Design And Development Of An External Cardiac Defibrillator

A dissertation submitted in partial fulfillment of requirement for the degree of Bachelor of Science in Electrical and Electronic Engineering.

Islamic University of Technology (IUT)

The Organization of Islamic Cooperation (OIC)

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A Thesis Presented to

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Abstract

Defibrillator is used for the treatment of fibrillation (an arrhythmia of heart). The technology of defibrillation was invented more than a century ago and it's more than half a century since it's been used on human being. Almost all the industries and public places of the developed countries keep Automated External Defibrillators (AEDs). This technology has advanced to such a stage that wearable and implantable defibrillators are used at a frequent rate by the patient of the developed countries. But like many other inventions of science this invention also failed to reach all the people around the world. In the third world countries yet there are hospitals where there is not a single external defibrillator which could have saved a lot of lives.

Coronary Heart Disease Deaths in Bangladesh is 163,769 or 17.11% of total deaths (WHO, April 2011). This death rate ranks Bangladesh 25 in the world. Price of defibrillators imported to Bangladesh varies from 3 lakhs to 15 lakhs or more. So most often government hospitals and private clinics cannot afford to keep sufficient defibrillators. Again once these devices start malfunctioning they cannot be repaired locally. Sometimes device warranty also doesn't work out. People of the remote areas, attacked by fibrillation die long before reaching the town hospitals. Every minute passes, the chance of a patient attacked by fibrillation coming back to life decreases. A defibrillator at the union health complex could have changed the picture.

As a populated place & an international university IUT Medical Center must have at least one defibrillator also as anyone at any time might be attacked by fibrillation.

All these things motivated us to go for a locally made defibrillator which would be cheap but efficient, easy to handle & easy to repair. We have a hope to launch it commercially without any profit. Thus this technology will reach the people of all classes and save the lives of a lot of people.

The defibrillator circuit was built using locally available equipment. Several circuits were made proceeding from the simpler to the complex one. For high voltage generation CRT TV Flyback Transformer has been used which is available at the market within 300tk only. The main cost of the device is the capacitor. The cost of the defibrillator is about 1, 20,00tk only, which will be affordable to the poor people also.

Acknowledgement

Firstly, we are grateful to Almighty Allah for giving us this much knowledge to work with this project. Then we want to express our gratitude to our project supervisor Professor K. Siddique-e-Rabbani, who supervised us in his very busy time schedule and taught us everything from the very basic level with patience. The most interesting thing that we learnt from him was intuitive learning of everything. This made the project easy for us and we firmly believe that it will help us in the future life also. Our project co-supervisor Dr. Kazi Khairul Islam always used to ask about the update of our thesis and gave us inspiration. Our departmental head Professor Dr. Md. Shahidullah also inspired us and ensured that he would help to manage the funding for the thesis. We are thankful to the department of Biomedical Physics & Technology of University of Dhaka for letting us using their lab and also to the staffs for their cooperation in many ways. Help and guidance from Mr. Kamrul Hasan Sunny, Mr. Zaman, Mr. Raihan Abir, Mr. Maruf Ahmed Dhali, Mr. Alamgir, Engr. Masud, Engr. Golam Haider, Mr. Golam Mostafa, Mr. Najrul and many other people helped us to bring this project to this far. We are also thankful to all of our teachers, families and friends for their suggestions and inspiration.

Dedicated to our families

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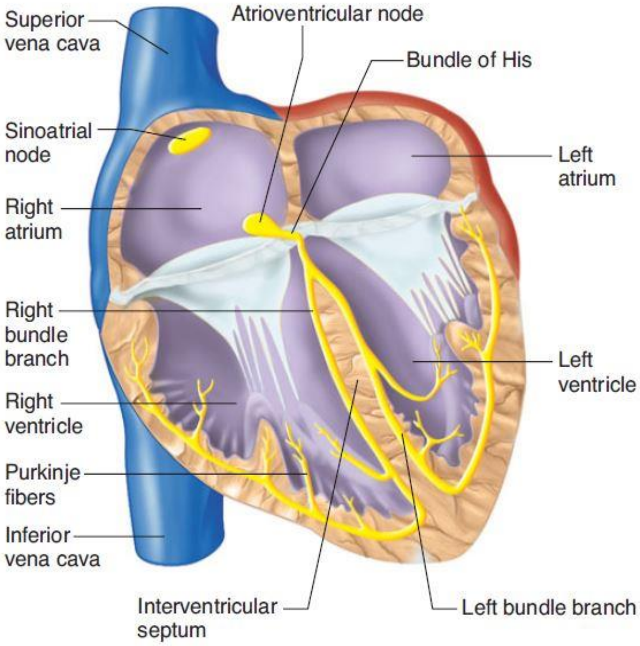
Chapter 1

Normal functions and rhythm of heart

1.1 The Heart's Electrical Conduction System:

The heart is primarily made up of muscle tissue. A network of nerve fibers coordinates the contraction and relaxation of the cardiac muscle tissue to obtain an efficient, wave-like pumping action of the heart.

The parts of the heart normally beat in orderly sequence: Contraction of the atria **(atrial systole)** is followed by contraction of the ventricles **(ventricular systole),** and during **diastole** all four chambers are relaxed. The heartbeat originates in a specialized **cardiac conduction system** and spreads via this system to all parts of the myocardium. The structures that make up the conduction system (Figure 1.1) are the **sinoatrial node (SAnode),** the **internodal atrial pathways,** the **atrioventricularnode (AV node),** the **bundle of His** and its branches, and the **Purkinje system.**



The various parts of the conduction system and under abnormal conditions, parts of the myocardium, are capable of spontaneous discharge. However, the SA node normally discharges most rapidly, with depolarization spreading from it to the other regions before they discharge spontaneously. The SA node is therefore the normal **cardiac pacemaker,** with its rate of discharge determining the rate at which the heart beats. Impulses generated in the SA node pass through the atrial pathways to the AV node, through this node to the bundle of His, and through the branches of the bundle of His via the Purkinje system to the ventricular muscle.

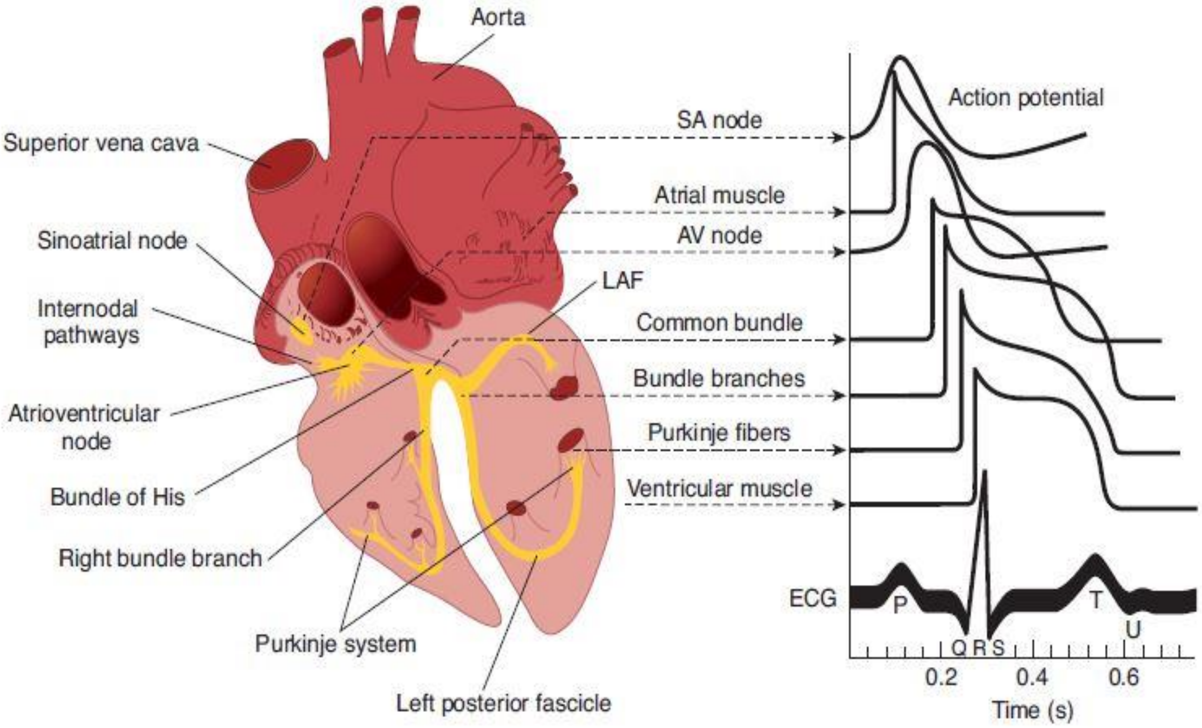


Figure 1.1: **Conducting system of the heart.**

Left:
Anatomical depiction of the human heart with additional focus on areas of the conduction system.

Right:
Typical trans-membrane action potentials for the SA and AV nodes, other parts of the conduction system, and the atrial and ventricular muscles are shown along with the correlation to the extra cellularly recorded electrical activity, that is, the electrocardiogram (ECG). The action potentials and ECG are plotted on the same time axis but with different zero points on the vertical scale. LAF, left anterior fascicle.

1.2 The Electrocardiogram (ECG):

Because the body fluids are good conductors (i.e., the body is a **volume conductor**), fluctuations in potential that represent the algebraic sum of the action potentials of myocardial fibers can be recorded extracellularly. The record of these potential fluctuations during the cardiac cycle is the **Electrocardiogram (ECG).**

The small **P wave** represents the spread of the excitatory signal throughout the atria. The **QRS complex** results from the ventricular depolarization, as the signal spreads via the AV bundle and the Purkinje fibers. The **T wave** results from the repolarization or return to the resting state, of the ventricles. The QRS complex masks the corresponding wave representing atrial repolarization. When these features are analyzed for any indication of arrhythmia, the size and shape of each curve is examined. Any damage to the pacemaker cells of the SA node may require implantation of an electrical pacemaker to maintain the proper rhythm of heartbeats.

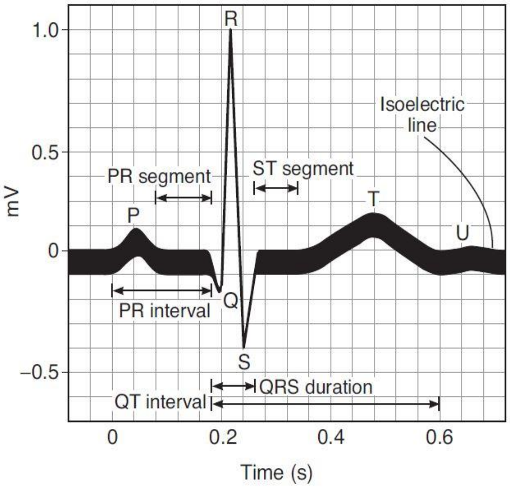


Figure 1.2: **Waves of the ECG.**

One complete cardiac cycle represents all of the events that occur in sequence from the start of one heartbeat until the start of the next (Figure 1.3). Examining this complete cycle will allow us to better understand and coordinate the electrical activity of the heart with its corresponding contractile functions. Fluids, like blood, will only move from one region to another if a pressure gradient exists. For blood to move from an atrium to a ventricle, therefore, blood pressure in the atrium must be higher than the pressure in the ventricle. The flow of blood between these two chambers will stop once the pressures are equal. The heart valves prevent blood from flowing from the ventricles back into atria. If the electrical events and phases are matched with pressure changes within the heart chambers, a picture of what occurs during atrial and ventricular systole begins to emerge.

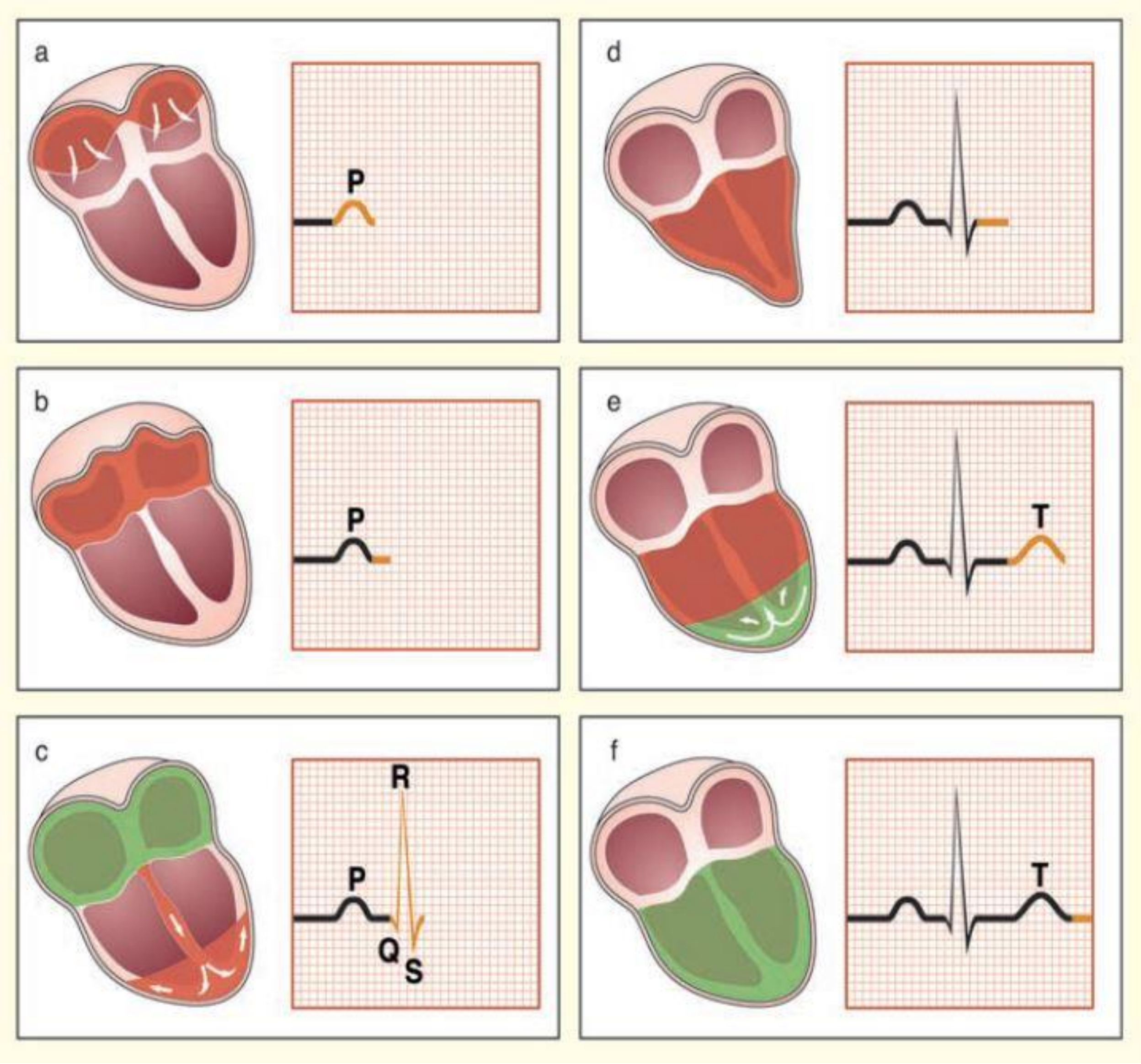


Figure 1.3: The relationship between the electrocardiogram and the electrical activity of the heart is illustrated here. The portions of the heart that are in depolarization and are therefore being stimulated to contract are shown in red. Green represents the initiation of repolarization (relaxation phase).

Chapter 2

Fibrillation & Defibrillation

2.1 Irregular Heart Rhythms:

Because the ECG records the electrical activity of the heart, it can also be used to detect irregularities in heart rhythm. The ECG can determine, for example, whether the heart is beating too fast, a condition called tachycardia, or too slow, a condition known as bradycardia, by measuring the amount of time elapsed from one QRS complex to the next.

A cardiac patient may exhibit particularly dangerous forms of tachycardia in the ventricles of the heart known as ventricular flutter or fibrillation. These forms of tachycardia typically occur when an area of the ventricle becomes auto rhythmic, overriding the slower signal arriving from the SA node. Ventricular tachycardia can cause the ventricles to contract as many as 300 times per minute, a rate too fast to effectively move blood through the circulatory system. Rapid intervention is required with this condition to prevent complete heart failure. Other types of irregularities may involve a block in the conducting pathway that relays the electrical signal from the SA node to the ventricular muscle, potentially resulting in a loss of coordination between atrial and ventricular contractions. A prolonged P-R interval, the amount of time elapsed between the P and R waves, may indicate blockage in the AV node. Ischemia, a decrease in the blood supply in the heart, may show up on an ECG as an inverted T wave, where the T wave is reflected downward rather than upward. In addition, if a heart attack occurs, in which blood flow and oxygen supply to a region of the heart are reduced significantly for a period of time, an ECG can help a cardiologist identify which area of the heart muscle was affected as well as the extent of the damage.

2.2 Fibrillation:

Cardiac muscle is intrinsically active in that it will contract periodically in the absence of any neural connections. If a piece of cardiac muscle is removed from the heart and placed in an organ bath then oscillating electrical potentials can be recorded from the piece of tissue. Now in the intact heart all the pieces of cardiac muscle interact with each other such that they all oscillate at the same frequency and so contract regularly at that frequency. However, if part of the heart muscle is damaged or disrupted then the interaction can be disrupted and fibrillation can occur (Figure 2.1). All the pieces of cardiac muscle are still oscillating but at different frequencies so that there is no coordinated contraction.

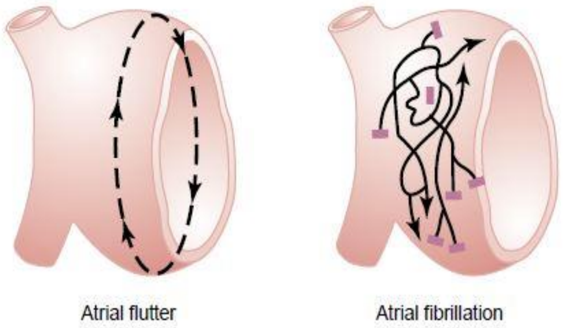
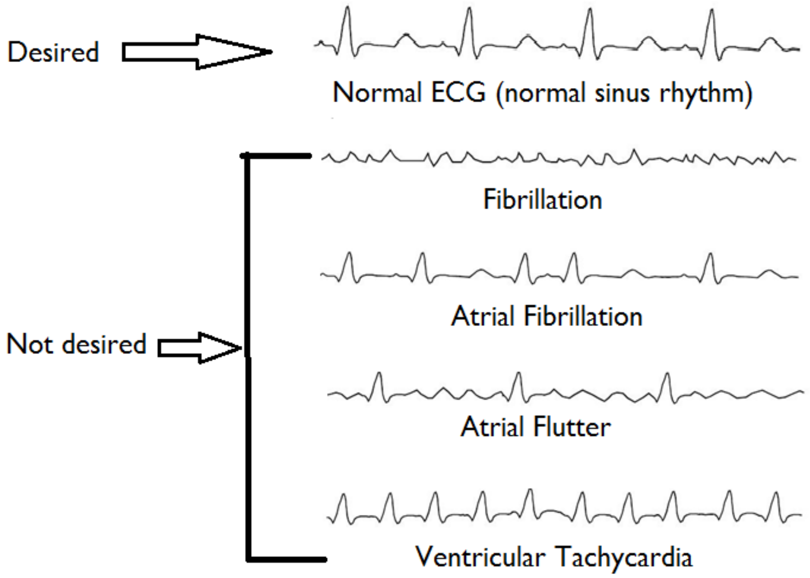


Figure 2.1: **Pathways of impulses in atrial flutter and atrial fibrillation.**

Either the ventricles or the atria can fibrillate but the consequences to the patient are very different. Under atrial fibrillation the ventricles still function but with an irregular rhythm. Because atrial filling with blood does not depend upon atrial contraction there is still blood for the ventricles to pump, so that whilst the patient may be aware of the very irregular heart beat blood is still circulating. Ventricular fibrillation is much more dangerous as the ventricles are unable to pump blood so that death will occur within a few minutes. Ventricular fibrillation is not self-correcting so that patients at risk of ventricular fibrillation have to be monitored continuously and defibrillation equipment must be immediately to hand.



Fibrillation is obvious in the resulting ECG as shown. There are still potential changes during fibrillation but they are apparently random and the amplitude is less than occurs during normal sinus rhythm. Care has to be taken in recognizing fibrillation from the ECG as other conditions may change the appearance of the ECG waveform.

2.2.1 Main causes of fibrillation:

1. Commonly ischemia of heart tissue
2. Electric shock
3. Drugs
4. Electrolyte disorders
5. Drowning
6. Hypothermia.

Exposure of the body to high-voltage electricity, especially low-frequency alternating current (e.g., in an electrical outlet) and low contact resistance (bare feet, bathtub accidents), primarily affects the conduction of impulses in the heart and can cause ventricular fibrillation.
Direct current usually acts as a stimulus only when switched on or off: High-frequency alternating current (>15 kHz), on the other hand, cannot cause depolarization but heats the body tissues. Diathermy works on this principle.

Fibrillation is the most serious medical emergencies of the cardiac patient. Lack of blood flow to the brain for more than 5 to 8 minutes usually causes permanent mental impairment or even destruction of brain tissue. Even if the heart is revived, the person may die from the effects of brain damage or may live with permanent mental impairment.

2.3 Defibrillators:

Defibrillators are devices that are used to apply a large electric shock to the heart. They are used to restore a normal sinus rhythm to a heart which is still active but not contracting in a coordinated fashion. The use of a defibrillator on a patient following a heart attack is an emergency procedure, as the pumping action of the heart has to be restarted within a few minutes if the patient is to survive. The defibrillator is therefore a 'safety-critical' device; if it fails to work when required then the patient will die.

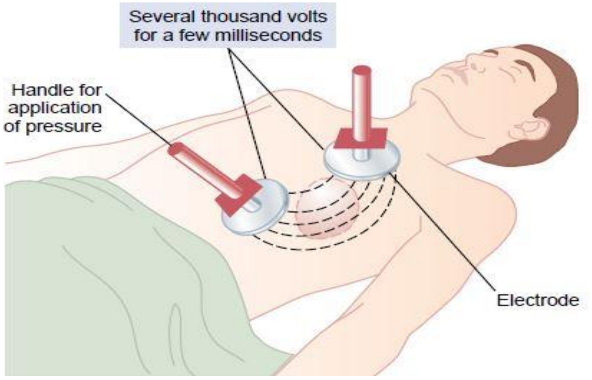


Figure 2.2: Application of electrical current to the chest to stop ventricular fibrillation.

Although a moderate alternating-current voltage applied directly to the ventricles almost invariably throws the ventricles into fibrillation, a strong high voltage alternating electrical current passed through the ventricles for a fraction of a second can stop fibrillation by throwing all the ventricular muscle into refractoriness simultaneously. This is accomplished by passing intense current through large electrodes placed on two sides of the heart. The current penetrates most of the fibers of the ventricles at the same time, thus stimulating essentially all parts of the ventricles simultaneously and causing them all to become refractory. All action potentials stop, and the heart remains quiescent for 3 to 5 seconds, after which it begins to beat again, usually with the sinus node or some other part of the heart becoming the pacemaker. However, the same re-entrant focus that had originally thrown the ventricles into fibrillation often is still present, in which case fibrillation may begin again immediately.

When electrodes are applied directly to the two sides of the heart, fibrillation can usually be stopped using 110 volts of 60-cycle alternating current applied for 0.1 second or 1000 volts of direct current applied for a few thousandths of a second. When applied through two electrodes on the chest wall, as shown in Figure, the usual procedure is to charge a large electrical capacitor up to several thousand volts and then to cause the capacitor to discharge for a few thousandths of a second through the electrodes and through the heart.

2.4 History of Defibrillator:

Defibrillators have a long history in that some animal work was done in 1899, but emergency human defibrillation was not carried out until the 1950s. They have been in widespread use since the 1960s.

As early as 1899, French physiologists, Jean Louis Prevost and Frederic Battelli were able to stop ventricular fibrillation in a dog by applying an electric shock to the animal's exposed heart. In 1930, William B. Kouwenhoven, an American electrical engineer at Johns Hopkins University, developed with colleagues a closed-chest defibrillator that sent alternating current (AC) electrical shocks to the heart through electrodes placed on a dog's chest. In 1947, Claude Beck, professor of surgery at Case Western Reserve University, first successfully resuscitated a human patient by internal cardiac massage and electrical defibrillation; American cardiologist Paul Zoll applied AC defibrillator to human patients in 1961; and the direct current (DC) defibrillator introduced by Lown and Neuman in 1962 provided greater reliability and safety.

Defibrillators greatly improved the ability of patients to survive heart surgery, invasive cardiac diagnostic and treatment techniques, and heart attacks, all of which can send the heart into ventricular fibrillation. Since the 1970s, most hospital emergency rooms have been equipped with electric defibrillators, and portable devices have becoming standard equipment for ambulances.

Most recently, **Automated external defibrillators (AEDs)**, light-weight, portable, user-friendly devices about the size of a lunch box, can be found at sports stadiums, hotels and casinos, in coast guard marine vehicles and police cars, and many other places where people gather. These devices can be used by operators with much less training than paramedics, and are intended for use by on-site personnel like fire fighters until paramedics arrive. Sometimes called the "smart" defibrillator, they provide audio instructions and visual prompts to walk the operator through the defibrillating process, as well as recording the sequences of events such as when the operator connected the analyzer and pushed the shock button.

Wearable cardioverter defibrillator (WCD) is worn by patients at risk for sudden Cardiac Arrest (SCA) that provides protection as changing conditions are assessed.

An implantable device, called the **Automatic implantable cardioverter defibrillator (AICD)** was invented by Mieczyslaw Mirowski of the Johns Hopkins University Medical School to stop heart arrhythmias. Approved for use by the Food and Drug Administration in October 1985, Mirowski's AICD senses two kinds of abnormal heart rhythms - ventricular fibrillation and ventricular tachycardia -automatically sending an electric shock to the heart to correct the disturbance. As a defibrillator, the device jolts the heart out of ventricular fibrillation; as a cardioverter, it shocks the heart out of an abnormally fast heartbeat called ventricular tachycardia, restoring normal heart rate. Because the AICD requires a heftier power pack than the standard cardiac pacemaker, the battery pack for the AICD is separately implanted in the patient's abdomen. The lithium batteries can deliver 100 to 150 shocks during their three-year lifetime. The AICD is a potential lifesaver for the 700,000 people in the United States who survive heart attacks each year and are therefore at risk for potentially fatal arrhythmias. The AICD is also routinely used for patients whose arrhythmias cannot be treated with medication or surgery.

A century has passed since the defibrillator has been invented. But it is matter of shame that yet this simple technology failed to reach all the class of people around the world which could save a lot of lives.

2.5 Principles of defibrillation:

A defibrillation shock aims to totally stop the heart, or at least to stop enough cells to inhibit fibrillation, in the hope that the heart will restart in an orderly fashion after the shock. If sufficient current is used to stimulate all the musculature of the heart then when the shock stops all the heart muscle fibers enter their refractory period at the same time, after which normal heart rhythm may resume.

Of the two major categories of muscle, striated (skeletal) and smooth, cardiac muscle is most like smooth muscle. Skeletal muscle is composed of long muscle fibers and does not produce activity unless it receives impulses along an associated motor nerve. Smooth muscle is composed of much shorter and smaller cells and it is intrinsically active. Neural impulses and circulating hormones will influence the activity but smooth muscle can contract in isolation. Cardiac muscle is intrinsically active.

Skeletal muscle can be electrically stimulated and will produce an action potential in response to a stimulus of duration 100 µs or less .Cardiac muscle is more difficult to stimulate, in part because it is intrinsically active so that our ability to stimulate the muscle depends upon what the muscle is doing at the time we apply our stimulus. Longer duration pulses are required to stimulate cardiac muscle than striated muscle, although high-amplitude stimuli of short duration will have the same effect as lower amplitude impulses of longer duration. This is illustrated in figure in the form of a curve often referred to as a strength–duration curve. The ‘current’ curve shows that the amplitude of current required for defibrillation decreases as duration increases, but that there is a minimum current required whatever the stimulus duration. This is called the rheobase. The current required is several amps, which is a very high current to apply to the human body.

Figure 2.3 also shows the charge (*Q*) and energy (*E*) associated with the current pulse. The charge is the product of the current ***I*** and the pulse duration *t*. The energy is I^2Rt where ***R*** is the resistance into which the current is delivered. It can be seen that there is a minimum energy required at a pulse width of about 4ms.

One reason for the large current which is required for defibrillation is that only a small fraction of the current applied to the chest will actually flow through the heart; if defibrillation is applied directly to the heart during open heart surgery then smaller currents are required.

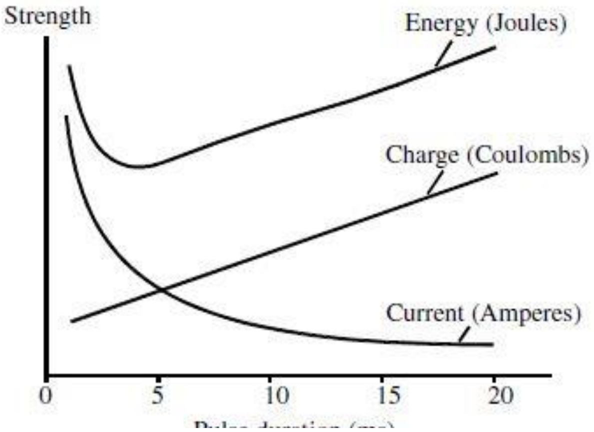


Figure 2.3: A strength–duration curve for defibrillation applied across the thorax. Curves showing the associated charge and energy are also shown.

Another important variable related to the current and pulse duration required for defibrillation is the size of the subject. It has been shown that larger animals require higher currents to defibrillate than smaller ones. It is also true that larger animals are more likely to suffer from fibrillation than smaller ones. Large people require higher defibrillation currents than small people and, in particular, children require low currents.

Chapter 3

Defibrillator circuit and waveforms

3.1 Pulse shapes for defibrillation:

The stimulus waveform which is used in most striated muscle stimulators, such as those used in physiotherapy, is rectangular. However, defibrillators produce more complex waveforms. The reason for this is partly physiological, but it is also related to the way in which the impulses are generated. It is actually quite difficult to generate a very high current rectangular pulse, whereas it is relatively easy to charge up a capacitor to a high voltage and then discharge it through the patient. However, the current waveform then produced has a high peak and a long exponential tail. There is evidence that the long exponential tail can refibrillate the heart and so reverse the defibrillation. For this reason a damped exponential current waveform is used.

Defibrillators before about 1960 were ac models. These machines applied 5 to 6 A of 60 Hz ac across the patient’s chest for 250 to 1000 ms. The success rate for ac defibrillators was rather low, however, and the technique was useless for correcting atrial fibrillation. In fact, attempting to correct atrial fibrillation using ac often results in producing ventricular fibrillation, a much more serious arrhythmia.

Since 1960, several different dc defibrillators have been devised. These machines store dc charge that can be delivered to the patients. The principle difference between dc defibrillators is in the wave shapes of the charge delivered to the patient. The most common forms are **Lown**, **monopulse**, **tapered (dc) delay** and **trapezoidal waveforms.**

In 1962, Dr. Bernard Lown of Harvard University introduced the waveform that bears his name. The Lown waveform, shown in Figure 3.1, shows the voltage and current applied to the patient’s chest plotted against time. The current will rise very rapidly to about 20 A under the influence of slightly less than 3 KV. The waveform then decays back to zero within 5 ms, and then produces a smaller negative pulse, also of about 5 ms.

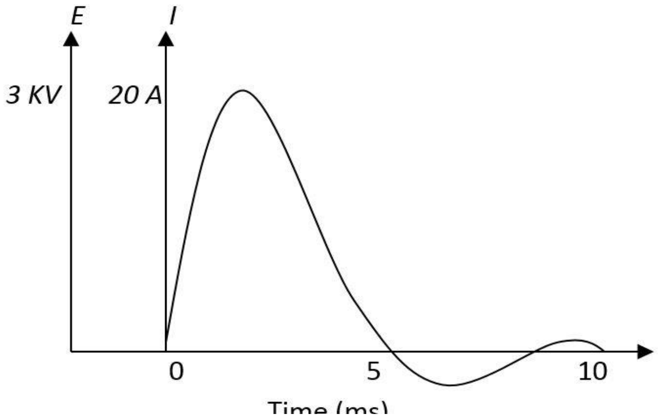


Figure 3.1: **Output Lown waveform from a DC defibrillator**

3.2 Basic circuitry of a DC defibrillator:

A pulse output with a long tail is undesirable because this can cause refibrillation. In order to remove the long tail of the capacitor discharge an inductor *L* is usually added in series with the defibrillator output as shown in figure.

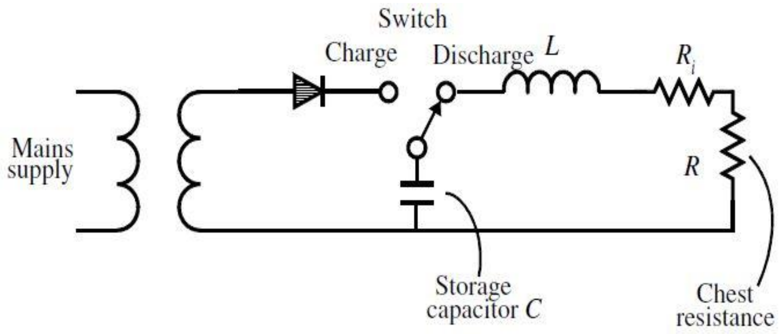


Figure 3.2: **Basic circuit diagram of a DC defibrillator**

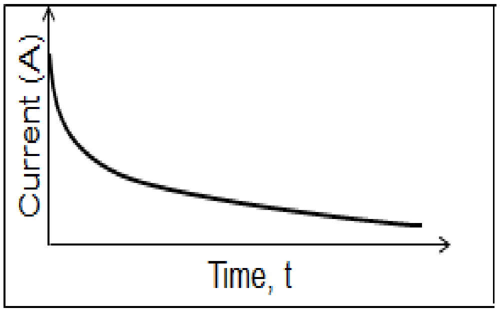


Fig.: **Capacitor current vs. time curve**

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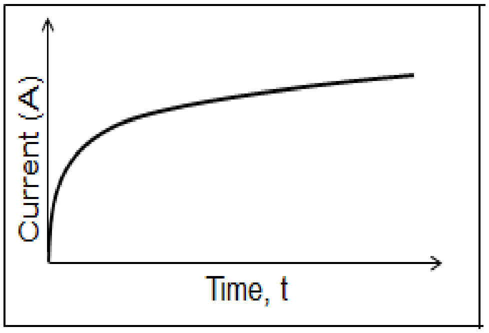


Fig.: **Inductor current vs. time curve**

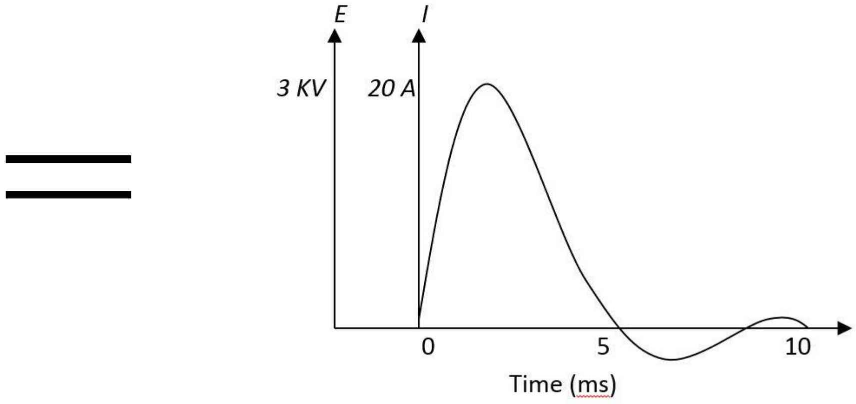


Figure 3.3: **Output waveform from of a DC defibrillator**

We can calculate the shape of the output current as follows. Applying Kirchhoff's law we

Obtain:-

$$L\frac{d^2i}{dt^2} + (R_i + R)\frac{di}{dt} + \frac{i}{C} = 0$$

Where,

i is the current

L the inductance

C the storage capacitor

R the resistance presented by the patient &

R_i is the internal resistance of the defibrillator circuit.

The solution of this differential equation has three forms; the first is oscillatory, the second an aperiodic discharge and the third, the fastest aperiodic discharge when the circuit is critically damped. The solution in this case is given by:-

$$i = \frac{CV(R + R_i)^2}{4L^2} te^{-((R+R_i)/2L)t}$$

$$\& \qquad L = (R + R_i)^2 \frac{C}{4}$$

As *R, R_i* & *C* should be known, the value of *L* can be calculated from the equation above.

3.3 Stored and delivered energy:

The operator can set the charge level using the *set energy* knob on the front panel. The knob controls the dc voltage produced by the high-voltage power supply and so can set the maximum charge on the capacitor. The energy stored in the capacitor is given by:

$$U = \frac{1}{2}CV^2$$

Where,

U is the energy in joules (J)

C is the capacitance of C_1 in farads (F)

V is the voltage across C_1 (V)

The stored energy is indicated by a voltmeter connected across the capacitor. The scale of voltmeters is calibrated in energy units. The energy regulations require that the delivered energy be indicated. Some energy is lost in the relay switching contacts and in the ohmic resistance of inductor L.

Not all the energy stored in the capacitor will be delivered into the chest of the patient because of losses within the output circuit of the defibrillator. The main source of loss is the resistance of the inductor and this is represented as R_i in Now the stored energy in the capacitor charged to voltage V is $\frac{1}{2}CV^2$, but is easy to show that the delivered energy to the patient will be $\frac{1}{2}CV^2 \times R/(R + R_i)$.

Typically the delivered energy will be about 10% less than the stored energy so that a defibrillator of 400J maximum stored energy might actually deliver a maximum of 360 J.
When the capacitor has discharged, the coil's field collapses, dumping energy back into the circuit. The sequence of events is describes as follows:

1. The operator turns the **set energy** control to the desired level and presses the **charge** button.

2. Capacitor C begins charging and will continue to charge until the voltage across the capacitor is equal to the selected supply voltage.

3. The operator positions paddle electrodes on the patient's chest and presses the **discharge** button.

4. A relay disconnects the capacitor from the power supply and then connects it to the output circuit.

5. Capacitor C discharges its energy into the patient through L, R_i, and the paddle electrodes. This action occurs in the first 4 to 6ms and gives rise to the high-voltage positive excursion of the defibrillation waveform.

6. The magnetic field built up around L collapses during the last 5ms of the waveform, producing the negative excursion of the defibrillation waveform.

3.4 An Example:

Let, we have a patient in hand who is having Ventricular Fibrillation. To stop fibrillation we need to store **300 J** Energy in the Capacitor to be discharged & want to deliver **90%** Energy in Heart in **8ms**. The chest resistance of the patient, $\mathbf{R_{chest}}$(typically**)= 50 Ω**

To deliver this amount of energy we have to select the voltage according to energy. Again, to design the device we have to find out the value of the Capacitance, **C** & Inductance**, L.**

We know,

$V_{Chest}(t) = V_C(0)e^{-t/RC}$; $t \geq 0$

where,

V_C= Capacitor voltage after charging

&V_{Chest} = Voltage applied across the chest of the patient

Energy stored in capacitor,

$$E = ½\ CV_C^2(0) \qquad \text{… … … (3.1)}$$

Energy delivered to chest,

$$E_{chest} = (V^2_{\ chest}/R_{chest}) * t$$

$$\text{So, } E_{chest} = V_C^2 e^{-2t/RC}\ t \ /\ R_{chest} \qquad \text{… … … (3.2)}$$

Equating (1) and (2), we get,

$$0.9 * ½\ CV_C^2 = V_C^2 e^{-2t/RC}\ t \ /\ R_{chest}$$

$$\text{or, } 0.9 * C = 2 * e^{-2t/RC}\ t \ /\ R_{chest}$$

From this expression we find the value of the Capacitance:

C = 54.3 µF

Now, Capacitor voltage:

$V_C(0) = \sqrt{(2E/C)}$

Or, $V_C(0) = 3.332$ KV

Inductance of sharp rise reducing inductor:
From the equation below we can find out the value of L.

$$L = (R + R_i)^2 \frac{C}{4}$$

If we assume the circuit resistance R_i to be 5 Ohms then the value of *L* will be 41mH.

3.5 Options for HV Generation:

It can be said that the high voltage generation circuit is the heart of the defibrillator circuit. Though high voltage can be generated in different ways and several circuits were tried by us, most efficient & cost effective option were the main criteria to select the high voltage generation circuit.

We worked with the circuits below to generate the high voltage:

3.5.1 Amplifier circuit:

This was the first circuit we started with. Our aim was to start from the simpler one and then proceed to the next option. For amplifier circuitry a high frequency signal was given to the input and then the signal was amplified to a higher voltage. As the frequency remains high from the amplifier output a high frequency transformer was used to step up the voltage to a higher stage. The main reason behind choosing this circuitry was the high frequency transformer which becomes smaller in size.

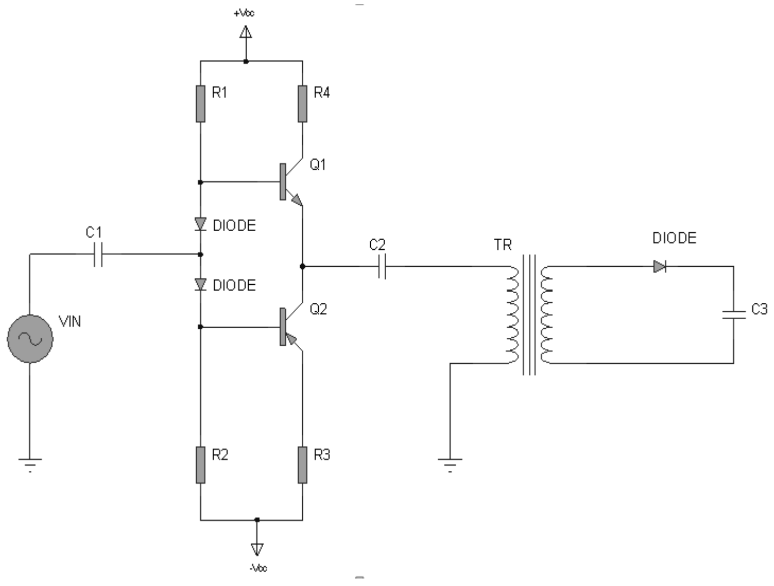


Figure 3.4: **Basic Amplifier Circuit to generate high voltage**

Cascade circuitry was also taken into account. It is a two-stage amplifier composed of a transconductance amplifier followed by a current buffer. Compared to a single amplifier stage, this combination may have one or more of the following characteristics: higher input-output isolation, higher input impedance, high output impedance, high gain or higher bandwidth. The Cascade improves input-output isolation as there is no direct coupling from the output to input.

Another amplifier circuitry was made using high power audio amplifier IC. Though several amplifier ICs were taken into account,finally the complete circuitry was made with **TDA 7295**. It is an **80V - 80W DMOS AUDIO AMPLIFIER.** It has a feature of mute and stand-by which were used for the switching of the amplifier as well as the HV generating circuit.

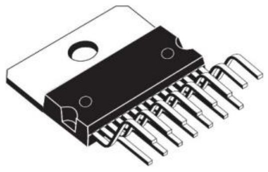


Figure 3.5: **TDA 7295**

The main disadvantage of the amplifier circuit was the heat generated from the amplifier because of less efficiency. The high frequency transformer core for the desired voltage was not easily available also and for this reason it was costly if available.

3.5.2 Cockcroft Walton Multiplier:

It is a voltage multiplier that converts AC or Pulsing DC electrical power from a low voltage level to a higher DC voltage level. It is made up of a voltage multiplier ladder network of capacitors and diodes to generate high voltages.

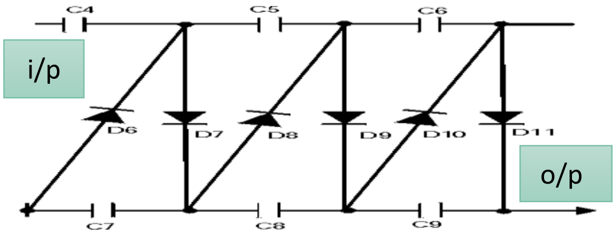


Figure 3.6: **Cockcroft Walton Multiplier**

Unlike transformers, this method eliminates the requirement for the heavy core and the bulk of insulation/potting required. Using only capacitors and diodes, these voltage multipliers can step up relatively low voltages to extremely high values, while at the same time being far lighter and cheaper than transformers. The voltage across each stage of the cascade is equal to only twice the peak input voltage in a half wave rectifier. It has the advantage of requiring relatively low cost components and being easy to insulate.

The problem with this circuit is that it has very poor voltage regulation, that is, the voltage drops rapidly as a function the output current. The output V/I characteristic is roughly hyperbolic, so it serves well for charging capacitor banks to high voltages at roughly constant charging power. This circuit has another disadvantage that the ripple on the output, particularly at high loads, is quite high.

3.5.3 Series-Parallel Capacitors:

Same voltage and capacitance value capacitors are used in this circuit. Capacitors are charged in parallel and are discharged in series. There are some switching mechanisms like photo diodes, SCRs etc. to connect the capacitors in series or parallel.

The disadvantage of it is, if any one or two of the Capacitors are damaged, the whole circuit will not work. All the capacitors may not be same capacitance as they are rated.

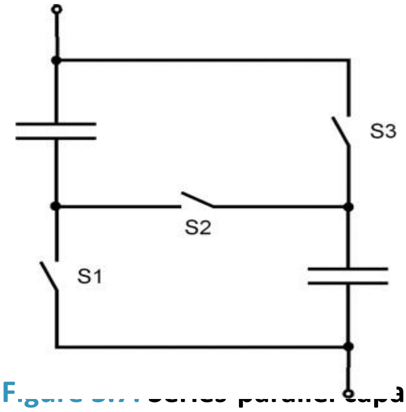


Figure 3.7: Series-parallel capacitors

3.5.4 Flyback Transformer:

Fly back transformers are relatively used to Generate high voltage in high frequency. The design cost is comparably lower than other high voltage transformers. These types of transformers are very reliable and efficient to generate high voltage. It is used extensively in switched mode power supplies for both low (3V) and high voltage (over 10 kV) supplies.

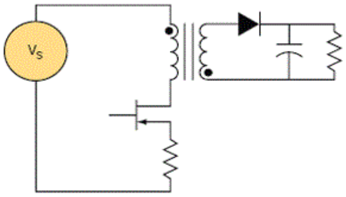


Figure 3.8: Flyback Transformer

The fly back transformer is used in the operation of CRT display devices such as television sets and CRTcomputer monitors. Fly back transformer typicallyoperates with switched currents at much higher frequencies in the range of 15 kHz to 50 kHz.

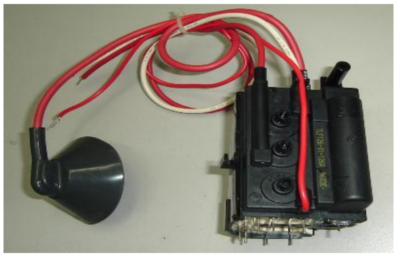


Figure 3.9: A typical TV flyback transformer

Though we designed a flyback transformer, we found that if the FBTs available at the market for CRT display is used for the high voltage generation then the cost reduces to 80% for the flyback transformer. We selected two flyback transformers from the market. One was FBT-BSC-25-4813 which is used for color television & another one was FBT- SALSON 1245AL which is used for black & white television

3.6 Fly back Transformer Design:

3.6.1 Calculation of number of joules required to charge the capacitor:

$$\mathrm{J} = \frac{\mathrm{CV}^2}{2}$$

$$\mathrm{J} = \frac{54 * 10^{-6} * 4000^2}{2}$$

$\mathrm{J} = 432$ Joules(Let’s consider 400J)

3.6.2 Calculation of number of charging pulses in the stated time:

Number of pulses (N) = 10 seconds * 1000 pulses per second

= 10,000 pulses

3.6.3 Calculation of energy required per charging pulse:

Energy per pulse (J) $= \frac{\mathrm{Joules}}{\mathrm{N}}$

$= \frac{400}{10{,}000}$

= 0.04J/pulse

$$\text{Joules from DC sourse}, \mathrm{J} = \frac{\text{Joules per pulse}}{\text{Efficiency}}$$

$$= \frac{.04\mathrm{J}}{.8}$$

$$= .05\mathrm{J/pulse}$$

3.6.4 Calculation of current:

$$\mathrm{L} = \frac{\mathrm{E}\,\partial \mathrm{t}}{\mathrm{Ip}}$$ I_p= peak current

or, $\mathrm{L} = \frac{24*900\mu}{\mathrm{Ip}}$ … … … (3.3)

Again,

$$\mathrm{J} = \frac{\mathrm{LIp}^2}{2}$$

So,

$$\mathrm{L} = \frac{2\mathrm{J}}{\mathrm{Ip}^2},$$

or, $\mathrm{L} = \frac{2*.05}{\mathrm{Ip}^2}$ … … … (3.4)

From (3.3) & (3.4) we get,

$$\frac{24 * 900\mu}{\mathrm{I\text{-}p}} = \frac{2 * .05}{\mathrm{Ip}^2}$$

$$\frac{\mathrm{Ip}^2}{\mathrm{Ip}} = \frac{2 * .05}{24 * 900\mu}$$

$$\mathrm{Ip} = \frac{2 * .05}{24 * 900\mu}$$

$$\mathrm{Ip} = 4.63\mathrm{Amp}$$

$$\mathrm{L} = \frac{\mathrm{Np}^2\mu \mathrm{A}}{\mathrm{l}}\text{Henry}$$

From this equation, we can find the number of turns in primary, N_p
Besides,

$$N_s = n*N_p$$

3.6.5 Calculation of inductance, L:

$$\mathrm{L} = \frac{2 * .05}{4.63^2}$$

$$= 4.665\mathrm{mH}$$

3.7 Block Diagram of the planned circuitry:

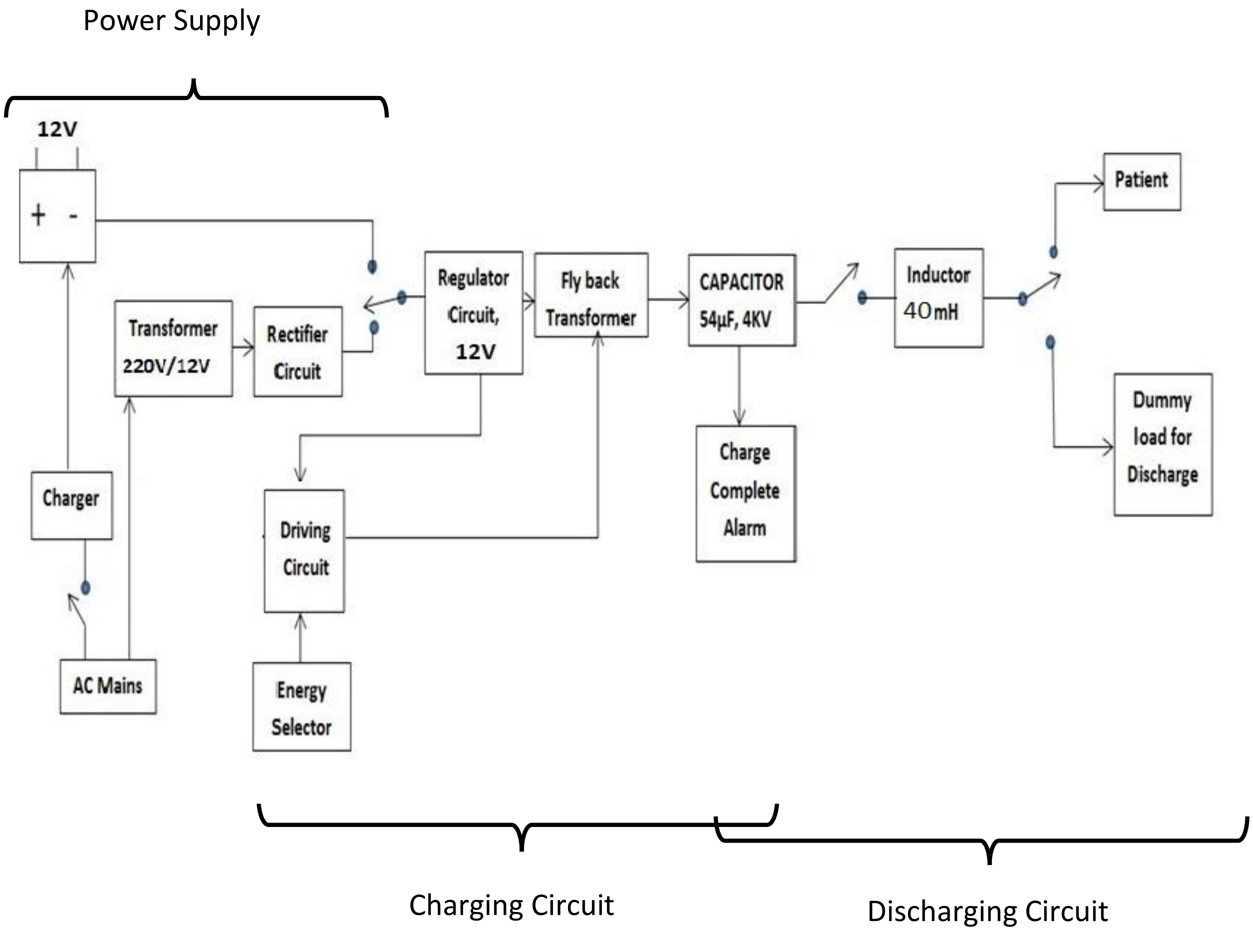


Figure 3.10: **Block Diagram of the planned circuitry**

Options for power supply from both the mains and battery is kept. In case of main line power failure or load-shedding the defibrillator might be used by the battery power supply. A driver circuit also powered by 12V drives the flyback transformer. Then the capacitor is charged. When the capacitor charge completes the charge complete alarm sounds. Pressing a button the operator can disconnect the capacitor from the charging circuit & connect it to the discharging circuit. Lately, if the button fitted on the defibrillator paddle is pressed then it discharges through patient’s chest. If the energy is not needed to be discharged through the patient then another switch can discharge it through a dummy load or the defibrillator testing circuit.

This planned circuit was tested in the lab on a dummy load, but the capacitor value was 10 μF, 2000 V & the inductor was designed as 20 mH and wound by hand on a silicon core.

3.7.1 Power supply:

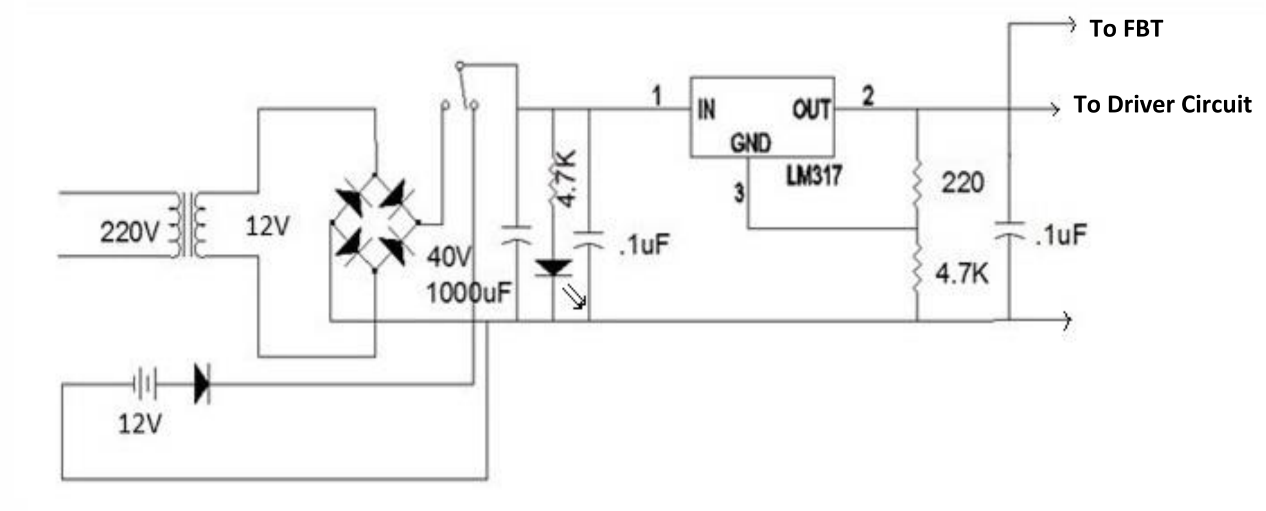


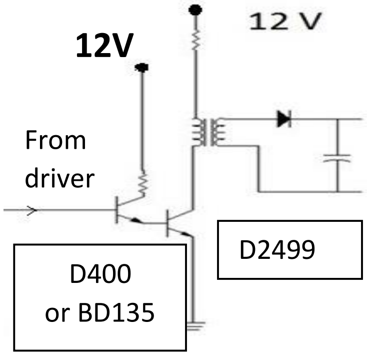
Figure 3.11: **Power supply unit of the defibrillator**

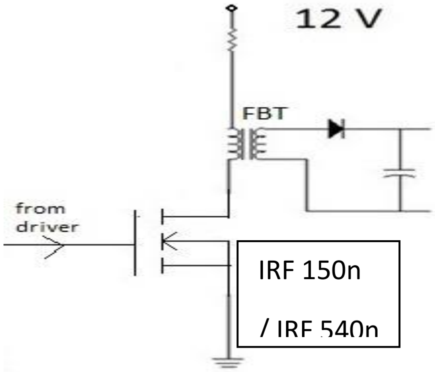
From AC mains, a 220/12V transformer steps down the voltage which is rectified by a bridge rectifier. A three way switch is used for the selection of the power source between mains and battery. LM317 is used for the regulation of constant 12V. An LED indicates the power availability. This 12V goes to the FBT & to the driver circuit for the FBT.

3.7.2 Charging circuit:

Firstly the switching of the flyback transformer was done with BJT. BJT D400 was used for the amplification of current to drive the BJT D2499. D2499 did the switching of the FBT. Also BD135 was used in exchange of D400 as it was easier to use heat sink with BD135. This circuit was problematic to bias properly. Also charge storage effect of the BJTs was causing the distortion of the waveform as the switching was not working perfectly. For this reason MOSFET was chosen for switching.

As the driver circuit supplies a small amount of current & MOSFET is voltage driven,there is no need to amplify the current &it is perfect for switching. IRF540n& IRF150n was used for the switching of the flyback transformer.





3.7.3 Discharge Circuit:

After charging the capacitor, it might be discharged in two ways. One is through the inductor to the patient body; another is through the defibrillator simulation circuit or a dummy load if it is not needed to discharge through patient. A switching mechanism is used to control this discharge path. The inductor is 40mH and the dummy load is 50ohms. The chest resistance of patient is typically 50 ohms.

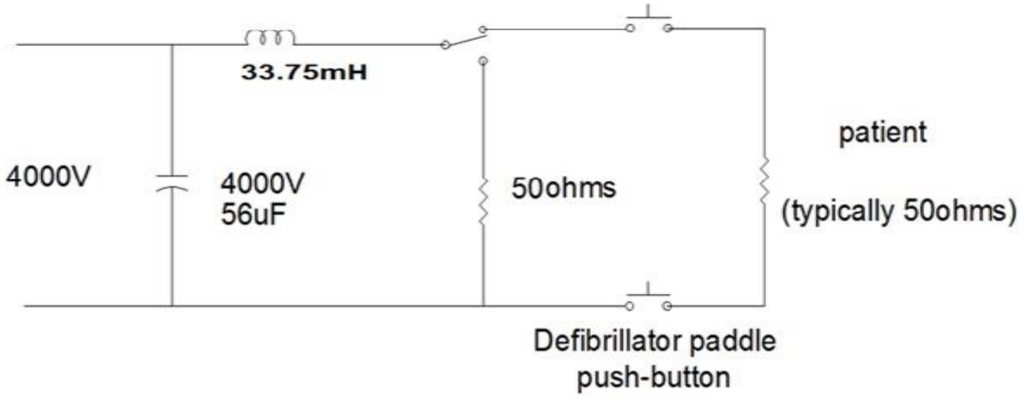


Figure 3.12: Discharge circuit

3.7.4 Driver Circuit:

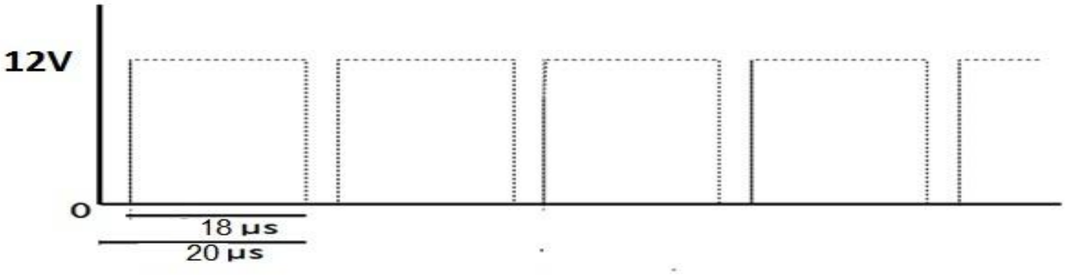


Figure 3.13: Pulse from Driver Circuit

Several driver circuits were made using op-amps and 555 timer&a potentiometer was used as regulator for changing the duty cycle. To vary the energy by varying the defibrillator energy regulator in an increasing or decreasing sequence, the output voltage of the FBT should also increase or decrease in a sequential way. Changing the driver PWM and keeping the frequency constant it can be done. Butwhile changing the duty cycle of the astable multivibrators made by op-amps & 555 timers, the output voltage of the FBT was also changing because of frequency variation. But the problem with these circuits was that during changing the duty cycle the frequency could not be kept constant. For this reason the output voltage at the FBT was not increasing or decreasing in a sequence.

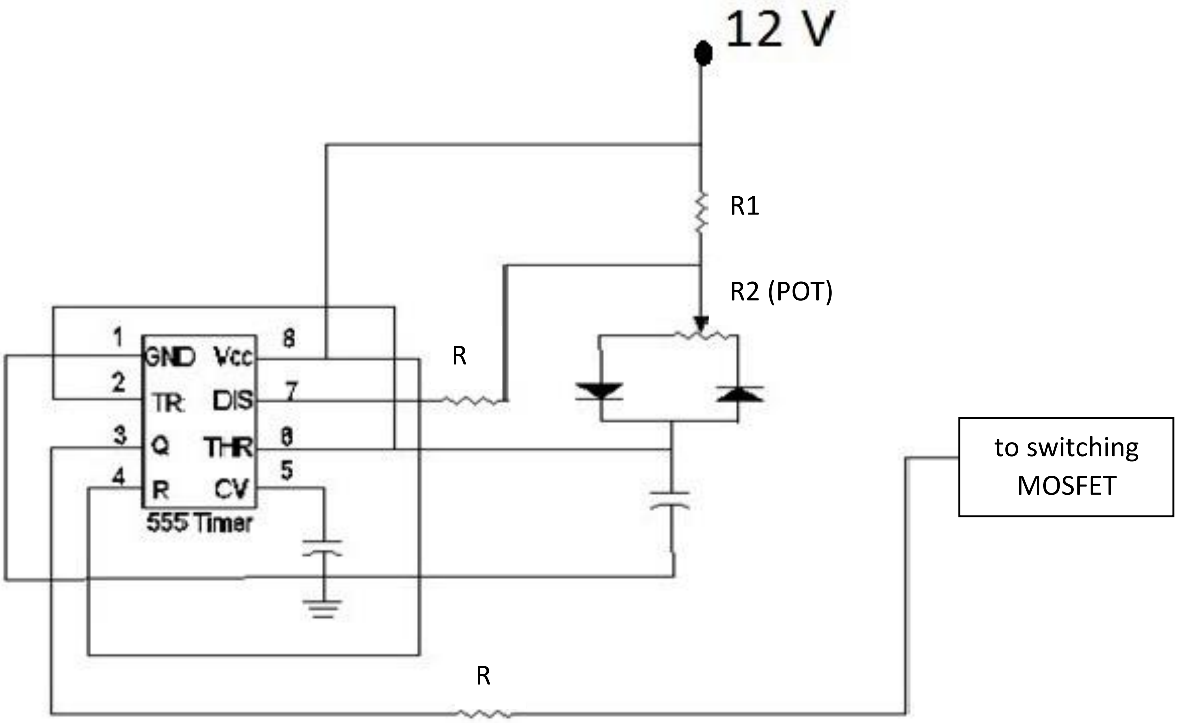


Figure 3.14: **An astable multivibrator using 555 timer which ideally should not change frequency during PWM.**

Using different formations of the diodes, resistances and capacitances the 555 timer ideally should generate PWM with constant frequency. But practically the scenario was different. Cascaded 555 timers also did not work perfectly in this purpose.

For perfect duty cycle and high frequency (50 KHz) micro-controllers are very useful. Some micro controller units have built in PWM options. PIC 16F887 have built in PWM and ADC options. So later on it was used for PWM.

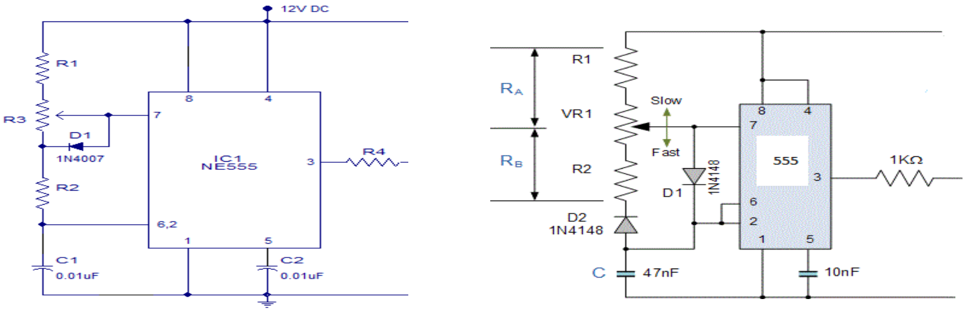


Figure3.15: **Other 555 circuits for constant frequency PWM**

PWM & Charge complete signaling using PIC 16F887

4.1 PIC 16F887:

Port RC1 (PIN: 16) was used for PWM output. This pin is connected to the switching device (i.e.: MOSFET) as the reference for switching the FBT.

Port RA0 (PIN: 2)has been used to get analog signal from the op-amp, which measures the differential voltage across a resistance and detects whether the charge is complete or not.

Port RA1 (PIN: 3) has been used for buzzer and Port RA2 (PIN: 4) has been used for LED.

ADC continuously measures the voltage at Pin: 2 and when the charge is completed, PICsends signal to switch the LED and Buzzer ON.

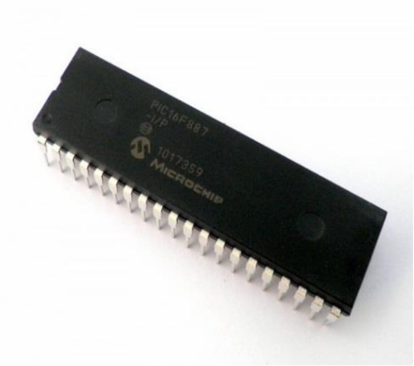


Figure 4.1: PIC16F887 Unit

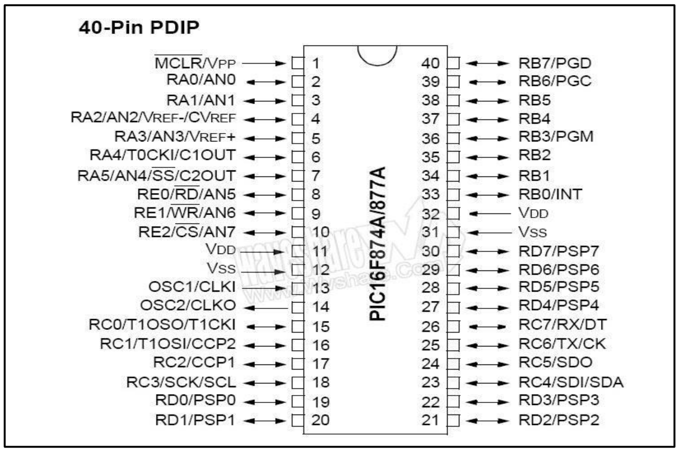


Figure 4.2: Pin configuration of PIC 16F887

A high power ceramic resistor of 0.2 Ω has been connected to energy storage capacitor. Across this resistor the input was taken to the op-amp and the differential output has been given to the microcontroller.

To get a gain of 4, R1 & R2 were taken as 10 KΩ and R_f and R_g were taken as 40 KΩ.

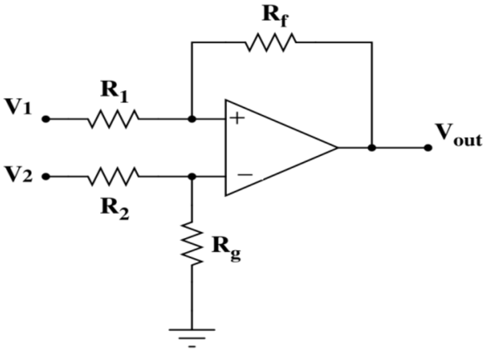


Figure 4.3: Differential amplifier

4.2 Program for PIC 16F887:

```
// pulse width modulation using keypad, LCD, pic16f887
//using keypad input duty cycle: 10%, 20%, 50% or any input and get 50khz PWM
unsigned short kp,a1,b,i,g,kl,again,pa,here;
float VREF = 5.00;
char txt[6];
void ADC_Init();
void ADC_Get_Sample();
sbit buzzer at PORTA.A1;                //initialize Pin 3 for buzzer input
sbit led at PORTA.A2;                      //initialize Pin 4 for LED input
                                 // keypad module connections
char  keypadPort at PORTD;
                                 // end keypad module connections

                                 // LCD module connections
sbit LCD_RS at RB4_bit;
sbit LCD_EN at RB5_bit;
sbit LCD_D4 at RB0_bit;
sbit LCD_D5 at RB1_bit;
sbit LCD_D6 at RB2_bit;
sbit LCD_D7 at RB3_bit;

sbit LCD_RS_Direction at TRISB4_bit;
sbit LCD_EN_Direction at TRISB5_bit;
sbit LCD_D4_Direction at TRISB0_bit;
sbit LCD_D5_Direction at TRISB1_bit;
sbit LCD_D6_Direction at TRISB2_bit;
sbit LCD_D7_Direction at TRISB3_bit;

// end lcd module connections
void pulsewidth()
{
   Lcd_Chr(1, 15, kp);
   b=(b*255)/100;
    g=floor(b);
    PWM1_Init(50000);           // initialize pwm1 module at 50khz
   PWM2_Init(50000);            // initialize pwm2 module at 50khz
    while (1)
{                                // endless loop
    Delay_ms(40);
    PWM1_Start();               // start pwm1
    PWM2_Start();               // start pwm2
     PWM1_Set_Duty(g);          // set current duty for pwm1
```

```
    PWM2_Set_Duty(g);                  // set current duty for pwm2
    }
go to again;
}

    void keycall()
    kp = 0;                            // reset key code variable

    // wait for key to be pressed and released
    do
      // kp = Keypad_Key_Press();      // store key code in kp variable
      kp = Keypad_Key_Click();         // store key code in kp variable
    while (!kp);
                           // prepare value for output, transform key
                           to it's ASCII value
    switch (kp) {

      case  1: kp = 49; break;              // 1  // uncomment this
block for keypad4x4
      case  2: kp = 50; break;              // 2
      case  3: kp = 51; break;              // 3
      case  4: kp = 65; break;              // A
      case  5: kp = 52; break;              // 4
      case  6: kp = 53; break;              // 5
      case  7: kp = 54; break;              // 6
      case  8: kp = 66; break;              // B
      case  9: kp = 55; break;              // 7
      case 10: kp = 56; break;              // 8
      case 11: kp = 57; break;              // 9
      case 12: kp = 67; break;              // C
      case 13: kp = 42; break;              // *
      case 14: kp = 48; break;              // 0
      case 15: kp = 37; break;              // %
      case 16: kp = 68; break;              // D

    }
       if(kp==48)  {
       a1=0;
       i++;
    }
        if(kp==49)  {
       a1=1;
       i++;
    }
     if(kp==50)  {
     a1=2;
     i++;
    }
```

```
   if(kp==51)  {
   a1=3;
   i++;
   }
   if(kp==52)  {
   a1=4;
   i++;
   }
   if(kp==53)  {
   a1=5;
   i++;
   }
   if(kp==54)  {
   a1=6;
   i++;
   }
   if(kp==55)  {
   a1=7;
   i++;
   }
   if(kp==56)  {
   a1=8;
   i++;
   }
   if(kp==57)  {
   a1=9;
   i++;
   }
     if(Kp==37) {
     pulsewidth();
     }
     if(Kp==67) {
     kl=1;
     i++;
     }
     if(Kp==65) {
     pa=1;
     Lcd_Chr(1, 16, kp);
     }
     }

  void keypadfunction(){
  again:
   Keypad_Init();            // Initialize Keypad
   pa=0;
kl=0  ;

 i=0;
```

```
  if(i==0) {
  keycall();
  if(Kl==1) {
  goto again;

      }

  }

  if(i==1){
  Lcd_Chr(1, 12, kp);
  b=a1;                    // print key ASCII value on LCD
  keycall();
  if(Kl==1) {
  goto again;

      }

  }

  if(i==2){
  Lcd_Chr(1, 13, kp);
  b=b*10;                   // print key ASCII value on LCD
  b=b+a1;
  keycall();
  if(Kl==1) {
      goto again;
      }
  }

  if(i==3){
  Lcd_Chr(1, 14, kp);                 // print key ASCII value on
LCD
  b=b*10;
  b=b+a1;
  keycall();
  if(Kl==1) {
      goto again;
      }
  }
  do{
  keycall();
  if(pa==1){

  goto again;


// Buzzer ON
```

```
//LED ON
do
{
delay();
ADC_Init();
delay();
ADC_Get_Sample(1);
delay();

adc = ADC_read(0)
value=  adc * VREF / 1023;

if(value<.2)  //compare if less than .2 volt
PWM1_Stop(); // stop pwm1
PWM2_Stop(); // stop pwm2

led=1;  // Led ON
buzzer=1; // Buzzer ON

else
led=0;  // Led OFF
buzzer=0;  // Buzzer OFF

}
while(1);
}
void delay()
{
int i,j;
for(i=0;i<255;i++)
{
 for(j=0;j<255;j++);
 }
}
  goto again;
  }
  }
while(1);
  }


void main() {
ANSEL  = 0;                            // configure an pins as
digital i/o
  ANSELH = 0;
  TRISB=TRISC=0;                       // initialize LCD
  Lcd_Init();
  Lcd_Cmd(_LCD_CLEAR);                   // clear display
```

```
  Lcd_Cmd(_LCD_CURSOR_OFF);                    // cursor off
  Lcd_Out(1, 1, "Duty cycle:");                // write message text on
LCD

keypadfunction();
}
```

4.3 Connection Diagram for PIC 16F887:

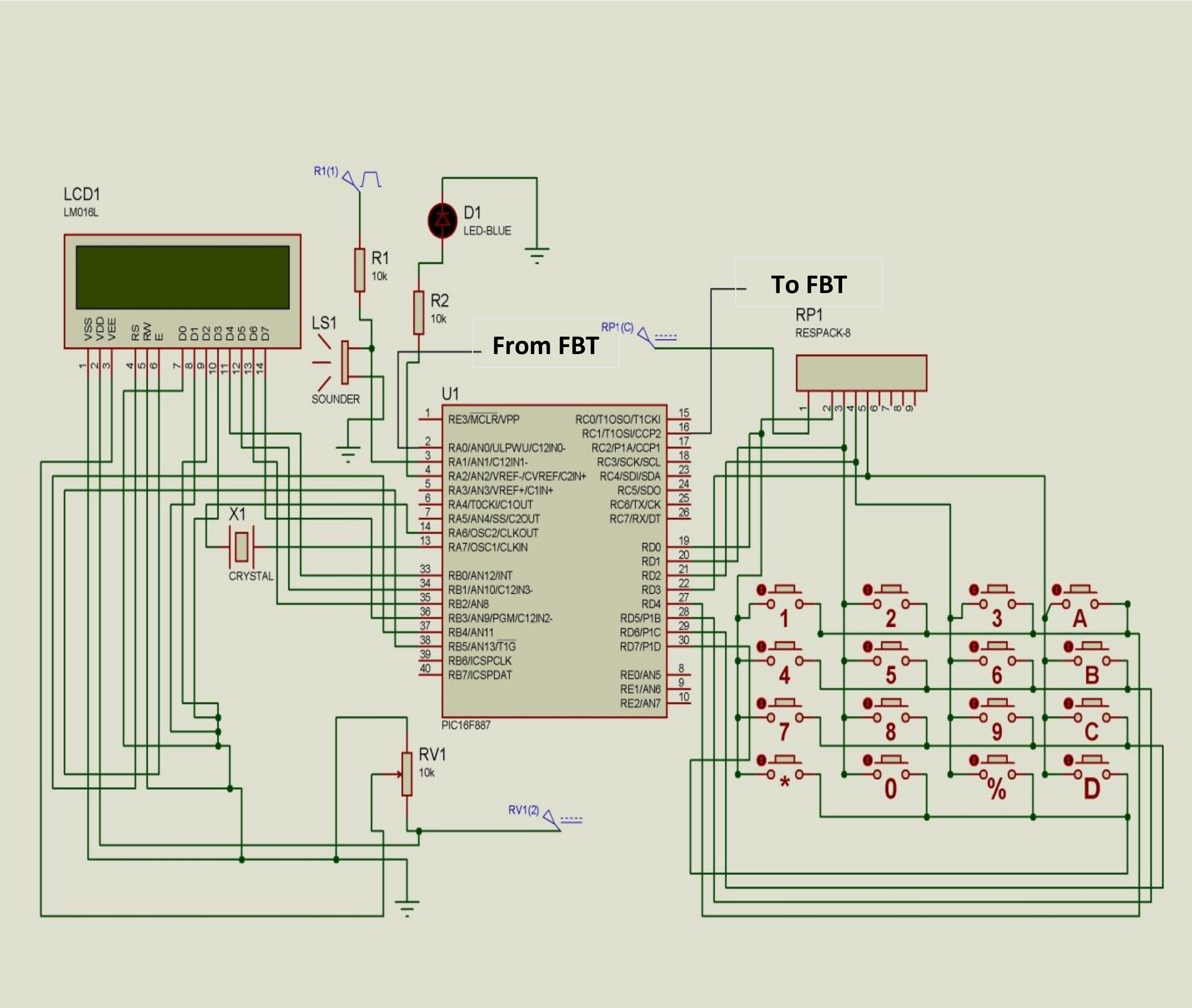


Figure 4.4: Circuit Diagram of PWM using PIC 16F887

Chapter 5

Experimental Results from Lab

5.1 Measurement of High Output Voltage of FBT:

The high output voltage was measured with the help of a resistance chain of 27MΩ. At the end of this resistance chain, across a 10K resistance the voltage was measured by an Oscilloscope. So the multiplier was 2700 to get the actual voltage from the measured Oscilloscope voltage.

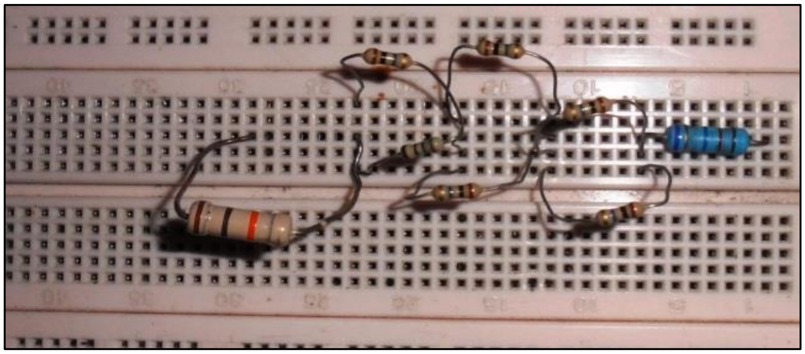


Figure 5.1: Resistance chain of 27 MΩ

5.2: Output voltage for different input voltage between different pins of the flyback transformers:

B&W TV FBT (SALSON 1245AL) (5V Input):

Input Pin Number	Vout (V)
Between 1&2	1525
Between 1&4	1525
Between 1&3	1906.25
Between 5&6	1525
Between 1&2	1525

B&W TV FBT (SALSON 1245AL) (15V Input):

Input Pin Number	Vout (V)
Between 1&2	7625
Between 1&3	6710
Between 1&4	6100

Color TV FBT (BSC-25-4813) (5V Input):

Input Pin Number	Vout (V)
Between 1&2	3050
Between 1&3	762.5
Between 1&4	305
Between 1&5	1067.5
Between 1&6	1525
Between 2&6	2287.5
Between 2&5	1525
Between 2&4	457.5
Between 2&3	1143.75
Between 7&8	3431.25

The output directly from the flyback had ripples because of its inductive effect. But when the storage capacitor was added across it the ripple was reduced to almost zero.

5.3 Discharge pulse across dummy load:

As mentioned before a 10 µF capacitor was charged. Then the charged capacitor was discharged through a dummy load. Dummy loads of different values were used.

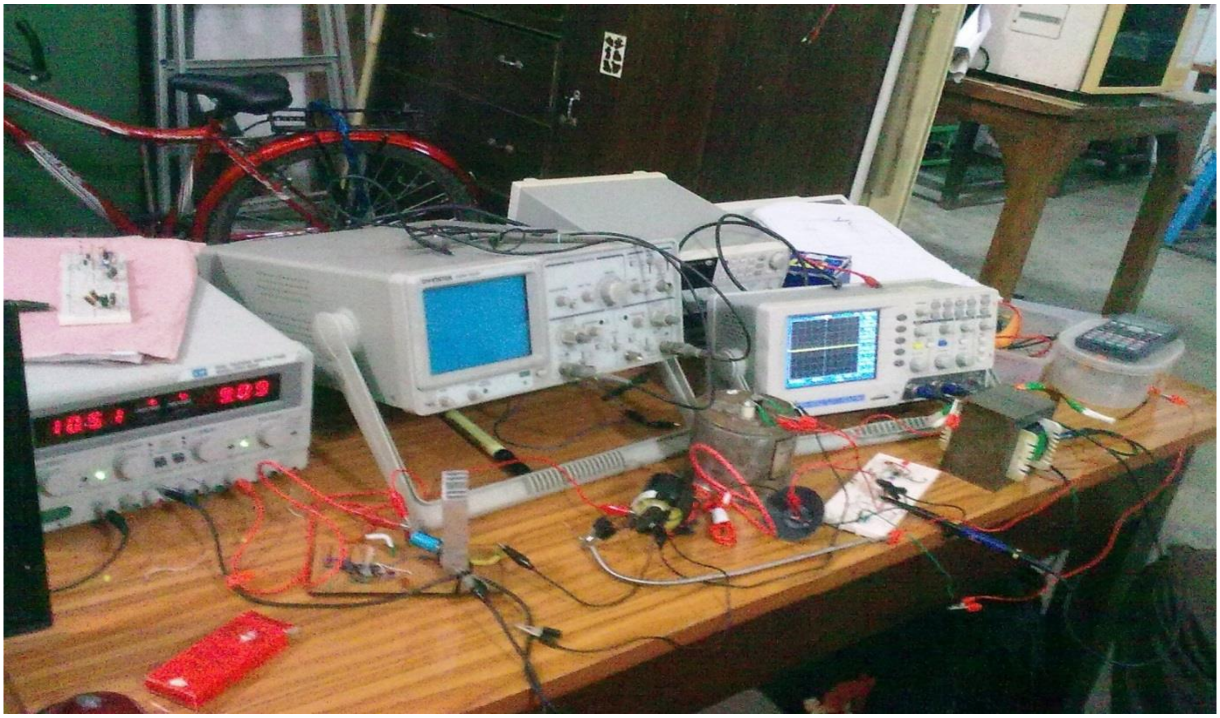


Figure 5.2: A picture from the last lab set up of the defibrillator circuit at Biomedical Physics & Technology Department of University of Dhaka

The discharge pulses were captured with the help of a Digital Storage Oscilloscope. Then different values regarding the waveforms were calculated from the captured pulse.

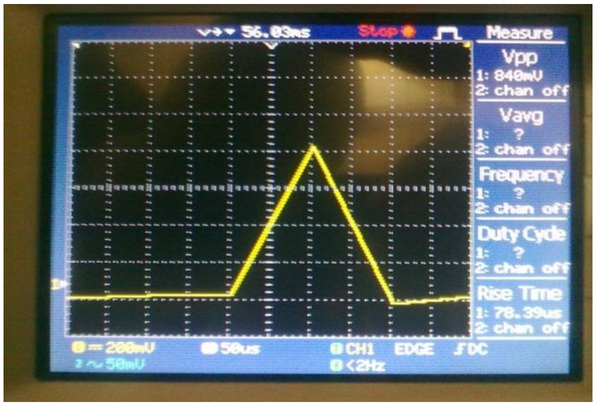


Figure 5.3: Discharge pulse through a 35 Ω load

Figure 5.4: Discharge pulse through a 100 Ω load

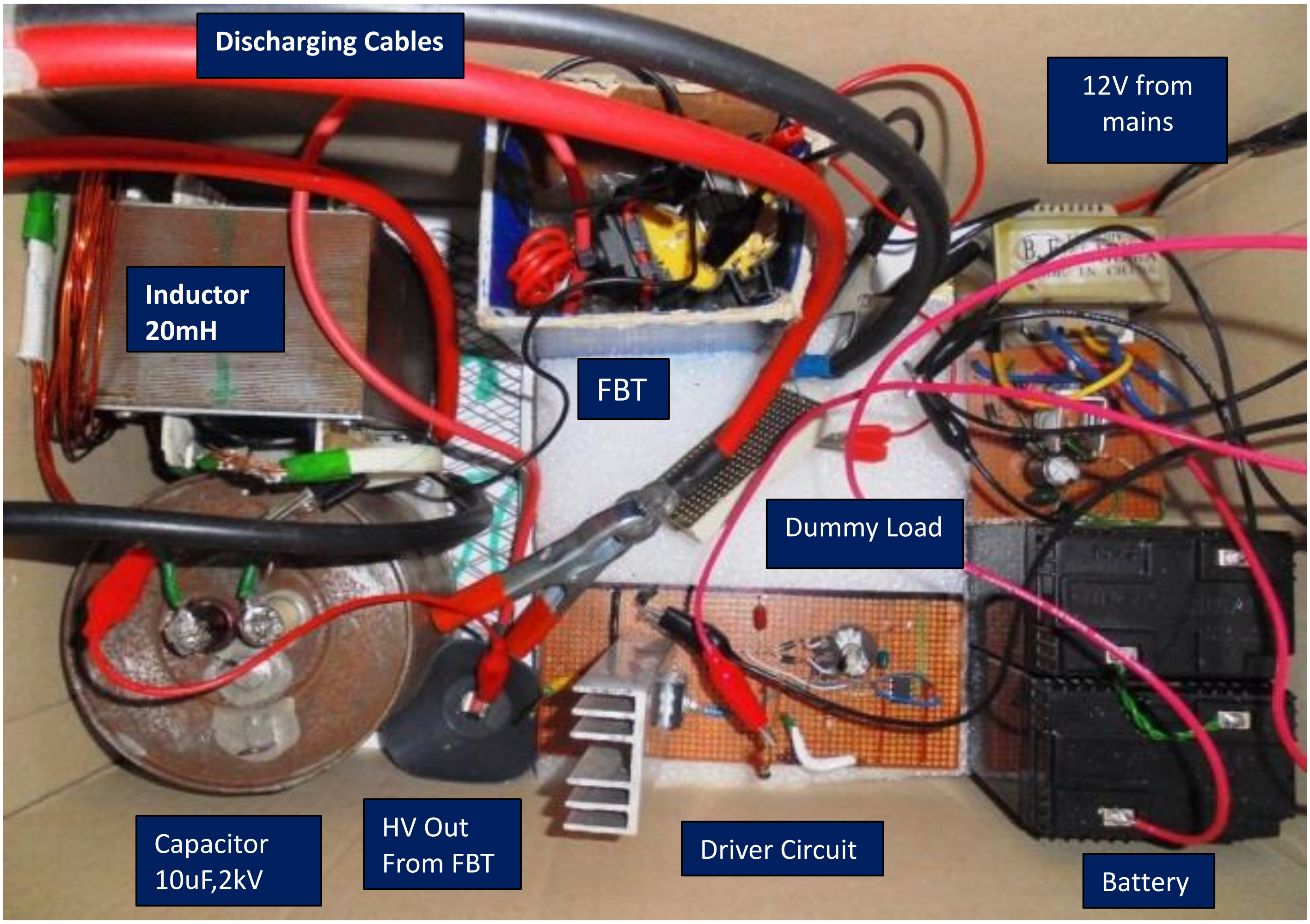


Figure 5.5: **A picture of the inside circuitry of the defibrillator**

Chapter 6

Defibrillator Electrodes

The energy from a defibrillator is delivered through a set of high-voltage paddle electrodes. The discharge cable and the operating push button switch mounted on the electrodes are made sure to be well insulated. Electrodes are metal made with 70-100 cm^2 surface area.They must be coupled to skin using conductive material (otherwise can burn patient) .

Electrodes might be of Two types:

Hand-held: Conductive gel must be manually applied, reusable.

Adhesive: Adhesive conducting material holds electrode to skin, disposable.

Figure 6.1: **Adhesive type**

6.1 Some hand held type electrodes:

The type shown in Figure 4.1 is called an *anterior* paddle. In this design the insulated handgrip is perpendicular to the metal electrode surface. The high-voltage cable enters from the side. A thumb-switch to control the discharge is mounted at the top of the grip. A defibrillator paddle and cable set using two of these electrodes is called an *anterior-anterior* set. To defibrillate, one electrode is placed on the chest directly over the heart, while the second electrode is placed on the left side of the patient's chest. A conductive paste is smeared on the electrodes to ensure an inefficient transfer of charge and reduce any burning of the patient's skin.

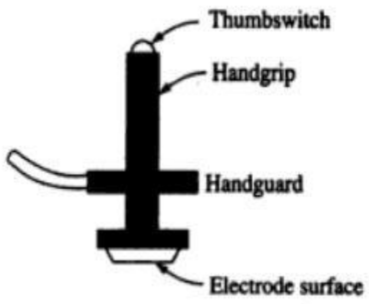
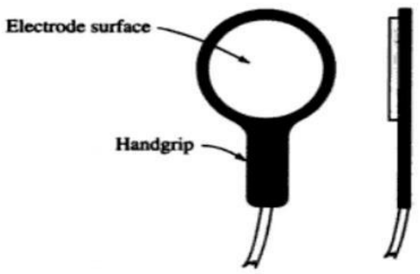


Figure 6.2: **Anterior paddle**

A *posterior* paddle is shown in Figure 4.2. This electrode is constructed flat and is designed so that the patient can lie on it. Posterior paddles are always paired with one anterior paddle to form an *anterior-posterior* pair.



A more modern anterior paddle is a *D-ring* type shown in Figure 4.3.This type of paddle is used on most current model defibrillators and has been popular on portable models for some time.

Figure 4.3: posterior paddle

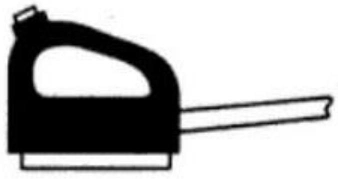


Figure 4.4:*D-ring* type anterior paddle

One final form of paddle set is the *internal* type shown in Figure 4.4. Internal paddle sets use two of these electrodes but one may not have the thumb-switch. These paddles are used during open-heart surgical procedures to apply the electrical shock directly to the myocardium.

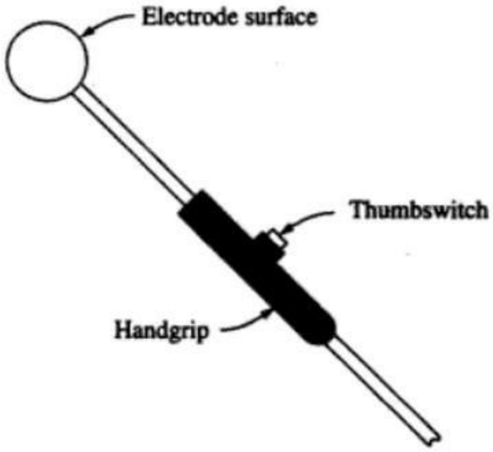


Figure 4.5: *internal* type paddle

Chapter 7

Cost Analysis

Components Name	**Quantity**	**Price (BDT)**
Electronics	IC's, resistors, capacitors, MOSFET's, regulators	350
Miscellaneous		450
High Voltage Capacitor	1 piece	5000
Inductor	1 piece	550
Fly Back Transformer	1 piece	250
220V/12V Transformer	1 piece	300
Battery(6V)	2 piece	900
PCB Cost (Estimated)	1 piece	650
Defibrillator Cables	2 piece	550
Defibrillator Electrodes (Estimated)	2 piece	1450
Defibrillator Casing (Estimated)	1 piece	1500
		Total: BDT 11,950

Chapter 8

Uses of Defibrillator,
Defibrillator Safety & Security

8.1 There are basically three uses for defibrillators:

1. The first is direct defibrillation of the heart during surgery. During cardiac surgery the heart may spontaneously fibrillate or the surgeon may intentionally produce fibrillation. The maximum output used to defibrillate directly is about 50 J.

2. The second major use of defibrillators is for cardioversion. This is a synchronized shock which is applied across the chest to correct for atrial fibrillation, atrial flutter or ventricular tachycardia. Energies from about 20–200 J are used for cardioversion.

3. The third use for defibrillators is emergency defibrillation in cases of ventricular fibrillation. Cardiopulmonary resuscitation is often used to keep the patient alive until the defibrillator is ready for use. Often a first pulse of 200 J will be followed by higher shocks if the first is not successful in restoring a normal sinus rhythm.

8.2 The patient and safety issues associated with defibrillators:

8.2.1 Patient Issues:

Successful defibrillation depends on delivery of the electrical charge to the myocardium. Only part of the total current delivered (about 35 A) flows through the heart. The rest is dissipated. First, the skin and the rest of the body counteract the flow of the current. The skin and thoracic wall act as resistors in series.

$R\ (eq) = R1 + R2 + R3$
Other intrathoracic structures act as resistors in parallel.
$R\ (eq) = (1/R1) + (1/R2) + (1/R3)$
The total impedance is about 50–150 ohms; however, repeated administration of shocks in quick succession reduces impedance.

8.2.2 Safety:

Key safety concerns exist regarding the use of defibrillators. These concerns must be taken into account before using a defibrillator on a patient with irregular cardiac rhythms:

1. The patient must not already be in sinus (normal) rhythm.
2. The leads of the defibrillator must be properly connected, ensuring current flow.
3. Placement of paddles should follow specific guidelines: they should be placed along the long axis of the heart, they should not cover the transdermal patches because they are flammable, they should not be placed near metal objects because currents will travel through the metal (path of least resistance) and cause burning.
4. All sources of oxygen must be removed from the patient during defibrillation, because it supports combustion.
5. No one from the medical staff should touch the bed, patient or any equipment connected to the patient during defibrillation.
6. Fluids may conduct electricity; therefore it is important to ensure that the immediate area is clean and dry.
7. The defibrillator should not be charged until the paddles are applied to the patient's chest, because accidental discharge from open paddles may cause injury.
8. Technical Earthing (TE) and Potential Earthing (PE) have to be ensured.

Chapter 9

Future Works

The final defibrillator circuit was made with 10μF, 2KV capacitor & 20mH inductor. But for making a useable one it has to be made with 54μF, 4KV capacitor & 40mH inductor. Recently we are working with this circuit. The electrodes have not been designed yet. It will be designed soon including the paddle switch with proper safety and insulation. After that the circuitry will be boxed in a proper way ensuring safety. The casing will be insulated and grounding will be done properly. The circuit will be tested by professionals and Bangladesh Institute for Biomedical Engineering & Appropriate Technology (BiBEAT) has ensured us to help in this work. This organization also wants to launch the product in the market without any profit if the circuit is proved to be an effective one after testing.

We also want to make an AED in future which would be able to detect abnormal ECG and defibrillate the heart if necessary. We have a dream to reach this technology to everyone of the world. Our motto is "Bio-medical Technology for all."

Appendix

A.

Cardioversion:

In certain types of arrhythmia (e. g., atrial fibrillation), the patient's ventricles maintain their ability to pump blood, as evidence by the existence of an R wave feature in the ECG waveform. These arrhythmias are also correctable by electrical shock to the heart, but it is necessary to avoid delivering the shock during the ventricles' refractory period (the T wave of the ECG waveform), or the shock intended to correct the problem will create much more serious arrhythmia such as ventricular fibrillation. The shock is usually timed to occur approximately 30 µs after the R wave peak.

Human operators cannot be trusted to time the ECG waveform properly to avoid this problem, so an automatic electronic circuit is used. A machine is equipped with the synchronizer circuit is called a *cardioverter.*

A switch on the machine allows the operator to select either *defibrillate* or *cardiovert* modes. In some machines, notably the Hewlett-Packard models, this control is labeled either *synchronized-instantaneous* or *sync-defib*.

B.

The **monopulse** waveform shown in Figure A2 is a modified **Lown** waveform and is commonly found in certain portable defibrillators. It is created by a circuit such as the one in Figure A1 but without inductor L_1 to create the negative second pulse. Consequently, the waveform decays to zero in the exponential manner expected of an *R-C* network.

Another form of dc defibrillator waveform is the **tapered delay** shown in Figure A3. This waveform differs from the two previous pulses in that it uses a lower amplitude and longer duration to achieve the energy level. The energy transferred is proportional to the area under the square of the curve, so we may attain the same energy as in other waveforms. The double-humped waveform characteristics of tapered delay machines are achieved by placing two *L-C* sections.

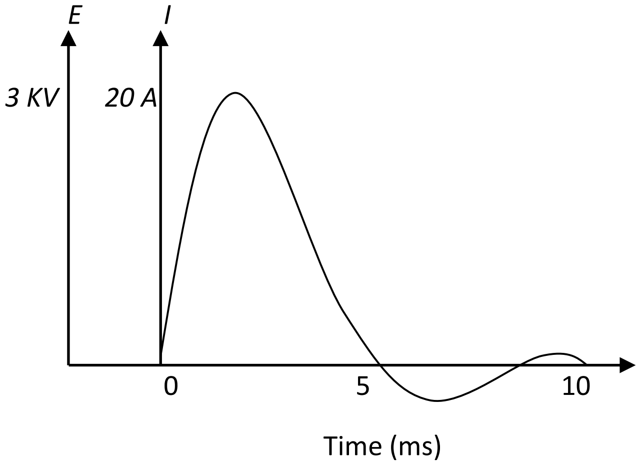


Figure A1: **Lown defibrillator waveform**

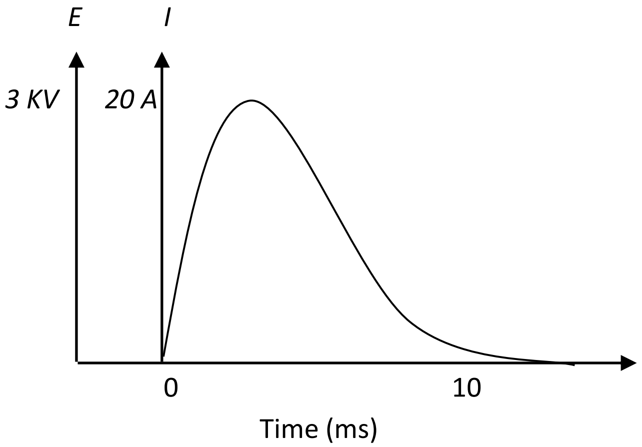


Figure A2: **Monopulse defibrillator waveform**

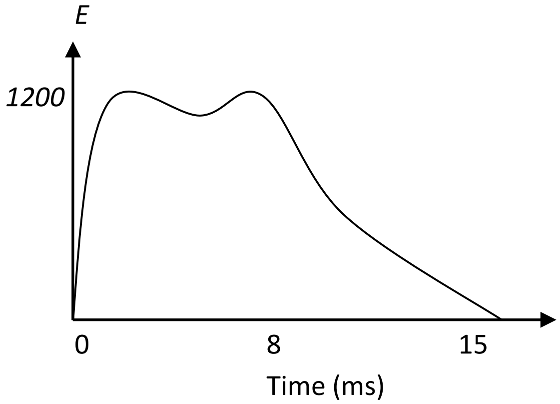


Figure A3: **Tapered dc delay defibrillator waveform**

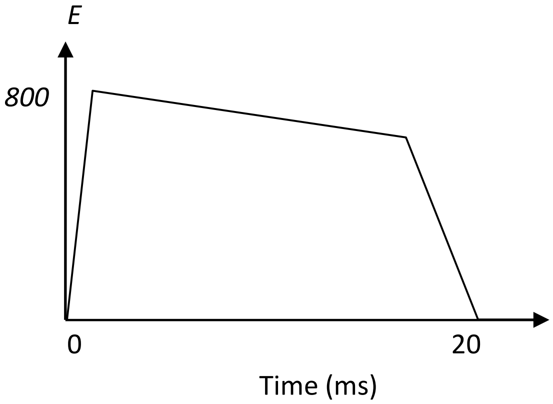


Figure A4: **Trapezoidal defibrillator waveform**

C.

Pictures of different Defibrillators:

Figure A5: **Typical External Defibrillator**

Figure A6: **Typical Automated External Defibrillator (AED)**

Figure A7: **Wearable Cardioverter Defibrillator (WCD)**

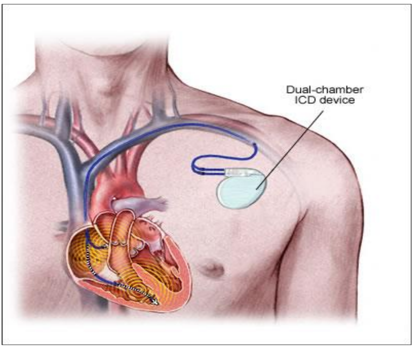


Figure A8: **Internal Cardioverter Defibrillator (ICD)**

D.

Derivation of the flyback converter:

The flyback converter is based on the buck-boost converter. Its derivation is illustrated in Figure A9. Figure A9 (a) depicts the basic buck-boost converter, with the switch realized using a MOSFET and diode. In Figure A9 (b), the inductor winding is constructed using two wires, with a 1:1 turns ratio. The basic function of the inductor is unchanged, and the parallel windings are equivalent to a single winding constructed of larger wire. In Figure A9 (c), the connections between the two windings are broken. One winding is used while the transistor *Q1* conducts, while the other winding is used when diode *D1* conducts. The total current in the two windings is unchanged from the circuit of Figure A9 (b); however, the current is now distributed between the windings differently. The magnetic fields inside the inductor in both cases are identical. Although the two-winding magnetic device is represented using the same symbol as the transformer, a more descriptive name is “two winding inductor”. This device is sometimes also called a “flyback transformer”.

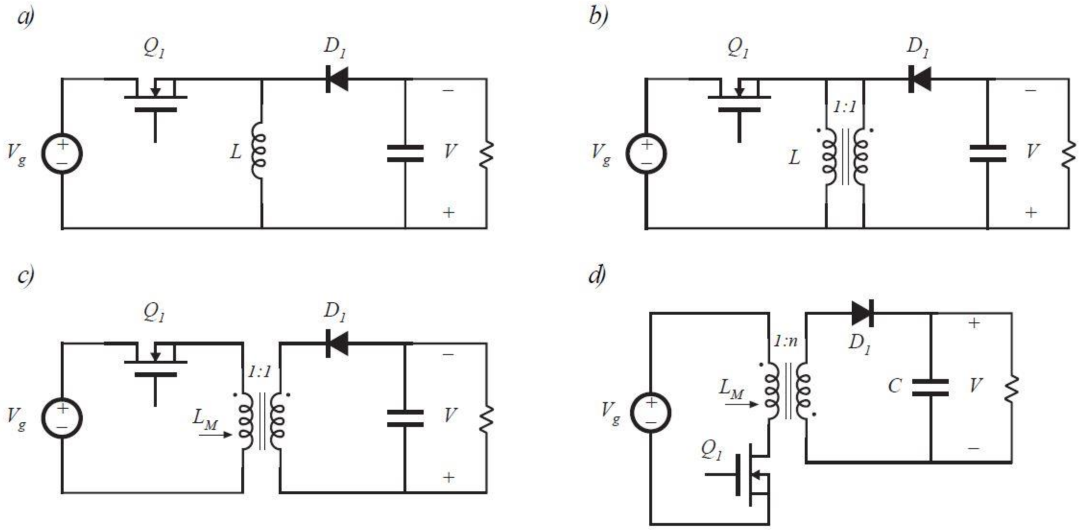


Figure A9: **Derivation of the flyback converter: (a) buck-boost converter, (b) inductor *L* is wound with two parallel wires, (c) inductor windings are isolated, leading to the flyback converter, (d) with a 1:*n* turns ratio and positive output.**

Unlike the ideal transformer, current does not flow simultaneously in both windings of the flyback transformer. Figure A9 (d) illustrates the usual configuration of the flyback converter. The MOSFET source is connected to the primary-side ground, simplifying the gate drive circuit. The transformer polarity marks are reversed, to obtain a positive output voltage. A 1:*n* turns ratio is introduced; this allows better converter optimization.

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