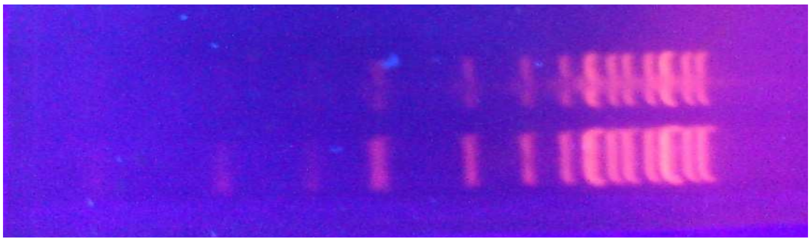


Figure 4.28: DNA separation with 100VDC using new container

4.8.4 Gel Electrophoresis experiment with 120VDC using new container

Figure 4.29 and 4.30 shows the result of Gel Electrophoresis DNA separation with 100VDC using new container. The process of this experiment takes less than 50 minutes to complete the DNA separation.

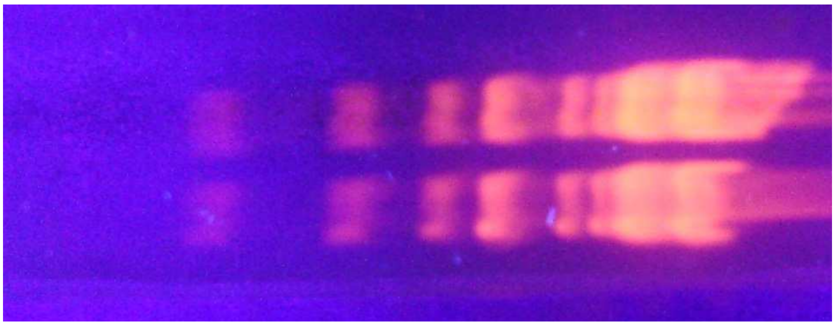


Figure 4.29 DNA separation with 120VDC using new container

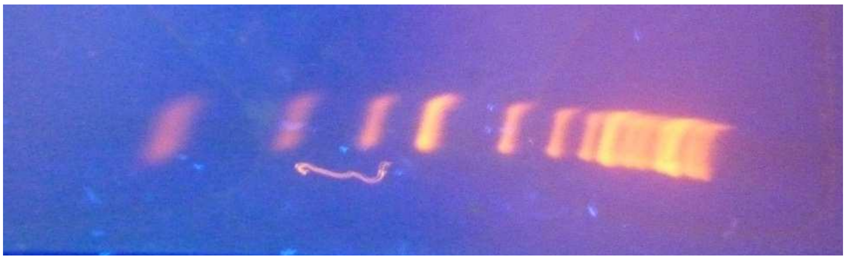


Figure 4.30 DNA separation with 120VDC using new container

5. CONCLUSION

The results and validations on the new design of Gel Electrophoresis DNA separation unit in science laboratory under typical conditions clearly shows that this research had fulfilled the stated objective within the clarified scope of the study. The theoretical formulation for reduce DNA separation time using high efficiency switch mode power supply of a gel electrophoresis unit has been demonstrated through the algorithm development (pseudo code). This container had clearly served the purpose of DNA separation whereby controlled the temperature is essential to get the electrophoresis process working.

As a conclusion, the new design of Gel Electrophoresis DNA separation unit is capable to reduce the time of the electrophoresis separation process. Furthermore, this implementation is more likely to be a cost saving project with optimized design rule custom made for electrophoresis process.

6. RESEARCH OUTPUT

a. Citation Details of Articles

- Nil -

b. Citation Details of Conference Papers

- Nil-

c. Citation Details of Other Publications - books / standards etc. (Please specify)

1- Poster presentation at i-ENVEX2011

d. Details of IPR *(Please specify)*

- Nil-

7. HUMAN CAPITAL DEVELOPMENT

a. Details of Human Capital Development *(Name and qualification sought)*

1. One undergraduate student
2. One PhD student

8. AWARDS / ACHIEVEMENT

a. Details of Recognition Received

1. Gold medal (i-ENVEX2011)
2. Best Award (i-ENVEX2011)
3. MOHE Grand price (I-ENVEX2011)

REFERENCES

[1] Arne Tiselius(1937), *a new apparatus for electrophoretic Analysis of colloidal mixtures*, Transactions of the Faraday Society , Institute ofPhysical Chemistry, Upsala University, Sweden. , received on 25th january, 1937.

[2] B.D. Hames & D. Rickwood, *Gel Electrophoresis of Proteins: a Practical Approach,* IRL Press, 1981

[3] Beckmen Coulter, *Introduction to capillary electrophoresis*, 1995.

[4] Dogan Ibrahim , *Advanced PIC Microcontroller, Projects in C,* United States of America,2008

[5]T.Carter, *Switch mode power supplies*: an EMI Enginenrs's point of view. Conference Paper, 29-31 Mar 1994, pp. 295-300.

[6]Odon Frenczi, *Power Supplies Part B- Switch Mode Power Supplie.* Budapest: Elservier Science Publisher 1997.

[7].J. Michael Jacob, *Power Electronics: Principle and Application*. New York: Delmar 2002

[8].H.W. Whittington, B. W. Flynn and D.E. Macpherson, *Switch mode power supplies-Design and construction*. Research Studies Press Ltd. England, 1997

[9]. K. Kit Sum, *Switch Mode Power Conversion – Basic Theory and Design*. New York: Marcel Dekker Inc, 1994

[10] B. K. Bose, *Modern Power Electronics – Evolution, Technology and Applications*. New York :IEEE, 1992
[11].Ferroxcube, "Soft Ferrites – Application, "*Data Handbook Soft Ferrites and Accessories*, 2003.
[12].Abraham I. Pressman, "*Switching Power Supply Design*", 2nd Edition, Mc Graw Hill, 2001
[13].Unitrode Seminar Manual SEM1000 and SEM1100, "*Deriving the quivalent Electrical Circuit from the Magnetic Device Physical Properties"*,John Wiley and Sons Ltd, December 2002.
[14] P.C Sen, " *Principle of Electrical Machines and Power Electronics"*, second edition, John Wiley and Sons, 1997.
15] Marc E Herniter, "*Flyback Switching Power Supply Design Discontinuos Mode Operation"*, EC Department, Terre Haute, January 2003.
[16].Steven Watkins, "*History and development of switched mode power supply*", 1998

APPENDIX – Pseudo Code program

Software programming

```
// LCD module connections
sbit LCD_RS at Rc2_bit;
sbit LCD_EN at Rc3_bit;
sbit LCD_D4 at RC4_bit;
sbit LCD_D5 at RC5_bit;
sbit LCD_D6 at RC6_bit;
sbit LCD_D7 at RC7_bit;
sbitLCD_RS_Direction at TRISc2_bit;
sbitLCD_EN_Direction at TRISc3_bit;
sbit LCD_D4_Direction at TRISC4_bit;
sbit LCD_D5_Direction at TRISC5_bit;
sbit LCD_D6_Direction at TRISC6_bit;
sbit LCD_D7_Direction at TRISC7_bit;
// End LCD module connections

// Tact switches and Relay ports
sbit buzzer at Rc0_bit;
sbitSS_Select at RB2_bit;  // Start Stop Time Select
sbitUnit_Button at RB0_bit;
sbitTen_Button at RB1_bit;
char Message0[] = "ELECTROPHORESIS";
char Message00[] = "SYSTEM";
char Message1[] = "Voltage:";
char Message2[] = "Current:";
char Message22[] = "mA";
char message3[] = "Temperature:";
char message4[] = "C";
char Message5[] = "Time:";
char Message6[] = "minute";

unsigned short unit=0, ten=0, ON_OFF=0, index=0, clear, time;
unsignedintADC_Value, DisplayVolt,temp, Ammeter,tmin,show;
unsigned char op[12], lcd[5];
unsigned short i, j,k,l
```

```
char volt[] = "000.0";
char current[] = "00.00";
char digit[] = "00" ;
char dis[] = "00";


voidDisplay_Digits(){
digit[1]=unit+48;         //   tukarascii
digit[0]=ten+48;
Lcd_Out(4,6,digit);
}

voidstart_timer(unsigned short tmin){
unsigned short temp1, temp2;
buzzer = 0;
 ON_OFF = 1;
Lcd_Out(4,1,Message5);
 INTCON = 0x90;
for (i=0; i<tmin; i++){
  temp1 = (tmin-i)%10 ;
  temp2 = (tmin-i)/10 ;
Lcd_Chr(4, 6, temp2+48);
Lcd_Chr(4, 7, temp1+48);
  j=1;
do {
Delay_ms(1000);
j++;

ADC_Value = ADC_Read(1);                              //read analog at AN1
DisplayVolt = ADC_Value*25.01;
volt[0] = DisplayVolt/10000 + 48;
volt[1] = (DisplayVolt/1000)%10 + 48;
volt[3] = (DisplayVolt/100)%10 + 48;
volt[4] = (DisplayVolt/10)%10 + 48;
Lcd_Out(1,9,volt);
delay_ms(1000);

   Ammeter = DisplayVolt/16.69;
current[0] =(Ammeter/100) + 48;
current[1] = (Ammeter/10)%10 + 48;
current[2] = Ammeter%10 + 48;
current[4] = Ammeter + 48;
Lcd_out(2,9,current);

 //read temperature
     TEMP = ADC_Read(0);
if (TEMP >57)
    {
    PORTc.f1= 1;                      // Turn ON LEDs on PORTD
      }
else {
     PORTc.f1= 0;                      // Turn ON LEDs on PORTD
          }

show = TEMP*100;                      // Convert to string in "op"
```

```
show = show/225;
  // dis[3] =(show/1000) + 48;
  // dis[4] = (show/100)%10 + 48;
dis[0] = (show/10)%10 + 48;
dis[1] = show%10 + 48;
Lcd_Out(3,13,dis);                    // Output to LCD

  } while(((j<=59) && (Clear ==0)));
if (Clear) {
buzzer = 1;
Delay_ms(1000);
   INTCON = 0x00;
goto stop;
   }
 }
stop: buzzer = 1;
Delay_ms(1000);
buzzer = 1;
ON_OFF = 1;
unit = 0;
ten = 0;
index = 0;
clear = 1;
}

void interrupt(void){

if (INTCON.INTF == 1)          // Check if INTF flag is set
     {
     Clear = 1;
     INTCON.INTF = 0;             // Clear interrupt flag before exiting ISR
    }
   }

void main() {
  TRISA = 0xff;
  TRISB = 0xff;
  TRISC = 0x00;
buzzer = 0;
  ADCON0 = 0xff;                  // Analog channel select @ AN2
  ADCON1 = 0x80;                  // Use Vref = +5V

Lcd_Init();                       // Initialize LCD
Lcd_Cmd(_LCD_CLEAR);             // CLEAR display
Lcd_Cmd(_LCD_CURSOR_OFF);        // Cursor off
Lcd_Out(2,3,Message0);
Lcd_Out(3,8,Message00);
delay_ms(2000);
Lcd_Cmd(_LCD_CLEAR);             // CLEAR display
Lcd_Cmd(_LCD_CURSOR_OFF);        // Cursor off
Lcd_Out(1,1,Message1);
Lcd_Chr(1,14,'V');
Lcd_Out(2,1,Message2);
Lcd_Out(2,14,Message22);
Lcd_Out(3,1,Message3);
```

```
Lcd_Chr(3,16,223);
Lcd_out(3,17,message4);
Lcd_out(4,1,message5);
Lcd_out(4,9,message6);

start:
clear = 0;
Display_Digits()  ;
do {
ADC_Value = ADC_Read(0);                //read analog at AN1
DisplayVolt = ADC_Value*26.01;
volt[0] = DisplayVolt/10000 + 48;
volt[1] = (DisplayVolt/1000)%10 + 48;
volt[2] = (DisplayVolt/100)%10 + 48;
volt[4] = (DisplayVolt/10)%10 + 48;
Lcd_Out(1,9,volt);
delay_ms(1000);


  Ammeter = DispayVolt/16.69;
current[0] =(Ammeter/100) + 48;
current[1] = (Ammeter/10)%10 + 48;
current[3] = Ammeter%10 + 48;
current[4] = Ammeter%5 + 48;
Lcd_out(2,9,current);
delay_ms(1000);

if(!Unit_Button){
 //    Delay_300();
unit ++;
if(unit==10) unit=0;
Display_Digits();
   }                          // If !Unit_Button

if(!Ten_Button){
   // Delay_300();
ten ++;
if(ten==10) ten=0;
Display_Digits();
   }                           // If !Ten_Button

if(!SS_Select){
  //  Delay_300();
time = ten*10+unit ;
if(time > 0) start_timer();
   }                           // If !SS_Select
if(clear){

goto start;
   }

   } while(1)
```