DUAL CHANNEL MARX GENERATOR

Project Stage-I
Report submitted
in
partial fulfillment of requirement
***for the award of* degree of**

Bachelor of Engineering
in
Electrical Engineering

Submitted by

Khan Bushra	**16EE01**
Fodkar Maaz	**17DEE47**
Maurya Sandeep	**17DEE54**
Mazumdar Akash	**17DEE55**

Under The Guidance Of
Prof. Ankur Upadhyay

Department of Electrical Engineering
Anjuman-I-Islam's Kalsekar Technical Campus, Panvel
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CERTIFICATE

This is to certify that the dissertation titled "**Dual Channel Marx Generator**", which is being submitted herewith for the award of the, **'Bachelor of Engineering'** in **Electrical Engineering** of Anjuman-I-Islam's Kalsekar Technical Campus, New Panvel (M.S., India). This is the result of the original research work and contribution by **'Mr. Maaz Fodkar, Mr. Akash Mazumdar, Mr. Sandeep Maurya and Miss. Bushra Khan'** under my supervision and guidance. The work embodied in this dissertation has not formed earlier for the basis of award of any degree or compatible certificate or similar title of this for any other diploma/examining body or university to the best of knowledge and belief.

Place: Panvel

Date:

Name of Guide
Prof. Ankur Upadhyay

H.O.D
Prof. Kaleem Syed

Name of Director
Abdul Razzak Honnutagi

DECLARATION

I hereby declare that I have formed, completed and written the dissertation entitled "**Dual Channel Marx Generator**". It has not previously submitted for the basis of the award of any degree or diploma or either similar title of this for any other diploma/examining body/university.

Place: Panvel

Date:

Akash Mazumdar
Bushra Khan
Maaz Fodkar
Sandeep Maurya

ACKNOWLEDGEMENT

It is a matter of great pleasure and proud privilege to be able to present this project "DUAL CHANNEL MARX GENERATOR".

We would like to express our deep regards and gratitude to the Head of the department **Mr. Sayyed Kaleem.**

The completion of this project work is a milestone in student life and its execution is inevitable in the hands of a guide. We are highly indebted to our project guide **Prof. Ankur Upadhyay**, for his invaluable guidance and appreciation for giving form and substance to this report. It is due to his enduring efforts, patience, and enthusiasm which has given this project a sense of direction and purposefulness to this project and ultimately made it in success.

We would also like to tender our sincere thanks to the staff members for their co-operation.

We would also like to thank the non-teaching staff and our friends who have helped us all the time in one way or another.

ABSTRACT

Marx generators can produce high voltage pulses using multiple, identical stages that operate at a fraction of the total output voltage without the need for a step-up transformer that limits the pulse risetimes and lowers the efficiency of the system. Each Marx stage includes a capacitor or pulse forming network and a high voltage switch. Typically, these switches are spark gaps resulting in Marx generators with low repetition rates and limited lifetimes. The development of economical, compact, high voltage, high di/dt, and fast turn-on solid state switches makes it easy to build economical, long lifetime, high voltage Marx generators capable of high pulse repetition rates. We have constructed a Marx generator using our 24 kV thyristor-based switches, which are capable of conducting 14 kA peak currents with ringing discharges at > 25 kA/μs rate of current risetimes. The switches have short turn-on delays, less than 200 ns, low timing jitters and are triggered by a single 10 V isolated trigger pulse. This project will include a description of a 4-stage solid state Marx and triggering system.

LIST OF FIGURES

INDEX/CONTENT

1. INTRODUCTION

1.1 Introduction:

Marx Generator Marx generator is a device that is used to generate high-voltage pulse. The operation of this device is based on the following principle: the capacitors connected in parallel are first charged with electric current, and then connected in series with the help of various switching devices. This results in the output voltage increasing in proportion to the number of connected capacitors.

When the capacitors are charged the generator is launched after the first discharger goes off. Overvoltage at different dischargers forces all the chargers to be actuated almost simultaneously, which triggers the series connection of the charged capacitors.

Marx generators can be used to produce pulses of tens of kilo-volts to ten millions of volts. The generated pulse frequencies depend upon the generator's pulse capacity and constitutes anything from single pulses per hour to several tens of Hertz. Small laboratory Marx generators of up to 100-200 kilovolts can come with air insulation, whereas their more powerful counterparts are supplied with vacuum, gas or oil insulation, which helps prevent parasitic air breakthroughs and charge drain as a result of corona discharges.

The main drawback of Marx generator is that at the charge volume of (50-100)x103 Volts it needs to contain 5-8 steps with the same number of spark switches, which is associated with the decrease of specific energy, mass and dynamic parameters and lower efficiency. In the discharge mode the total losses are represented by the losses in the capacitors and the spark gaps, and the load resistance.

Marx's high-voltage pulse generator is used in various scientific studies and in performing all kinds of technical tasks. In some units the generators operate instead of the surge current generators. In science Marx generators come in handy in nuclear and thermonuclear studies for speeding up various atomic particles, they are used as a powerful pumping source for optical amplifiers, applied for the studies of plasma states and pulse electromagnetic radiation.

In the military industry this device is viewed as an electromagnetic weapon. In general, industrial equipment Marx generators are together with the other pulse voltage and current sources used in electrohydraulic metal processing, crushing, drilling, soil and concrete consolidation.

1.2 Objective:

The objective of our project is to generate an excessive voltage pulse. The use of some of capacitors in parallel to charge up during the on time after which connected in collection to increase higher voltage during the off length.

This precept is used to generate voltages in the range of KV’s in actual-time for testing the insulation of the digital home equipment like transformers and the insulation of the power carrying lines. MOSFET is used as a switch; diodes are used to charge the capacitor at every degree without power loss. A 555 timer generates pulses for the capacitors to charge in parallel during ON time. During OFF time of the pulses the capacitors are brought in series with the assist of MOSFET switches.

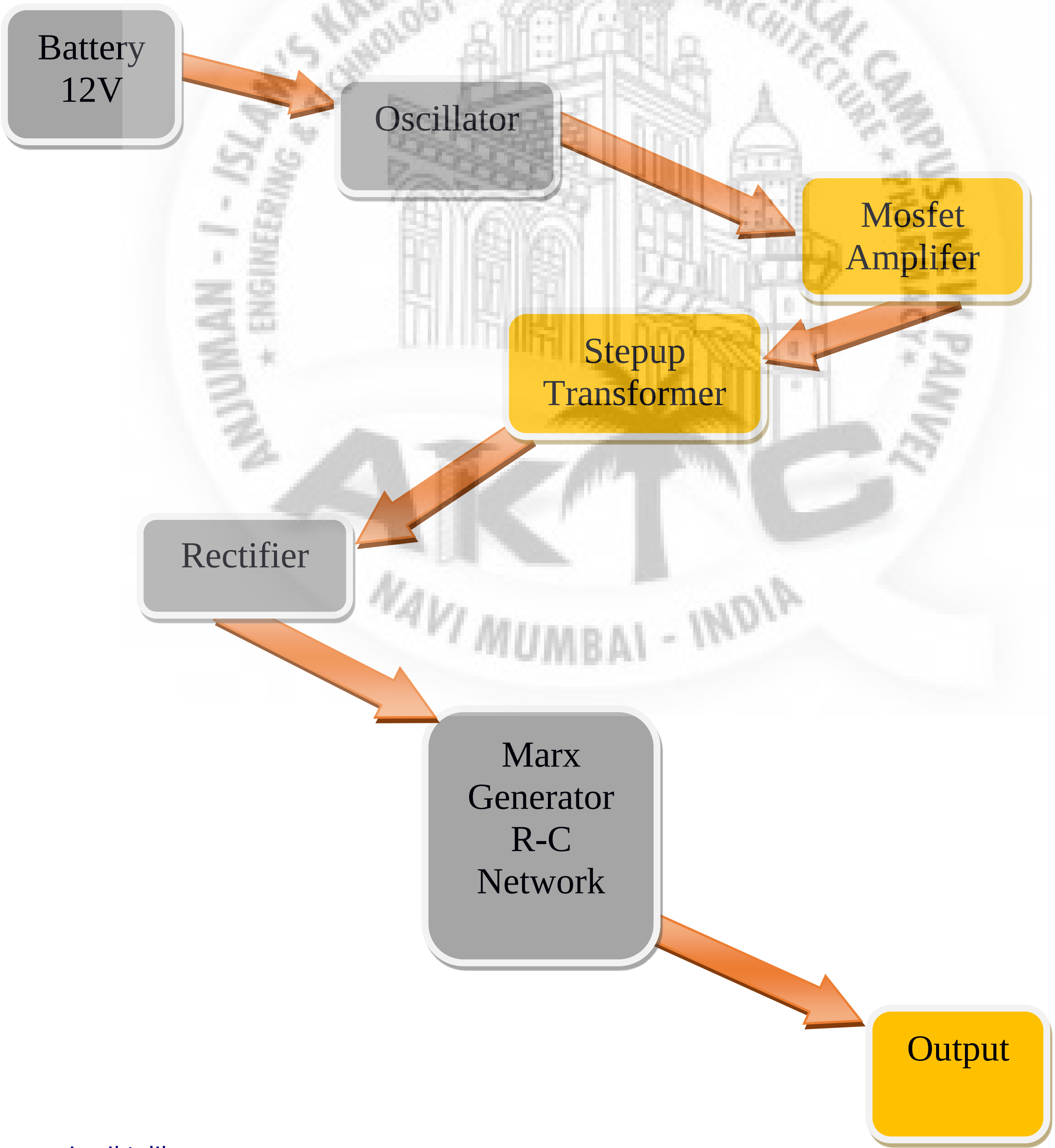
Subsequently, wide variety of capacitors utilized in series (Six in our project) adds up the voltage to approximately 5 (6 capacitors-1 capacitor) instances the supply voltage. This device shape gives compactness and easiness to make entire system.

2. AIM AND BLOCK DIAGRAM

- **Aim of this Project:**

To produce high voltage pulses using multiple, identical stages that operate at a fraction of the total output voltage without the need for a step-up transformer that limits the pulse rise times and lowers the efficiency of the system.

- **Block Diagram:**

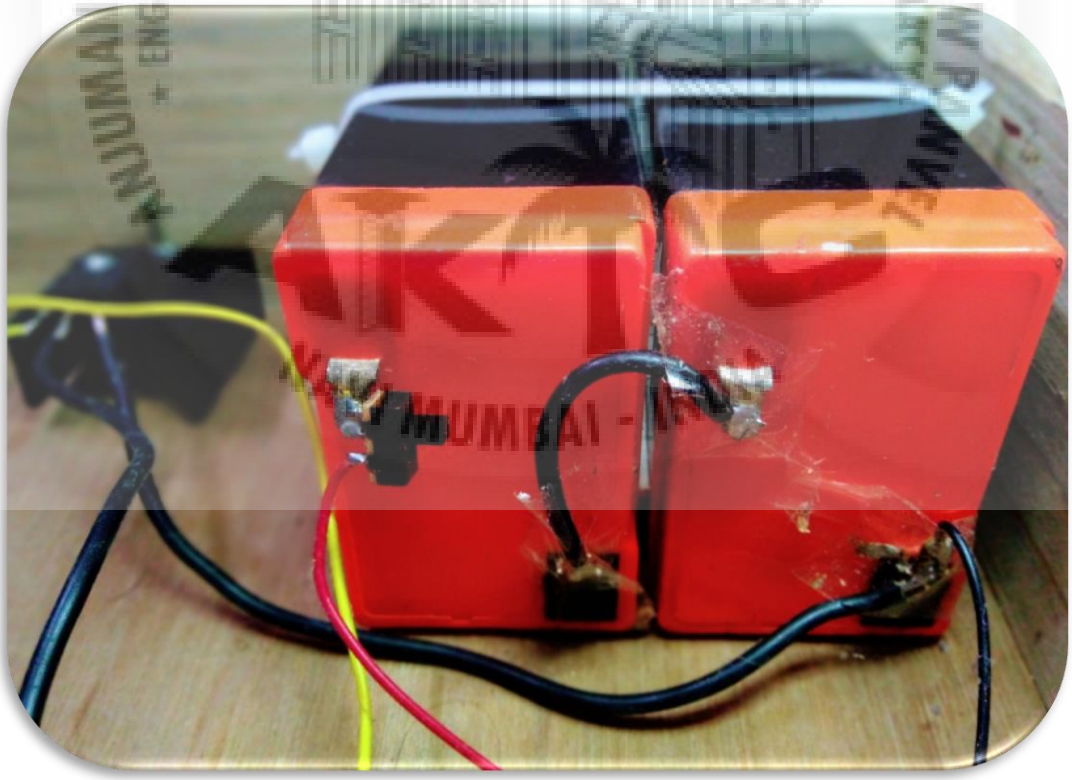


3. COMPONENTS USED

1. 12v Battery
2. MOSFET Amplifier
3. 555 Timer
4. Flyback Transformer
5. Rectifiers
6. Resistors
7. Capacitors

3.1 BATTERY:

- **Lead Acid Battery**



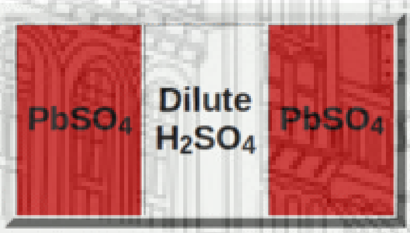
Lead–acid batteries, invented in 1859 by French physicist Gaston Planté, are the oldest type of rechargeable battery. Despite having a very low energy-to-weight ratio and a low energy-to-volume ratio, their ability to supply high surge currents means that the cells maintain a relatively large power-to-weight ratio. These features, along with their low cost, make them attractive for use in motor vehicles to provide the high current required by automobile starter motors.

- **HISTORY:**

In 1859, Gaston Planté's lead-acid battery was the first battery that could be recharged by passing a reverse current through it. Planté's first model consisted of two lead sheets separated by rubber strips and rolled into a spiral. His batteries were first used to power the lights in train carriages while stopped at a station. In 1881, Camille Alphonse Faure invented an improved version that consisted of a lead grid lattice into which a lead oxide paste was pressed, forming a plate. This design was easier to mass-produce.

The lead-acid battery is still used today in automobiles and other applications in which greater weight is acceptable. In the 1970s the valve-regulated lead acid battery (often called "sealed") was developed; it used a gel electrolyte instead of a liquid, allowing the battery to be used in different positions without leakage.

- **DISCHARGING**



Fully Discharged: Two identical lead sulphate plates

In the discharged state both the positive and negative plates become lead sulphate (PbSO4) and the electrolyte loses much of its dissolved sulfuric acid and becomes primarily water. The discharge process is driven by the conduction of electrons from the negative plate back into the cell at the positive plate in the external circuit.

Negative plate reaction (Anode Reaction):

Pb(s) + HSO−

4(aq) → PbSO

4(s) + H+

(aq) + 2-e

Positive plate reaction (Cathode Reaction):

PbO

2(s) + HSO−

4(aq) + 3H+

(aq) + 2-

e → PbSO

4(s) + 2H

2O(l)

Hence, total reaction can be written:

Pb(s) + PbO

2(s) + 2H

2SO

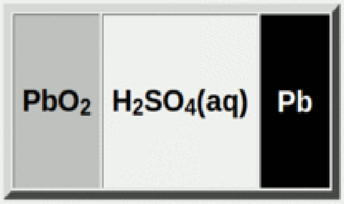
4(aq) → 2PbSO

4(s) + 2H

2O(l)

The sum of the molecular weights of the reactants is 642.6, so theoretically a cell can produce two faradays of charge from 642.6 g of reactants, or 83.4 amp-hours per kg (or 13.9 amp-hours per kg for a 12-volt battery). At 2 volts per cell, this comes to 167 watt-hours per kg, but lead-acid batteries in fact give only 30 to 40 watt-hours per kg due to the weight of the water and other factors.

- **CHARGING**



Fully Charged: Lead and Lead Oxide plates

In the charged state, each cell contains negative plates of elemental lead (Pb) and positive plates of lead(IV) oxide (PbO2) in an electrolyte of approximately 33.5% *v*/*v* (4.2 Molar) sulfuric-acid(H2SO4). The charging process is driven by the forcible removal of electrons from the positive plate and the forcible introduction of them to the negative plate by the charging source.

Negative plate reaction: PbSO

4(s) + H+

(aq) + 2-

e → Pb(s) + HSO−

4(aq)

Positive plate reaction: PbSO

4(s) + 2H

2O(l) → PbO

2(s) + HSO−

4(aq) + 3H+

(aq) + 2-e

3.2 MOSFET:

- **Introduction:**

As well as the Junction Field Effect Transistor (JFET), there is another type of Field Effect Transistor available whose Gate input is electrically insulated from the main current carrying channel and is therefore called an Insulated Gate Field Effect Transistor.

The most common type of insulated gate FET which is used in many different types of electronic circuits is called the Metal Oxide Semiconductor Field Effect Transistor or MOSFET for short.

The IGFET or MOSFET is a voltage-controlled field effect transistor that differs from a JFET in that it has a "Metal Oxide" Gate electrode which is electrically insulated from the main semiconductor n-channel or p-channel by a very thin layer of insulating material usually silicon dioxide, commonly known as glass.

MOSFETs also have comparatively higher on state resistance per unit area of the device cross section which increases with the blocking voltage rating of the device. Consequently, the use of MOSFET has been restricted to low voltage (less than about 500 volts) applications where the ON state resistance reaches acceptable values. Inherently fast switching speed of these devices can be effectively utilized to increase the switching frequency beyond several hundred kHz. From the point of view of the operating principle a MOSFET is a voltage-controlled majority carrier device. As the name suggests, movement of majority carriers in a MOSFET is controlled by the voltage applied on the control electrode (called gate) which is insulated by a thin metal oxide layer from the bulk semiconductor body. The electric field produced by the gate voltage modulate the conductivity of the semiconductor material in the region between the main current carrying terminals called the Drain (D) and the Source (S). Power MOSFETs, just like their integrated circuit counterpart, can be of two types:

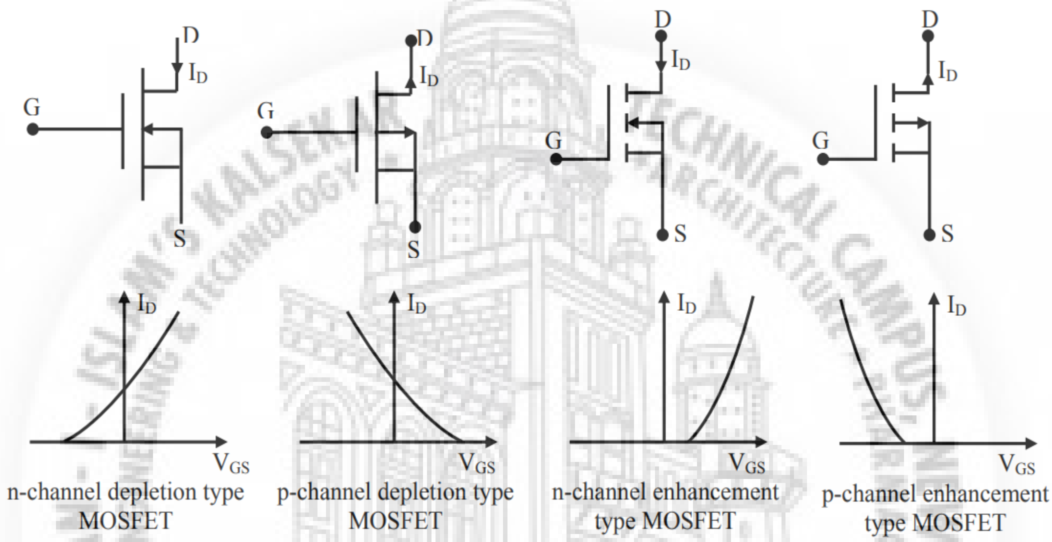
(i) Depletion type –

The transistor requires the Gate-Source voltage (V_{GS}), to switch the device "OFF". The depletion mode MOSFET is equivalent to a "Normally Closed" switch.

(ii) <u>Enhancement type –</u>

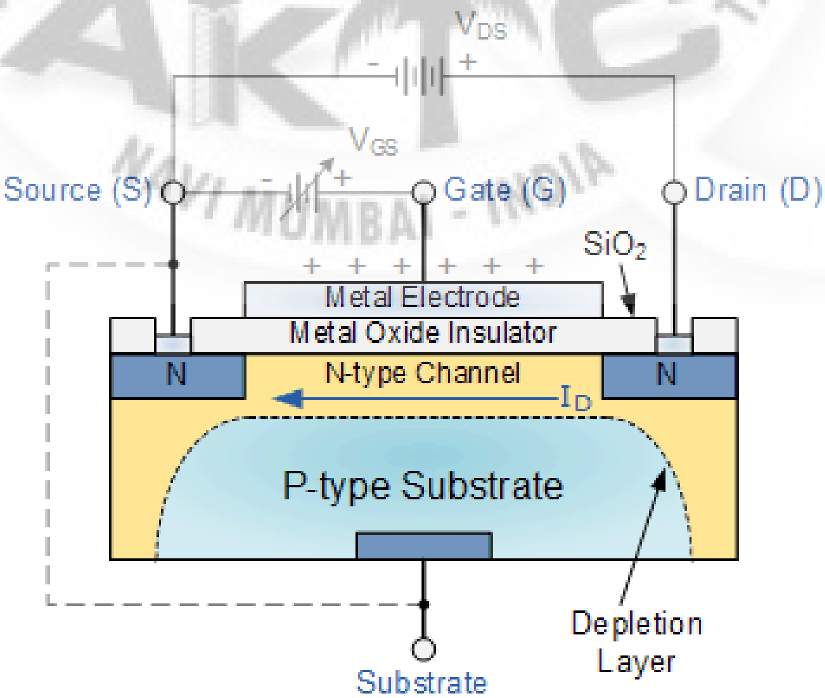
the transistor requires a Gate-Source voltage (V_{GS}), to switch the device "ON". The enhancement mode MOSFET is equivalent to a "Normally Open" switch.

Both of these can be either n- channel type or p-channel type depending on the nature of the bulk semiconductor. Fig 6.1 (a) shows the circuit symbol of these four types of MOSFETs along with their drain current vs gate-source voltage characteristics (transfer characteristics).



(a)

- **<u>Constructional features of Power MOSFET</u>**



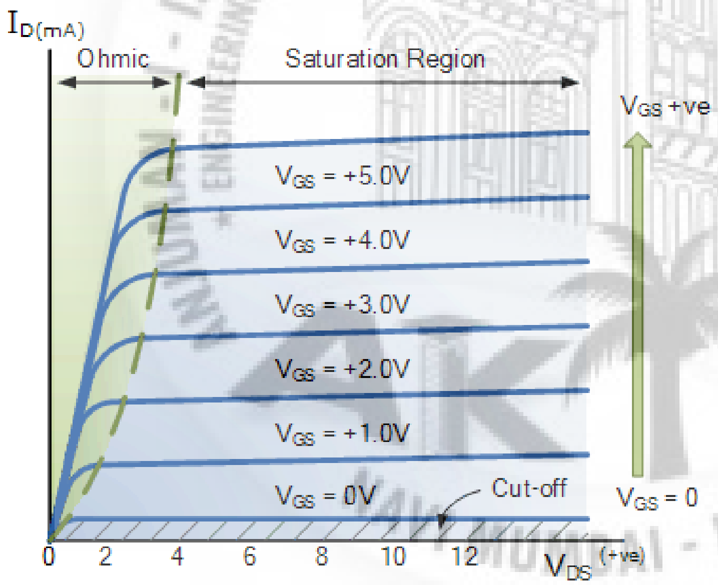
The construction of the Metal Oxide Semiconductor FET is very different to that of the Junction FET. Both the Depletion and Enhancement type MOSFETs use an electrical field produced by a gate voltage to alter the flow of charge carriers, electrons for n-channel or holes for P-channel, through the semi conductive drain-source channel. The gate electrode is placed on top of a very thin insulating layer and there are a pair of small n-type regions just under the drain and source electrodes.

- **Enhancement-mode MOSFET:**

The more common Enhancement-mode MOSFET or eMOSFET, is the reverse of the depletion-mode type. Here the conducting channel is lightly doped or even undoped making it non-conductive. This results in the device being normally "OFF" (non-conducting) when the gate bias voltage, V_{GS} is equal to zero.

Increasing this positive gate voltage will cause the channel resistance to decrease further causing an increase in the drain current, I_D through the channel. In other words, for an n-channel enhancement mode MOSFET: $+V_{GS}$ turns the transistor "ON", while a zero or $-V_{GS}$ turns the transistor "OFF". Thus, the enhancement-mode MOSFET is equivalent to a "normally-open" switch

- **Why N-Channel MOSFET?**



For the n-channel enhancement MOS transistor a drain current will only flow when a gate voltage (V_{GS}) is applied to the gate terminal greater than the threshold voltage (V_{TH}) level in which conductance takes place making it a transconductance device.

The application of a positive (+ve) gate voltage to a n-type eMOSFET attracts more electrons towards the oxide layer around the gate thereby increasing or enhancing (hence its name) the thickness of the channel allowing more current to flow. This is why this kind of transistor is called an enhancement mode device as the application of a gate voltage enhances the channel.

Enhancement-mode MOSFETs make excellent electronics switches due to their low "ON" resistance and extremely high "OFF" resistance as well as their infinitely high input resistance due to their isolated gate.

One interesting feature of the MOSFET cell is that the alternating n+ n- p n+ structure embeds a parasitic BJT (with its base and emitter shorted by the source metallization) into each MOSFET cell as shown in Fig 6.3. The nonzero resistance between the base and the emitter of the parasitic **npn** BJT arises due to the body spreading resistance of the p type substrate. In the design of the MOSFET cells special care is taken so that this resistance is minimized and switching operation of the parasitic BJT is suppressed. With an effective short circuit between the body and the source the BJT always remain in cut off and its collector-base junction is represented as an anti-parallel diode (called the body diode) in the circuit symbol of a Power MOSFET.

- **Operating principle of a MOSFET**

At first glance it would appear that there is no path for any current to flow between the source and the drain terminals since at least one of the p n junctions (source – body and body-Drain) will be reverse biased for either polarity of the applied voltage between the source and the drain. There is no possibility of current injection from the gate terminal either. However, application of a positive voltage at the gate terminal with respect to the source will convert the silicon surface beneath the gate oxide into an n type layer or "channel", thus connecting the Source to the Drain as explained next.

The gate region of a MOSFET which is composed of the gate metallization, the gate (silicon) oxide layer and the p-body silicon forms a high-quality capacitor. When a small voltage is application to this capacitor structure with gate terminal positive with respect to the source (note that body and source are shorted) a depletion region forms at the interface between the SiO2 and the silicon.

The positive charge induced on the gate metallization repels the majority hole carriers from the interface region between the gate oxide and the p type body. This exposes the negatively charged acceptors and a depletion region is created. Further increase in VGS causes the depletion layer to grow in thickness. At the same time the electric field at the oxide-silicon interface gets larger and begins to attract free electrons.

The immediate source of electron is electron-hole generation by thermal ionization. The holes are repelled into the semiconductor bulk ahead of the depletion region. The extra holes are neutralized by electrons from the source. As VGS increases further the density of free electrons at the interface becomes equal to the free hole density in the bulk of the body region beyond the depletion layer.

The layer of free electrons at the interface is called the inversion layer. It has all the properties of an n type semiconductor and is a conductive path or "channel" between the drain and the source which permits flow of current between the drain and the source. Since current conduction in this device takes place through an n- type "channel" created by the electric field due to gate source voltage it is called "Enhancement type n-channel MOSFET".

The value of VGS at which the inversion layer is considered to have formed is called the "Gate – Source threshold voltage VGS(th)". As VGS is increased beyond VGS(th) the inversion layer gets somewhat thicker and more conductive, since the density of free electrons increases further with increase in VGS. The inversion layer screens the depletion layer adjacent to it from increasing VGS. The depletion layer thickness now remains constant.

- **Astable Operation:**

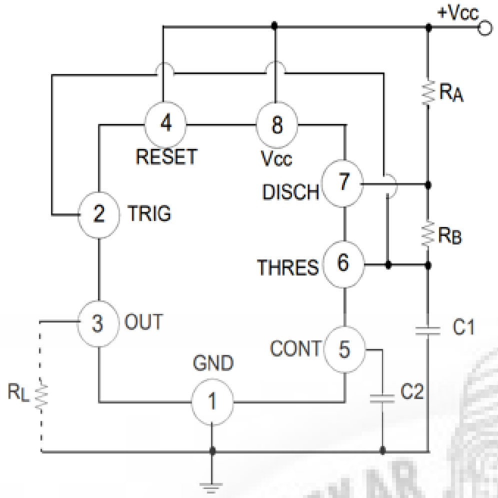


Fig.1) Astable Circuit

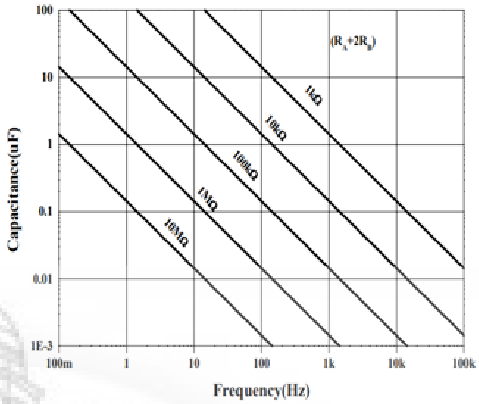


Fig.2) Capacitance & resistance vs frequency

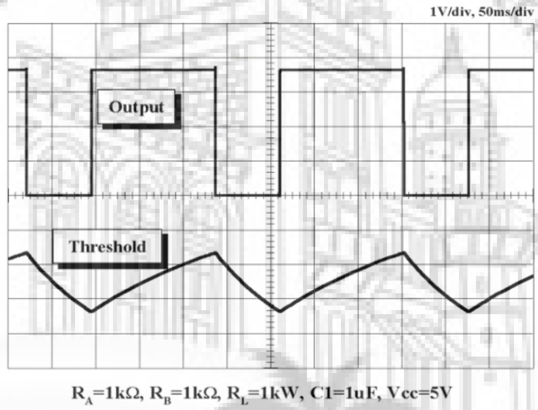


Fig.3) Waveforms of astable Operation

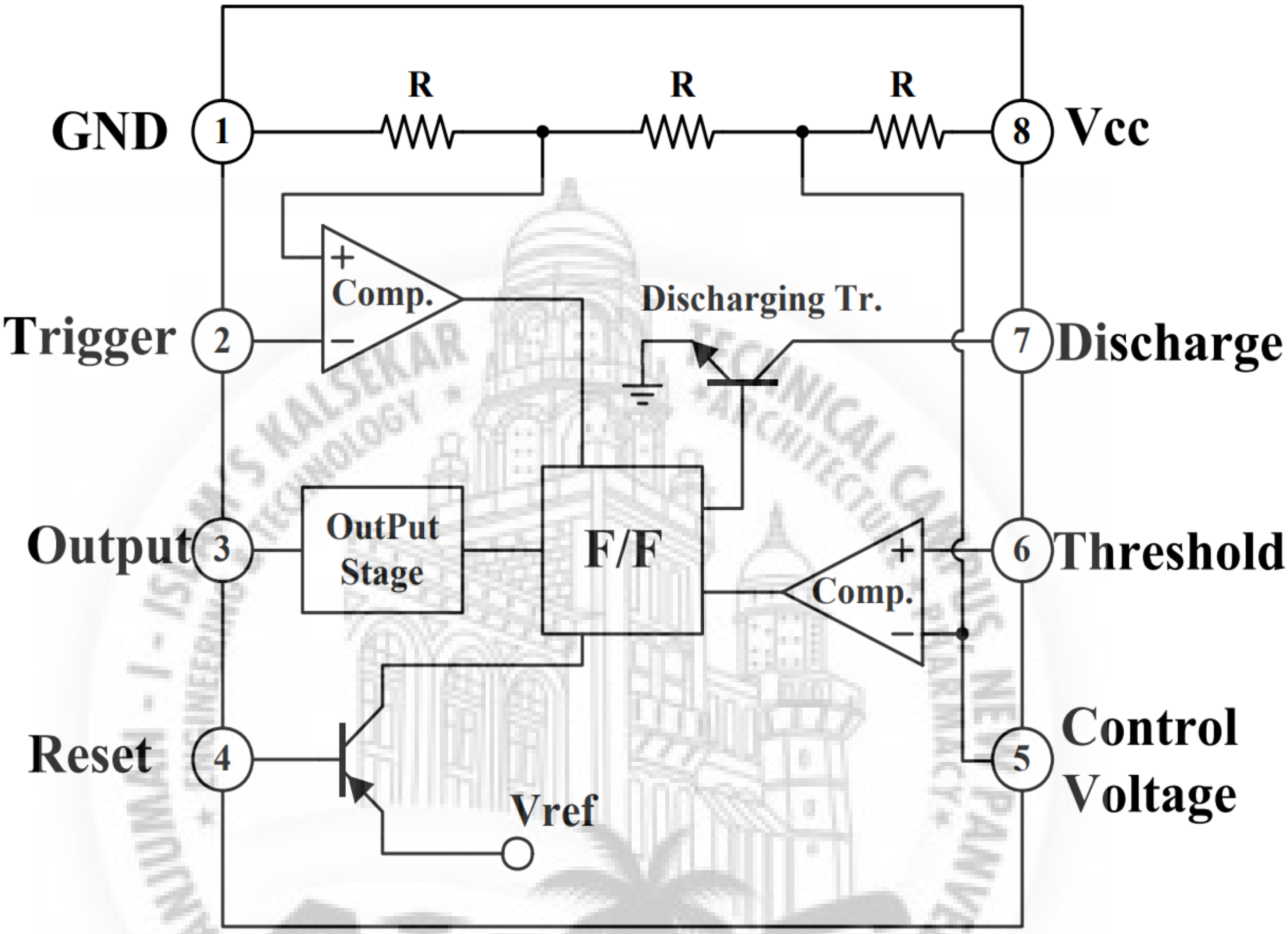
In the astable operation, the trigger terminal and the threshold terminal are connected so that a self-trigger is formed, operating as a multi vibrator. When the timer output is high, its internal discharging Tr. turns off and the VC1 increases by exponential function with the time constant (RA+RB)*C.

When the VC1, or the threshold voltage, reaches 2Vcc/3, the comparator output on the trigger terminal becomes high, resetting the F/F and causing the timer output to become low. This in turn turns on the discharging Tr. and the C1 discharges through the discharging channel formed by RB and the discharging Tr. When the VC1 falls below Vcc/3, the comparator output on the trigger terminal becomes high and the timer output becomes high again. The discharging Tr. turns off and the VC1 rises again.

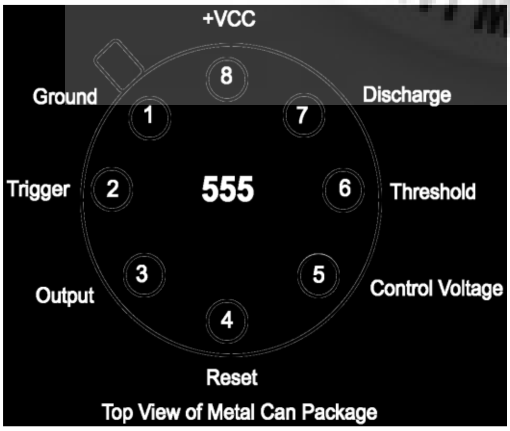
In the above process, the section where the timer output is high is the time it takes for the VC1 to rise from Vcc/3 to 2Vcc/3, and the section where the timer output is low is the time it takes for the VC1 to drop from 2Vcc/3 to Vcc/3.

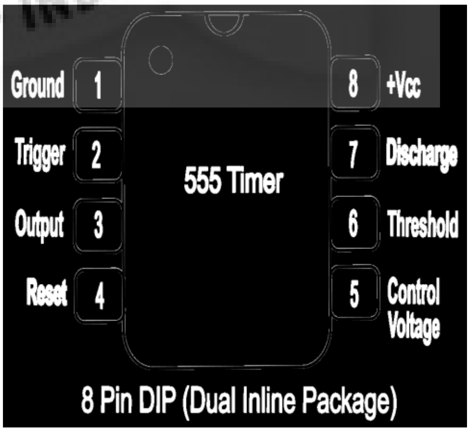
3.3 IC 555 TIMER:

- **555 Internal Construction:**



- **555 IC, 8 Pin Pinout Diagrams:**





- **Features:**

• High Current Drive Capability (200mA)

• Adjustable Duty Cycle

• Temperature Stability of 0.005%/°C

• Timing From micro-Seconds to Hours

• Turn off Time Less Than 2μSec

- **Description:**

The LM555 is a highly stable controller capable of producing accurate timing pulses. With a monostable operation, the time delay is controlled by one external resistor and one capacitor. With an astable operation, the frequency and duty cycle are accurately controlled by two external resistors and one capacitor.

- **Applications:**

• Precision Timing

• Pulse Generation

• Time Delay Generation

• Sequential Timing

- **Explanation of Terminals for 8 pin 555**

- **Pin 1**: **Grounded Terminal:**

  All the voltages are measured with respect to this terminal.

- **Pin 2: Trigger Terminal:**

  This pin is an inverting input to a comparator that is responsible for transition of flip-flop from set to reset. The output of the timer depends on the amplitude of the external trigger pulse applied to this pin.

- **Pin 3: Output Terminal:**

  Output of the timer is available at this pin. There are two ways in which a load can be connected to the output terminal either between pin 3 and ground pin (pin 1) or between pin 3 and supply pin (pin 8). The load connected between pin 3 and the supply pin is called the normally on load and the load connected between pin 3 and ground pin is called the normally off load.

- **Pin 4: Reset Terminal:**

  To disable or reset the timer a negative pulse is applied to this pin due to the fact it is referred to as reset terminal. When this pin is not to be used for reset purpose, it should be connected to + VCC to avoid any possibility of false triggering.

- **Pin 5: Control Voltage Terminal:**

  The function of this terminal is to control the threshold and trigger levels. Thus, either the external voltage or a pot connected to this pin determines the pulse width of the output waveform. The external voltage applied to this pin can also be used to modulate the output waveform. When this pin is not used, it should be connected to ground through a 0.01 micro Farad to avoid any noise problem.

- **Pin 6**: **Threshold Terminal:**

  This is the non-inverting input terminal of comparator 1, which compares the voltage applied to the terminal with a reference voltage of 2/3 VCC. The amplitude of voltage applied to this terminal is responsible for the set state of flip-flop.

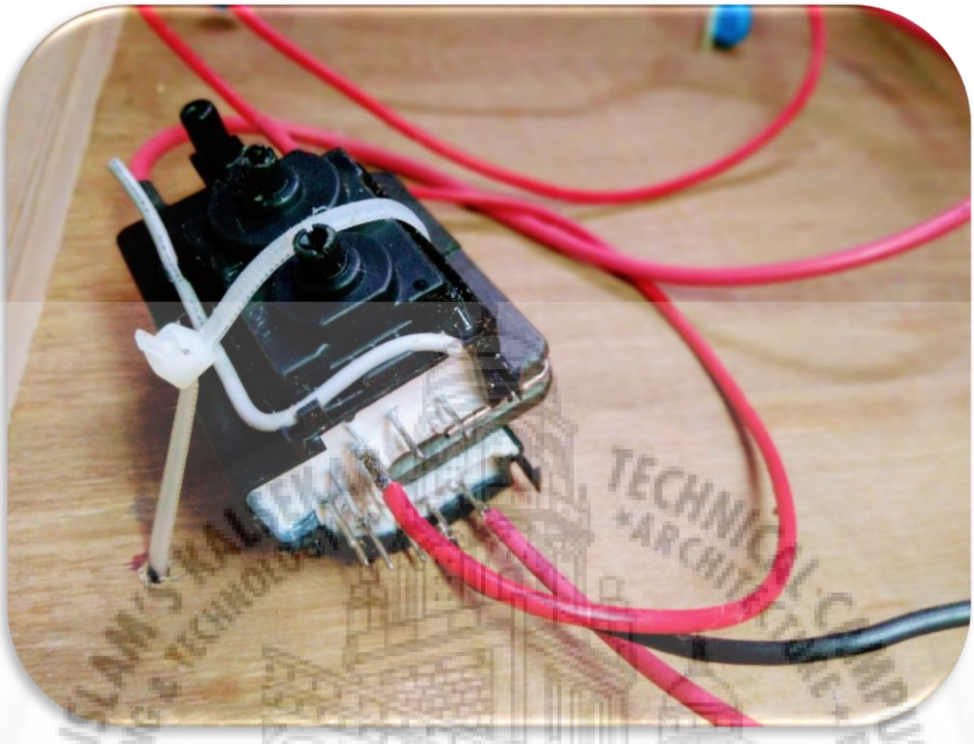
- **Pin 7: Discharge Terminal:**

  This pin is connected internally to the collector of transistor and mostly a capacitor is connected between this terminal and ground. It is called discharge terminal because when transistor saturates, capacitor discharges through the transistor. The capacitor charges at a rate determined by the external resistor and capacitor, when the transistor is cut-off.

- **Pin 8: Supply Terminal:**

  A supply voltage of + 5 V to + 18 V is applied to this terminal with respect to ground (pin 1).

3.4 FLYBACK TRANSFORMER



- **Introduction:**

A flyback transformer (FBT), also called a line output transformer (LOPT), is a special type of electrical transformer. It was initially designed to generate high voltage sawtooth signals at a relatively high frequency. In modern applications, it is used extensively in switched-mode power supplies for both low (3 V) and high voltage (over 10 kV) supplies.

A flyback transformer is a coupled inductor with a gapped core. During each cycle, when the input voltage is applied to the primary winding, energy is stored in the gap of the core. It is then transferred to the secondary winding to provide energy to the load. Flyback transformers are used to provide voltage transformation and circuit isolation in flyback converters.

Flyback transformers are the most popular choice for cost-effective, high-efficiency isolated power supply designs up to approximately 120 Watts. They provide circuit isolation, the potential for multiple outputs and the possibility of positive or negative output voltages. They can also be regulated over a wide range of input voltage and load conditions.

Because energy is stored in the transformer, the flyback topology does not require a separate output filter inductor like the other isolated topologies. This reduces the component count and simplifies the circuit requirements. This article discusses flyback transformers and applications for which they are best suited.

Flyback Transformers EE16 (1 to 10 W) is the one we used in our Marx Generator Project. Its specifications are as given below:

• Ambient Temperature ≤ 50°C

• Primary Reflected Voltage = 90 to 120V

• Dielectric Strength ≥ 3750Vac

• Creepage Distances ≥ 6mm

• Construction conforms to CEI950, CEI335, CEI61558 for reinforced insulation

• Secondaries may be series connected

• Output power can be delivered with any combination of secondaries within the max current limits.

- **Construction:**

The primary is wound first around a ferrite rod, and then the secondary is wound around the primary. This arrangement minimizes the leakage inductance of the primary. Finally, a ferrite frame is wrapped around the primary/secondary assembly, closing the magnetic field lines. Between the rod and the frame is an air gap, which increases the reluctance. The secondary is wound layer by layer with enameled wire, and Mylar film between the layers. In this way parts of the wire with higher voltage between them have more dielectric material between them.

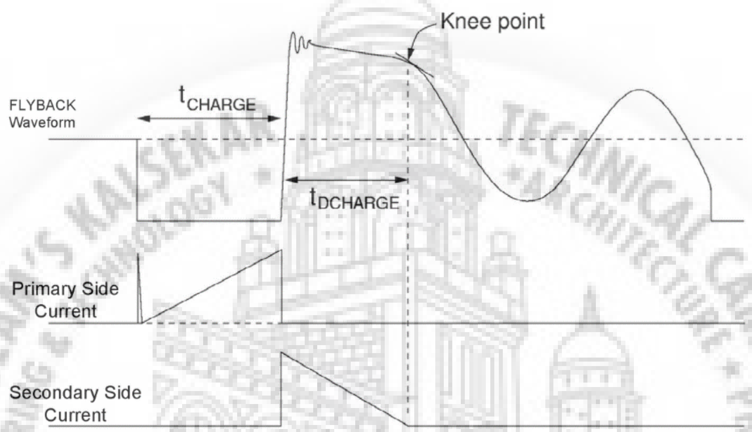
- **Operation and usage:**

The primary winding of the flyback transformer is driven by a switch from a DC supply (usually a transistor). When the switch is switched on, the primary inductance causes the current to build up in a ramp. An integral diode connected in series with the secondary winding prevents the formation of secondary current that would eventually oppose the primary current ramp

When the switch is turned off, the current in the primary falls to zero. The energy stored in the magnetic core is released to the secondary as the magnetic field in the core collapses. The voltage in the output winding rises very quickly (usually less than a microsecond) until it is limited by the load conditions. Once the voltage reaches such level as to allow secondary current, the charge flow is in the form of a descending ramp.

The cycle can then be repeated. If the secondary current is allowed to discharge completely to zero (no energy stored in the core), then it is said that the transformer works in discontinuous mode (DCM). When some energy is always stored in the core (and the current waveforms look trapezoidal rather than triangular), then this is continuous mode (CCM). This terminology is used especially in power supply transformers.

The low voltage output winding mirrors the sawtooth of the primary current and, e.g. for television purposes, has fewer turns than the primary, thus providing a higher current. This is a ramped and pulsed waveform that repeats at the horizontal (line) frequency of the display. The flyback (vertical portion of the sawtooth wave) can be a potential problem to the flyback transformer if the energy has nowhere to go: the faster a magnetic field collapses, the greater the induced voltage, which, if not controlled, can flash over the transformer terminals. The high frequency used permits the use of a much smaller transformer. In television sets, this high frequency is about 15 kilohertz (15.625 kHz for PAL, 15.734 kHz for NTSC), and vibrations from the transformer core caused by magnetostriction can often be heard as a high-pitched whine. In modern computer displays, the frequency can vary over a wide range, from about 30 kHz to 150 kHz.



The transformer can be equipped with extra windings whose sole purpose is to have a relatively large voltage pulse induced in them when the magnetic field collapses as the input switch is turned off. There is considerable energy stored in the magnetic field and coupling it out via extra windings helps it to collapse quickly, and avoids the voltage flash over that might otherwise occur. The pulse train coming from the flyback transformer windings is converted to direct current by a simple half wave rectifier. There is no point in using a full wave design as there are no corresponding pulses of opposite polarity. One turn of a winding often produces pulses of several volts.

- **Why Flyback Transformer?**

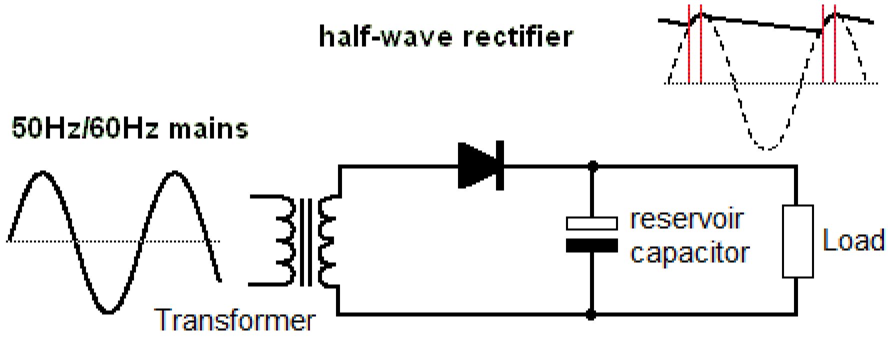
One advantage of operating the transformer at the flyback frequency is that it can be much smaller and lighter than a comparable transformer operating at mains (line) frequency.

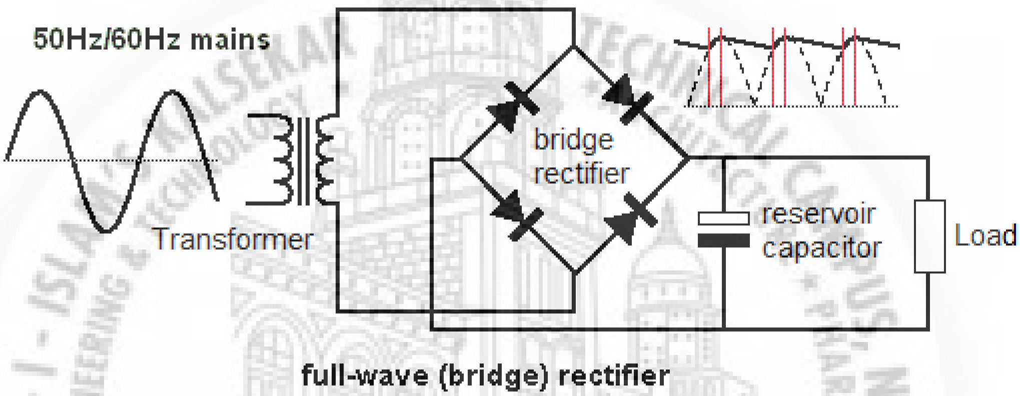
One of the main advantages of a flyback converter is that it's a low-cost alternative for stepping power up or down. Another key advantage of a flyback converter is that it's very basic with a limited number of components compared with other switch-mode power supply units

It's also useful when you want to isolate multiple output voltages from the primary. Finally, it provides the convenience of a single control for regulating multiple output voltages.

It generates voltage from a few kilovolts up to 50 kilovolts with high-frequency currents from 17 kHz to 50 kHz.

3.5 RECTIFIER





A rectifier is an electrical device that converts alternating current (AC), which periodically reverses direction, to direct current (DC), which flows in only one direction.

The process is known as rectification, since it "straightens" the direction of current. Physically, rectifiers take a number of forms, including vacuum tube diodes, wet chemical cells, mercury-arc valves, stacks of copper and selenium oxide plates, semiconductor diodes, silicon-controlled rectifiers and other silicon-based semiconductor switches. Historically, even synchronous electromechanical switches and motors have been used. Early radio receivers, called crystal radios, used a "cat's whisker" of fine wire pressing on a crystal of galena (lead sulfide) to serve as a point-contact rectifier or "crystal detector".

Rectifiers have many uses, but are often found serving as components of DC power supplies and high-voltage direct current power transmission systems. Rectification may serve in roles other than to generate direct current for use as a source of power. As noted, detectors of radio signals serve as rectifiers. In gas heating systems flame rectification is used to detect presence of a flame.

Depending on the type of alternating current supply and the arrangement of the rectifier circuit, the output voltage may require additional smoothing to produce a uniform steady voltage. Many applications of rectifiers, such as power supplies for radio, television and computer equipment, require a steady constant DC voltage (as would be produced by a battery). In these applications the output of the rectifier is smoothed by an electronic filter, which may be a capacitor, choke, or set of capacitors, chokes and resistors, possibly followed by a voltage regulator to produce a steady voltage.

3.6 RESISTOR

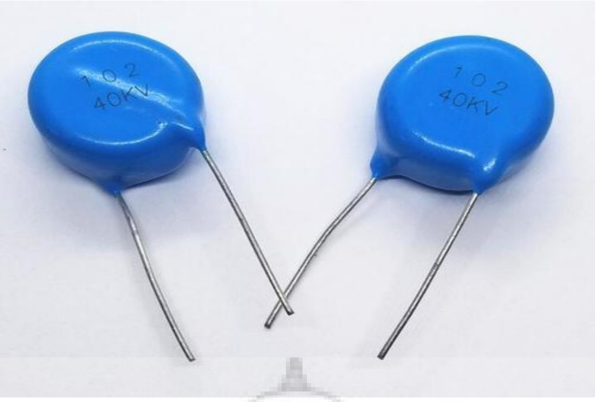
A resistor is a passive two-terminal electrical component that implements electrical resistance as a circuit element. In electronic circuits, resistors are used to reduce current flow, adjust signal levels, to divide voltages, bias active elements, and terminate transmission lines, among other uses. High-power resistors that can dissipate many watts of electrical power as heat, may be used as part of motor controls, in power distribution systems, or as test loads for generators. Fixed resistors have resistances that only change slightly with temperature, time or operating voltage. Variable resistors can be used to adjust circuit elements (such as a volume control or a lamp dimmer), or as sensing devices for heat, light, humidity, force, or chemical activity.

Resistors are common elements of electrical networks and electronic circuits and are ubiquitous in electronic equipment. Practical resistors as discrete components can be composed of various compounds and forms. Resistors are also implemented within integrated circuits.

The electrical function of a resistor is specified by its resistance: common commercial resistors are manufactured over a range of more than nine orders of magnitude. The nominal value of the resistance falls within the manufacturing tolerance, indicated on the component.

The rating of the resistors we used for this project is **1 Mega Ohms** each.

3.7 CAPACITOR



A capacitor is a device that stores electrical energy in an electric field. It is a passive electronic component with two terminals.

The effect of a capacitor is known as capacitance. While some capacitance exists between any two electrical conductors in proximity in a circuit, a capacitor is a component designed to add capacitance to a circuit. The capacitor was originally known as a condenser or condensator. This name and its cognates are still widely used in many languages, but rarely in English, one notable exception being condenser microphones, also called capacitor microphones.

The physical form and construction of practical capacitors vary widely and many types of capacitor are in common use. Most capacitors contain at least two electrical conductors often in the form of metallic plates or surfaces separated by a dielectric medium. A conductor may be a foil, thin film, sintered bead of metal, or an electrolyte. The nonconducting dielectric acts to increase the capacitor's charge capacity. Materials commonly used as dielectrics include glass, ceramic, plastic film, paper, mica, air, and oxide layers. Capacitors are widely used as parts of electrical circuits in many common electrical devices. Unlike a resistor, an ideal capacitor does not dissipate energy, although real-life capacitors do dissipate a small amount (see Non-ideal behavior). When an electric potential, a voltage, is applied across the terminals of a capacitor, for example when a capacitor is connected across a battery, an electric field develops across the dielectric, causing a net positive charge to collect on one plate and net negative charge to collect on the other plate. No current actually flows through the dielectric. However, there is a flow of charge through the source circuit. If the condition is maintained sufficiently long, the current through the source circuit ceases. If a time-varying voltage is applied across the leads of the capacitor, the source experiences an ongoing current due to the charging and discharging cycles of the capacitor.

The capacitors we used for our project is **Super High Voltage Ceramic Capacitor 40KV 1nF**.

Capacitance - 1NF
Operating Temperature - 40/21/85 Celsius (oC)
Rated Voltage - 40K Volt (V)
Material - Ceramic Disc
Temperature Range - -40+85 Celsius (oC)

Electrical Characteristics:
Rated Voltage: 1KVDC ~ 30KVDC
Capacitance Range: 10pF ~ 47000pF
Test Voltage: 1KVa URa 2KV, 2UR for 1 Min.

4. SYSTEM DESIGN

4.1 PCB designing and layout

- **Introduction**

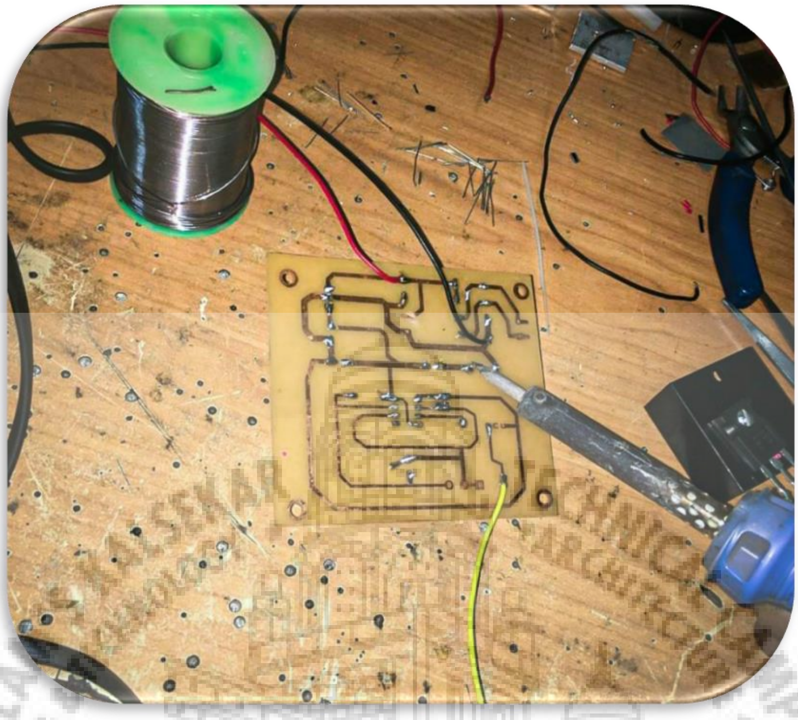
We designed our circuit, perhaps even bread boarded a working prototype, and now it's time to turn it into a nice Printed Circuit Board (PCB) design. For some designers, the PCB design will be a natural and easy extension of the design process. But for many others the process of designing and laying out a PCB can be a very daunting task. There are even very experienced circuit designers who know very little about PCB design, and as such leave it up to the "expert" specialist PCB designers. Many companies even have their own dedicated PCB design departments. This is not surprising, considering that it often takes a great deal of knowledge and talent to position hundreds of components and thousands of tracks into an intricate (some say artistic) design that meets a whole host of physical and electrical requirements. Proper PCB design is very often an integral part of a design. In many designs (high speed digital, low level analog and RF to name a few) the PCB layout may make or break the operation and electrical performance of the design. It must be remembered that PCB traces have resistance, inductance, and capacitance, just like your circuit does. This article is presented to hopefully take some of the mystery out of PCB design. It gives some advice and "rules of thumb" on how to design and lay out your PCBs in a professional manner. It is, however, quite difficult to try and "teach" PCB design. There are many basic rules and good practices to follow, but apart from that PCB design is a highly creative and individual process. It is like trying to teach someone how to paint a picture. Everyone will have their own unique style, while some people may have no creative flair at all! Indeed, many PCB designers like to think of PCB layouts as works of art, to be admired for their beauty and elegance. "If it looks good, it'll work good." is an old catch phrase.

- **Standards:**

There are industry standards for almost every aspect of PCB design. These standards are controlled by the former Institute for Interconnecting and Packaging Electronic Circuits, who are now known simply as the IPC (www.ipc.org). There is an IPC standard for every aspect of PCB design, manufacture, testing, and anything else that you could ever need. The major document that covers PCB design is IPC-2221, "Generic Standard on Printed Board Design". This standard superseded the old IPC-D-275 standard (also Military Std 275) which has been used for the last half century. Local countries also have their own various standards for many aspects of PCB design and manufacture, but by and large the IPC standards are the accepted industry standard around the world.

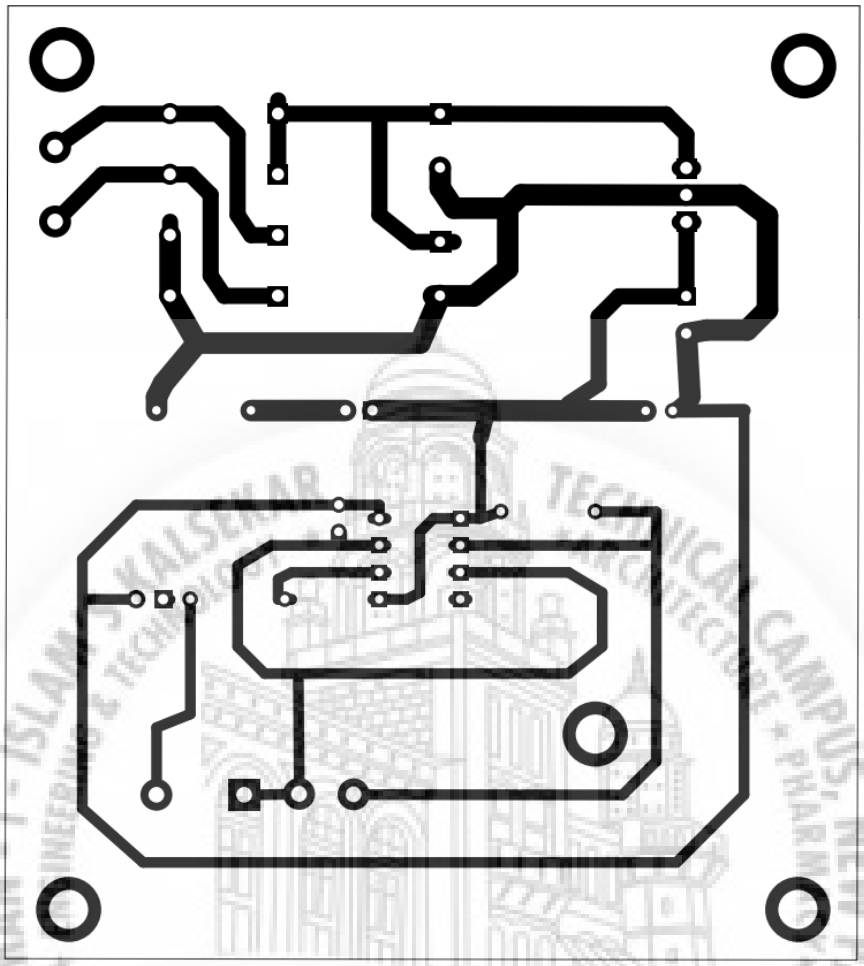
As a rule of thumb, a 10degC temperature rise in your track is a nice safe limit to design around. A handy reference table has been included in this article to give you a list of track widths vs current for a 10degC rise. The DC resistance in milli ohms per inch is also shown. Of course, the bigger the track the better, so don't just blindly stick to the table.

- **PCB fabrication:**



- PCB is printed circuit board which is of insulating base with layer of thin copper foil.
- The circuit diagram is then drawn on the PCB with permanent marker and then it is dipped in the solution of ferric chloride so that unwanted copper is removed from the PCB, thus leaving components interconnection on the board.
- The specification of the base material is not important to know in most of the application, but it is important to know something about copper foil which is drawn through a thin slip.
- The resistance of copper foil will have an affect on the circuit operation.
- Base material is made of lamination layer of suitable insulating material such as treated paper, fabric; or glass fibers and binding them with resin. Most commonly used base materials are formed paper bonded with epoxy resin.
- It is possible to obtain a range of thickness between 0.5 mm to 3 mm.
- Thickness is the important factor in determining mechanical strength particularly when the commonly used base material is "**Formea"** from paper assembly.
- Physical properties should be self-supporting these are surface resistivity, heat dissipation, dielectric, constant, dielectric strength.
- Another important factor is the ability to withstand high temperature.

- **Designing The Layout:**



- For designing the layout of our PCB, we used a software called EasyEDA, which is a web-based EDA tool suite that enables hardware engineers to design, simulate, share - publicly and privately - and discuss schematics, simulations and printed circuit boards. Other features include the creation of a Bill of Materials, Gerber and pick and place files and documentary outputs in PDF, PNG and SVG formats.
- EasyEDA is a web based EDA tool suite that enables hardware engineers to design, simulate, share publicly and privately, discuss schematics, simulations and printed circuit boards. Other features include the creation of a bill of materials, Gerber files and pick and place files and documentary outputs in PDF, PNG and SVG formats.
- EasyEDA allows the creation and editing of schematic diagrams, SPICE simulation of mixed analogue and digital circuits and the creation and editing of printed circuit board layouts and, optionally, the manufacture of printed circuit boards.
- EasyEDA is an integrated browser-based tool for schematic capture, SPICE circuit simulation, based on Ngspice, and PCB layout.
- Import from Altium Designer, CircuitMaker, Eagle, Kicad and LTspice file formats as well as generic SPICE netlists is supported. SPICE netlists can be exported to third party simulation tools and export of PCB netlists in Altium, PADS and Free PCB formats is also supported.

- The ability to import LTspice schematics and symbols provides a useful way to port schematics to PCB layout without having to redraw them from scratch.
- The tool also includes sharing and collaboration features and a comprehensive part and an expanding SPICE model library.
- While designing a layout, it must be noted that size of the board should be as small as possible.
- Before starting, all components should be placed properly so that an accurate measurement of space can be made.
- The component should not be mounted very close to each other or far away from one another and neither one should ignore the fact that some component reed ventilation, which considerably the dimension of the relay and transformer in view of arrangement, the bolting arrangement is also considered.
- The layout is first drawn on paper then traced on copper plate which is finalized with the pen or permanent marker which is efficient and clean with etching.
- The resistivity also depends on the purity of copper, which is highest for low purity of copper. The high resistance paths are always undesired for soldered connections.
- The most difficult part of making an original printed circuit is the conversion from, theoretical circuit diagram into wiring layout. without introducing cross over and undesirable effect.
- Although it is difficult operation, it provides great amount of satisfaction because it is carried out with more care and skill.
- The board used for project has copper foil thickness in the range of 25 40 75 microns.
- The soldering quality requires 99.99% efficiency.
- It is necessary to design copper path extra-large. There are two main reasons for this,

  i) The copper may be required to carry an extra-large overall current.

  ii) It acts like a kind of screen or ground plane to minimize the effect of interaction.

- The first function is to connect the components together in their right sequence with minimum need for interlinking i.e. the jumpers with wire connections.
- It must be noted, that when layout is done, on the next day it should be dipped in the solution and board is move continuously right and left after etching perfectly the board is cleaned with water and is drilled.

- After that holes are drilled with 1 mm or 0.8 mm drill. Now the marker on the P.C.B. is removed.

- The Printed Circuit Board is now ready for mounting the components on it.

- **Soldering:**

- For soldering of any joints first the terminal to be soldered are cleaned to remove oxide film or dirt on it. If required flux is applied on the points to be soldered.

- Now the joint to be soldered is heated with the help of soldering iron. Heat applied should be such that when solder wire is touched to joint, it must melt quickly.

- The joint and the soldering iron is held such that molten solder should flow smoothly over the joint.

- When joint is completely covered with molten solder, the soldering iron is removed.

- The joint is allowed to cool, without any movement.

- The bright shining solder indicates good soldering.

- In case of dry solder joint, an air gap remains in between the solder material and the joint. It means that soldering is improper. This is removed and again soldering is done.

- This is this way all the components are soldered on PCB.

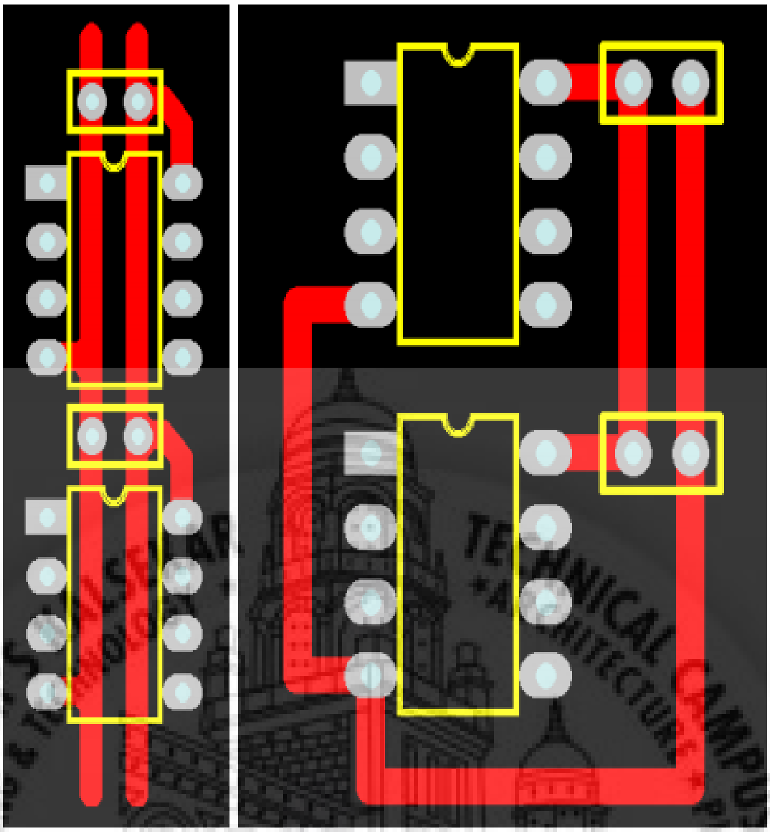
- **Basic Routing**

Now it's time for some basic routing rules.

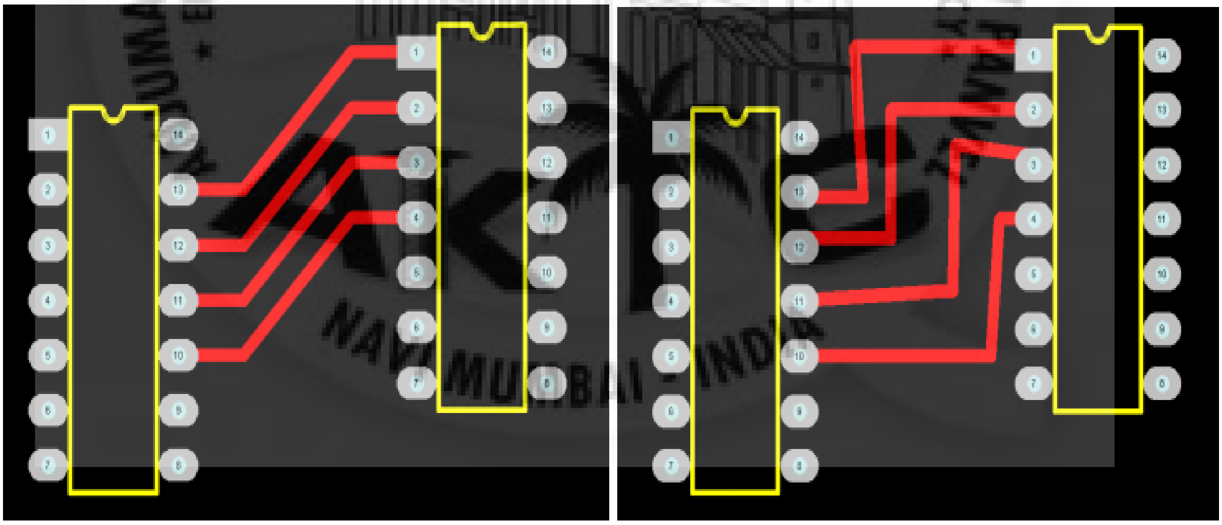
Routing is also known as "tracking". Routing is the process of laying down tracks to connect components on your board. An electrical connection between two or more pads is known as a "net".

Keep nets as short as possible. The longer your total track length, the greater it's resistance, capacitance and inductance. All of which can be undesirable factors.

- Tracks should only have angles of 45 degrees. Avoid the use of right angles, and under no circumstances use an angle greater than 90 degrees. This is important to give a professional and neat appearance to your board.
- "Snake" your tracks around the board, don't just go "point to point". Point to point tracking may look more efficient to a beginner at first, but there are a few reasons you shouldn't use it. The first is that it's ugly, always an important factor in PCB design! The second is that it is not very space efficient when you want to run more tracks on other layers.
- Enable your Electrical grid, which is sometimes referred to as a "snap to center" or "snap to nearest" option. Let the software find the centers of pads and ends of tracks automatically for you. This is great for when you have pads and tracks which aren't lined up to your current snap grid.
- Always take your track to the center of the pad, don't make your track and pad "just touch".
- Make sure your tracks go right through the exact center of pads and components, and not off to one side. Use of the correct snap grid will ensure that you get this right every time. If your track doesn't go through the exact center then you are using the wrong snap grid.
- Only take one track between 100 thou pads unless absolutely necessary. Only on large and very dense designs should you consider two tracks between pads.
- If your power and ground tracks are deemed to be critical, then lay them down first. Also, make your power tracks as BIG as possible.
- Keep power and ground tracks running in close proximity to each other if possible, don't send them in opposite directions around the board. This lowers the loop inductance of your power system, and allows for effective bypassing.
- Don't leave any unconnected copper fills (also called "dead copper"), ground them or take them out.
- Try and use through hole component legs to connect top tracks to bottom tracks. This minimizes the number of vias. Remember that each via adds two solder joints to your board. The more solder joints you have, the less reliable your board becomes. Not to mention that that it takes a lot longer to assemble.

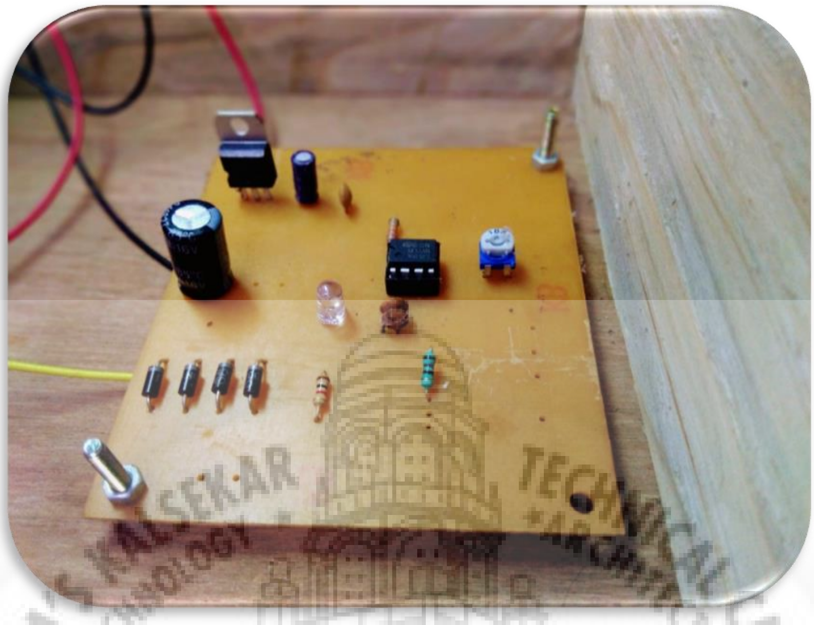


An example of GOOD power routing (Left) and BAD power routing (Right)



An example of GOOD routing (Left) and BAD routing (Right)

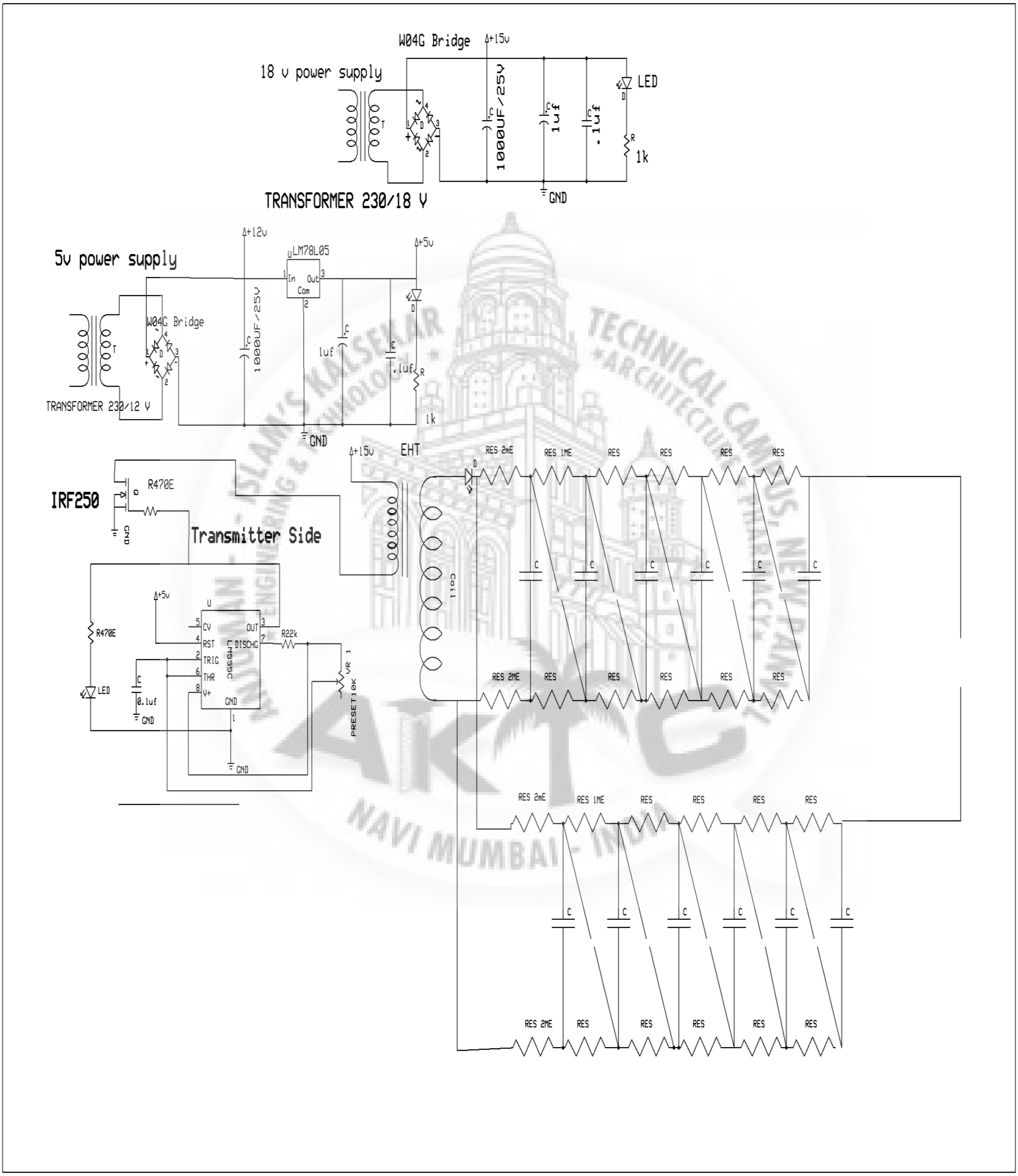
- **Final Assembly:**



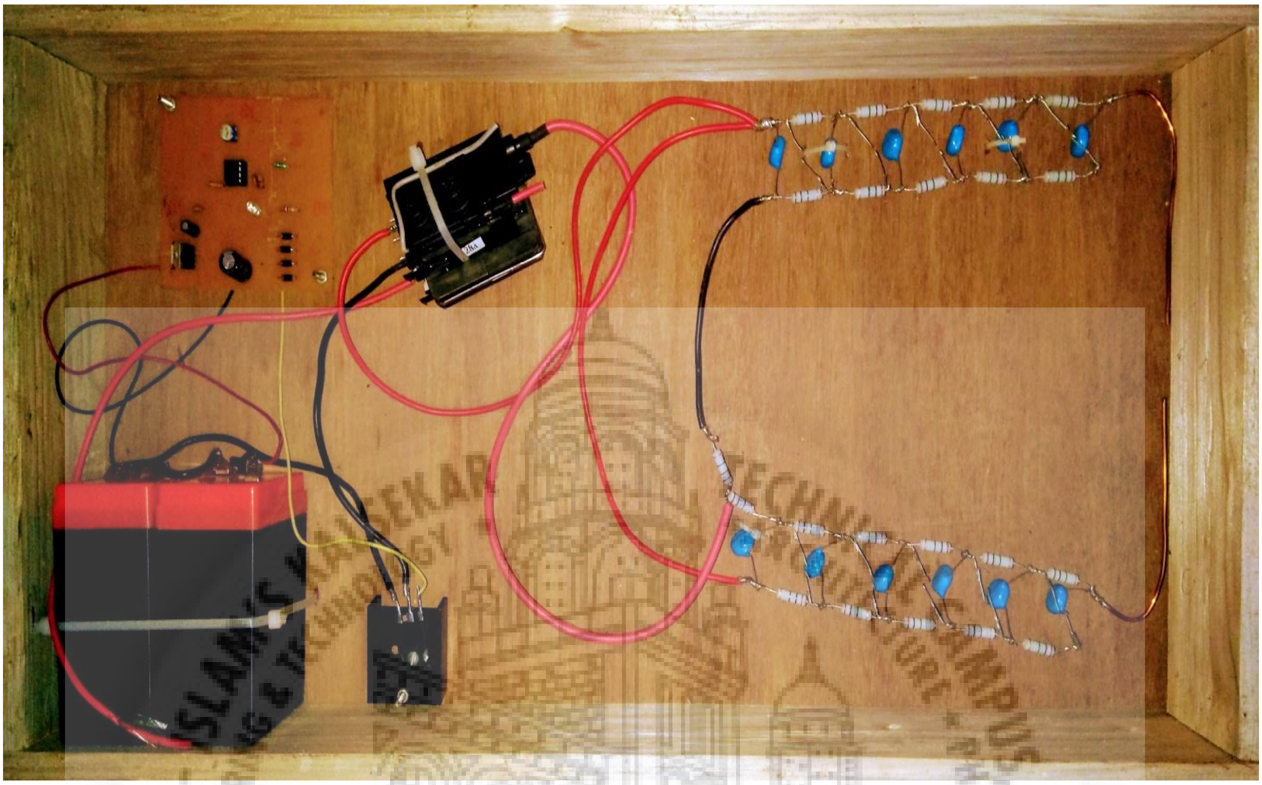
Once you have finished all your routing, your board isn't done quite yet. There are a few last-minute checks and finishing touches you should do.

- If you have thin tracks, then it's nice to add a "chamfer" to any "T" junctions, thus eliminating any 90-degree angles. This makes the track more physically robust, and prevents any potential manufacturing etching problems. But most importantly, it looks nice.
- Check that you have any required mounting holes on the board. Keep mounting holes well clear of any components or tracks. Allow room for any washers and screws.
- Minimize the number of hole sizes. Extra hole sizes cost you money, as the manufacturer will charge you based on not only the number of holes in your boards, but the number of different hole sizes you have. It takes time for the very high-speed drill to spin down, change drill bits, and then spin up again. Check with your manufacturer for these costs
- Double check for correct hole sizes on all your components. Nothing is more annoying than getting your perfectly laid out board back from the manufacturer, only to find that a component won't fit in the holes! This is a very common problem
- Ensure that all your vias are identical, with the same pad and hole sizes. Remember your pad to hole ratio. Errors here can cause "breakouts" in your via pad, where the hole, if shifted slightly can be outside of your pad.
- Check that there is adequate physical distance between all your components. Watch out for components with exposed metal that can make electrical contact with other components, or exposed tracks and pads.
- Change your display to "draft" mode, which will display all your tracks and pads as outlines. This will allow you to see your board "warts and all", and will show up any tracks that are tacked on or not ending on pad centers.

5. SYSTEM DESIGN & CONNECTION CIRCUIT:



- **Circuit Explanation:**



- **About Marx Network:**

It is a combination of resistors and capacitors which is used for doubling/multiplying the voltage.

High voltage can be obtained from these sequences of elements, i.e. by connecting the resistors and capacitors in a certain configuration.

- **Working:**

All the capacitors are charged in parallel and discharged in series. To overcome charging constraints of capacitors, we use dual (double) Marx Network in order to obtain more voltage, and avoid failure of capacitors.

It will be a discharging output, i.e. discontinuous output or pulsating high voltage at output (DC). Since output is high, a high DC input of around 2-3kv is required in order to produce 25-30kv at the output of a single channel network.

So, we need a rectifier circuit with a diode for unidirectional power flow. Also, to raise the voltage, we use a transformer. The transformer we used is called as a flyback transformer.

Here, output of flyback transformer is AC in nature, which is rectified and fed to the Marx network. The primary input of flyback transformer 6v DC which we give through n-channel MOSFET.

This n-channel MOSFET switches the DC signal with such a frequency that it acts as an AC signal.

A 6v DC from the battery is fed to the transformer. This DC signal is converted in frequency (Oscillations). For this, we required an oscillator circuit. Therefore, we used an oscillator circuit that produces 4kHz of frequency. This is not a power signal. To convert it into a power signal, we had to use an amplifier. More particularly, an n-channel MOSFET. Ferrite core is used since it is of high frequency applications. Thus, an arc of 2-3cm is produced.

- **Circuit Design:**

Battery: 12v, 4.5AH, Sealed maintenance free (SMF) Lead Acid Battery.

- **Stage 1:** 12v DC to 5v DC.

DC voltage level is 12v, DC. This 12v is supplied through an on/off switch, diode for reverse polarity protection to voltage regulator (7805). It is a 3-terminal device – input, ground and output. It has filters with power indication LED, Current limitting resistor. Capacitors around 7805 are 100microFarad and 10microFarad.

Stage 1 ends with output as 5v DC.

- **Stage 2:** Oscillator circuit

12v DC has to be converted into AC. We use oscillator (IC 555 timer), which is used in three modes:

i) Astable
ii) Bistable
iii) Monostable

We operated the oscillator circuit in astabe mode.

IC 555 timer pin configuration:

Pin no. 4,8 – Power Supply (+5v)

Pin no. 1 – Ground

Pin no. 5 – Capacitor

Pin no. 6,2 – Short

Pin no. 3 – Pulse output through current limiting resistor.

R1 R2 C: Designed such that output frequency can be obtained as required. (4KHz here)

R2: Variable can somewhat change output frequency 1kilo Ohm CLR.

Now the output square pulse needs to be amplified before being fed to the transformer. The voltage of output square pulse is same as oscillator input that is 5v and current will be 5v/1kOhm = 5milliAmpere.

To convert this to power signal, we connect MOSFET as an amplifier n-channel, common ground source to drain in series with primary of Flyback transformer.

Therefore, we give 12v supply to primary of flyback transformer (input), and get a 4kv output from secondary.

Now the question arises that how do we give DC to transformer? For this, the MOSFET is connected between one terminal of primary and ground, thus, we are not grounding the transformer directly. MOSFET here acts as a switch, and switches on as the pulse arrives at MOSFET.

We used ferrite core transformer since it operates at high frequency. If we use iron core transformer, iron losses are directly proportional to frequency, hence, higher the frequency, more will be the losses, and thus the efficiency of the transformer will decrease. This is why we don’t use iron core transformer for higher frequency operations.

- **Stage 3:** Marx network:

Capacitors connected in parallel are separated by resistors in order to limit current during charging.

Capacitor rating: 10nanoFarad, 15kv breakover voltage, will be charged up to 4kv.
Resistors rating: 1MegaOhms, 1w.

Each capacitor will be charged up to 4kv in parallel. A small spark gap is provided between each two parallel connected capacitors. Now the total voltage between these two capacitors is 8kv. The spark gap is of such a length that it cannot sustain 8kv and the air gap between them breaks down and arc is struck between them. Thus, connecting them in series. This process goes on for the next pair, and so on.

The result is that all the capacitors gets connected in series and discharge at the end point, thus multiplying the voltage.

If 5 capacitors are connected, each charged up to 4kv, then output will be around

$$5 \times 4 = 20\text{kv}$$

This charging and discharging happens within a very short period of time, so thee is no sustained arc, it is like high voltage pulses (Discharge).

6. TESTING AND TROUBLE SHOOTING

6.1 Flyback Transformer

Problems found in a flyback transformer:

1. A shorted turned in the primary winding.
2. Shorted internal high voltage diode in secondary winding.
3. Flyback Transformer breakdown at full operating voltage (breakdown when under load).
4. Short circuit between primary and secondary winding.

- **Symptoms**

1. If there is a shorted turned in primary winding:
   - No high voltage
   - Power blink
   - Horizontal output transistor will get very hot and later become shorted.
2. If capacitor is shorted:
   - No display (No high voltage)
   - B+ voltage drop.
   - Secondary diode (UF5404) will burned or shorted.
   - Horizontal output transistor will get shorted.

- **How to check if a primary winding is good or bad in a Flyback Transformer?**

- By using a flyback/LOPT tester, this instrument identifies faults in primary winding by doing a ‘ring’ test.
- It can test the winding even with only one shorted turned.
- Just simply connect the probe to primary winding.
- The readout is a clear ‘bar graph’ display which show you if the flyback transformer primary winding is good, or shorted.

- **How to diagnose if the internal capacitor is open or shorted?**

By using a normal analog multimeter and a digital capacitance meter. A good capacitor has the range from 1.5 nano-farad to 3 nano-farad.

1. First set your multimeter to X10K range.
2. Place your probe to anode and cold ground.
3. You must remove the anode cap in order to get a precise reading.
4. Cold ground means the monitor chassis ground.
5. If the needle of the multimeter shows a low ohm reading, this mean the internal capacitor is shorted.
6. If the needle does not move at all, this doesn’t mean that the capacitor is O.K.
7. You have to confirm this by using a digital capacitance meter.
8. If the reading from the digital capacitance meter shows 2.7nf, this mean the capacitor is within range (O.K.).
9. And if the reading showed 0.3nf, this mean the capacitor is open.

6.2 MOSFET

MOSFET failure modes-

- Avalanche failure.
- dv/dt failure (Motor brush noise)
- Excess power dissipation.
- Excess Current.
- 'Foreign' objects.
- Jammed (or blocked) motor.
- Rapid acceleration/deceleration.
- Short-circuited load.

- **Following testing procedure is for use with a digital multimeter in the diode test-rang e with a minimum of 3.3 volt over d.u.t. (diode-under-test)**

Connect the source of the MOSFET to the meter's negative lead.

1. Hold the MOSFET by the case or the tab but don't touch the metal parts of the test probes with any of the other MOSFETs terminals until needed.
2. First, touch the meter's positive lead on to the MOSFET gate.
3. Now move the positive probe to the drain. You should get a low reading. The MOSFETs internal capacitance on the gate has now been charged up by the meter and the device is turned on.
4. With the meter positive still connected to the drain, touch a finger between source and gate. The gate will be discharged through your finger and the meter reading should be high, indicating a non-conductive device

- **Remedies**

When MOSFETs fail, they often go short circuit drain-to-gate. This can put the drain voltage back on to the gate, where of course it feeds into the drive circuitry, possibly glowing that section. It will also get to any other paralleled MOSFET gates, glowing them also.

So, if the MOSFETs are deceased, check the drivers as well. This fact is probably the best reason for adding a source-gate Zener diode. Zener fail short circuit and a properly connected Zener can limit the damage in a failure.

- **In this way you avoid failures of the switching transistor and driver circuit:**

- There are different voltage thresholds of driver ICs and MOSFET gates. They have to fit together, read the datasheets for details and study the small print!
- High-impedance times are always present at the gate and dangerous because disturbances can trigger the switching transistor. Therefore, always install a resistor from the gate to source very close (e.g. 4.7 to 22 kΩ).

7. CONCLUSION

- **Conclusion:**

Marx generators are effective systems for efficient voltage multiplication. For short pulse generation the Marx should operate near its critical damping due to a balance between voltage efficiency and overshoot. The transient wave erection Marx should be used where fast risetimes are critical.

- **Applications:**

  - Marx generators are used to provide high-voltage pulses for the testing of insulation of electrical apparatus such as large power transformers, or insulators used for supporting power transmission lines. Voltages applied may exceed two million volts for high-voltage apparatus.

  - The major application of the impulse generator circuit is to test high voltage devices. Lightning arresters, Fuses, TVS diodes, different types of surge protectors, *etc.* are tested using the Impulse voltage generator. Not only in the testing field, but the Impulse generator circuit is also an essential instrument that is used in nuclear physics experiments as well as in lasers, fusion and plasma device industries.

  - The Marx generator is used for the simulation purposes of lightning effects on power-line gear and in aviation industries. It is also used in X-Ray and Z machines. Other uses, such as insulation testing of electronic devices are also tested using impulse generator circuits.

  - Large scale Generators are used in the Aero-scope Industry to examine what lightning pulses do to outer skin of Jet Aircraft and Passenger Planes.

  - High voltage insulation test and ignitions.

  - One application is so- called boxcar switching of a Pockels cell. Four Marx generators are used, each of two electrodes of the Pockels cell being connected to a positive pulse generator and a negative pulse generator. Two generators of opposite polarity one on each electrode, are first fired to charge the Pockels cell into one polarity. This will also party charged bore-hand. Leakage through the Marx resisters needs to be compensated by a small bias current through the generator. At the trailing edge of the boxcar, the two other generators are fired to “reverse” the cell.

  - For the industrial food applications, Marx generator is used to generate pulsed Electric Fields for bacteriological inactivation. The industrial bipolar generator which is based on Marx principle, which decreases the complexity and the cost of the circuit which is used to generate positive and negative pulses into food processing uses for microorganism cleaning.

  - For the dv/dt testing of the power semiconductor devices.

  - A solid-state modular Marx generator was used for the dV/dt testing of the power semiconductor devices (MOSFET), which produces voltage transients up to 1kV with the rise time of the order of 10 ns. The testing was done to know the dV/dt rating of the power semiconductor devices because the dV/dt induced turn-on can result in the sudden failure of the device. The results which were shown include the dV/dt testing of resistive and power semiconductor loads.

- Output pulses of the solid-state Marx Generator is applied to the Load as Liquid. Here liquid can be waste water or liquid food. The liquid is flowing through or placed between two electrodes, which constitute a treatment chamber gap where two electrodes are placed at certain distance.

- By controlling duty cycle of device output pulse waveform can be control. Bacteria in liquid can be eliminated by high voltage pulse electric (PEF).

- A Pulsed high voltage is used to remove microorganisms in liquid. The generated high voltage and high repletion rate pulses produces strong Pulse electric field through liquid. This applied pulse electric field through liquid. This applied Pulse electric field (PEF) will physically damage the microorganism cell and bacteria membrane. In the PEF technology, the process can be done without increasing temperature of liquid so that we can prevent the loss of vitamins, taste, and color from the product.

- **Future Scope:**

- Suitable for parking at multiplexes, mall, toll booths, signals.

- New non thermal pasteurization process on liquid can be done with reduced overall cost and saving in energy. The presented topology can bring a completely new extent of capability in bacterial inactivation process for liquid food and waste water.

- Uses: charging batteries and using them to light up the streets, etc.

- Such speed breakers can be designed for heavy vehicles, thus increasing input torque and ultimately output of generator.

- More suitable and compact mechanisms to enhance efficiency, and ultimately, we can make the earth clean.

- **Advantages:**

i) Proven and reliable way of producing high impulse voltages.
ii) Easy circuit configuration.
iii) Low power absorption.
iv) Low input voltage.
v) Output voltage can be increased with small changes in the existing circuit.
vi) Higher life cycle of circuit elements due to short discharge cycle.

- **Disadvantages of the Marx Generator**

  - Long charge time:

Marx generator uses resistors to charge the capacitor. Thus, the charge time gets higher. The capacitor that is closer to the power supply gets charged faster than the others. This is due to the increased distance because of increased resistance between the capacitor and the power supply. This is a major drawback of the Marx generator unit.

  - Loss of efficiency:

Due to the same reason as previously described, as the current flows through the resistors, the efficiency of the Marx generator circuit is low.

  - The short life span of the spark gap:

The repetitive cycle of discharge through the spark gap shortens the lifetime of the electrodes of a spark gap that needs to be replaced from time to time.

  - The repetition time of charge and discharge cycle:

Due to the high charge time, the repetition time of the impulse generator is very slow. This is another major drawback of the Marx generator circuit.

8. DATASHEETS

- **For MOSFET:**

IRFP250N

Power Dissipation-Max (Abs)	214 W
Package Description	FLANGE MOUNT, R-PSFM-T3
Pin Count	**3**
Additional Feature	AVALANCHE RATED
Avalanche Energy Rating (Eas)	315 mJ
Case Connection	DRAIN
Configuration	SINGLE WITH BUILT-IN DIODE
DS Breakdown Voltage-Min	200 V
Drain Current-Max (Abs) (ID	30 A
Drain-source On Resistance-Max	0.075 Ω
Number of Terminals	3
Operating Mode	ENHANCEMENT MODE
Operating Temperature-Max	175 °C
Operating Temperature-Min	-55 °C
Polarity/Channel Type	N-CHANNEL

- **For PCB:**

Track Width Reference Table (for 10deg C temp rise). Track Width is in Thous (mils)			
Current (Amps)	Width for 1oz	Width for 2 oz	milli Ohms/Inch
1	10	5	52
2	30	15	17.2
3	50	25	10.3
4	80	40	6.4
5	110	55	4.7
6	150	75	3.4
7	180	90	2.9
8	220	110	2.3
9	260	130	2.0
10	300	150	1.7

- **For 555 timer:**

Parameter	Symbol	Conditions	Min.	Typ.	Max.	Unit
Supply Voltage	V_{CC}	-	4.5	-	16	V
Supply Current (Low Stable) (Note1)	I_{CC}	V_{CC} = 5V, $R_L = \infty$	-	3	6	mA
		V_{CC} = 15V, $R_L = \infty$	-	7.5	15	mA
Timing Error (Monostable) Initial Accuracy (Note2) Drift with Temperature (Note4) Drift with Supply Voltage (Note4)	ACCUR $\Delta t/\Delta T$ $\Delta t/\Delta V_{CC}$	R_A = 1kΩ to100kΩ C = 0.1μF	-	1.0 50 0.1	3.0 0.5	% ppm/°C %/V
Timing Error (Astable) Intial Accuracy (Note2) Drift with Temperature (Note4) Drift with Supply Voltage (Note4)	ACCUR $\Delta t/\Delta T$ $\Delta t/\Delta V_{CC}$	R_A = 1kΩ to 100kΩ C = 0.1μF	-	2.25 150 0.3	-	% ppm/°C %/V
Control Voltage	V_C	V_{CC} = 15V	9.0	10.0	11.0	V
		V_{CC} = 5V	2.6	3.33	4.0	V
Threshold Voltage	V_{TH}	V_{CC} = 15V	-	10.0	-	V
		V_{CC} = 5V	-	3.33	-	V
Threshold Current (Note3)	I_{TH}	-	-	0.1	0.25	μA
Trigger Voltage	V_{TR}	V_{CC} = 5V	1.1	1.67	2.2	V
		V_{CC} = 15V	4.5	5	5.6	V
Trigger Current	I_{TR}	V_{TR} = 0V		0.01	2.0	μA
Reset Voltage	V_{RST}	-	0.4	0.7	1.0	V
Reset Current	I_{RST}	-		0.1	0.4	mA
Low Output Voltage	V_{OL}	V_{CC} = 15V I_{SINK} = 10mA I_{SINK} = 50mA	-	0.06 0.3	0.25 0.75	V V
		V_{CC} = 5V I_{SINK} = 5mA	-	0.05	0.35	V
High Output Voltage	V_{OH}	V_{CC} = 15V I_{SOURCE} = 200mA I_{SOURCE} = 100mA	12.75	12.5 13.3	-	V V
		V_{CC} = 5V I_{SOURCE} = 100mA	2.75	3.3	-	V
Rise Time of Output (Note4)	t_R	-	-	100	-	ns
Fall Time of Output (Note4)	t_F	-	-	100	-	ns
Discharge Leakage Current	I_{LKG}	-	-	20	100	nA

- **For Flyback Transformer:**

MYRRA Part N°	Control IC	Mains	Total output Power (max)	Outputs S1		S2		Frequency	Primary Inductance	Pinout	Remarks
		Voltage Range Vac	Watts	Voltage Range Vdc	Max Current Adc	Voltage Range Vdc	Max Current Adc	kHz	µH		
74000	VIPer20	85 - 265	4	4,5 - 6	0,95	11 - 15	0,35	70	3900	Fig.1	
	TOP221P	85 - 265	4	3,3 - 7	1,2	8 - 17	0,35	100			
74001	VIPer20	85 - 265	6	5	1,2			70	3000	Fig.2	Note 1
	VIPer20	85 - 265	3	5	0,6			40			Note 1
	TOP221P	185 - 265	6	3 - 6	1,2			100			
	TOP221P	85 - 265	4,5	3 - 6	0,9			100			
	MC33369	85 - 265	6	3,3 - 6	1,2			100			
	TDA16831	185 - 265	6	4 - 6	1,2			100			
74002	VIPer20	85 - 265	6	14	0,43			70	3000	Fig.2	Note 1
	VIPer20	85 - 265	3	14	0,21			40			Note 1
	TOP221P	185 - 265	6	9 - 18	0,5			100			
	TOP221P	85 - 265	4,5	9 - 18	0,4			100			
	MC33369	85 - 265	6	10 - 18	0,5			100			
	TDA16831	185 - 265	6	11,5 - 17	0,5			100			
74003	VIPer20	85 - 265	6	2,5 - 3,5	1,8	4 - 5,2	1,2	70	3000	Fig.3	
	VIPer20	85 - 265	3	2,5 - 3,5	0,9	4 - 5,2	0,6	40			
	TOP221P	85 - 265	4,5	2 - 4	1,8	3 - 6	1,2	100			
	TOP221P	185 - 265	5	2 - 4	1,8	3 - 6	1,2	100			
	MC33369	85 - 265	6	2,5 - 4	1,8	3,8 - 6	1,2	100			
	TDA16831	185 - 265	6	3 - 4	1,8	4,5 - 6	1,2	100			
74010	VIPer20	85 - 265	8	4,5 - 6	1,6	11 - 15	0,7	70	1660	Fig.1	
	VIPer20	185 - 265	10	4,5 - 6	2	11 - 15	0,85	70			
	TOP222P	85 - 265	8	3,3 - 7	1,6	8 - 17	0,7	100			
	TOP222P	185 - 265	10	3,3 - 7	2	8 - 17	0,85	100			
	MC33369	85 - 265	8	4 - 7	1,6	10 - 17	0,7	100			
	MC33369	185 - 265	10	4 - 7	2	10 - 17	0,85	100			
	TDA16831	92 - 265	7,5	4,8 - 6	1,5	12 - 15	0,62	100			
	TDA16831	185 - 265	10	4,8 - 6	2	12 - 15	0,85	100			
	KA5L0165R	85 - 265	7	5 - 7	1,4	12,5 - 17	0,6	50			
	KA5H0165RN	185 - 265	10	5,6 - 7	1,8	14 - 17	0,7	100			

- **General purpose diodes - IN4007:**

Maximum Ratings:

Rating	Symbol	1N4001	1N4002	1N4003	1N4004	1N4005	1N4006	1N4007	Unit
*Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	50	100	200	400	600	800	1000	Volts
*Non–Repetitive Peak Reverse Voltage (halfwave, single phase, 60 Hz)	V_{RSM}	60	120	240	480	720	1000	1200	Volts
*RMS Reverse Voltage	$V_{R(RMS)}$	35	70	140	280	420	560	700	Volts
*Average Rectified Forward Current (single phase, resistive load, 60 Hz, see Figure 8, T_A = 75°C)	I_O	1.0							Amp
*Non–Repetitive Peak Surge Current (surge applied at rated load conditions, see Figure 2)	I_{FSM}	30 (for 1 cycle)							Amp
Operating and Storage Junction Temperature Range	T_J T_{stg}	– 65 to +175							°C

Electrical Characteristics:

Rating	Symbol	Typ	Max	Unit
Maximum Instantaneous Forward Voltage Drop (i_F = 1.0 Amp, T_J = 25°C) Figure 1	v_F	0.93	1.1	Volts
Maximum Full–Cycle Average Forward Voltage Drop (I_O = 1.0 Amp, T_L = 75°C, 1 inch leads)	$V_{F(AV)}$	—	0.8	Volts
Maximum Reverse Current (rated dc voltage) (T_J = 25°C) (T_J = 100°C)	I_R	0.05 1.0	10 50	µA
Maximum Full–Cycle Average Reverse Current (I_O = 1.0 Amp, T_L = 75°C, 1 inch leads)	$I_{R(AV)}$	—	30	µA

- **Carbon Film Leaded Resistor:**

■Electrical Specifications

Type \ Item	Power Rating at 70°C	Operating Temp. Range	Max. Working Voltage	Max. Overload Voltage	Dielectric Withstanding Voltage	Resistance Range ±5%
Carbon	0.125W	-55 ~ +155°C	150V	300V	300V	0.1Ω - 22MΩ
Carbon	0.25W		250V	500V	500V	1Ω - 10MΩ
Carbon(H)	0.5W		300V	500V	500V	0.1Ω - 22MΩ
Carbon(H)	1W		400V	800V	800V	1Ω - 10MΩ
Carbon(H)	2W		500V	1000V	1000V	0.1Ω - 10MΩ

- **Voltage Regulator L7805:**

Electrical characteristics of L7805:

Symbol	Parameter	Test conditions	Min.	Typ.	Max.	Unit
V_O	Output voltage	T_J = 25°C	4.8	5	5.2	V
V_O	Output voltage	I_O = 5 mA to 1 A, V_I = 8 to 20 V	4.65	5	5.35	V
ΔV_O(1)	Line regulation	V_I = 7 to 25 V, T_J = 25°C		3	50	mV
		V_I = 8 to 12 V, T_J = 25°C		1	25	
ΔV_O(1)	Load regulation	I_O = 5 mA to 1.5 A, T_J = 25°C			100	mV
		I_O = 250 to 750 mA, T_J = 25°C			25	
I_d	Quiescent current	T_J = 25°C			6	mA
ΔI_d	Quiescent current change	I_O = 5 mA to 1 A			0.5	mA
		V_I = 8 to 25 V			0.8	
$\Delta V_O/\Delta T$	Output voltage drift	I_O = 5 mA		0.6		mV/°C
eN	Output noise voltage	B =10 Hz to 100 kHz, T_J = 25°C			40	µV/V_O
SVR	Supply voltage rejection	V_I = 8 to 18 V, f = 120 Hz	68			dB
V_d	Dropout voltage	I_O = 1 A, T_J = 25°C		2	2.5	V
R_O	Output resistance	f = 1 kHz		17		mΩ
I_{sc}	Short circuit current	V_I = 35 V, T_J = 25°C		0.75	1.2	A
I_{scp}	Short circuit peak current	T_J = 25°C	1.3	2.2	3.3	A

9. References

A. IEEE Papers.

1. Solid state Marx Generator using series-connected IGBTs. (2005) – Ju Won Baek, Dong Wook Yoo.

2. Marx generator design and performance (2002) – W.J. Carey and J.R. Mayes.

3. Repetitive and High Voltage Marx Generator Using Solid-state Devices (2007) – Yifan Wu, Kefu Liu, Jian Qiu

B. Marx Generator Operation.

1) David A. Platts, "Gigawatt Marx Bank Pulsers", Ultra-Wideband Radar: Proceedings of the First Los Alamos Symposium, 1990, CRC Press.

C. Triggering and, high repetition rate systems.

2) J. R. Mayes and W. J. Carey, "Spark Gap Switching with Photoconductive Switches," presented at the 12th IEEE International Pulsed Power Conference, Monterey, California, 1999.

3) J. R. Mayes W. J. Carey, W. C. Nunnally, and L. Altgilbers, "Sub-nanosecond jitter operation of Marx generators", presented at the 13th IEEE International Pulsed Power Conference, Las Vegas, Nevada, 2001.

4) M. G. Grothaus, S. L. Moran and L. W. Hardesty, "High-Repetition-Rate Hydrogen Marx Generator," Proc. of the 20th Power Modulator Symposium, June 1992, Myrtle Beach, SC.

5) S. L. Moran, M. G. Grothaus, L. W. Hardesty, "Five Pulse, 10 GW, High Repetition-Rate Hydrogen Spark Switch Experiment," Proc. of the 20th Power Modulator Symposium, June 1992, Myrtle Beach, SC.

6) J. O'Loughlin, J. Lehr, D. Loree, "High repetition rate charging a Marx type generator", presented at the 13th IEEE International Pulsed Power Conference, Las Vegas, Nevada, 2001.

D. Systems and applications.

7) J. R. Mayes W. J. Carey, W. C. Nunnally, and L. Altgilbers, "The Marx generator as an ultra-wideband source," presented at the 13th IEEE International Pulsed Power Conference, Las Vegas, NV, 2001.

8) J. R. Mayes W. J. Carey, W. C. Nunnally, and L. Altgilbers, "The Gatling Marx generator system", presented at the 13th IEEE International Pulsed Power Conference, Las Vegas, NV, 2001.

E. Low jitter and solid-state systems.

9) J. R. Mayes and W. J. Carey, “Spark Gap Switching with Photoconductive Switches,” presented at the 12th IEEE International Pulsed Power Conference, Monterey, California, 1999.

10) W. J. Carey, “Generation of sub-nanosecond pulses using a solid-state Marx circuit with TRAPATT diode switches,” presented at the 21th International Power Modulator Symposium, Costa Mesa, California, 1994.

F. Pulse Forming Network.

11) S. C. Glidden and H. D. Sanders, “Solid State Spark Gap Replacement Switches”, Proceedings of the 15th IEEE Pulsed Power Conference, Monterey CA, June 2005.

12) Pulsed Inductively Generated, Streaming Plasma Ion Source for Heavy Ion Fusion Linac, DoE Grant DEFG02-01ER83147.

13) S. Glidden, “Compact High Voltage Solid State Switch”, United States Patent number 6,624,684 B2 (2003).

14) S. C. Glidden and H. D. Sanders, “Multi-Stage High Voltage Solid State Switch”, United States Patent Application number 10/905,982.

G. Internet.

https://www.utm.edu/staff/leeb/mostest.ht

https://www.power-and-beyond.com/mosfet-driver-a-common-cause-of-failure-a-883520/

https://www.power-and-beyond.com/mosfet-driver-a-common-cause-of-failure-a-883520/

https://www.digchip.com/datasheets/parts/datasheet/161/NE555DX-pdf.php

https://www.findchips.com/compare/IRFP250N--vs--IRFP250?medium