SIMULATION AND DEVELOPMENT OF PORTABLE PULSE POWER GENERATOR

Major Project Report

Submitted in Partial Fulfillment of the Requirements for the degree of

MASTER OF TECHNOLOGY

IN

ELECTRICAL ENGINEERING

(Power Apparatus & Systems)

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CERTIFICATE

This is to certify that the Major Project Report entitled "**SIMULATION AND DEVELOPMENT OF PORTABLE PULSE POWER GENERATOR**" submitted by **Mr. PATEL DHAVAL RAMESHBHAI (05MEE007)** towards the partial fulfillment of the requirements for the award of degree in Master of Technology (Electrical Engineering) in the field of Power Apparatus & Systems of Nirma University of Science and Technology is the record of work carried out by him/her under our supervision and guidance. The work submitted has in our opinion reached a level required for being accepted for examination. The results embodied in this major project work to the best of our knowledge have not been submitted to any other University or Institution for award of any degree or diploma.

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Dhaval R. Patel

ABSTRACT

Pulsed power is defined as an energy storage system where energy is released in the form of an intense pulse or pulses. Pulsed power technology is characterized by the concentration of energy, both in time and space, to pulses of high intensity. Pulsations of energy augment power efficiency and enables new applications that are not possible with the conventional continuous flow of energy. In the past, absence of pulsed power technology was ascribed to the limitations of the energy storage components and switching components. But now, better capacitors, inductors and switches have made the new application of pulse technology possible. In recent years, several new technologies are introduced for the high voltage and high repetition rate pulse generation. Development of high voltage high repetition rate pulse generator having compact size is important for bringing revolution in pulsed power applications. Hence it is very important to make compact and portable pulse power generator which can be use in aircraft launching as in defense application, high current utility back storage and high current testing of electrical apparatus.

A compact and portable pulsed power generator driven by portable battery has been designed and developed to produce the maximum peak current pulsed into high inductive load. Capacitor bank is used to store energy and that energy is discharged into inductive load to produced multi kilo-ampere current pulsed into high inductive load, so exploration of capacitor is needed. Electrolytic capacitors are used to make capacitor bank. A fly back converter is used as charging unit of capacitor bank. It steps up battery voltage to the high dc voltage to charge capacitor bank.. Full bridge rectifier rectifies a voltage at the secondary of flyback transformer. A relay timer circuit is also provided to stop the capacitor bank charging after required charged voltage. To avoid spurious triggering and to eliminate the ground interference optical isolation circuit is provided to driver circuit. A SCR with proper ratings is used as discharge switch. A triggering circuit of SCR also designed and tested. A proper value of inductive load is designed. To make circuit critically damped a proper value of resistor is also inserted into the load side.

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NOMENCLATURE

A	Area of cross section of inductor coil in meter square
PPG	Pulse power generator
CESS	Capacitive energy storage system
CT	Current transformer
C	Capacitance in faraday
E	Energy store in joule
IES	Inductive energy storage system
IGBT	Insulated gate bipolar transistor
I	Current in amps.
Ic	Collecter current
Ig	Gate current
Ib	Base current
LC	Inductive-capacitive network
L	Inductance in henries
L	Length of the coil in meter
MOSFET	Metal oxide surface field effect transistor
N1	Number of primary turns of pulse transformer
N2	Number of secondary turns of pulse transformer
N	Number of turns
PDE	Pulsed detonation engine
Q	Charge in coulomb
R_g	Gate to cathode resistance
SCR	Silicon control rectifier
T_{STEP}	Time period of step pulse
T	Time period in secs.
V_{STEP}	Voltage of base pulse
Vb	Base voltage
V_{CE}	Collector-emitter voltage
μ_0	Permeability free space = $4\pi \times 10^{-7}$ H/m
μ_r	Relative permeability of core material = 1

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CHAPTER 1
INTRODUCTION

1.1 INTRODUCTION OF PULSE POWER SYSTEM

Pulsed power is defined as an energy storage system where energy is released in the form of an intense pulse or pulses. Pulsed power technology is characterized by the concentration of energy, both in time and space, to pulses of high intensity. Pulsations of energy augment power efficiency and enables new applications that are not possible with the conventional continuous flow of energy. Chemical and physical processes are characterized by non-linearity, where a critical threshold, such as activation energy, has to exceed before the reaction or process takes place. By supplying energy in pulses, peak power of the pulses can well exceed the critical threshold while maintaining a moderate average power demand. The high flux of energy into the treated object is also much faster than the energy transported away from treated area, preventing energy from being diluted in the workplace. Recent advances in the numerous components of pulsed power systems-batteries, capacitors, inductors and charging systems-have made it possible to economically apply pulsed power technology to the commercial and industrial environment.

In the past, absence of pulsed power technology was ascribed to the limitations of the energy storage components and switching components. But now, better capacitors, inductors and switches have made the new application of pulse technology possible. In recent years, several new technologies are introduced for the high voltage and high repetition rate pulse generation. Development of high voltage high repetition rate pulse generator having compact size is important for bringing revolution in pulsed power applications. Pulsed power technology is a new and promising field with a large number of existing and emerging areas. Among these are plasma assisted combustion flame ignition, pulsed volume discharges for generation of ozone, breaking crude oil emulsions, bioelectric, water purification using pulsed streamer discharges in micro bubbled water [1], nitrogen oxide removal [2], aircraft pulsed detonation engine (PDE) ignition, and lastly, plasma source ion implantation [3] which is an emerging technology for surface treatment of metals and polymer materials.

Pulsed electric fields are also known to affect the transport processes of the outer membrane of biological cell. Based on capacitive coupling to cell substructures, it has the potential to affect transport processes across sub cellular membranes and can be used for gene transfer into the cell nuclei. It also triggers intracellular processes, such as programmed cell death that can be used for cancer treatment. There is a need to develop high voltage, high repetition rate pulse power generator for its use in wide range of applications.

1.2 BASIC BLOCK DIAGRAM OF PULSE POWER GENERATOR

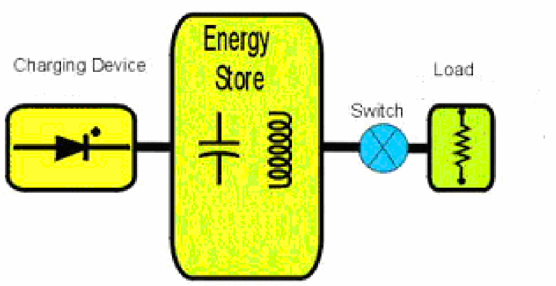


Figure 1.2 Basic block diagram of pulse power generator

Pulsed power is defined as an energy storage system where energy is released in the form of an intense pulse or pulses. Pulsed power technology is characterized by the concentration of energy, both in time and space, to pulses of high intensity. Pulsed power science and technology deals with the physical and technical foundations for the production and application of high voltage pulses with very high power (>1 Gigawatt) and pulse energies (>1 Kilojoules). A generator scheme for the production of high power electric pulses is always based on an energy store that is charged slowly at relatively low charging power and – by activating a switch – is discharged rapidly. To achieve the desired power multiplication this process can be repeated several times if necessary, by shortening the charge and discharge period from step to step.

In pulsed power system energy stored into energy storage system by power supply and that energy is further discharged into load through a discharge switch in very short time duration to produce large power (Power=Energy/Time). This can be use in aircraft launching as in defense application, high current back up utility storage and high current testing of electrical apparatus. There are two ways in pulsed power generation and compression. One is called “capacitive energy storage” and another is called “inductive energy storage”. In this system capacitive energy storage system is used because of some disadvantages of inductive energy storage system. It is also essential to select proper type of capacitor to make compact capacitor bank. Electrolytic capacitor can not able to with stand the voltage reversal across it. So it is great challenge to avoid any voltage reversal across the capacitors. Electrostatic capacitor is store energy in the form of electrostatic field rather then in the form of chemical energy. So it can easily bare negative voltage across it whereas electrolytic capacitor is store energy in the form of chemical energy so it can not bare negative voltage across it. So circuit should be critically damped circuit.

Charging unit, generally used in laboratories, to charge capacitor bank is using A.C. input source. They are operated on 230 V, 50 Hz and having bulky step up transformer and rectifier with bulky output filters. So, they can not be used for remote application. Here our intention is to develop a charging unit which is battery operated, means having D.C. input source and by using high frequency we will have reduced size of transformer. So, overall we want to make the pulsed power generator as compact as possible for remote applications. Hence flyback converter with rectifier unit is used to develop charging unit for capacitor bank. Also MOSFET is used into flyback converter with clamp and snubber protection to protect the switch from voltage transient across it. A MOSFET driver circuit for 2 kHz frequency has been design and tested using 555 timer in astable mode with optical isolation circuit. To stop the charging of capacitor bank after required charge voltage relay timer circuit is also provided in charging side. Solid state switch is use to discharge the capacitor bank stored energy into the load to produce maximum peak current pulse of very short time duration. A proper rating of SCR is used as discharge switch. Also triggering circuit of SCR is designed and tested using pulse transformer.

1.3 OBJECTIVE OF THE PROJECT

Objective of the project i**s** developed compact and portable pulse power generator to produced maximum value of peak current pulsed into high inductive load. A peak current pulsed can be further amplify by reducing the inductive load because flux linkage remain constant. Exploration of pulsed power generation techniques and its comparative study. Exploration of controlled discharge switch and selection of proper switch. To develop battery powered charging unit for energy storage system.

1.4 ENERGY STORAGE SYSTEM IN PULSE POWER SYSTEM

1.4.1 COMPARISON OF CESS AND IES

Two type of energy storage:

A. Capacitive energy storage system (CESS)

B. Inductive energy storage system (IES)

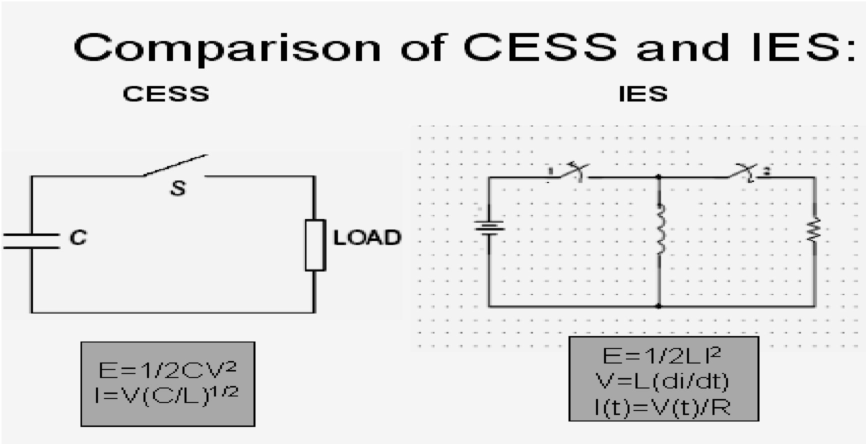


Figure 1.4.1 Comparison of CESS and IES

Generally capacitive energy storage system (CESS) rather then inductive energy storage system is used.

In case of IES the switch must carry the large coil current during the storage time, interrupt the current, and then withstand the high voltage generated by the coil current flowing through the load. The opening switch problem is difficult enough for single-shot operation in many applications.

Inductive energy storage systems have a higher energy density than capacitive systems. The drawback, however, is the fact that they need opening switches in order to commutate the current into the load. For such a system we investigated the turn-off behavior of the IGBT gas discharge and mechanical switches by semi conducting devices for different pulsed power applications. The reason is that solid state switches are superior in life time, maintenance, performance and flexibility.

The ideal opening switches for this application should possess the following characteristics:

- Fast opening (nanosecond or less)
- Fast recovery to achieve high repetition rate
- Controllable and long conduction times
- Zero resistance during conduction
- High impedance after opening
- Large current
- Large stand-off voltage
- Jitter free.

1.5 LITERATURE REVIEW

The need for compact and portable pulse power generator and its applications as discussed in the introduction are from different IEEE papers which are mentioned in the reference [A]. Exploration of pulsed power generation techniques and its Comparative study and viability issues has been discussed. [A]. Selection of energy storage system and capacitor has been referred [A]. Capacitive energy storage system is selected. Electrolytic capacitor is selected for energy storage system. The first step of the project is to design the capacitor bank. Selection of charging unit has been discussed. The flyback topology has been selected as charging unit. The topology of the driver circuit selected is 555 timer running in astable mode [D]. The switch selected for this project is MOSFET as it has high switching frequency. The data sheet of the MOSFET IRF150N has been attached in the Appendix. The next step is the topology selected in the first phase of the project. The main idea about different topologies has been taken from reference [B]. The flyback transformer plays an important role in the high voltage generation. The core chosen is ferrite core and the details of the ferrite core have been referred from [C]. The details of the flyback transformer are also available from Jochen's high voltage web pages and Power Lab web pages. The clamp and snubber protection is provided in the flyback converter [B]. The optical isolation is provided for safety purpose. When sufficient voltage is generated, it is used to charge the capacitor bank. The selection of discharge switch has been referred [A]. A SCR is selected as discharge switch. The data sheet of the SCR-5STP 17H5200 has been attached in the Appendix. The triggering circuit for discharge switch has been discussed [D]. The measurement of high voltage of the output of transformer is taken with the help of North Star probe having 1000X attenuation. A current transformer is used to measure the high current pulse.

CHAPTER 2

SELECTION OF CAPACITOR AND DISCHARGE SWITCH

In pulse power generator two type of energy storage system is there one is capacitive energy storage system and inductive energy storage system. In this project capacitive energy storage system is used because of some advantages of it over inductive energy storage system which is discussed in another chapter. So it is very essential to study different type of capacitor and select best suitable capacitor to make system compact. Into this system aluminum electrolytic capacitor is chosen because of its advantages which are discussed in another chapter. Here some different type of capacitor is given

2.1 CAPACITOR FAMILY TREE

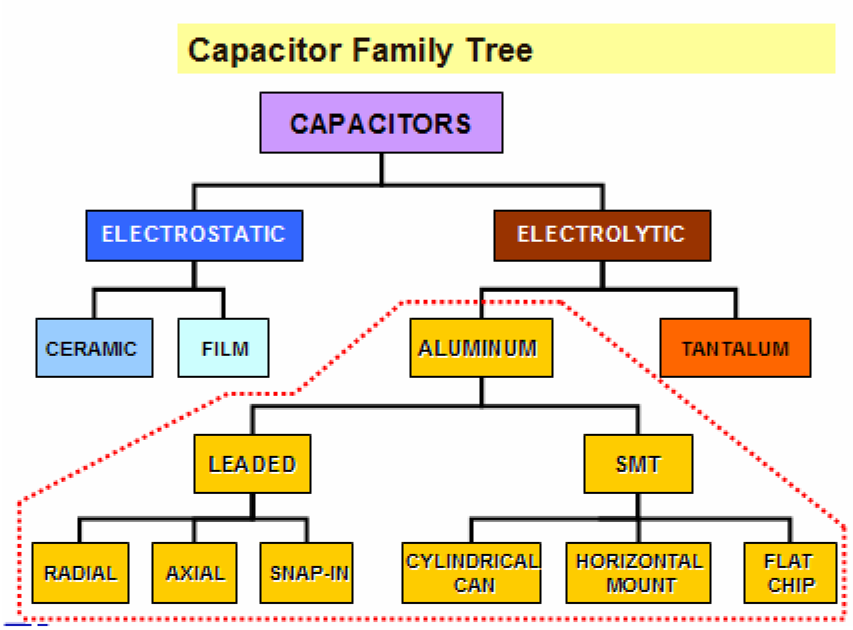


Figure 2.1 Capacitor family tree

2.2 COMPARISON OF VARIOUS TYPES OF CAPACITORS

Capacitor type	Dielectric used	Advantages/applications	Disadvantages
Paper Capacitors	Paper or oil-impregnated paper	Impregnated paper was extensively used for older capacitors, using wax, oil, or epoxy as an impregnate. Oil-Kraft paper capacitors are still used in certain high voltage applications. Has mostly been replaced by plastic film capacitors.	Large size. Also, paper is highly hygroscopic, absorbing moisture from the atmosphere despite plastic enclosures and impregnates. Absorbed moisture degrades performance by increasing dielectric losses (power factor) and decreasing insulation resistance.
Polystyrene Capacitor	Polystyrene	Excellent general purpose plastic film capacitor. Excellent stability, low moisture pick-up and a slightly negative temperature coefficient that can be used to match the positive temperature co-efficient of other components. Ideal for low power RF and precision analog applications	Maximum operating temperature is limited to about +85ºC. Comparatively bigger in size.

Aluminum Electrolytic Capacitors	Aluminum oxide	Very large capacitance to volume ratio, inexpensive, polarized. Primary applications are as smoothing and reservoir capacitors in power supplies.	Dielectric leakage is high, large internal resistance and inductance limits high frequency performance, poor low temperature stability and loose tolerances. May vent or burst open when overloaded and/or overheated. Limited to about 500 volts.
Tantalum Electrolytic Capacitors	Tantalum oxide	Large capacitance to volume ratio, smaller size, good stability, wide operating temperature range, long reliable operating life. Extensively used in miniaturised equipment and computers. Available in both polarised and unpolarised varieties. Solid tantalum capacitors have much better characteristics than their wet counterparts.	Higher cost than aluminum electrolytic capacitors. Voltage limited to about 50 volts. Explodes quite violently when voltage rating, current rating, or slew rates are exceeded, or when a polarized version is subjected to reverse voltage.

Energy Storage Capacitors	Kraft capacitor paper impregnated with electrical grade castor oil or similar high dielectric constant fluid, with extended foil plates	Designed specifically for intermittent duty, high current discharge applications. More tolerant of voltage reversal than many polymer dielectrics. Typical applications include pulsed power, electromagnetic forming, pulsed lasers, Marx generators, and pulsed welders.	Physically large and heavy. Significantly lower energy density than polymer dielectric systems. Not self-healing. Device may fail catastrophically due to high stored energy.
Vacuum Capacitors	Vacuum capacitors use highly evacuated glass or ceramic chamber with concentric cylindrical electrodes.	Extremely low loss. Used for high voltage high power RF applications, such as transmitters and induction heating where even a small amount of dielectric loss would cause excessive heating. Can be self-healing if arc-over current is limited.	Very high cost, fragile, physically large, and relatively low capacitance

2.3 ALUMINIUM ELECTROLYTIC CAPACITOR

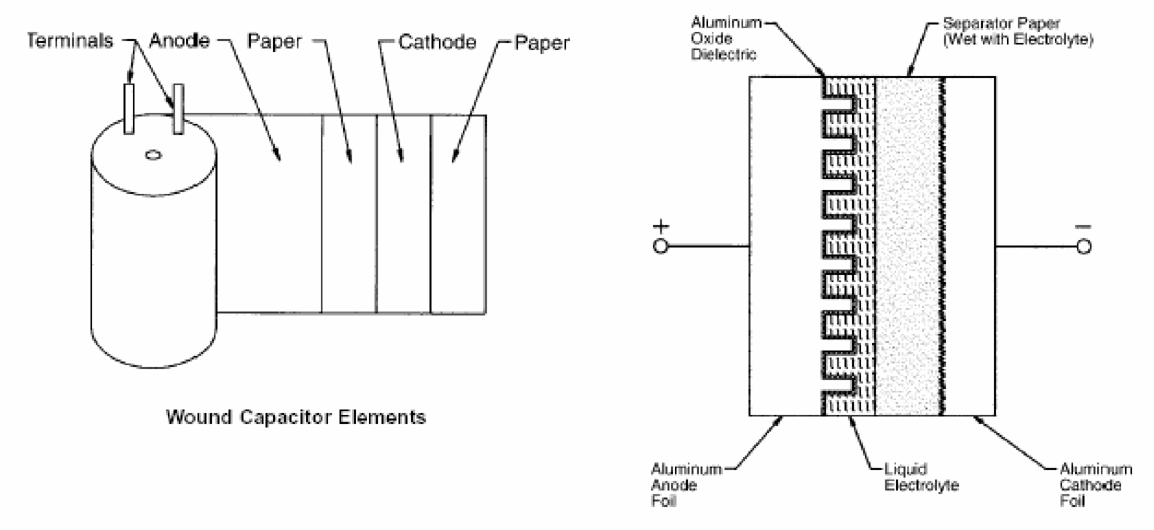


Figure 2.3 Aluminum electrolytic capacitor

An electrolytic capacitor is a type of capacitor with a larger capacitance per unit volume than other types, making them valuable in relatively high-current and low-frequency electrical circuits. This is especially the case in power-supply filters, where they store charge needed to moderate output voltage and current fluctuations, in rectifier output, and especially in the absence of rechargeable batteries that can provide similar low-frequency current capacity. They are also widely used as coupling capacitors in circuits where AC should be conducted but DC should not; the large value of the capacitance allows them to pass very low frequencies without carrying DC.

CONSTRUCTION

Aluminum electrolytic capacitors are constructed from two conducting aluminum foils, one of which is coated with an insulating oxide layer, and a paper spacer soaked in electrolyte. The foil insulated by the oxide layer is the anode while the liquid electrolyte and the second foil act as cathode. This stack is then rolled up, fitted with pin connectors and placed in a cylindrical aluminum casing. The two most popular geometries are axial leads coming from the center of each circular face of the cylinder, or two radial leads or lugs on one of the circular faces. Both of these are shown in the picture.

Tantalum capacitors are more expensive than aluminum-based capacitors, and generally only usable at low voltage, but they have much higher capacitance per unit volume and thus are popular in miniature applications such as cellular telephones.

POLARITY

Electrolytic capacitors have a polarity, unlike most capacitors. This is due to the fact that the aluminum oxide layer is held in place by the electric field, and when reverse-biased, it dissolves into the electrolyte. This allows a short circuit between the electrolyte and the aluminum. The liquid heats up and the capacitor may explode. The aluminum oxide layer is the dielectric, and the thinness of this layer, along with its ability to withstand electric field strength of the order of 10^9 volts per meter, is what produces the high capacitance. Modern capacitors have a safety valve on one circular face to vent the hot gas/liquid, but the rupture is still loud. The correct polarity is indicated on the packaging by a stripe with minus signs and possibly arrowheads, indicating the lead that should be more negative than the other.

This is the only reason for the polarity requirement. Electrolytic will behave like any other capacitor if reverse biased, up to the point that they are destroyed. Most survive with no DC bias or with only AC, and can even withstand a reverse bias for a period of time, but circuits should be designed so that there is not a constant reverse bias for any significant amount of time. A constant forward bias also increases the life of the capacitors.

SAFETY

The electrolyte is usually boric acid or sodium borate in water with some sugars or ethylene glycol added to retard evaporation. While you should not eat this, nor get it in your eyes, it is not very corrosive or dangerous. Simply wash it off your skin after coming into contact with it. It is important, however, to always be careful and the wearing of safety glasses is always advised. Wet-slug tantalum electrolytic contains sulfuric acid.

ELECTRICAL BEHAVIOR OF ELECTROLYTIC

A common modeling circuit for an electrolytic capacitor has the following schematic:

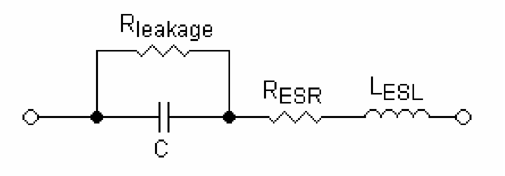


Figure 2.3(a) Equivalent circuit of Electrolytic capacitor

Where $R_{leakage}$ is the leakage resistance, R_{ESR} is the equivalent series resistance, L_{ESL} the equivalent series inductance (L being the conventional symbol for inductance).

R_{ESR} must be as small as possible since it determines the loss power when the capacitor is used to smooth voltage. Loss power scales quadratically with the ripple current flowing through and linearly with R_{ESR}. Low ESR capacitors are imperative for high efficiencies in power supplies. It should be pointed out that this is only a simple model and does not include all the effects associated with real electrolytic capacitors. Since the electrolytes evaporate, design life is most often rated in hours at a set temperature.

ADVANTAGES

1. High energy density to volume ratio
2. Small size
3. Inexpensive
4. Self healing

DISADVANTAGES

1. High ESR and ESL
2. High dielectric leakage
3. Poor low temperature stability
4. Bust when over heated, over loaded and connected in reverse polarity

2.4 ENERGY STORAGE CAPACITOR

Kraft capacitor paper impregnated with electrical grade castor oil or similar high dielectric constant fluid, with extended foil plates. Designed specifically for intermittent duty, high current discharge application. Capacitors store their energy in an electrostatic field rather than in chemical form. They consist of two electrodes (plates) of opposite polarity separated by an electrolyte. The capacitor is charged by applying a voltage across the terminals which causes charge to migrate to the surface of the electrode of opposite polarity. The energy stored is related to the charge at each interface, **q** (Coulombs) , and potential difference, **V** (Volts), between the electrodes. The energy, **E** (Joules), stored in a capacitor with capacitance **C** (Farads) is given by the following formula.

$$\mathbf{E = \tfrac{1}{2}\, q\, V = \tfrac{1}{2}\, CV^2}$$

Since capacitors store charge only on the surface of the electrode, rather than within the entire electrode, they tend to have lower energy storage capability and lower energy densities. The charge/discharge reaction is not limited by ionic conduction into the electrode bulk, so capacitors can be run at high rates and provides very high specific powers but only for a very short period

ADVANTAGES

More tolerant of voltage reversal than many polymer dielectrics, used in pulsed power, electromagnetic forming, pulsed lasers, Marx generators and pulsed welders.

DISADVANTAGES

Physically large and heavy, lower energy density.

2.5 DIFFERENT DISCHARGE SWITCHES FOR PULSE POWER SYTEM

In this system SCR is used as a discharge switch because of advantages of semiconductor switches over conventional discharge switches.

High current discharge switches are:

1. Ignitron
2. Thyratron
3. Krytron
4. Spark gap

2.5.1 IGNITRON

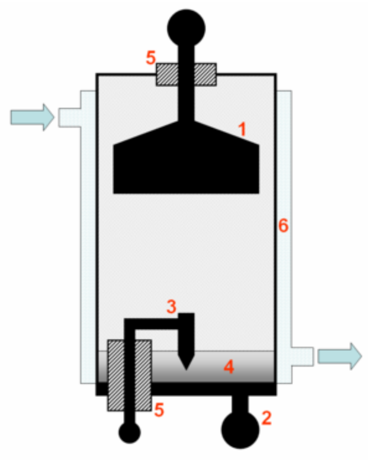


Figure 2.5.1 Ignitron

(1) Anode, (2) Cathode, (3) Ignitor, (4) Mercury, (5) Ceramic insulators, (6) Cooling fluid An **ignitron** is a type of controlled rectifier dating from the 1930s.

Invented by Joseph Slepian while employed by Westinghouse, Westinghouse was the original manufacturer and owned trademark rights to the name "Ignitron".

It is usually a large steel container with a pool of mercury in the bottom, acting as a cathode. A large graphite cylinder, held above the pool by an insulated electrical connection, serves as the anode. An igniting electrode (called the "ignitor") is briefly pulsed to create an electrically conductive mercury plasma, triggering heavy conduction between the cathode and anode.Ignitrons were long used as high-current rectifiers in major industrial installations where thousands of amperes of AC current must be converted to DC, such as aluminum smelters. Large electric motors were also controlled by ignitrons used in gated fashion, in a manner similar to modern semiconductor devices such as silicon controlled rectifiers and triacs. Many electric locomotives used them in conjunction with transformers to convert high voltage AC from the catenary to relatively low voltage DC for the motors.

Because they are far more resistant to damage due to overcurrent or back-voltage, ignitrons are still manufactured and used in preference to semiconductors in certain installations. For example, specially constructed **pulse rated** ignitrons are still used in certain pulsed power applications. These devices can switch hundreds of kiloamperes and hold off as much as 50,000 volts. The anodes in these devices are fabricated from a refractory metal, usually molybdenum, to handle reverse current flow during ringing (or oscillatory) discharges without damage. Pulse rated ignitrons usually operate at very low duty cycles. They are often used to switch high energy capacitor banks during electromagnetic forming, electrohydraulic forming, or for emergency short-circuiting of high voltage power sources ("crowbar" switching).

2.5.2 THYRATRON

Figure 2.5.2 Thyratron

Giant GE hydrogen thyratron, used in pulsed radars, next to miniature 2D21 thyratron used to trigger relays in jukeboxes

A **Thyratron** is a type of gas filled tube used as a high energy electrical switch. Triode, Tetrode and Pentode variations of the thyratron have been manufactured in the past, though most are of the triode design. Gases used include mercury vapor, xenon, neon, and (in special high-voltage applications or applications requiring very short switching times) hydrogen. Unlike a vacuum tube, a thyratron cannot be used to amplify signals linearly.

A typical hot-cathode thyratron uses a heated filament cathode, completely contained within a shield assembly with a control grid on one open side, which faces the plate-shaped anode. When positive voltage is applied to the anode, if the control electrode is kept at cathode potential, no current flows. When the control electrode is made slightly positive, gas between the anode and cathode ionizes and conducts current. The shield prevents ionized current paths that might form within other parts of the tube. The gas in a thyratron is typically at a fraction of the pressure of air at sea level; 15 to 30 millibars (1.5 to 3 kPa) is typical.

Both hot and cold cathode versions are encountered. A hot cathode is an advantage, as ionization of the gas is made easier; thus, the tube's control electrode is more sensitive. Once turned on, the thyratron will remain on (conducting) as long as there is a significant current flowing through it. When the anode voltage or current falls to zero, the device switches off.

2.5.3 KRYTRON

The **Krytron** is a cold-cathode gas filled tube intended for use as a very high-speed switch and was one of the earliest developments of the EG&G Corporation.

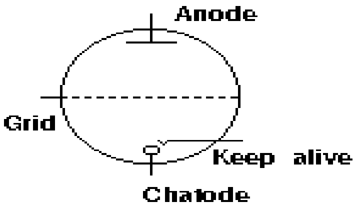


Figure 2.5.3 Krytron

There are four electrodes in a krytron. Two are conventional anode and cathode. One is a keep-alive electrode, arranged to be close to the cathode. The keep-alive has a low positive voltage applied, which causes a small area of gas to ionize near the cathode. High voltage is applied to the anode, but primary conduction does not occur until a positive pulse is applied to the trigger electrode. Once started, arc conduction carries a considerable current. In place of or in addition to the keep-alive electrode some krytrons may contain a very tiny amount of radioactive material (usually nickel-63) which emits beta particles (high-speed electrons) to make ionization easier. The amount of radiation in a krytron is very small and not harmful.

CHAPTER 3

DESIGN OF PORTABLE PULSE POWER GENERATOR PARTS

3.1 BLOCK DIAGRAM OF THE PROJECT

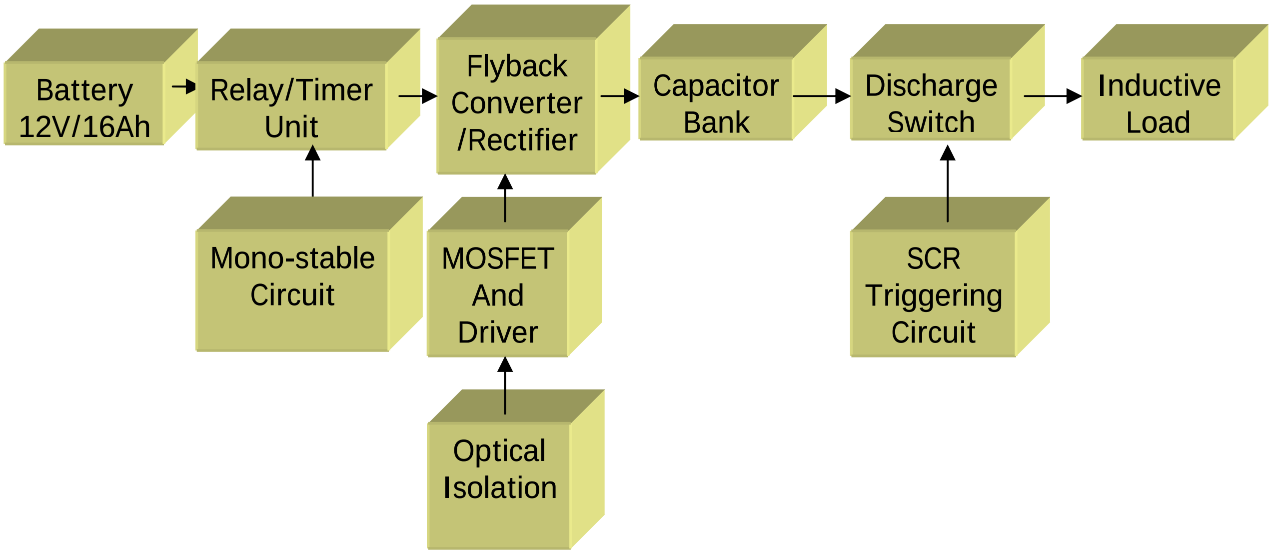


Figure 3.1 Schematic diagram of PPG

3.2 DESCRIPTION

To make this pulsed power generator primary power supply is portable battery. Here inductive load is used to produce high magnetic field in solenoid by high peak current pulse. In this pulse making capacitor bank uses power generator capacitive energy storage system. Electrolytic capacitor has been used to store energy because of its high energy density. It is usually used in filter application. Because it is polarized it can be withstand with reversal across it, so circuit should be critically damped. Capacitor bank charge up to 900 volts. Here to stop the capacitor bank-charging unit after specific time period relay timer unit is provided.

Flyback converter is used to as a charging unit for capacitor bank. A MOSFET is used in a charging unit and 555 timer is used as its driver circuit with optical isolation circuit.

A SCR is used to discharge stored energy of the capacitor bank into the load which will produce peak current pulsed into inductive load. A triggering circuit of SCR is made by TTL logic using pulse transformer.

3.3 APPLICATION

- Air Craft Launching as in defense application.
- High current back up utility storage system.
- High current testing of electrical apparatus.
- To produced ultra high magnetic field in the solenoid.
- In Rock fragmentation.
- Can crushing.
- Disk shooter.
- Rail gun.

3.4 VARIOUS PARTS OF PULSE POWER GENERATOR CIRCUIT

- Battery
- Flyback Converter
- Capacitor Bank
- Damping Resistor And Inductive Load
- Discharge Switch

3.5 DESIGN OF VARIOUS PARTS OF PULSE POWER GENERATOR

3.5.1 DESIGN OF CAPACITOR BANK

A capacitor bank of electrolytic capacitor to store 1905 J is made.

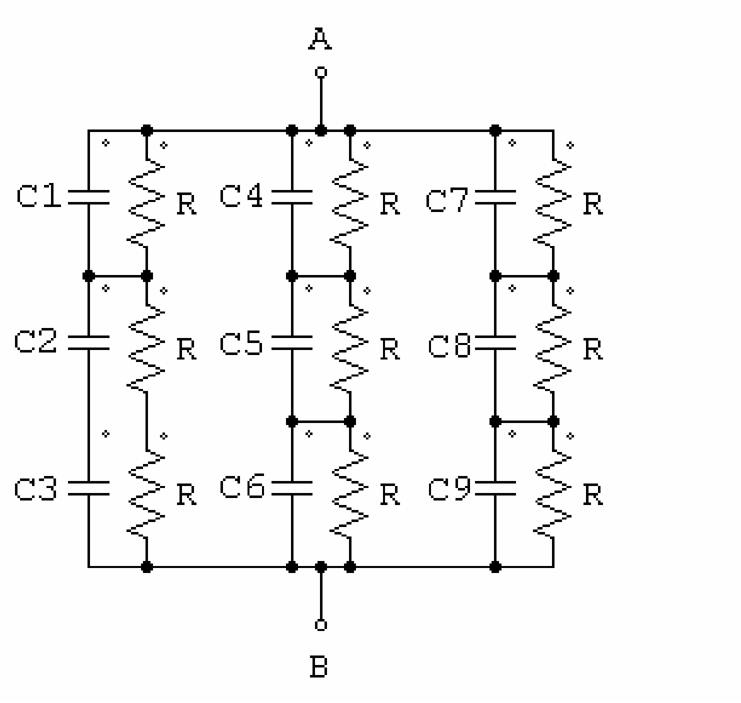


Figure 3.5.1 Schematic diagram of capacitor bank

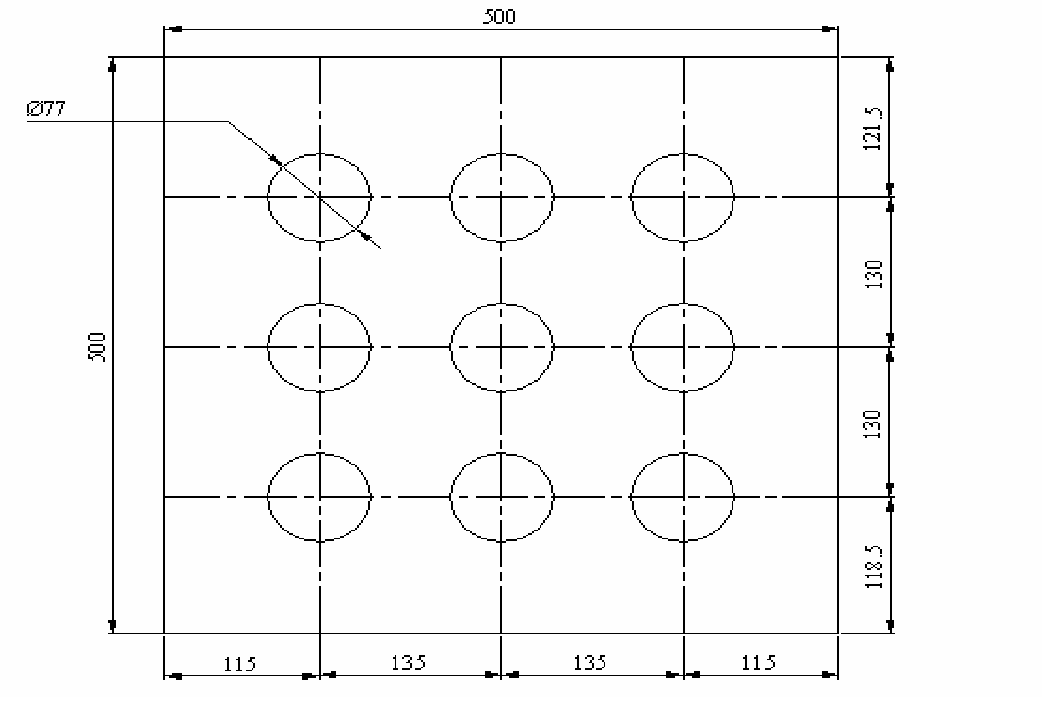


Figure 3.5.2 AutoCAD design of capacitor bank setup

Figure 3.5.2(a) Snap of capacitor bank setup

Basically there are two types of energy storage system in pulse power system one is capacitive energy storage system and inductive energy storage system. Because of opening switch problem in case of inductive energy storage system, capacitive energy storage system is more advantageous. Capacitive energy storage system is used in this system. Above figure shows the capacitor bank which is made up of totals nine capacitor connected in series-parallel connection. A high value of equal value resistor is connected parallel to each capacitor. It serves two things. It equally distributes voltage across each capacitor and avoid short circuit. It is known as bleeder. It should have very large value than charging resistor to increase time constant of discharge circuit otherwise capacitor will not charge.

Rating of each capacitor = 4700μF, 350 volts

Capacitance of each capacitor = 4700μF

Charged voltage of each capacitor = 300 volts

Equivalent capacitance of capacitor bank = 4700μF

Energy store in one capacitor = $0.5CV^2$

$= 0.5*4700*10^{-6}*300^2$

= 211.5 J

Total energy stored in nine capacitor = 211.5*9

= 1905 J

Value of each bleeder resistor = 250 KΩ

In this project capacitor bank is used to store the energy and that energy will be further discharges into the inductive load in very short time duration. Electrolytic capacitors are used because they are very compact and portable than energy storage capacitor. They are having some more advantages over energy storage capacitor Because electrolytic capacitors are polarized they are not able to withstand with negative voltage across it. So one should have entire circuit critically damped. A layout of the capacitor bank has been design in AutoCAD. At starting capacitor bank is lying on the ground and require more space. So to make system compact and portable this type of setup has been made. Also in this setup Charging resistor, Damping resistor and Inductive load have been connected. To make connection between to capacitor copper strip are used.

3.5.2 DESIGN OF INDUCTOR

Inductor is used as a load in this system. Objective of project is to produce the high amount of magnetic field in the solenoid. Here inductor is air core type with solenoid. Here it is trying that maximum current should pass trough load. Inductor value will affect the rise time of the pulse as well as total width of the pulse. Inductor value is also affect the selection of damping resistor.

Design for **4µH** inductor:
Dimensions of solenoid:
Length = $118.3*10^{-3}$ m
Diameter = 75*10-3 m

$$L = \frac{\mu_0 \mu_r N^2 A}{l}$$

L = Inductance in henries

μ_0 = permeability of free space = $4\pi \times 10^{-7}$ H/m

μ_r = relative permeability of core material = 1

N = number of turns

A = area of cross-section of the coil in square meters (m^2) = $4.42*10^{-3}$ m

l = length of coil in meters (m) = $118.3*10^{-3}$ m

By putting the value of all respective parameter we get the number of turns,

N = 6.52=7.

3.5.3 DESIGN OF DAMPING RESISTOR

Figure 3.5.3 Snap of damping resistor

In this system electrolytic capacitor is going to be use first time. Generally electrolytic capacitor is used in filter application and this is new principle to use electrolytic capacitor in pulse power system. Because of its high capacitance value its having the higher energy density. Electrolytic capacitor is used to make capacitor bank to store energy which will be further discharge into to inductor to produce high peak current. Here system should be critically damped to avoid the reversal across the electrolytic capacitor bank because it is having polarity. If any reversal come across it there will be dangerous blast occur. So it is very important to design damping resistor to make a system critically damped its known as damping resistor. Because high peak current pulse is discharge special type of resistor is inserted. For critically damped circuit condition is,

$R^2 = 4L/C$

Here L=4μH, C= 4700 μF

Value of damping resistor is, R = 0.05Ω

A ceramic composition type resistor is used. Figure shows the resistor of 0.1Ω. Similar three discs are connected to parallel. Because some of the resistor is added through circuit so it has inserted **0.033 Ω**.

Charging resistor of **10 kΩ** is inserted to limit the charging current.

3.5.4 DISCHARGE SWITCH (SCR)

SCR (5STP 17H5200) **Spark Gap**

Figure 3.5.4 SCR and Spark gap

Above pictures shows the SCR and spark gap. Spark gap is made up of two brass hemi sphere pieces.

In pulsed power system high current discharge switches used are:

Thyratron, Ignitron, Krytron and Spark gap

But these switches have limited life, more losses and high cost. Hence solid state switch is used as discharge switch because of its advantages over that switches.

ADVANTAGES OF SOLID STATE SWITCHES

Very high speed switching, No mechanical moment, bouncing and burning of contact, No maintenance, Small size and light weight, Delay and latch can be provided. Detect the over and under voltage and current, Safe in explosive environment.

RATING OF SCR

V_{DSM} = 5200 V

I_{TAVM} = Max average on state current = 1975 A

I_{TRMS} = RMS on state current =3100 A

I_{TSM} = Max Peak Non-Repetitive surge current = 29000 A

V_{T0} = Threshold voltage = 1.02V

$r_T = 0.320 m\Omega$

CHAPTER 4

DESIGN AND DEVELOPMENT OF CHARGING UNIT

4.1 CONVENTIONAL CHARGING UNIT:

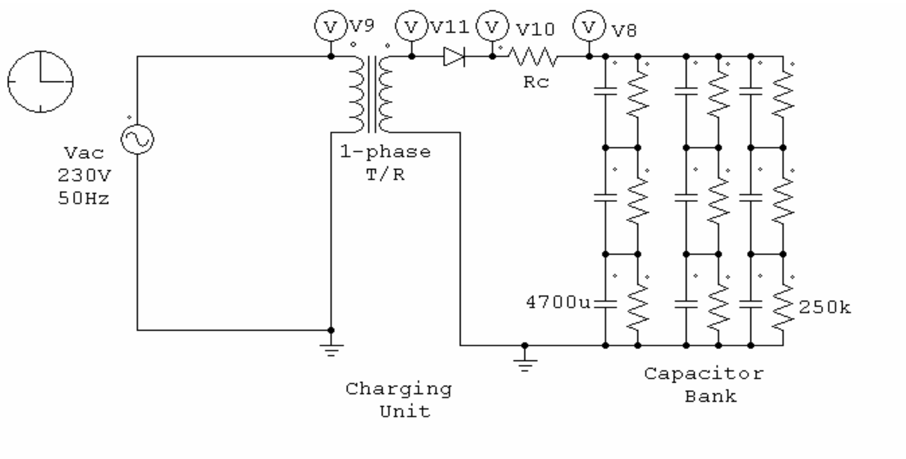


Figure 4.1 Conventional charging unit

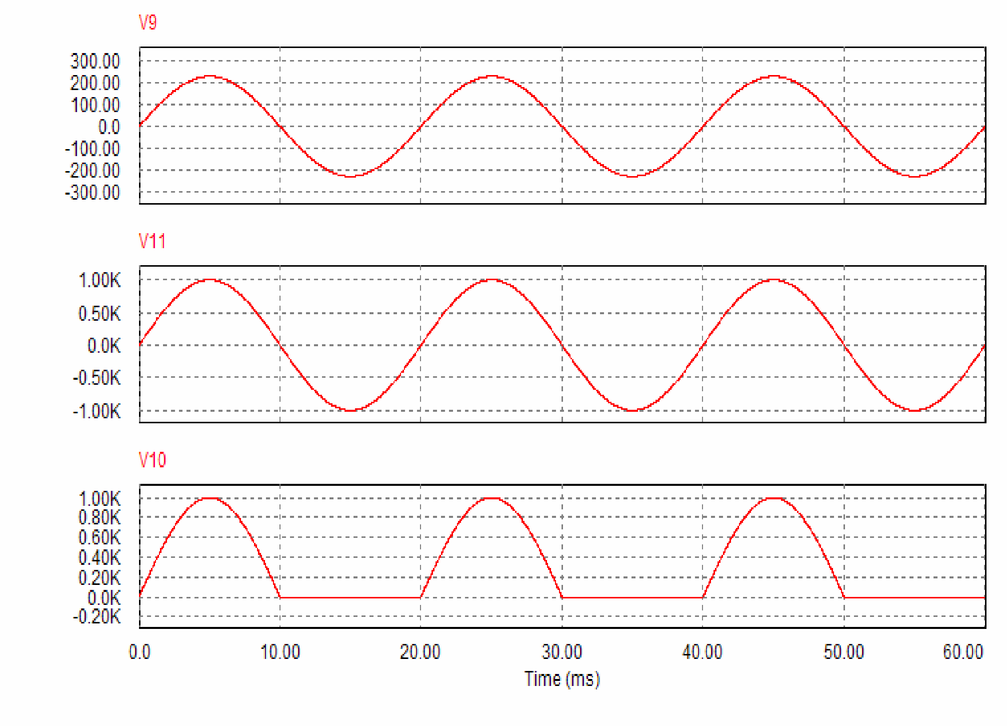


Figure 4.1 (a) simulation result of conventional charging unit

4.2 CAPACITOR BANK CHARGING UNIT USING THE FLYBACK CONVERTER

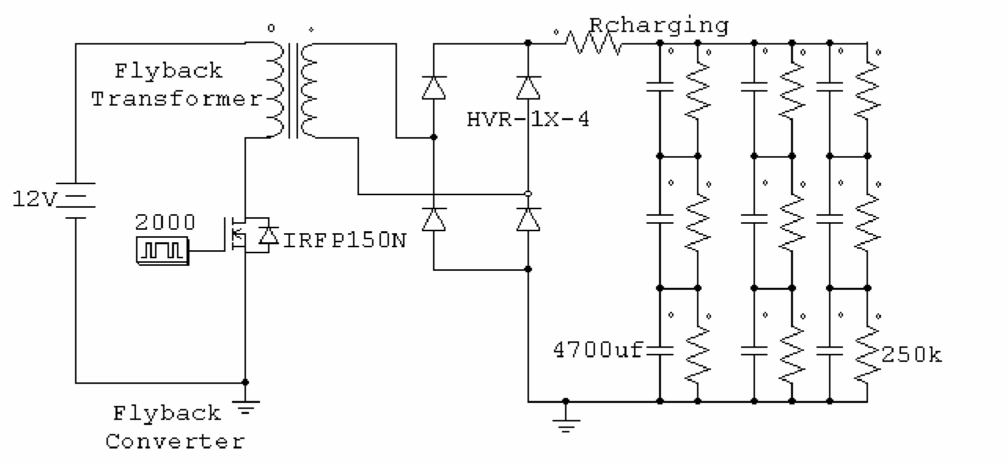


Figure 4.2 capacitor bank charging using flyback converter

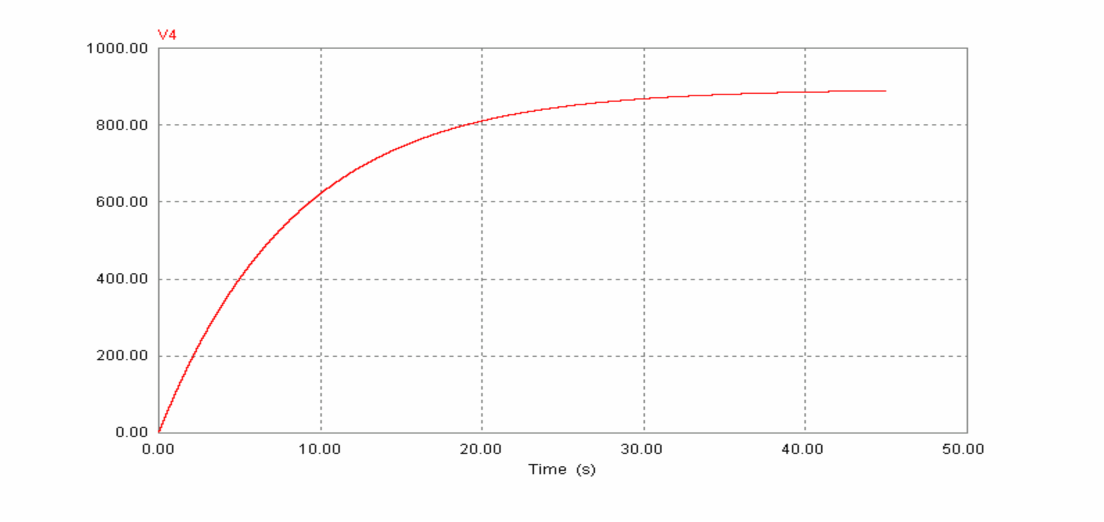


Figure 4.2(a) Simulation result of capacitor bank charging

Here two types of the charging unit for capacitor bank are shown above. Conventional method for charging capacitor is used step up single phase transformer and half wave rectifier circuit. A proper value of the charging resistor is inserted to limit the charging current. By using flyback converter capacitor bank can be charge. It is required battery, switching device, and flyback transformer and oscillator circuit. Hence flyback converter is more suitable as charging unit for this remote application. Simulation has been done in the PSIM.

4.3 COMPARISON OF CHARGING UNIT

	Conventional	**Flyback converter**
Cost	Less	More
Size	Large	Small
Supply	1-Φ AC	Battery
Complexity	Less	More
Portability	Not portable	Portable

So, flyback converter is costly than the conventional charging unit but the main advantage is that it is portable because the primary supply used is portable battery. Hence flyback converter has chosen to make system compact and portable. Flyback converter having less weight and compact. Also control circuit is less complex.

4.4 FLYBACK CONVERTER

The energy is stored in the primary inductance when the switch is made ON. When the switch is in OFF state then the energy is transferred to the secondary output. If n is the turns ratio such that:

$$n = \frac{N_s}{N_p}$$

$N_{p=}$ primary turns of the transformer and N_s = secondary turns of the transformer

$$Vout = \frac{Vin * \delta}{1 - \delta}$$

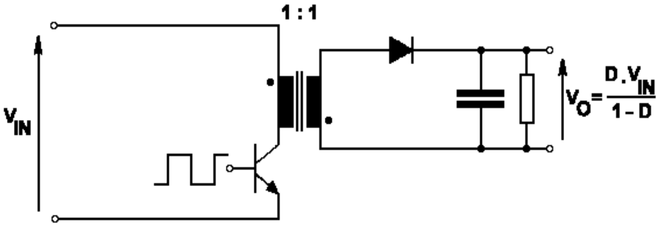


Figure 4.4 Flyback converter

The waveforms of discontinuous mode and continuous mode of flyback converter is shown below

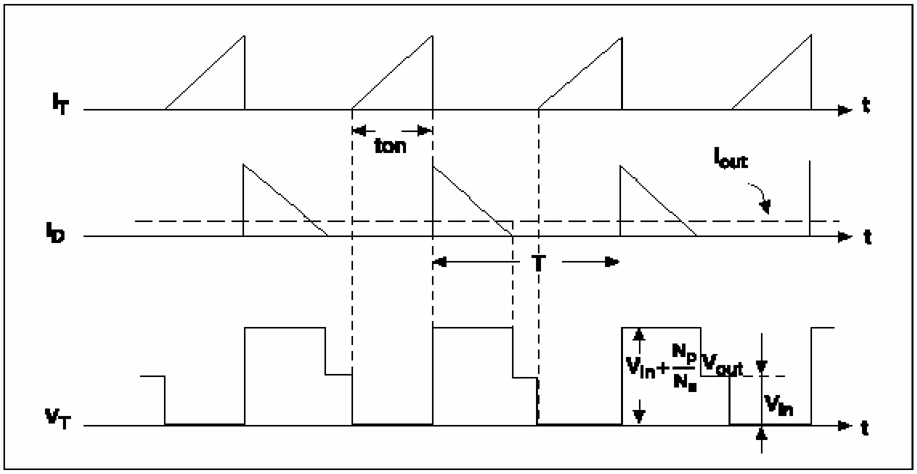


Fig4.4 (a) Waveform of discontinuous mode of flyback converter

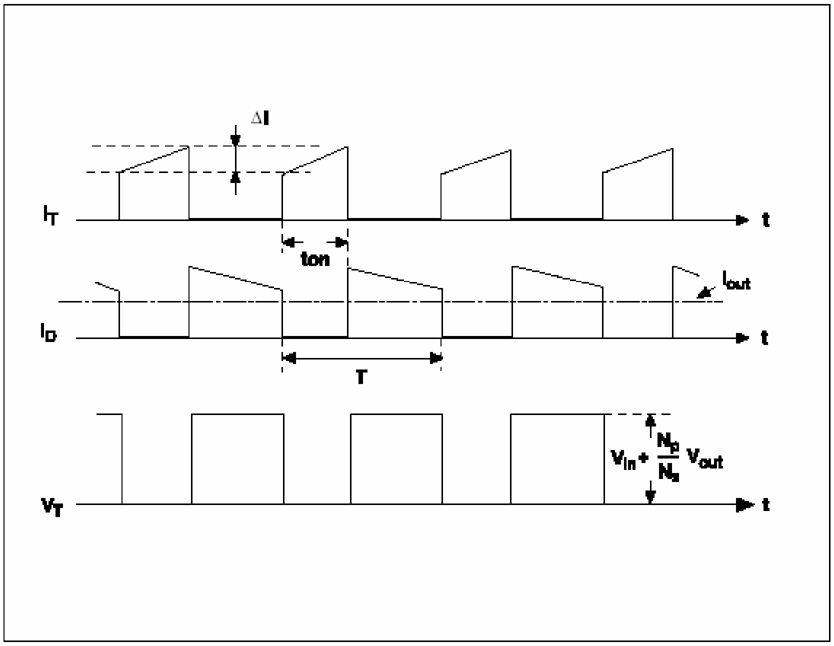


Fig.4.4 (b) Waveform of continuous mode of flyback converter

4.5 ADVANTAGES AND DISADVANTAGES OF FLYBACK TOPOLOGY

ADVANTAGES

1. Flyback is the ideal choice for generating low cost, multiple output supplies.
2. The flyback is also ideally suited for generating high voltage outputs.

DISADVANTAGES

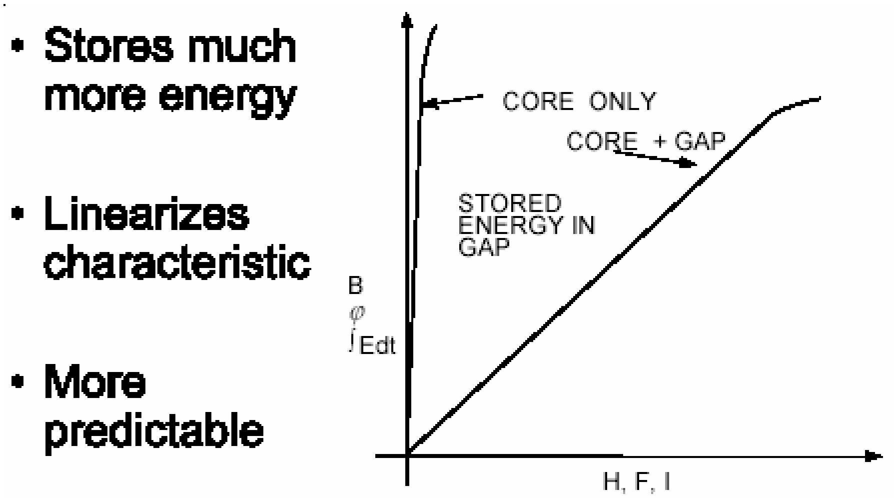
1. From the flyback waveforms it is clear that the output capacitor is only supplied during the transistor off time. This means that the capacitor has to smooth a pulsating output current, which has higher peak values than the continuous output current.
2. In order to achieve low output ripple, very large output capacitors are needed, with very low equivalent series resistance (e.s.r). It can be shown that at the same frequency, an LC filter is approximately 8 times more effective at ripple reduction than a capacitor alone. Hence, flybacks have inherently much higher output ripples than other topologies.
3. This, together with the higher peak currents, large capacitors and transformers, limits the flyback to lower output power applications in the 20 to 200W range. (It should be noted that at higher voltages, the required output voltage ripple magnitudes are not normally as stringent, and this means that the e.s.r requirement and hence capacitor size will not be as large as expected.)

APPLICATIONS

Lowest cost, multiple output supplies in the 20 to 200W range. E.g. mains input T.V. supplies, small computer supplies, E.H.T. supplies.

4.6 THEORY OF FERRITE CORE FOR FLYBACK TRANSFORMER

Ferrites are clearly the most popular cores used in switch-mode power supply applications. There are basically two families of ferrite materials: **Manganese-zinc**, which are somewhat lower in permeability, and they range in application from maybe 1-2 MHz; and then we have **nickel-zinc ferrites**, which operate up to the hundreds of MHz. They tend to be somewhat "lossier" but they have higher permeability. Now again looking at the characteristic shown here, which is fairly typical of power ferrite, expressed in volt-seconds versus current, clearly it does store some energy but most of that ends up as loss. And so this ferrite by itself does not make a very good energy storage element. But by introducing a gap, then it does serve this purpose where the energy is being stored in the air gap itself.



- Stores much more energy
- Linearizes characteristic
- More predictable

Figure 4.6(a) B-H curve linearization

Ferrites tend to be the lowest in cost of these available materials. The losses are lower at higher frequencies; they can be pushed to higher frequencies than the other materials we've discussed. And they're available in a much wider variety of shapes.

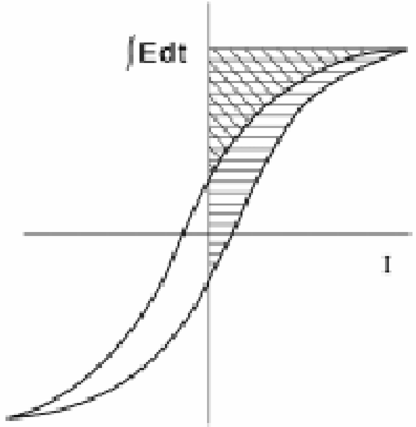


Figure 4.6(b) B-H curve for ferrites

Disadvantages to the ferrite is one of them is the fact that it's mechanically not as rugged as some of the other cores. It can be brittle; it can have problems of that nature, especially in a military environment, and the saturation flux density tends to be lower than the other materials, although that is not likely going to be a disadvantage in a transformer application or a flyback transformer operated in the continuous mode, where the flux swing will be limited by losses anyways.

4.7 DESIGN OF FLYBACK TRANSFORMER

SPECIFICATION OF THE DESIGN

$V_{outp\text{-}p}$ = 1 kV peak to peak..
V_{out}= 1 kV at 100 mAmp
V_{in} = 12 V from dc batteries.
Operating (Switching) frequency =2 kHz.
Maximum duty cycle (δ_{max}) = 0.5.
Efficiency (η) = 80%.

SWITCHING FREQUENCY

Because the magnetic components and filters will be smaller, the tendency is to have as high a switching frequency as possible. Unfortunately, the decision is not quite that clear cut. Core losses, gate charge currents, and switching losses increase with higher switching frequencies; peak currents increase with lower switching frequencies. A compromise must be reached between component size, current levels, and acceptable losses. Synchronization with other systems and backward compatibility may also be deciding factors. For this design, a fixed frequency (fs) of 2 kHz was chosen. At Dmax equal to 50%, ton (max) becomes 250 µs.

4.7.1 TRANSFORMER DESIGN

For the design of transformer the core used is UYF18/48 mix of Ni-Zn from Magnetic Company. The transformer has been designed for 2 kHz operation with primary voltage of 12V and a maximum output voltage of 1000 V and 100 mA current.
Output power rating of the transformer is given by:

$$P_{out} = \sum_{m=1}^{n} V_{out(n)} \times I_{out(n)}$$

$$P_{in} = \frac{P_{out}}{\eta}$$

$Pout = 1000 * 0.1 = 100$ Watts

Though the flyback converters are typically designed for efficiencies of 80%, therefore for the output power of 100 Watts, maximum input power will be 125 Watts.

`Input` average current

$$\mathrm{I}_{\mathrm{in(avg)}} = \frac{\mathrm{P}_{\mathrm{in}}}{\mathrm{V}_{\mathrm{in(nom)}}}$$

$$= 10.4 \text{ A}$$

Expression for the estimation of peak current drawn by primary is,

$$I_{peak} = k \times \frac{P_{out}}{V_{in}}$$

For flyback transformer k=5.5 and estimated peak current is 45.8 A.

$$\mathrm{I}_{\mathrm{rms}} = \sqrt{\frac{\delta_{\mathrm{max}} \times \mathrm{I}_{\mathrm{peak}}{}^{2}}{3}}$$

$$= 18.69 \text{ A}$$

Required primary inductance is:

$$L_p = \frac{V_{in} \times T_{on}}{I_{peak}}$$

With switching frequency of 2 kHz at 50% duty cycle T_{on}= 250μs. Hence the primary inductance will be L_p= 65.5 μH.

On the basis of core selection made energy storage in the air gap is:

$$E = L_p \times \frac{I_{peak}{}^{2}}{2} \approx 68.7mJ$$

Number of turns in the primary and secondary can be calculated using the following equations:

$$N_p = \frac{V_{in} \times \delta}{A_c \times B_m \times f} \approx 59turns.$$

Here δ=duty cycle

Ac= cross section are of core in mm^2

B_m =flux density

F=operating frequency

V_{in} =input voltage

Here the core chosen is UYF18/48 having Ac=255 mm^2, B_m=0.2 T. The operating frequency f=2 kHz.

Now turns ratio

$$n = \frac{N_s}{N_p} = \left(\frac{V_{out} + V_D}{V_{in}}\right) \times \left(\frac{1 - \delta_{\max}}{\delta_{\max}}\right) = 84$$

N_s=secondary turns of the transformer

$\delta_{\max}$=duty cycle = 0.5

$$N_s = n \times N_p \approx 4956 turns$$

Minimum air gap to be provided for storing 68.7mJ energy will be:

$$l_g = \frac{\mu_o \times N_p^{\ 2} \times A_c}{L_p} \approx 1.7 mm.$$

Calculated number of turns in primary and secondary side is 59/4956.

U type ferrite core is used in flyback transformer. Round leg allows easy winding, also of strip conductors. Because of the high voltages involved, the round shape helps to prevent corona effect.

Figure 4.7.1 snap of flyback transformer

HOW IS THE FLYBACK TRANSFORMER DIFFERENT FROM THE NORMAL TRANSFORMER?

- The main difference between a flyback transformer and a regular transformer is that a flyback transformer is designed to store energy in its magnetic circuit, i.e., it functions like a pure inductor, whereas a regular transformer is designed to transfer energy from its primary to secondary and to minimize stored energy.
- The reluctance of the magnetic circuit of a flyback transformer is usually much higher than that of a regular transformer. This is because of a carefully calculated air-gap for storing energy (it's an inductor).
- The voltages applied to a flyback transformer on the primary side are almost always rectangular (pulsed) whereas regular transformers usually have sinusoidal voltages applied to them.
- The currents flowing through either side of a flyback transformer are either increasing or decreasing linear sawtooths, whereas a regular transformer usually has sinusoidal currents.

Finally, due to the properties of core materials, flyback transformers are most conveniently operated in the range from 10^3 to 10^6 Hz, whereas regular transformers have a much wider range, from a few Hz to 10^12 Hz.

4.7.2 FABRICATION OF TRNASFORMER WINDING

For this high voltage application the secondary needs special insulation technique. Here Myler tape (Insulating tape) of 3kV has been used as inter layer insulation with cyanoacrylate as insulating liquid adhesive having breaking strength of 250 kV/cm. also extra covering of insulation have been provided at both the sides at a layer which is shown in the figure.

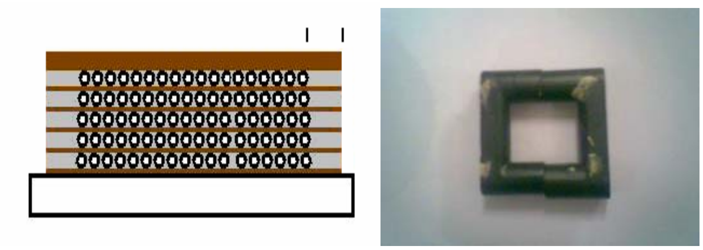


Figure 4.7.2 ferrite core and insulation technique

Here, in this figure gray color indicates cyanoacrylate liquid instant adhesive insulating material and it is also shown that at both the side of the winding layer there is extra covering of the insulating material of 5mm approximately. Total number of the layers is 40 and each is having 125 turns. Each layer is individually insulated during winding by cyanoacrylite. This insulation is best suited for this application because it is an instant adhesive having very fast setting time, having breaking strength of 250 kV/cm, highly insulating material with very good thermal conductivity and can work up to high temperature also. Its viscosity is also very high so it can penetrate throughout the winding to have best insulation. Below figure show the flyback transformers.

PROPERTIES OF THE INSULATION USED (CYANOACRYLATE):

Chemical Name: 2-Cyano-2-propenoic acid, ethyl ester
CH_2=C-CN
|-$CO_2CH_2CH_3$
$C_6H_7NO_2$
Mol.wt:125.13
Clear, colorless liquid with a very sharp odor
Solubility: Soluble in methyl ethyl ketone, toluene, acetone, nitromethane
Density: 1.05 g/ml
Viscosity: 13.9 cps
Flash Point: 181^{o}F

TECHNICAL PRODUCTS AND IMPURITIES: The composition of a typical Cyanoacrylate glue is 90.6% ethyl Cyanoacrylate, 9.0% polymethylmethacrylate, 0.4% hydroquinone, and trace amounts of organic sulphonic acid .

ELECTRICAL PROPERTIES:

Volume resistivity: 1×10^{16} Ω.cm
Dielectric strength: 25 kV /mm.

4.7.3 SELECTION OF SWITCHING DEVICE

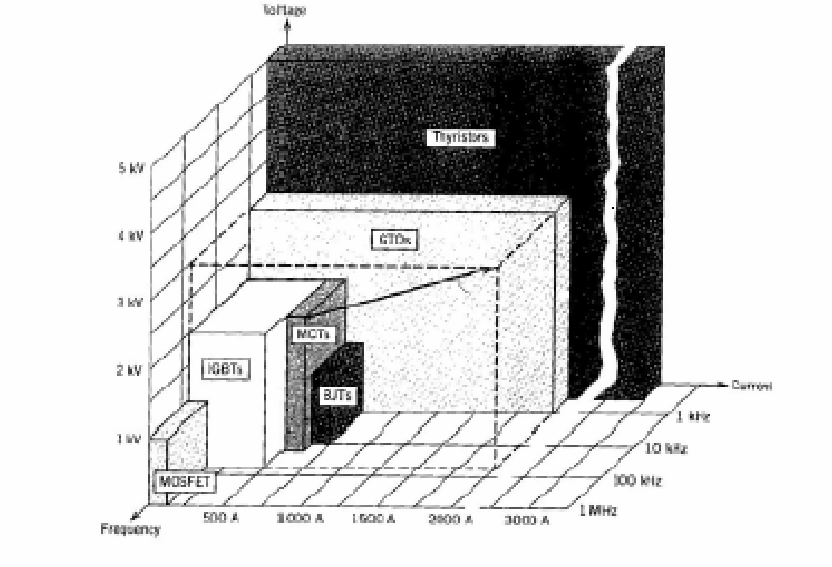


Figure 4.7.3 comparison of different switches

Above figure shows the comparison of different semi conductor switches with reference to voltage, current and frequency.

COMPARISON OF THE POWER TRANSISTOR AND MOSFET AS SWITCHING DEVICE

The two most common power semiconductors used in the S.M.P.S. are the bipolar transistor and the power MOSFET. The Bipolar transistor is normally limited to use at frequencies up to 30 kHz, due to switching loss. However, it has very low on-state losses and is a relatively cheap device, making it the most suitable for lower frequency applications. The MOSFET is selected for higher frequency operation because of its very fast switching speeds, resulting in low (frequency dependent) switching losses. The driving of the MOSFET is also far simpler and less expensive than that required for the Bipolar. However, the on-state losses of the MOSFET are far higher than the Bipolar, and they are also usually more expensive. The selection of which particular device to use is normally a compromise between the cost, and the performance required. IGBTs are having less switching as well as conduction losses. Also they can work at higher frequency then BJTs satisfactorily, but their cost is the limiting factor for their limited use in the SMPS.

VOLTAGE LIMITING VALUE

After deciding upon whether to use a Bipolar or MOSFET, the next step in deciding upon a suitable type is by the correct selection of the transistor voltage. For transformer coupled topologies, the maximum voltage developed across the device is normally at turn-off. This will be either half, full or double the magnitude of the input supply voltage, dependent upon the topology used. There may also be a significant voltage spike due to transformer leakage inductance that must be included. The transistor must safely withstand these worst case values without breaking down. Hence, for a bipolar device, a suitably high $V_{CE(max)}$ must be selected, and for a MOSFET, a suitably high $V_{BR(DSS)}$. At present 1750V is the maximum blocking voltage available for power Bipolars, and a maximum of 1000V for power MOSFETs.

CURRENT LIMITING VALUE

The Bipolar device has a very low voltage drop across it during conduction, which is relatively constant within the rated current range. Hence, for maximum utilization of a bipolar transistor, it should be run close to its I_{Csat} value. This gives a good compromise between cost, drive requirements and switching. The maximum current for a particular throughput power is calculated for each topology using simple equations. The MOSFET device operates differently from the bipolar in that the voltage developed across it (hence, transistor dissipation) is dependent upon the current flowing and the device "on-resistance" which is variable with temperature. Hence, the optimum MOSFET for a given converter can only be chosen on the basis that the device must not exceed a certain percentage of throughput (output) power. (5% loss in the MOSFET was assumed). A set of equations used to estimate the correct MOSFET $R_{DS(on)}$ value for a particular power level has been derived for this topology. The value of $R_{DS(on)}$ obtained was then used to select a suitable MOSFET device for each requirement. This method assumes negligible switching losses in the MOSFET. However for frequencies above 50 kHz, switching losses become increasingly significant.

For transformer coupled topologies, the maximum voltage developed across the device is normally at turn-off. The switching element in a flyback converter must have a voltage rating high enough to handle the maximum input voltage, the reflected secondary and the significant voltage spike which may occur due to transformer leakage inductance. The approximate voltage rating of the MOSFET required can be estimated using the given equation:

$$V_{ds} = \left[\left(V_{in(\max)} + V_L \right) + \left(\frac{N_p}{N_s} \right) \times \left(V_{OUT} + V_D \right) \right] \times 1.3$$

V_{ds}= Required drain to source voltage

V_L=Voltage spike due to the leakage inductance of the transformer, estimated to be thirty percent of $V_{in\ (max)}$ and the additional 1.3 factor includes an overall thirty percent margin.

N_p=Primary turns of the transformer

N_s= Secondary turns of the transformer

V_{OUT}= Secondary output voltage of the transformer

When 5V is given to the 555 timer and 12 to primary of the transformer then:

$$V_{ds} = \left[\left(V_{in(\max)} + V_L \right) + \left(\frac{N_p}{N_s} \right) \times \left(V_{OUT} + V_D \right) \right] \times 1.3.$$

$$= 36V$$

For a given device with a know $R_{ds\ (125^{o}C)}$, the maximum throughout power for this topology can be calculated.

$$P_{th(\max)} = \left[\frac{\tau \times V_{s(\max)}{}^{2} \times \delta_{\max}}{R_{ds(125^{oC})}} \right]$$

Here $P_{th(max)}$= Maximum throughout power

$\delta_{\max}$ =maximum duty cycle

τ=required efficiency (0.05+/- 0.005)

$R_{ds(125^oC)}$= On state resistance at 125°C

$V_{s(min)}$=Minimum dc link voltage

From this equation we get

$$R_{ds(125^o C)} = 0.03\Omega$$

For the flyback converter presented, the required minimum voltage rating of the MOSFET is calculated as 100 W for input 12V and peak primary current is 10.4 A.

The switch used in the flyback converter circuit is MOSFET IRFP 150N. The special features of these switches are as follows:

- Dynamic dv/dt rating
- Repetitive Avalanche Rated
- Ultra-Low On-Resistance
- Isolated central mounting hole
- 175°C Operating Temperature
- Fast Switching

The ratings of HEXFET Power MOSFET is,

Vdss=100 V

Rds=0.0036 Ω

Id=42 A

4.7.4 PROTECTION CIRCUITS

SNUBBER AND CLAMPS

Transformer leakage inductance imposes high transients in the switch, requiring a switching device with an excessive voltage rating. The primary side of the flyback transformer utilizes a passive polarized voltage clamp to suppress the voltage overshoot during the turn-off transition of the FET. This circuit limits the peak switch voltage, reducing the power dissipation in the switching device. The total dissipated energy remains the same, but it is now divided between the clamp resistor and the FET. The energy store in parasitic inductance of the transformer is discharged into the capacitor during each switching cycle. The value of the capacitor is selected based upon the amount of energy that this leakage inductance stores plus the initial energy stored in the capacitor from the input voltage and the reflected output voltage. Equation given below determines the minimum capacitor value.

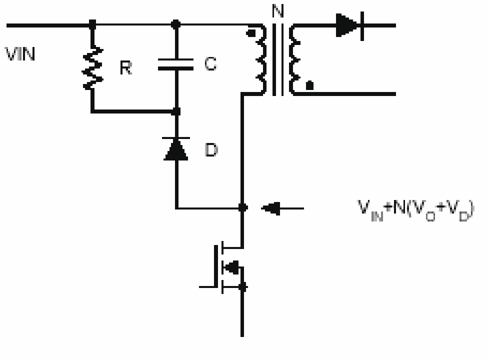


Figure 4.7.4 A passive polarized voltage clamp at primary side

$$C = \left[\frac{L_\ell \times I\,peak^2}{\Delta Vc \times (\Delta Vc + 2V)} \right]$$

In the above equation, ΔV_C is equal to the acceptable change of voltage across the capacitor, usually between 40 and 60V. L_ℓ is equal to the leakage inductance of the transformer. I_{peak} is equal to the peak current in the inductor at the time of turn-off. V is equal to the DC bias across the capacitor. This DC bias is a result of the DC path through the resistor and diode and the secondary side voltage reflected to the primary:

$$V = \left(\frac{Np}{Ns}\right) \times (Vout + Vd)$$

$$= 12 \text{ Volts.}$$

Also here L_ℓ can be estimated as 5% of L_M and it is estimated that L_ℓ =17 μH approx.and now the value of C can be calculated as

$$C = \left(\frac{17 \times 10^{-6} \times 45.8^2}{40 \times (40 + 24)}\right)$$

$$=14 \ \mu F$$

The resistor is selected such that the RC time constant is much longer than the switching period. This resistor must not only dissipate the energy stored in the leakage inductance, but also the voltage due to the DC bias of the capacitor. Here, R used is 5 kΩ, 2 Watts.

Here, turn off snubber across the MOSFET to protect the MOSFET from over voltages which occurs from the switching of the high inductor current.

Now, to design this snubber $\frac{dV}{dt}$ rating of MOSFET must be known. The rating is

$Cs = \frac{I}{\frac{dV}{dt}}$, $C_S > 2$ nF for 5 $\frac{\text{Volts}}{\text{nSec}}$, Take $C_S = 10$ nF.

For discharge $t = R_S \times C_S$, If t = on time then we have R_S=2500Ω

Hence, take R_S=5 kΩ, 2Watts.

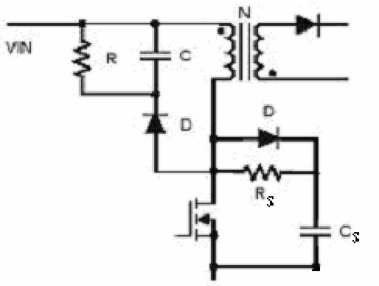


Figure 4.7.4(a) Turn off snubber for MOSFET

Here, diode used is rated for 75 volts, 1W. Ultra fast recovery diodes can also be used for the same application.

4.8 CONTROLLER CIRCUIT

When the relay operates then the oscillator circuit gets connected to the circuit. An oscillator circuit was prepared for 2 KHz frequency having 50% duty cycle. A square wave is being developed using astable multivibrator. By selecting the suitable resistors and keeping in consideration the duty cycle 2 KHz frequency is generated. Frequency f=1/ (tc+td), where tc is the positive pulse width and td is the negative pulse width.
The figure shown below is the diagram of 555 timer working in astable mode.

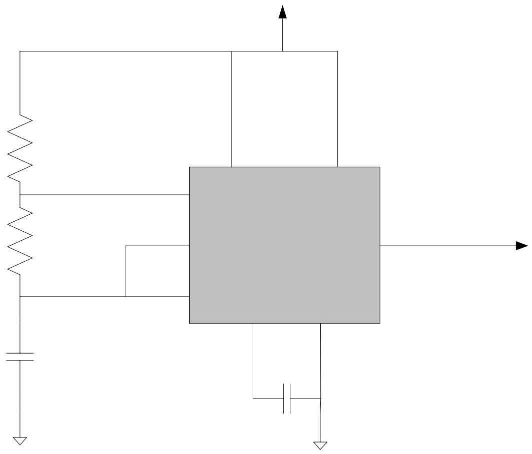


Fig.4.8 Circuit diagram of 555 timer

At power-up, the capacitor is discharged, holding the trigger low. This triggers the timer, which establishes the capacitor charge path through R1 and R2. When the capacitor reaches the threshold level of 2/3 Vcc, the output drops low and the discharge transistor turns on. The timing capacitor now discharges through R2. When the capacitor voltage drops to 1/3 Vcc, the trigger comparator trips and automatically retriggers the timer, creating an oscillator whose frequency is 2 KHz.

4.9 OPTICAL ISOLATION CIRCUIT

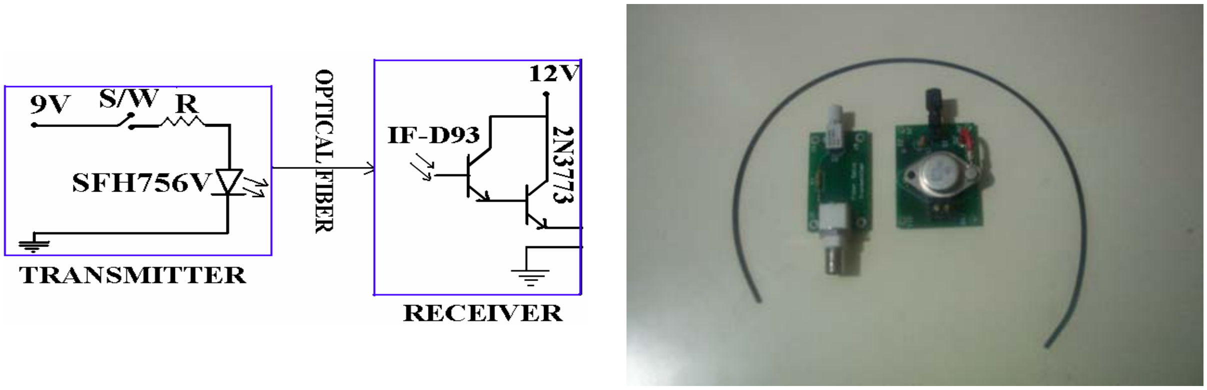


Fig.4.9 Schematic diagram of optical isolation circuit

- **TRANSMITTER**

The transmitter circuit basically comprises of SFH756V, which is a plastic fiber optic transmitter diode having 2.2mm aperture holding up to 1000micron plastic fiber. It has good linearity with forward current >2mA. It is mounted in a plastic connector housing. So the advantage is interference free transmission from light tight housing. It is free from any cross talk and transmitter and receiver can easily be positioned.

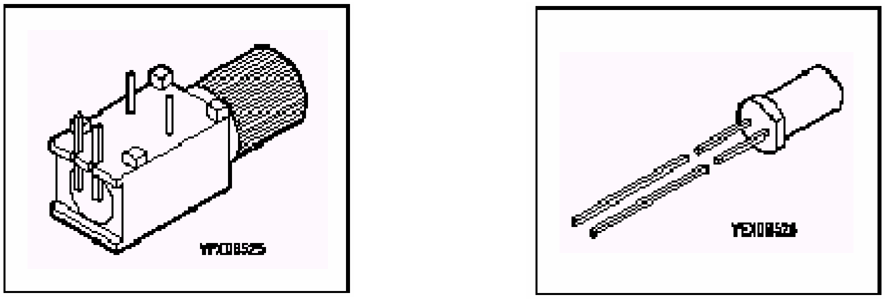


Figure 4.9(a) Transmitter

- **RECEIVER**

The receiver circuit comprises of IF-D93 which is a high sensitivity photo Darlington detector housed in a “connector less “style plastic fiber optic package. Optical response of IF-D93 extends from 400 to 1100 nm, making it compatible with a wide range of visible and near infrared LEDs and other optical sensors. The IF-D93 is suitable for low speed optical links requiring high sensitivity. Photodarlington transistor operation provides high optical gain, thus eliminating the need for amplification in this circuit.

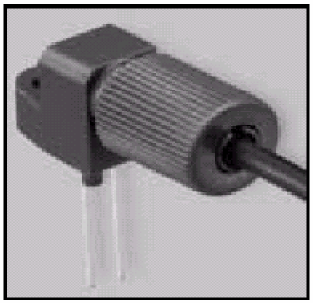
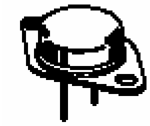


Figure 4.9(b) Receiver

This can be used in several applications like Electronics games, Robotic control, Process control, Medical Instruments etc.

- **POWER TRANSISTOR**

The transistor used in this circuit is 2N3773 which is a power transistor designed for high power audio, disk head positioners and other linear applications. It has a high safe operating area and is completely characterized for linear operation.



WORKING OF THE OPTICAL ISOLATION CIRCUIT

In the system when we turn on the “set” signal, the 9 V battery get connected to the transmitter circuit, the resistance of 10 ohms is connected in series with optical transmitter diode. So transmitter sends the signal to the optical photo Darlington transistor (receiver circuit) through fiber cable. Then this signal goes to the base of the transistor used in receiver circuit. Here the transistor used is 2N3773. This transistor is connected to the same supply as photo Darlington transistor i.e. 12 V. When the signal is given to its base, transistor conducts. Voltage gets developed across circuit connected to it.

CHAPTER 5

DESIGN OF DISCHARGE SWITCH (SCR) TRIGGERING CIRCUIT

5.1 BASICS OF PULSE TRANSFORMER TRIGGERING CIRCUIT

Pulse transformer is used in simultaneous triggering of the semiconductor switches. This transformer has usually four secondary. The turn ratio from primary to secondary is 1:1:1:1.These transformer are designed to have low winding resistances, low leakage reactance and low inter winding capacitance.

The advantages of using pulse transformers in triggering semiconductor devices are:

(i) The isolation of low voltage gate circuit from high voltage anode and

(ii) The triggering of two or more devices from the same trigger sources.

THE ADVANTAGES OF THIS ARRANGEMENT ARE ENLISTED BELOW

1. There need not be a variable strength pulse generator since the pulses may be of the same amplitude and the strength of the pulses may be increased by simply varying the dc voltage.
2. The operation of the circuit becomes independence of the pulse characteristics since the only role of the pulse plays is to turn on or turn off the transistor. Therefore, there is no effect of pulse distortion on the working of this circuit.

In the circuit shown in figure 5.1 (a), *L* is the magnetizing inductance of the pulse transformer and *Rg* is the resistance of gate cathode of the thyristor.

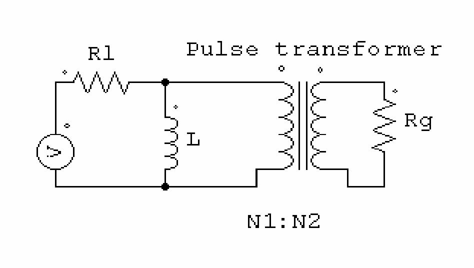


Figure 5.1(a)

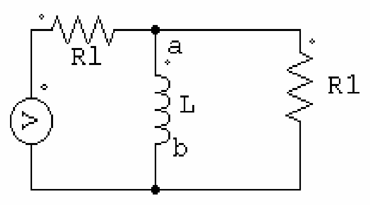


Figure 5.1(b)

Figure 5.1 (b) shows the transfer of *Rg* to pulse transformer primary as $R_1 = \left[\frac{N1}{N2}\right]^2 Rg$.

Analyze the circuit by applying Thevenin's theorem at the terminals a and b.

Figure 5.1 (c) shows the Thevenin's equivalent circuit, where

$$V_o = V_B \frac{R_1}{R_1 + R_l}$$

$$\text{and} \quad R_o = \frac{R_1 R_l}{R_1 + R_l}$$

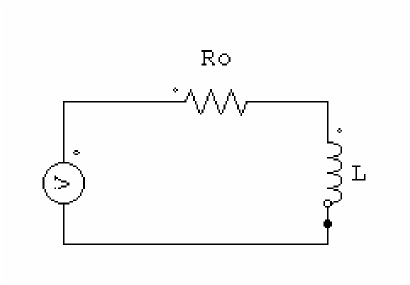


Figure 5.1 (c)

The voltage equation for figure 5.1 (c) is

$$V_o = R_o i + L\frac{di}{dt}$$

$$V_B \frac{R_1}{R_1 + R_l} = \frac{R_1 R_l}{R_1 + R_l} * i + L\frac{di}{dt}$$

Its solution is given by the equation;

$$i = \frac{V_B}{R_l}\left[1 - e^{-\frac{R_1 R_l}{L(R_1 + R_l)}t}\right]$$

The voltage across *L* appears as the output voltage. The magnitude of this voltage from pulse transformer is given by;

$$e = L\frac{di}{dt} = V_B \frac{R_1}{R_1 + R_l} e^{-\frac{R_1 R_l}{L(R_1 + R_l)}t}$$

$$e = L\frac{di}{dt} = V_B \frac{R_1}{R_1 + R_l} e^{-\frac{R_o}{L}t}$$

Depending upon the values of *Ro* and *L*, there are two functional modes of the transformer

(a) If L is so large as compared with R_o that $\frac{L}{R_o} > 10T$, where T is the pulse width of the input signal at g

$$e = V_B \frac{R_1}{R_1 + R_l} e^{-\frac{t}{10T}}$$

For $t = 0$,

$$e_o = V_B \frac{R_1}{R_1 + R_l}$$

And for $t = T$,

$$e_t = V_B \frac{R_1}{R_1 + R_l} e^{-0.1} = 0.904 e_o$$

Thus the fall in level during the transmission through the pulse transformer at is $t = T$ very small. This shows that when, $\frac{L}{R_o} > 10T$ the input pulse is faithfully transmitted as a square wave at the output terminals of the pulse transformer. This shown in figure 5.1 (e).

(b) If R_o is large as compared with L that $\frac{L}{R_o} < \frac{T}{10}$, then

$$e = V_B \frac{R_1}{R_1 + R_l} e^{-\frac{10t}{T}}$$

For $t = 0$,

$$e_o = V_B \frac{R_1}{R_1 + R_l}$$

For $t = T$

$$e_t = V_B \frac{R_1}{R_1 + R_l} e^{-10} = 0.0000453 e_o$$

This shows that $\frac{L}{R_o} < \frac{T}{10}$, the input pulse is transmitted in the form of exponentially decaying pulses. It is clearly depicted that for step rise in input voltage, the pulse transformer output is a positive voltage. The input signal is transmitted as a derivative of the input waveform for a step rise. Likewise for a step fall in the input voltage, a negative pulse appears at the pulse transformer output. This is shown in figure 5.1 (f).

The negative going pulse can be removed by using clipper.

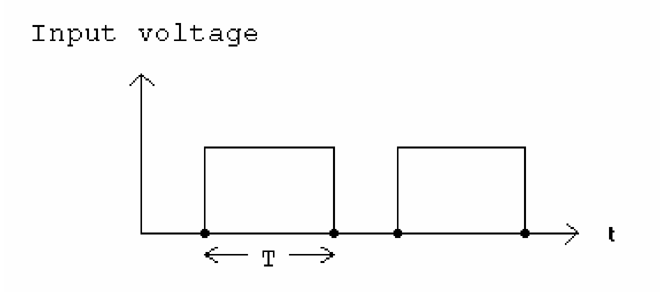


Figure 5.1(d) Input voltage given to the transformer

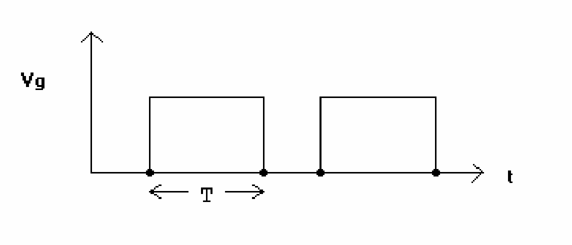


Figure 5.1 (e): Output voltage waveform of a pulse transformer for $\frac{L}{R_o} > 10T$

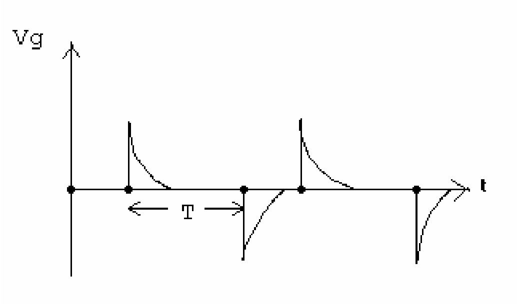


Figure 5.1 (f): Output voltage waveform of a pulse transformer for $\frac{L}{R_o} < \frac{T}{10}$

EXPONENTIALLY DECAYING TRIGGER PULSES ARE PREFERRED DUE TO THE FOLLOWING REASONS

- This pulse waveform is suitable for injecting a large carrier in the gate circuit for reliable turn on.
- The duration of this pulse is small; therefore no significant heating of the gate circuit is there.
- For the same gate-cathode power, it is permissible to rise V_B to a suitable high value so that a hard –drive of SCR is obtained. A device with a hard drive can withstand high $\frac{di}{dt}$ at the anode circuit, which is desirable.

5.2 TRIGGERING CIRCUIT DIAGRAM

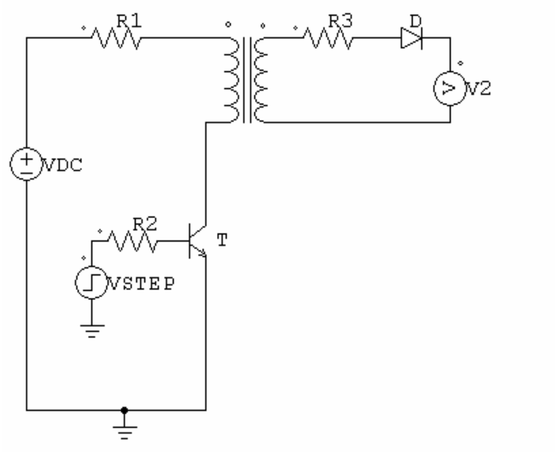


Figure 5.2 SCR triggering circuit

R1 = 5 Ω, R2 = 1 KΩ, R3 = 6.5 Ω

V2 = 2.6 VOLTS

V_{STEP} = 5 VOLTS

T_{STEP} = 3 μs

[A] RATING OF GATE PULSE REQUIRE FOR THYRISTOR

V = 2.6 VOLTS

I = 400 mA

T = 3 μS

[B] DESIGN OF TRIGGERING CIRCUIT

N1=N2

V2=2.6VOLTS

Ig = I2 = V2/R3=400 mA

Ib = Vb/R2 = VSTEP/R2= 500 mA

Ic = V1/R1 = 520 mA

5.3 WORKING OF TRIGGERING CIRCUIT

Here pulse trnsformer is used to trigger the SCR. Pulse transformer are quite often in firing circuits for SCRs. This pulse transformer has usually two or one secondaries. The turn rato for this pulse transformer pf primary and secondary side is 1:1. this transformer have low winding resistance and low inter winding capacitance. The advantages of using pulse transformer in triggering semiconductor device are,

1) The isolation of low voltage gate circuit from high voltage anode circuit.
2) The triggering of two or more devices from the same trigger source.

DC voltage is applied to primary of pulse transformer and transistor is used as a switch. When we give square pulse to base of the transistor it will turn on and work in saturation region. Before that transistor was in cut off region.

A base resistance of 1 KΩ is inserted to limit the base current of transistor. And a one more resistance of 5 Ω is inserted in the primary of pulse transformer to limit the collector current of transistor.

The gate pulse is required to give gate of thyristor is of 2.6vollt and 400mA of 3μs pulse width. So square pulse given to base of transistor should be of 3μs. and primary voltage of pulse transformer should be kept of 2.6volts.

The voltage come at secondary is 2.6volts and to limit the curret of gate of thyristor one resistance of 6.5Ω is inserted.

5.4 EXPERIMENTAL RESULTS OF CIRCUIT

5.4.1 OSCILLOSCOPE WAVEFORM OF PULSE GIVEN TO BASE OF TRANSISTOR

V_{STEP} = 5 Volts, T_{STEP} = 3 μs

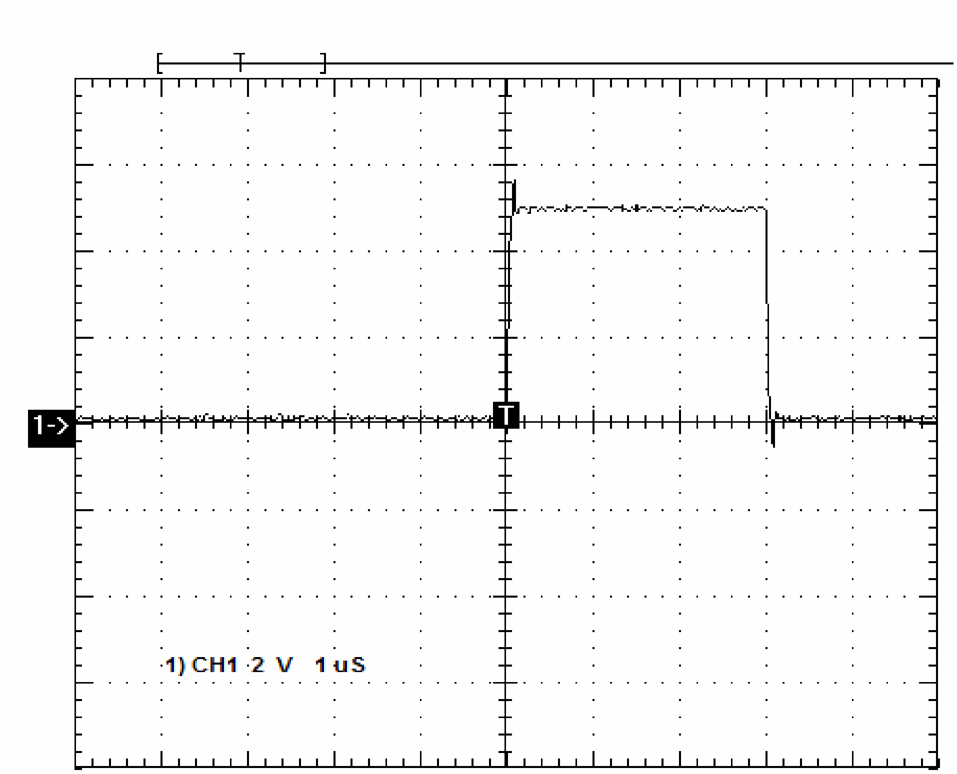


Figure 5.4.1 Waveform of pulse at the transistor base

This is the pulse, which is given to the base of the transistor of thyristor triggering circuit. Using the pulse generator generated it. A mono shot generator should be design to generate the 3 μs pulse with require amplitude. Still mono shot generator circuit is not design but it will be going to be design.

5.4.2 OSCILLOSCOPE WAVEFORM OF PULSE TRANSFORMER SECONDARY

V = 2.6 Volts, I = 400 mA, T = 3 μS

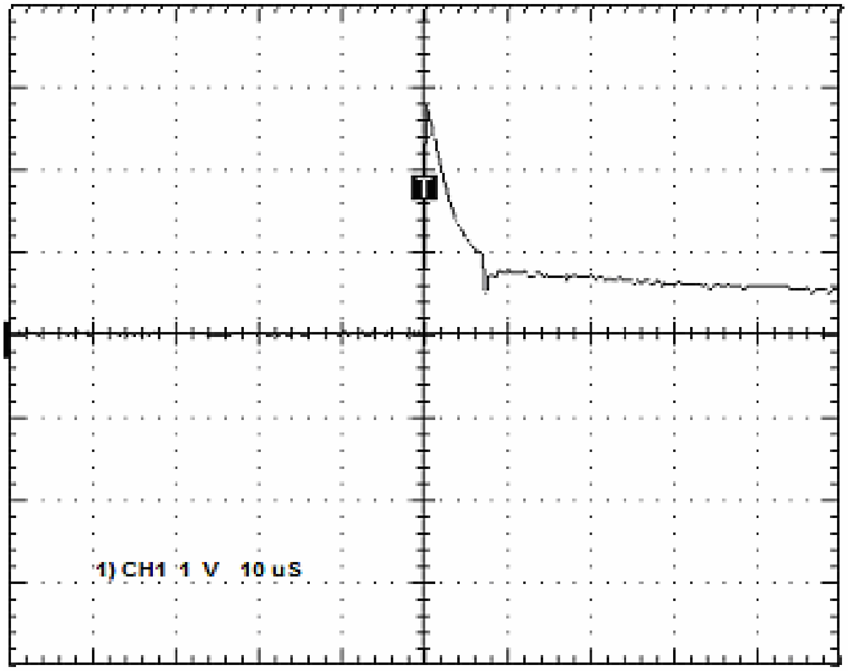


Figure 5.4.2 waveform of pulse transformer output

This is the gate triggering pulse produced at output of pulse transformer. This pulse is required to trigger the thyristor. This pulse is given to the gate of the thyristor so total energy store in the capacitor bank will discharge into load. The magnitude of the gate pulse should be such that it will able to turn on the thyristor. A pulse produce is as per requirement.

CHAPTER 6

SIMULATION AND EXPERIMENTAL REULTS

6.1 SIMULATION OF CAPACITOR BANK CHARGING USING FLYBACK CONVERTER AS A CHARGING UNIT

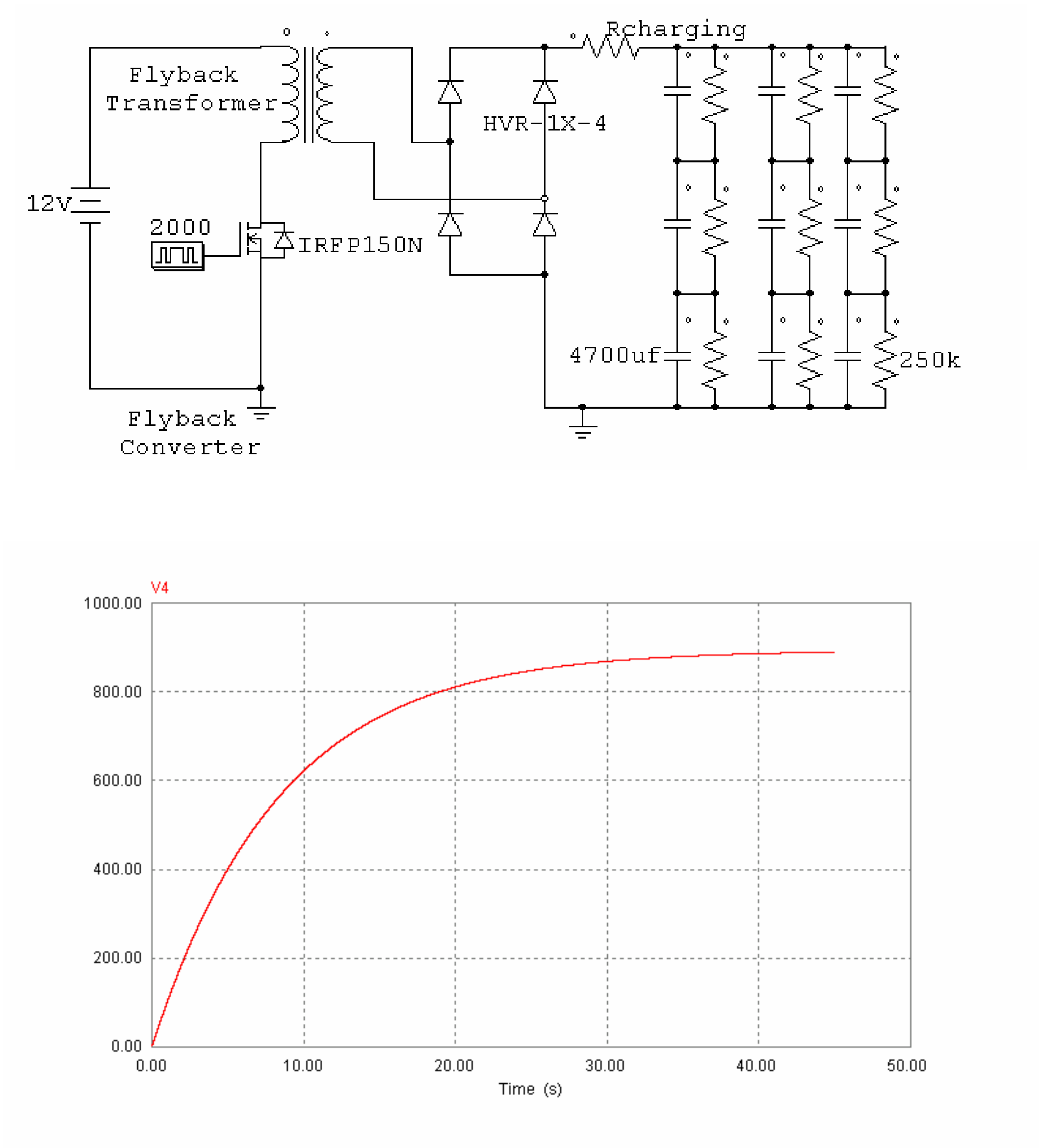


Figure 6.1 capacitor bank charging waveform

Above figure shows the charging waveform of capacitor bank using the flyback converter. A capacitor bank is taking 45 seconds to charge up to 900 V. Because relay timer circuit is provided to stop the charging of capacitor bank after required charging voltage it will stop to charge.

Charging time constant,

Tc=RC=10000*4700*10^-6=47 seconds

But actually it is taking 60 seconds to charge.

6.2 CHARGING UNIT (FLYBACK CONVERTER) OUTPUT

FLYBACK TRANSFORMER SECONDARY OUTPUT:

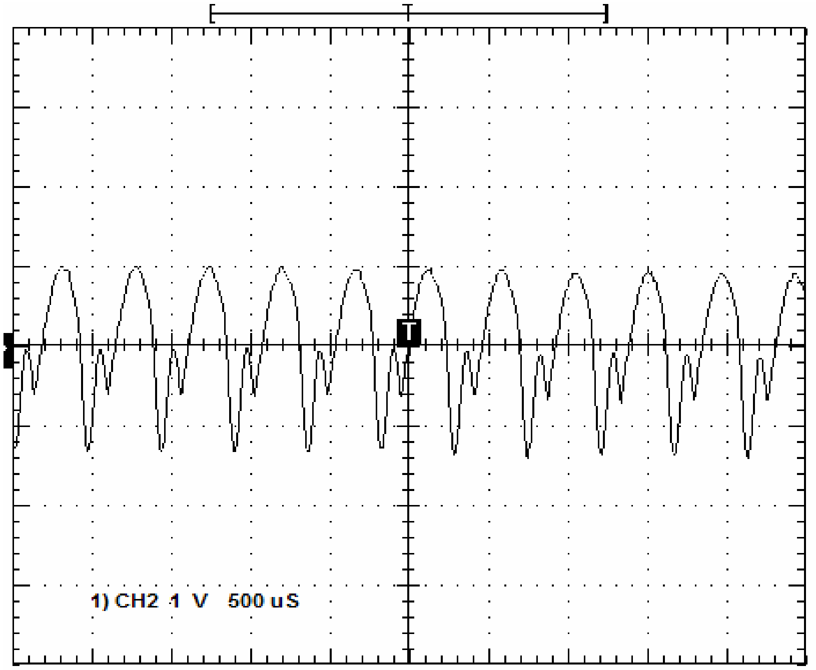


Figure 6.2 (a) Flyback transformer secondary output

FULL BRIDGE RECTIFIER OUTPUT:

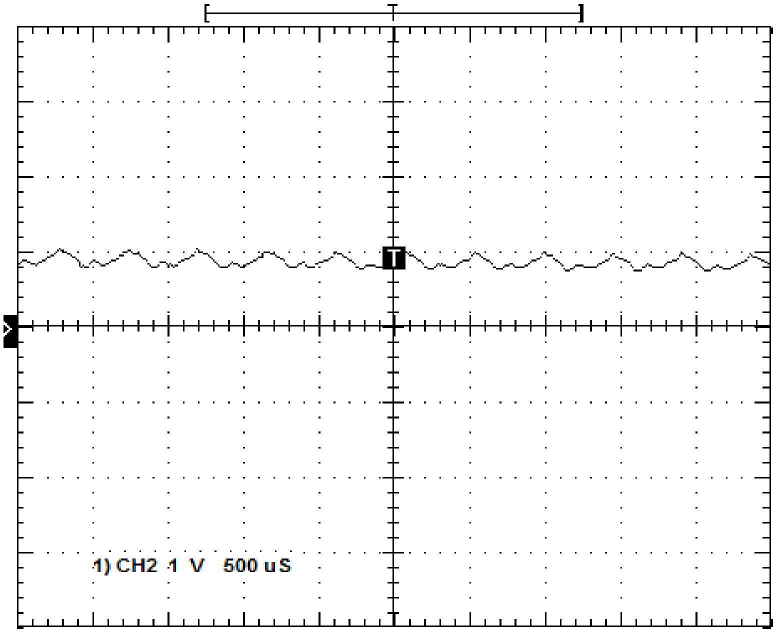


Figure 6.2 (b) Rectifier output

A conventional charging method of capacitor bank is by using step up transformer and rectifier unit. A single phase step up transformer is very bulky and its required single phase supply, it can not use for remote application. And system not becomes compact also. So charging unit is made which is compact and portable. A flyback converter is used as charging unit for capacitor bank. A flyback converter lift up the battery 12 v to the 1 kV p-p dc voltage to charge capacitor bank up to 900 v. to make flyback converter output full bridge rectifier is designed and developed. A ultra fast recovery diode has been used in the rectifier circuit.

Diode: HVR-1X-4

Ratings: 10 kV, 500 mA

6.3 CONTROLLER CIRCUIT OF MOSFET (2 kHz)

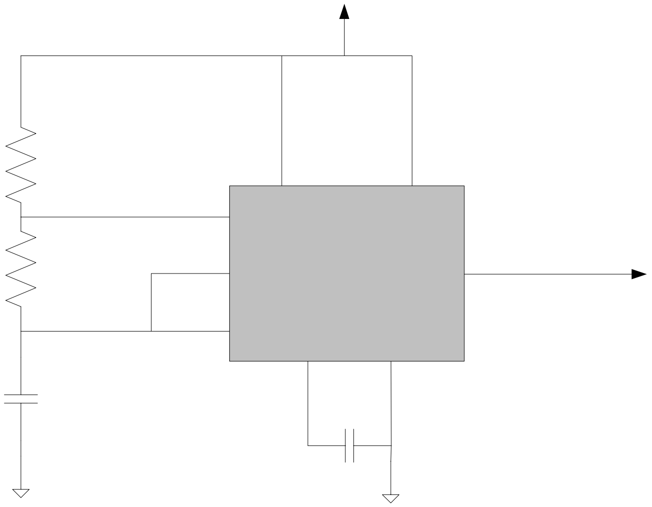
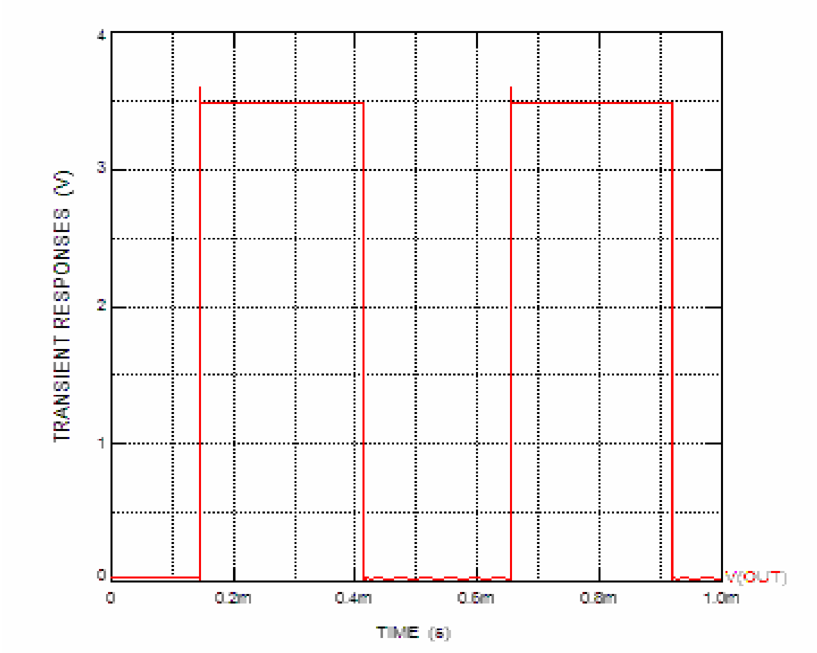


Figure 6.3 555 Controller (Astable mode)



RA

Figure 6.3(a) Simulation of 555 controller

RB

C

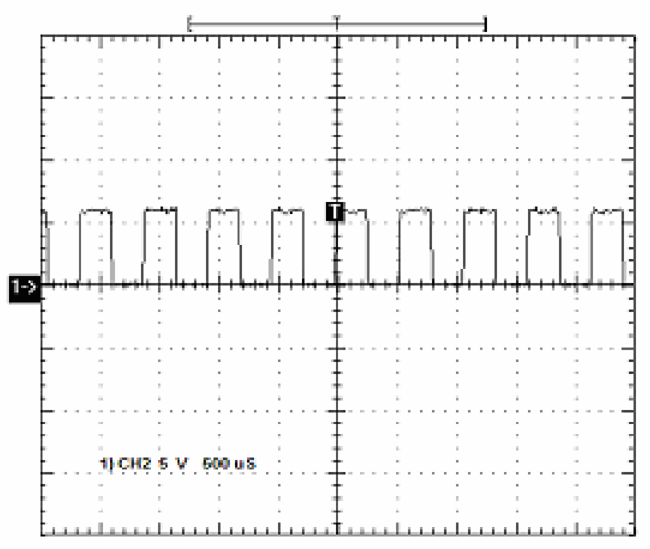


Figure 6.3(b) Experimental waveform of 555 controller

RA=36kΩ, RB=36kΩ, C=0.1μF, C1=0.01μF

A controller circuit for MOSFET is made by using the 555 timer. A 555 timer is operated into astable mode to generate 2 kHz frequency. A simulation of 555 timer for 2 kHz frequency is shown in above figure with 50% duty cycle. Above simulation is done in top spice software. To get 50% duty cycle a diode is connected across the R2. So both charging and discharging period of capacitor will become equal and it will give 50% duty cycle.

6.4 VOLTAGE STRESS ACROSS MOSFET

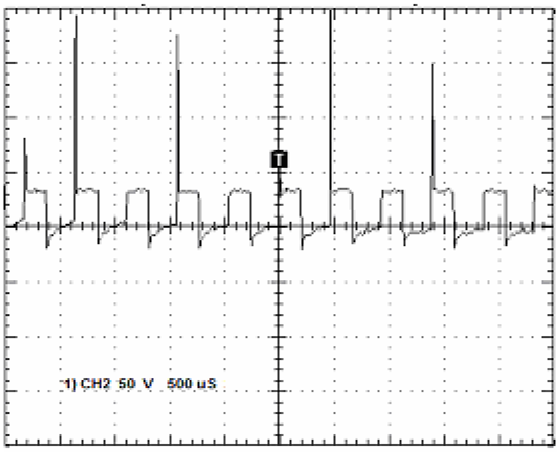


Figure 6.4(a) Waveform of voltage across MOSFET without snubber circuit

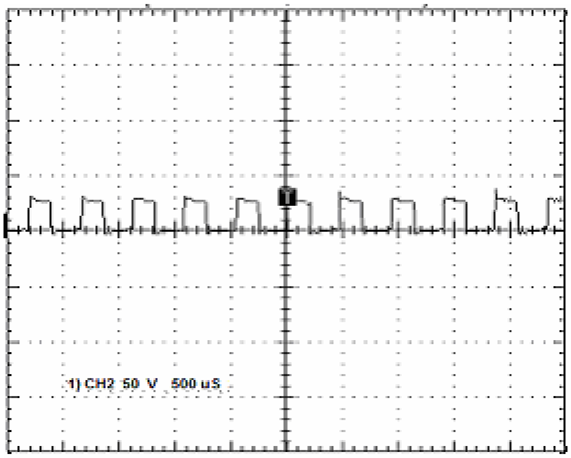
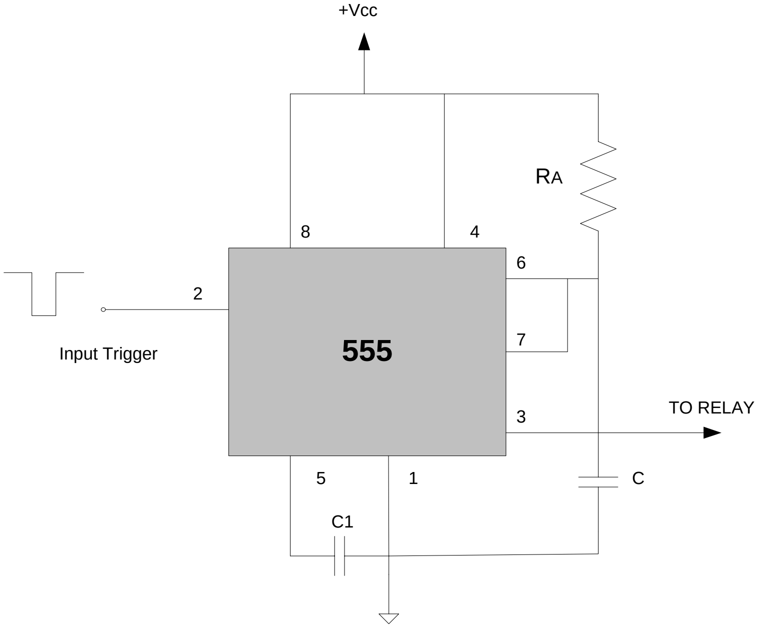


Figure 6.4(b) Waveform of voltage across MOSFET with snubber circuit

Above waveform shows the voltage across MOSFET with and without snubber protection. A first waveform shows that without snubber protection a voltage spikes generate due to the leakage inductance of the primary winding. To eliminate this voltage spikes a snubber protection has been provided. After providing snubber protection voltage across MOSFET becomes smooth as shown in second figure.

6.5 EXPERIMENTAL WAVEFORM OF MONOSTABLE OUTPUT FOR RELAY TIMER CIRCUIT



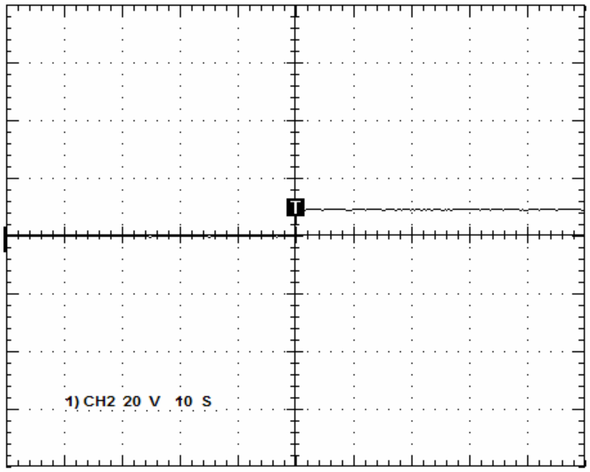


Figure 6.5 waveform of monostable circuit output

RA=5.5 MΩ, C=10 µF, C1=0.01µF (T=1.1RAC)

A relay timer unit is provided in the charging side to stop the capacitor bank charging after the specific charging voltage of the capacitor bank. Time duration of the pulsed is designed on the bases of charging time constant of the capacitor bank.

6.6 OSCILLOSCOPE WAVEFORM OF EXPERIMENT OF UNDERDAMPED CIRCUIT ON FILM CAPACITORS:

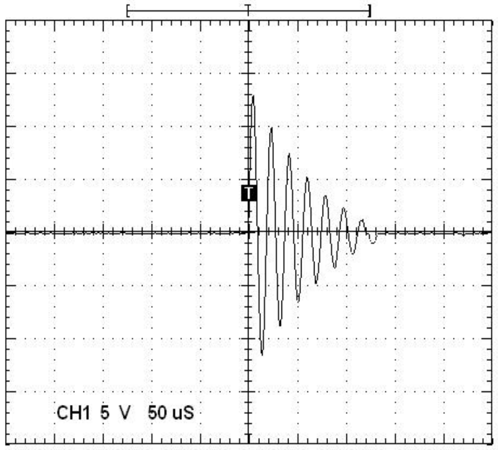


Figure 6.6(a) Experimental waveform of under damped

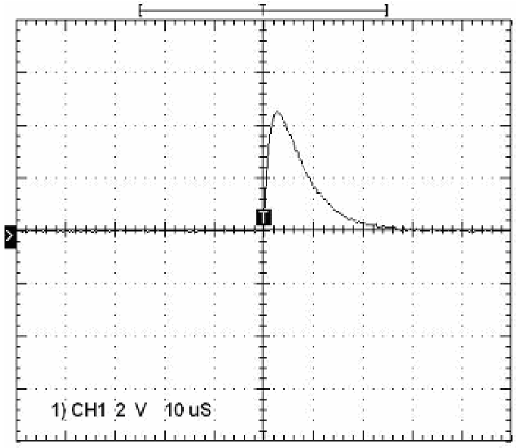


Figure 6.6(b) Experimental waveform of critically damped circuit

A) UNDER DAMPED CIRCUIT:

SPECIFICATIONS: C=3µF, L=4 µH, V=1335V
RESULTS: I=1.3KA, T=20µS

This experiment has been done to study the behavior of under damped circuit. Film capacitor has used in this circuit. Because they are non-polarized so it can able to withstand reversal across it. Whereas electrolytic capacitor is polarized so it cannot be use in the under damped circuit. Current Transformer (CT) has been used to measure the current passing through the load.

B) CRITICALLY DAMPED CIRCUIT:

SPECIFICATIONS: C=3μF, L=4 μH, V=1335V, R=2.5Ω
RESULTS: I=0.6 KA, T=4 μS

This experiment was done on film capacitor to study behavior of critically damped circuit. The proper value of damping resistance should be inserted in the circuit to make the system critically damped. Value of damping resistance can be easily calculated by using equation with having value of circuit inductance and capacitance. Electrolytic capacitor is polarized and it can not able to withstand reversal across it. .Because in this system electrolytic capacitor are used in capacitor bank to store energy system must be critically damped to avoid reversal across capacitor.

6.7 CAPACITOR BANK DISCHARGE WAVEFORM USING SCR AS A DISCHARGE SWITCH

1) Current, $i(t) = \frac{V_0 t}{L} e^{\frac{-R}{2L}t}$

2) Rise time for Peak Current, t = 2L/R

3) Peak Current, $I_{Peak} = \frac{2V_0}{eR} = 0.736\frac{V_0}{R}$

4) Pulse width, $T/2=\Pi^*(LC)^{1/2}$

5) Damping Resistor, $R = 2^*(L/C)^{1/2}$

1) ONE CAPACITOR DISCHARGE WAVEFORM:

SPECIFICATION:

C=4700 µF, R=0.05 Ω, L=4 µH, V=300 V

RESULT:

I=2.42 kA, T=400 µS, Trise=100 µS

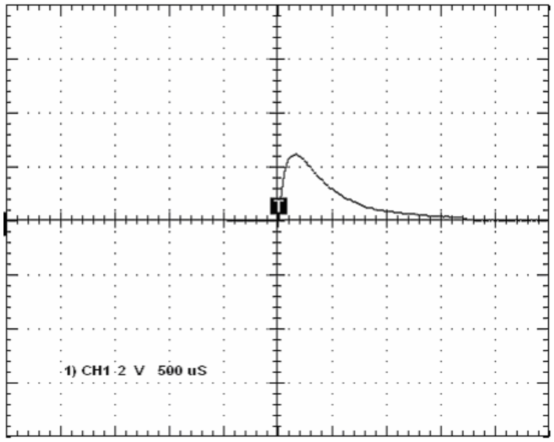


Figure 6.7 (a) One capacitor discharge waveform (CT Ratio: 1000:1)

2) TWO CAPACITORS ARE IN SERIES DISCHARGE WAVEFORM:

SPECIFICATION:

C=2350 µF, L=4 µH, V=600 V, R=0.1 Ω

RESULT:

I=3.48 kA, T=300 µS, Trise=100 µS

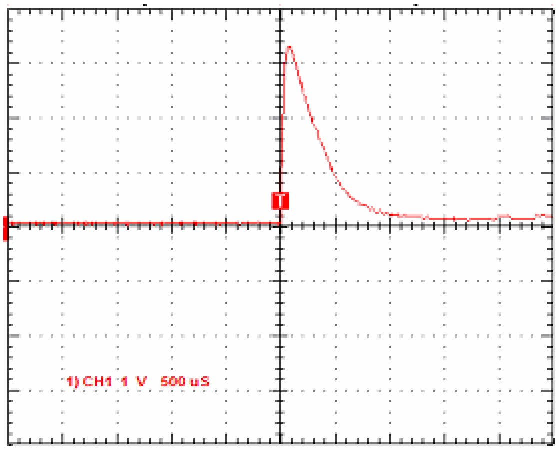


Figure 6.7 (b) Two series capacitor discharge waveform (CT Ratio: 1000:1)

3) THREE CAPACITORS ARE IN SERIES DISCHARGE WAVEFORM:

SPECIFICATION:

C=1567 µF, L=4 µH, V=900 V, R=0.1 Ω

RESULT:

I=4.44 kA, T=250 µS, Trise=80 µS

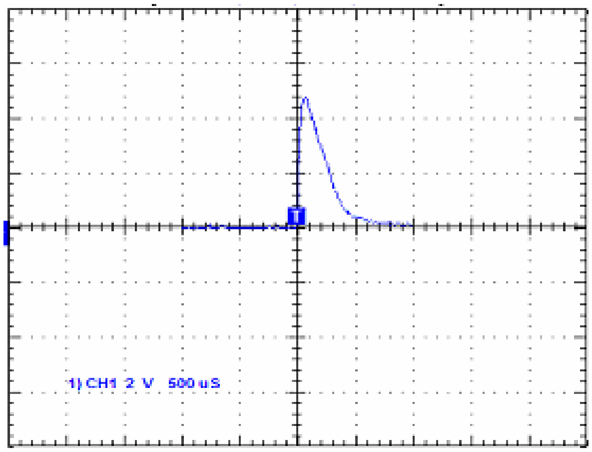


Figure 6.7 (c) Three series capacitors discharge waveform (CT Ratio: 1000:1)

4) SIX CAPACITORS ARE IN SERIES AND PARALLEL DISCHARGE WAVEFORM:

SPECIFICATION:

C=3134 µF, L=4 µH, V=900 V, R=0.1 Ω

RESULT:

I=5.48 kA, T=250 µS, Trise=100 µS

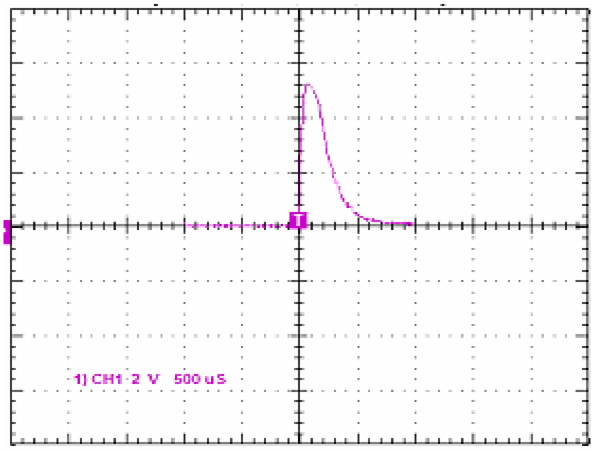


Figure 6.7 (d) Six series-parallel capacitors discharge waveform (CT Ratio: 1000:1)

5) NINE CAPACITORS ARE IN SERIES AND PARALLEL DISCHARGE WAVEFORM:

SPECIFICATION:

C=4700 µF, R=0.05 Ω, L=4 µH, V=900 V, E=1905 J

RESULT:

I=9 kA, T=400 µS, Trise=100 µS

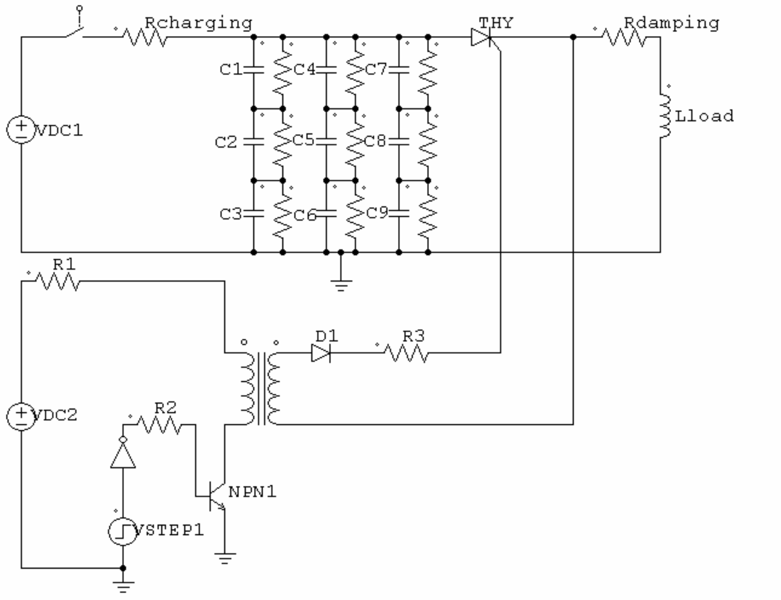


Figure 6.7(e) Capacitor bank discharge circuit

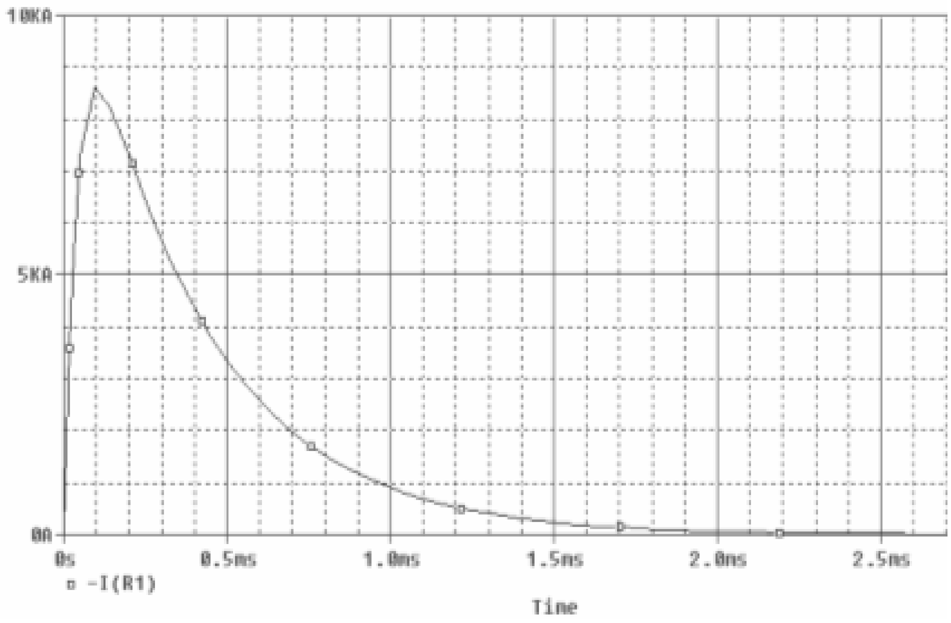


Figure 6.7 (f) Simulation result of capacitor bank discharge

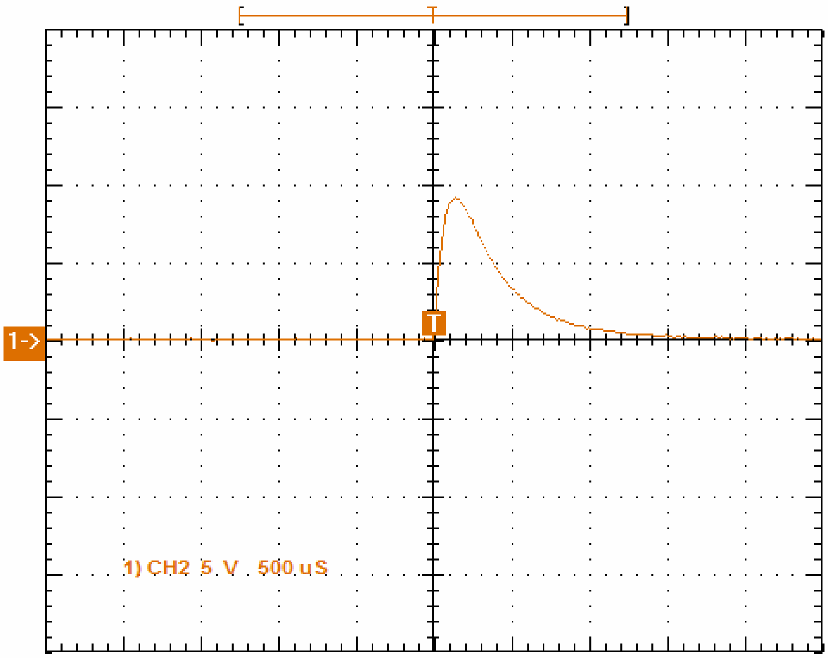


Figure 6.7 (g) Waveform of capacitor bank discharges (CT Ratio: 1000:1)

Before make capacitor bank some of above experiments was done on one, two, three, six and nine capacitor respectively. The similar shape waveform was got and the value of peak value of current pulse increase with increase with increase of capacitance. Because capacitance is increase by increasing the capacitor it will able to store more energy and produce more peak current pulse. Also rise time and pulse duration also change with the change in the value of capacitance.

Electrolytic capacitor is having higher energy density so it is used in energy storage capacitor bank in pulsed power system. The experiment was done on critically damped circuit using electrolytic capacitor. A table shows the various comparison of result got in experiment and simulation results.

6.8 ENTIRE PROJECT SETUP

Figure 6.8 snap of entire project setup

Above figure shows the entire project setup. Aim of the project is to make compact and portable pulse power generator which is driven by battery. A charging unit is made by Flyback converter and all PCB of MOSFET and its control circuit, Transmitter-Receiver circuit, Flyback Transformer and Rectifier and Relay/timer unit is fixed in black box. Also capacitor bank is mounted vertically by fixing them in the hole made in the two acrylic plates. Also charging resistor, damping resistor and inductive load is mounted on the same acrylic plates.

6.9 COMPARISON OF EXPERIMENTAL AND SIMULATION RESULTS OF CAPACITOR DISCHARGE

NOS. OF CAPACITOR DISCHARGE	EXPERIMENTAL RESULTS	SIMULATION RESULTS
ONE CAPACITOR • C=4700µF • R=0.05Ω • L=4 µH • V=300V	• I=2.42KA • T=400µS	• I=2.6KA • T=400µS
TWO CAPACITOR • C=2350µF • R=0.1Ω • L=4 µH • V=600V	• I=3.48KA • T=300µS	• I=3.55KA • T=280µS
THREE CAPACITOR • C=1567µF • R=0.1Ω • L=4 µH • V=900V	• I=4.44KA • T=250µS	• I=4.8KA • T=250µS
SIX CAPACITOR ARE IN SERIESE-PARALLEL • C=3134µF • R=0.1Ω • L=4 µH • V=900V	• I=5.48KA • T=250µS	• I=5.5KA • T=300µS
NINE CAPACITOR ARE IN SERIESE-PARALLEL • C=4700µF • R=0.033 Ω • L=4 µH • V=900V • E=1905J	• I=9 KA • T=400 µS	• I=9KA • T=400µS

6.10 DIFFERENT TYPES OF DIAGNOSTIC USED

6.10.1 NORTH STAR HIGH VOLTAGE PROBE

Voltage across the secondary of the flyback transformer is measured with the help of North star probe having attenuation factor of 1000.Figure 8.16 shows the North star probe used.

Figure 6.10.1: North Star probe PVM-1

6.10.2 MULTI FUNCTION GENERATOR

A function generator is used to give required width of voltage pulse to the base of the transistor of the SCR triggering circuit.

Figure 6.10.2: Function Generator

6.10.3 CURRENT TRANSFORMER (CT)

To get the multi kilo- ampere current pulse this current transformer has been used. It is having attenuation ratio of 1000:1. It is made by Pearson electronics, USA.

Figure 6.10.3 Current Transformer (1000:1)

CHAPTER 7

CONCLUSION & FUTURE SCOPE

CONCLUSION

After testing of entire project setup it is concluded that a portable and compact pulse power generator is made successfully. A pulsed power circuit is producing the required current pulse as per the design of the circuit. A flyback converter is used as a charging unit hence its current rating is low and takes more time to charge.

FUTURE SCOPE

A inductive energy storage system though have problem of fast switching device controlled but its have very high energy density so by proper controlling of switching device, it is more advantageous to use inductive energy storage system instead of capacitive energy storage system.

Also instead of flyback converter some other scheme which is have more current rating can be use as charging unit so it will lessen the charging time.

Modeling of MOSFET can also be done analyze the turn on and turn off characteristic of the MOSFET.

A capacitor bank can be expand to a some extend to produce more value of the current pulse as per the different application requirement.

The function generator drives a base of the transistor in SCR triggering circuit. It can be design a mono shot generator circuit.

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APPENDIX

1. Datasheet of Transistor IRFP 150N
2. Datasheet of SCR 5STP 17H5200

V_{DSM} = 5200 V
I_{TAVM} = 1975 A
I_{TRMS} = 3100 A
I_{TSM} = 29000 A
V_{T0} = 1.02 V
r_T = 0.320 mΩ

Phase Control Thyristor

5STP 17H5200

Doc. No. 5SYA1049-02 Sep. 01

- **Patented free-floating silicon technology**
- **Low on-state and switching losses**
- **Designed for traction, energy and industrial applications**
- **Optimum power handling capability**
- **Interdigitated amplifying gate**

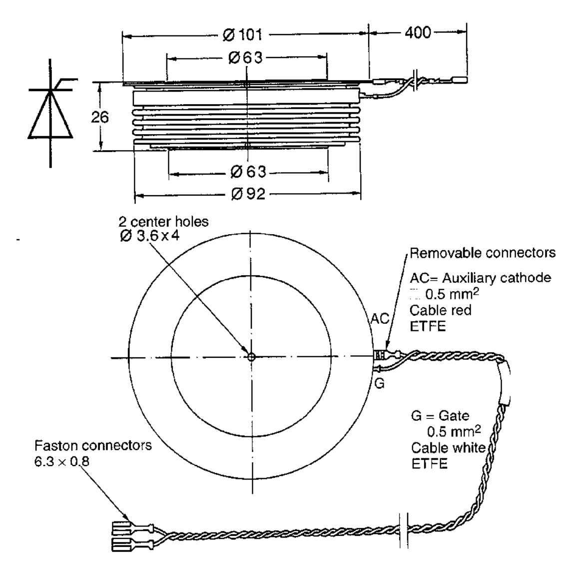
Blocking

Part Number	**5STP 17H5200**	**5STP 17H5000**	**5STP 17H4600**	Conditions	
V_{DSM} V_{RSM}	5200 V	5000 V	4600 V	f = 5 Hz, t_p = 10ms	
V_{DRM} V_{RRM}	4400 V	4200 V	4000 V	f = 50 Hz, t_p = 10ms	
V_{RSM1}	5700 V	5500 V	5100 V	t_p = 5ms, single pulse	
I_{DSM}	≤ 400 mA			V_{DSM}	T_j = 125°C
I_{RSM}	≤ 400 mA			V_{RSM}	
dV/dt_{crit}	2000 V/µs			Exp. to 0.67 x V_{DRM}, T_j = 125°C	

V_{DRM}/ V_{RRM} are equal to V_{DSM}/ V_{RSM} values up to T_j = 110°C

Mechanical data

F_M	Mounting force	nom.	50 kN
		min.	45 kN
		max.	60 kN
a	Acceleration Device unclamped Device clamped		 50 m/s^2 100 m/s^2
m	Weight		0.9 kg
D_S	Surface creepage distance		36 mm
D_a	Air strike distance		15 mm



On-state

I_{TAVM}	Max. average on-state current	1975 A	Half sine wave, $T_C = 70°C$	
I_{TRMS}	Max. RMS on-state current	3100 A		
I_{TSM}	Max. peak non-repetitive	29000 A	tp = 10 ms	$T_j = 125°C$
	surge current	31000 A	tp = 8.3 ms	After surge:
I^2t	Limiting load integral	4205 kA^2s	tp = 10 ms	$V_D = V_R = 0V$
		3990 kA^2s	tp = 8.3 ms	
V_T	On-state voltage	1.68 V	I_T = 2000 A	$T_j = 125°C$
V_{T0}	Threshold voltage	1.02 V	I_T = 1000 - 3000 A	
r_T	Slope resistance	0.320 mΩ		
I_H	Holding current	30-80 mA	T_i = 25°C	
		15-60 mA	T_i = 125°C	
I_L	Latching current	150- mA	T_i = 25°C	
		50-200 mA	T_i = 125°C	

Switching

di/dt_{crit}	Critical rate of rise of on-state current		100 A/µs	Cont. f = 50 Hz	$V_D \leq 0.67 \cdot V_{DRM}$, $T_j = 125°C$
			200 A/µs	60 sec. f = 50Hz	I_{TRM} = 3000 A I_{FG} = 2 A, t_r = 0.5 µs
t_d	Delay time		≤ 3.0 µs	$V_D = 0.4 \cdot V_{DRM}$	I_{FG} = 2 A, t_r = 0.5 µs
t_q	Turn-off time		≤ 700 µs	$V_D \leq 0.67 \cdot V_{DRM}$ dv_D/dt = 20V/µs	I_{TRM} = 3000 A, $T_j = 125°C$ V_R > 200 V, di_T/dt = -5 A/µs
Q_{rr}	Recovery charge	min	4800 µAs		
		max	6200 µAs		

Triggering

V_{GT}	Gate trigger voltage	2.6 V	T_j = 25°
I_{GT}	Gate trigger current	400 mA	T_j = 25°
V_{GD}	Gate non-trigger voltage	0.3 V	V_D =0.4 x V_{DRM}
I_{GD}	Gate non-trigger current	10 mA	V_D = 0.4 x V_{DRM}
V_{FGM}	Peak forward gate voltage	12 V	
I_{FGM}	Peak forward gate current	10 A	
V_{RGM}	Peak reverse gate voltage	10 V	
P_G	Gate power loss	3 W	

Thermal

T_{jmax}	Max. operating junction temperature range	125 °C	
T_{stg}	Storage temperature range	-40…140 °C	
R_{thJC}	Thermal resistance junction to case	20 K/kW	Anode side cooled
		20 K/kW	Cathode side cooled
		10 K/kW	Double side cooled
R_{thCH}	Thermal resistance case to heat sink	4 K/kW	Single side cooled
		2 K/kW	Double side cooled

Analytical function for transient thermal impedance:

$$Z_{thJC}(t) = \sum_{i=1}^{n} R_i(1 - e^{-t/\tau_i})$$

i	1	2	3	4
R_i(K/kW)	6.52	1.55	1.67	0.49
τ_i(s)	0.4562	0.0792	0.0088	0.0037

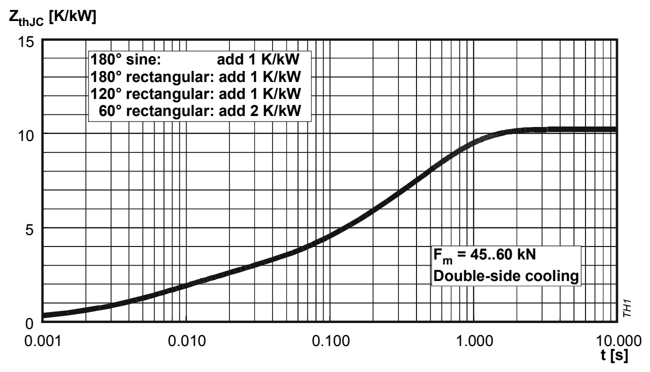


Fig. 1 Transient thermal impedance junction to case.

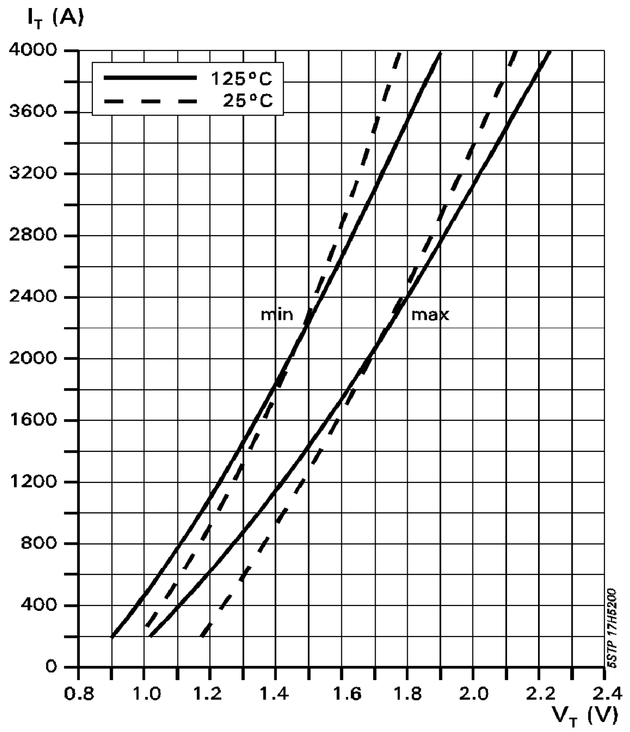


Fig. 2 On-state characteristics.

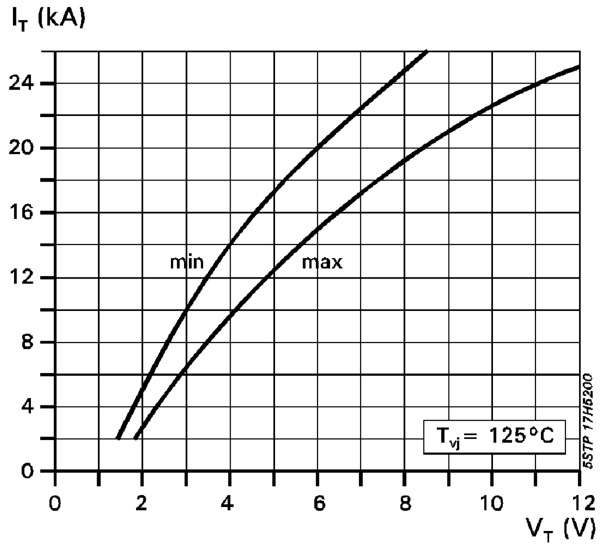


Fig. 3 On-state characteristics.
T_j=125°C, 10ms half sine

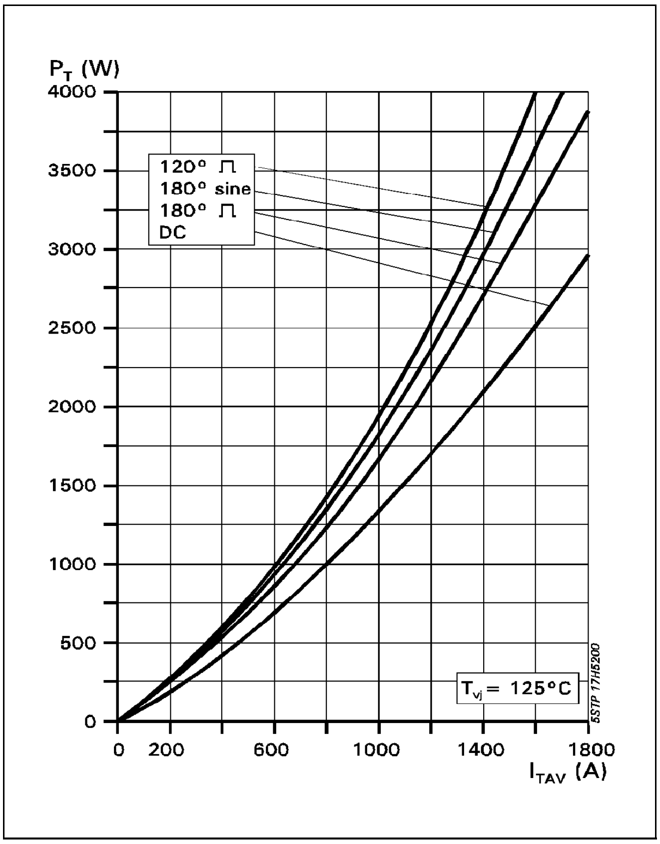


Fig. 4 On-state power dissipation vs. mean on-state current. Turn - on losses excluded.

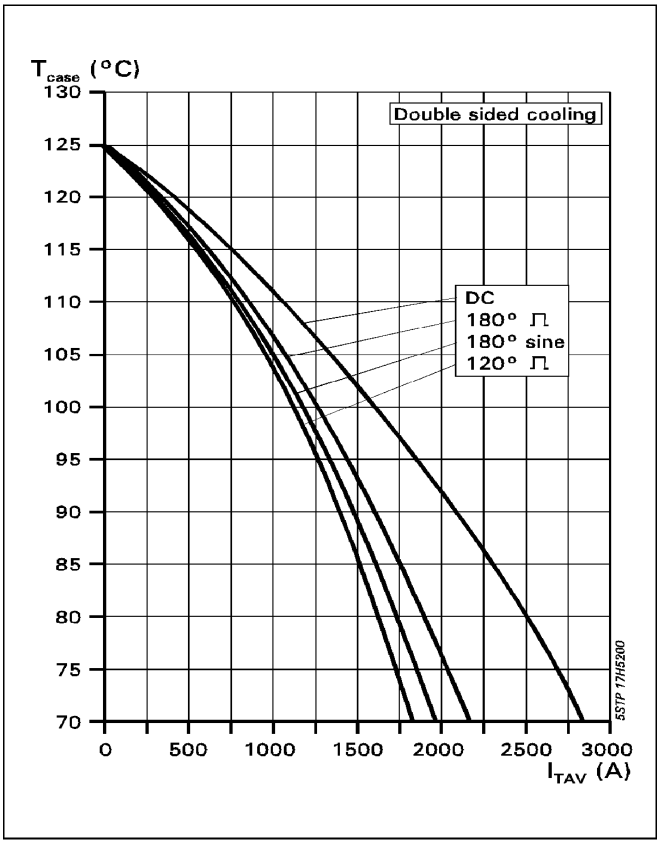


Fig. 5 Max. permissible case temperature vs. mean on-state current.

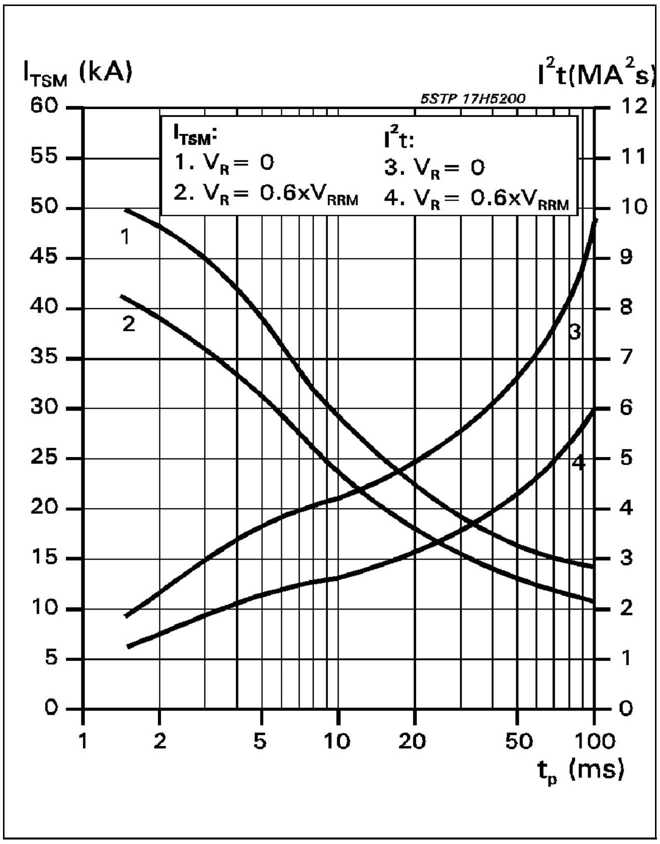


Fig. 6 Surge on-state current vs. pulse length. Half-sine wave.

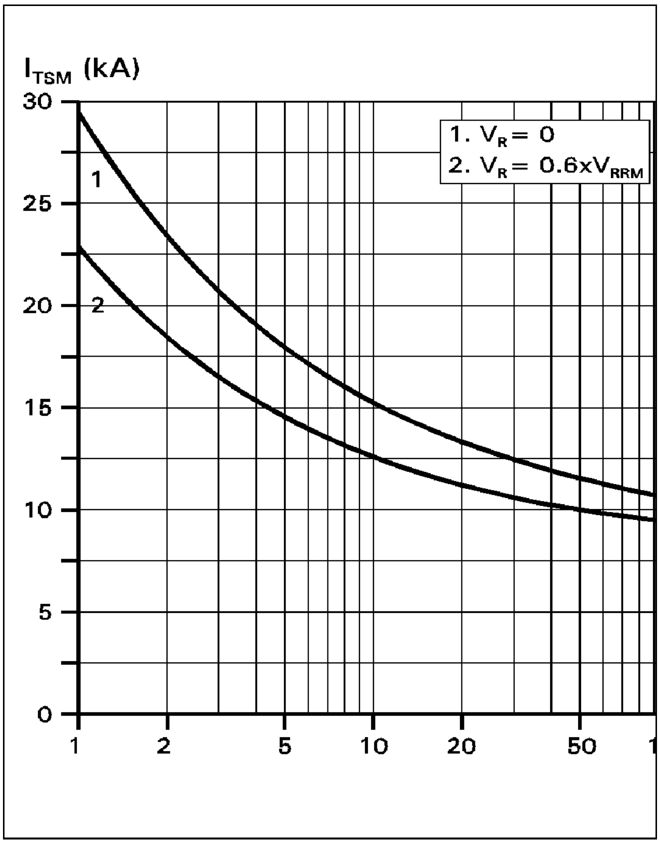


Fig. 7 Surge on-state current vs. number of pulses. Half-sine wave, 10 ms, 50Hz.

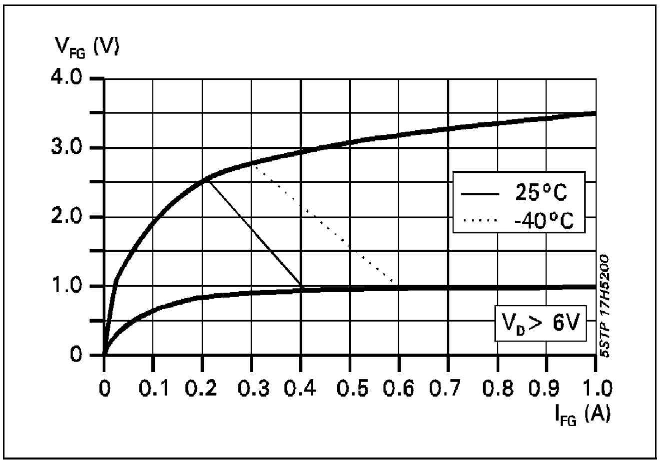


Fig. 8 Gate trigger characteristics.

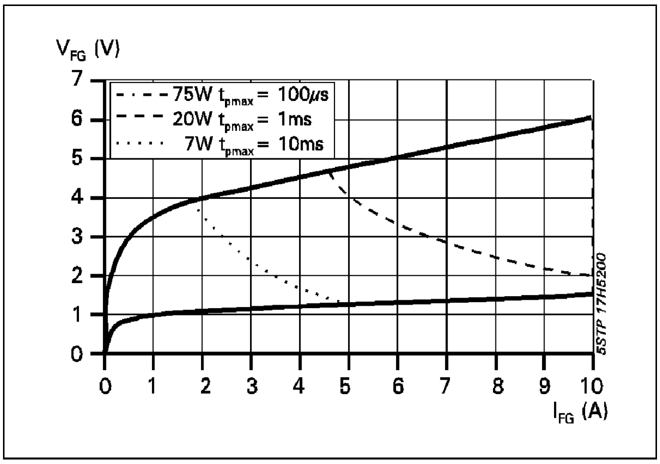


Fig. 9 Max. peak gate power loss.

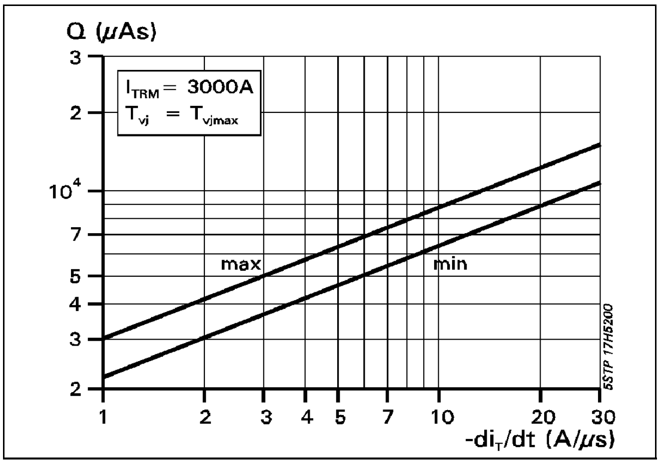


Fig. 10 Recovery charge vs. decay rate of on-state current.

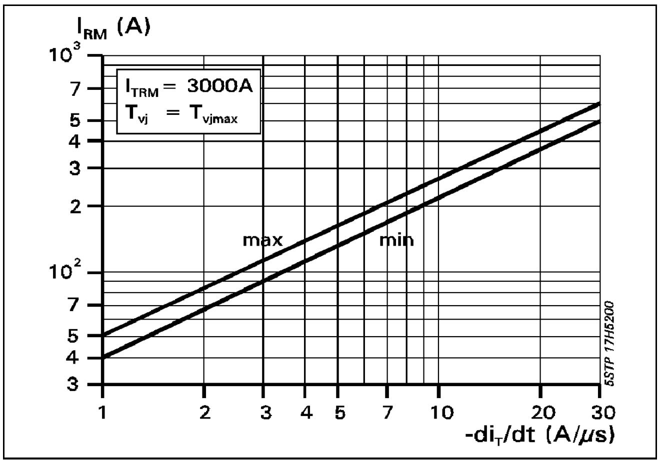


Fig. 11 Peak reverse recovery current vs. decay rate of on-state current.

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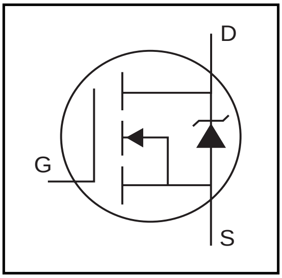
IRFP150N

HEXFET® Power MOSFET

- Advanced Process Technology
- Dynamic dv/dt Rating
- 175°C Operating Temperature
- Fast Switching
- Fully Avalanche Rated



V_{DSS} = 100V

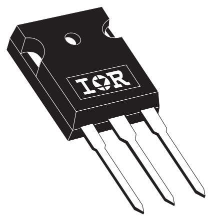
$R_{DS(on)}$ = 0.036Ω

I_D = 42A

Description

Fifth Generation HEXFETs from International Rectifier utilize advanced processing techniques to achieve extremely low on-resistance per silicon area. This benefit, combined with the fast switching speed and ruggedized device design that HEXFET Power MOSFETs are well known for, provides the designer with an extremely efficient and reliable device for use in a wide variety of applications.

The TO-247 package is preferred for commercial-industrial applications where higher power levels preclude the use of TO-220 devices. The TO-247 is similar but superior to the earlier TO-218 package because of its isolated mounting hole.


TO-247AC

Absolute Maximum Ratings

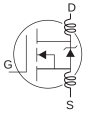
	Parameter	Max.	Units
I_D @ T_C = 25°C	Continuous Drain Current, V_{GS} @ 10V	42	A
I_D @ T_C = 100°C	Continuous Drain Current, V_{GS} @ 10V	30	
I_{DM}	Pulsed Drain Current ①⑤	140	
P_D @T_C = 25°C	Power Dissipation	160	W
	Linear Derating Factor	1.1	W/°C
V_{GS}	Gate-to-Source Voltage	± 20	V
E_{AS}	Single Pulse Avalanche Energy②⑤	420	mJ
I_{AR}	Avalanche Current①⑤	22	A
E_{AR}	Repetitive Avalanche Energy①	16	mJ
dv/dt	Peak Diode Recovery dv/dt ③⑤	5.0	V/ns
T_J T_{STG}	Operating Junction and Storage Temperature Range	-55 to + 175	°C
	Soldering Temperature, for 10 seconds	300 (1.6mm from case)	
	Mounting torque, 6-32 or M3 srew	10 lbf•in (1.1N•m)	

Thermal Resistance

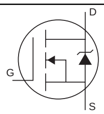
	Parameter	Typ.	Max.	Units
$R_{\theta JC}$	Junction-to-Case	——	0.95	°C/W
$R_{\theta CS}$	Case-to-Sink, Flat, Greased Surface	0.24	——	
$R_{\theta JA}$	Junction-to-Ambient	——	40	

07/15/02

Electrical Characteristics @ T_J = 25°C (unless otherwise specified)

	Parameter	Min.	Typ.	Max.	Units	Conditions
$V_{(BR)DSS}$	Drain-to-Source Breakdown Voltage	100	—	—	V	V_{GS} = 0V, I_D = 250μA
$\Delta V_{(BR)DSS}/\Delta T_J$	Breakdown Voltage Temp. Coefficient	—	0.11	—	V/°C	Reference to 25°C, I_D = 1mA⑤
$R_{DS(on)}$	Static Drain-to-Source On-Resistance	—	—	0.036	Ω	V_{GS} = 10V, I_D = 23A ④
$V_{GS(th)}$	Gate Threshold Voltage	2.0	—	4.0	V	V_{DS} = V_{GS}, I_D = 250μA
g_{fs}	Forward Transconductance	14	—	—	S	V_{DS} = 25V, I_D = 22A⑤
I_{DSS}	Drain-to-Source Leakage Current	—	—	25	μA	V_{DS} = 100V, V_{GS} = 0V
		—	—	250		V_{DS} = 80V, V_{GS} = 0V, T_J = 150°C
I_{GSS}	Gate-to-Source Forward Leakage	—	—	100	nA	V_{GS} = 20V
	Gate-to-Source Reverse Leakage	—	—	-100		V_{GS} = -20V
Q_g	Total Gate Charge	—	—	110	nC	I_D = 22A
Q_{gs}	Gate-to-Source Charge	—	—	15		V_{DS} = 80V
Q_{gd}	Gate-to-Drain ("Miller") Charge	—	—	58		V_{GS} = 10V, See Fig. 6 and 13 ④⑤
$t_{d(on)}$	Turn-On Delay Time	—	11	—	ns	V_{DD} = 50V
t_r	Rise Time	—	56	—		I_D = 22A
$t_{d(off)}$	Turn-Off Delay Time	—	45	—		R_G = 3.6Ω
t_f	Fall Time	—	40	—		R_D = 2.9Ω, See Fig. 10 ④⑤
L_D	Internal Drain Inductance	—	5.0	—	nH	Between lead, 6mm (0.25in.) from package and center of die contact 
L_S	Internal Source Inductance	—	13	—		
C_{iss}	Input Capacitance	—	1900	—	pF	V_{GS} = 0V
C_{oss}	Output Capacitance	—	450	—		V_{DS} = 25V
C_{rss}	Reverse Transfer Capacitance	—	230	—		f = 1.0MHz, See Fig. 5⑤

Source-Drain Ratings and Characteristics

	Parameter	Min.	Typ.	Max.	Units	Conditions
I_S	Continuous Source Current (Body Diode)	—	—	42	A	MOSFET symbol showing the integral reverse p-n junction diode. 
I_{SM}	Pulsed Source Current (Body Diode) ①⑤	—	—	140		
V_{SD}	Diode Forward Voltage	—	—	1.3	V	T_J = 25°C, I_S =23A, V_{GS} = 0V ④
t_{rr}	Reverse Recovery Time	—	180	270	ns	T_J = 25°C, I_F = 22A
Q_{rr}	Reverse RecoveryCharge	—	1.2	1.8	μC	di/dt = 100A/μs ④ ⑤
t_{on}	Forward Turn-On Time	Intrinsic turn-on time is negligible (turn-on is dominated by L_S+L_D)				

Notes:

① Repetitive rating; pulse width limited by max. junction temperature. (See fig. 11)

② Starting T_J = 25°C, L = 1.7mH R_G = 25Ω, I_{AS} = 22A. (See Figure 12)

③ I_{SD} ≤ 22A, di/dt ≤ 180A/μs, V_{DD} ≤ $V_{(BR)DSS}$, T_J ≤ 175°C

④ Pulse width ≤ 300μs; duty cycle ≤ 2%.

⑤ Uses IRF1310N data and test conditions.

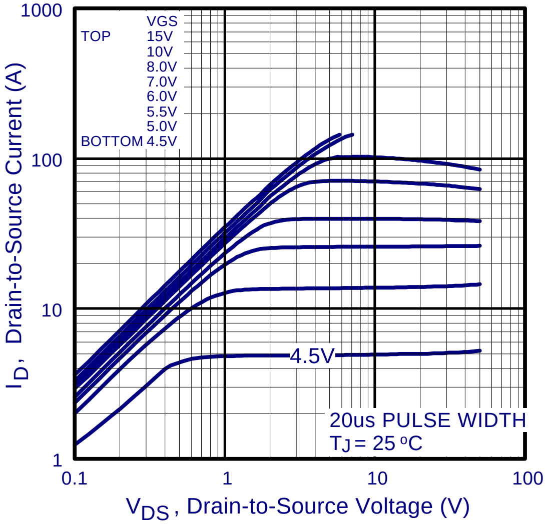


Fig 1. Typical Output Characteristics

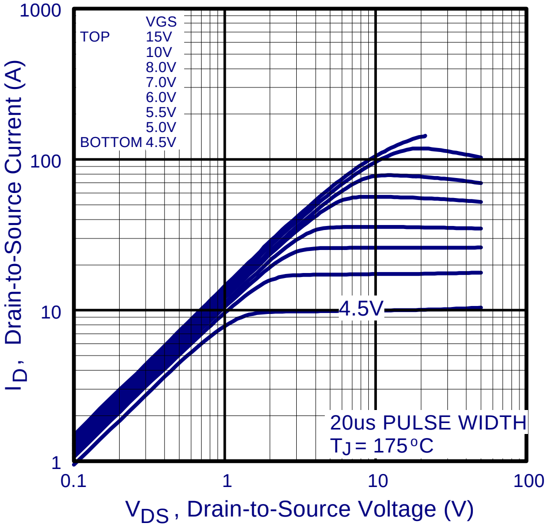


Fig 2. Typical Output Characteristics

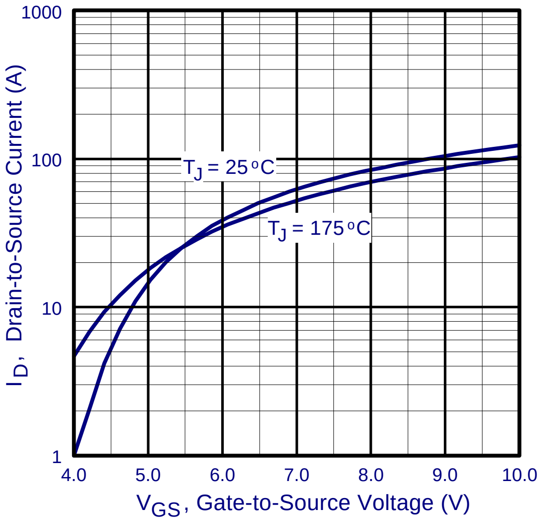


Fig 3. Typical Transfer Characteristics

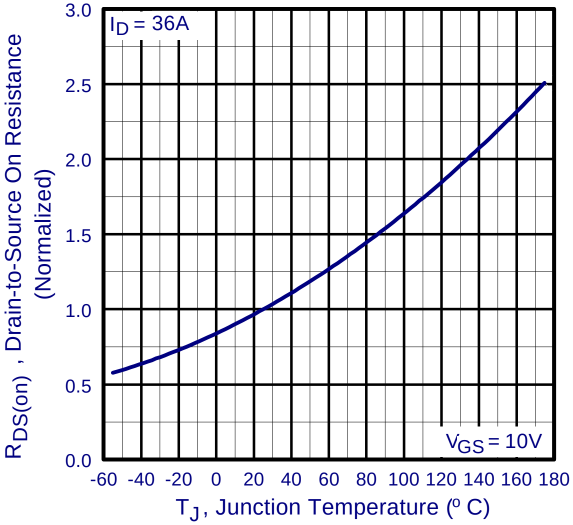


Fig 4. Normalized On-Resistance
Vs. Temperature

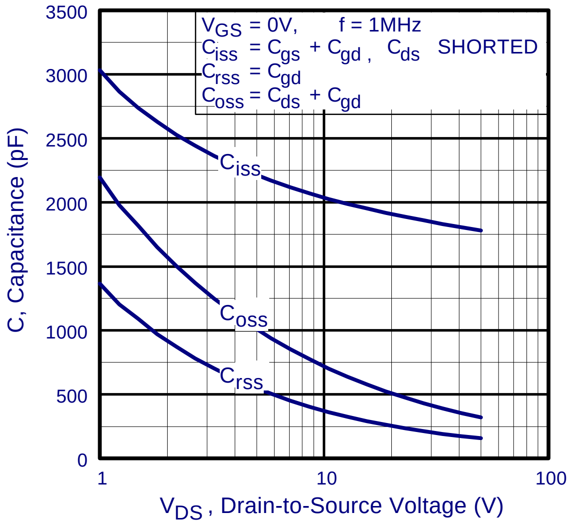


Fig 5. Typical Capacitance Vs.
Drain-to-Source Voltage

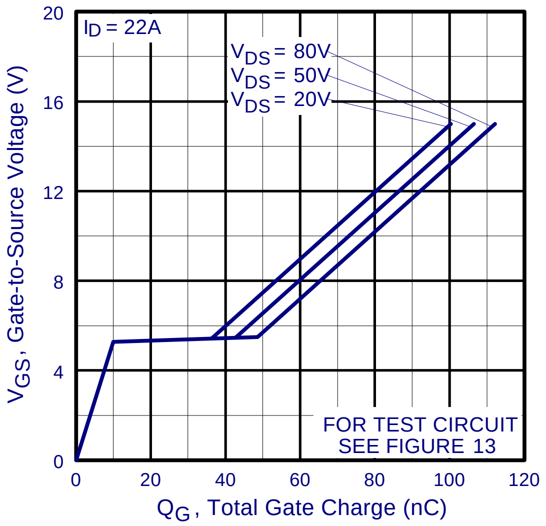


Fig 6. Typical Gate Charge Vs.
Gate-to-Source Voltage

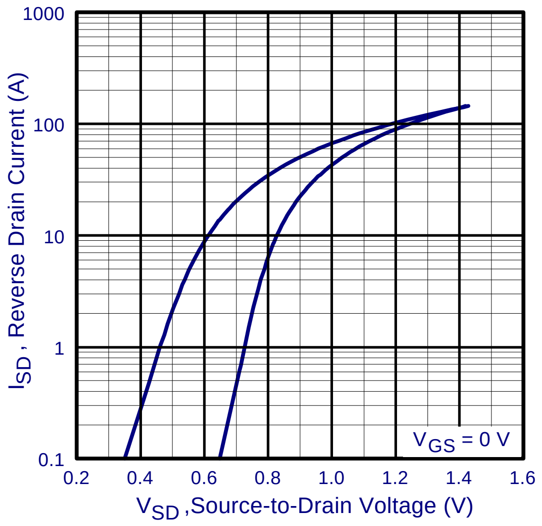


Fig 7. Typical Source-Drain Diode
Forward Voltage

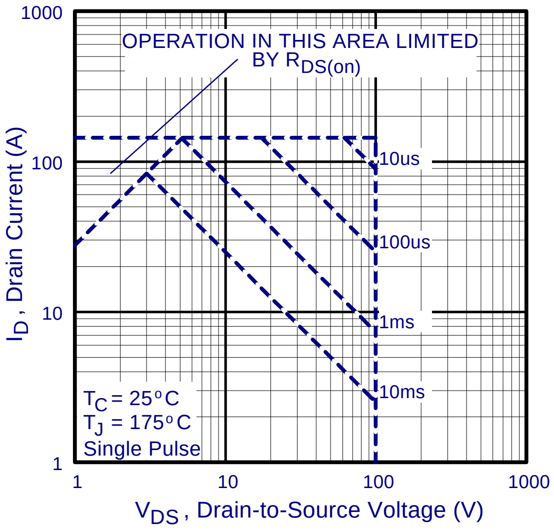


Fig 8. Maximum Safe Operating Area

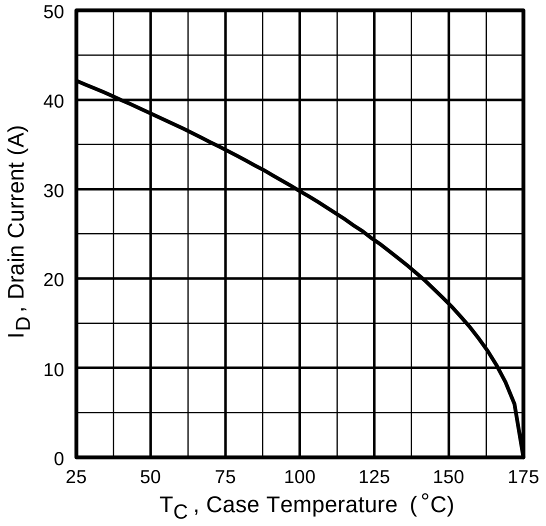


Fig 9. Maximum Drain Current Vs.
Case Temperature

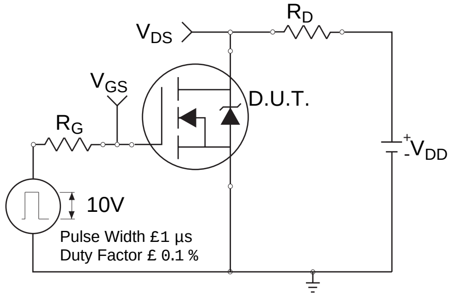


Fig 10a. Switching Time Test Circuit

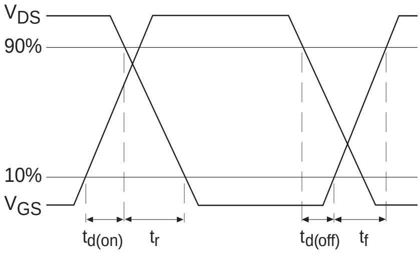


Fig 10b. Switching Time Waveforms

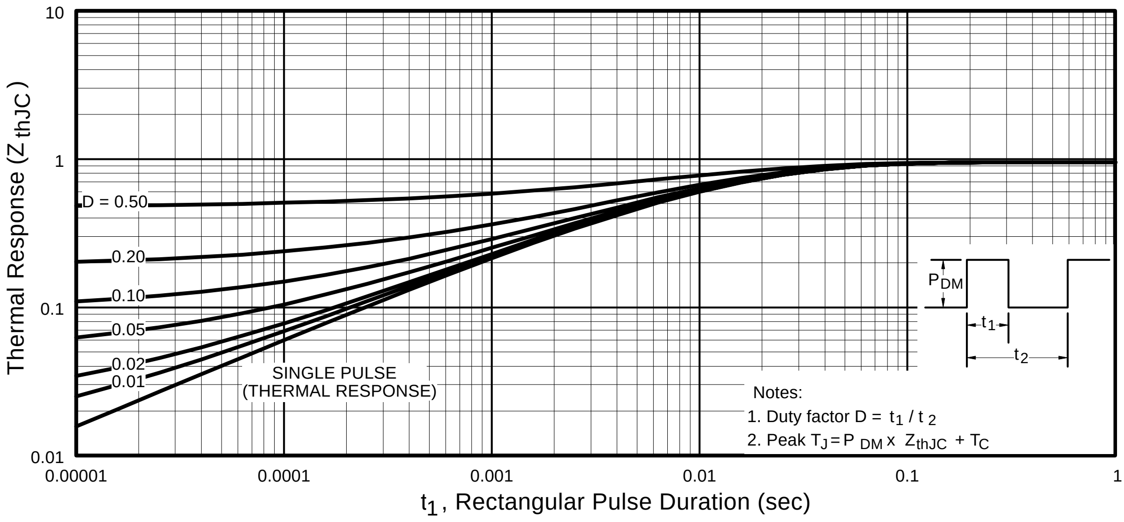


Fig 11. Maximum Effective Transient Thermal Impedance, Junction-to-Case

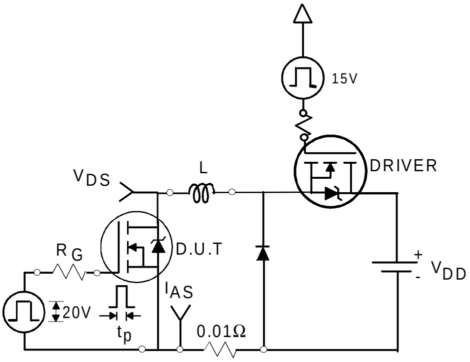


Fig 12a. Unclamped Inductive Test Circuit

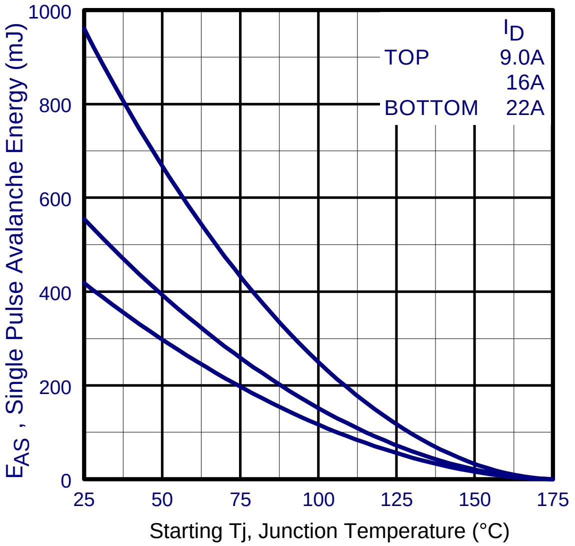


Fig 12c. Maximum Avalanche Energy
Vs. Drain Current

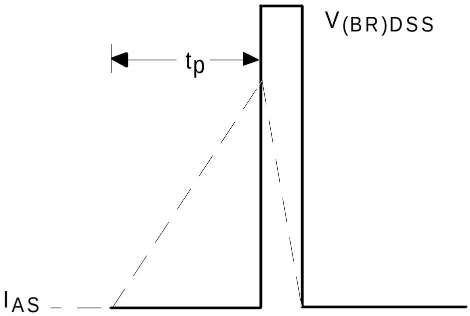


Fig 12b. Unclamped Inductive Waveforms

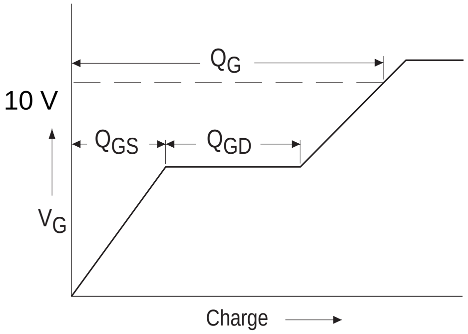


Fig 13a. Basic Gate Charge Waveform

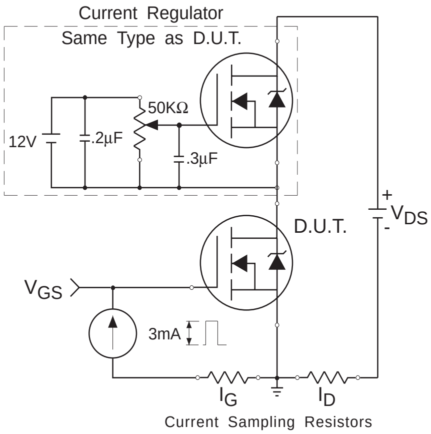
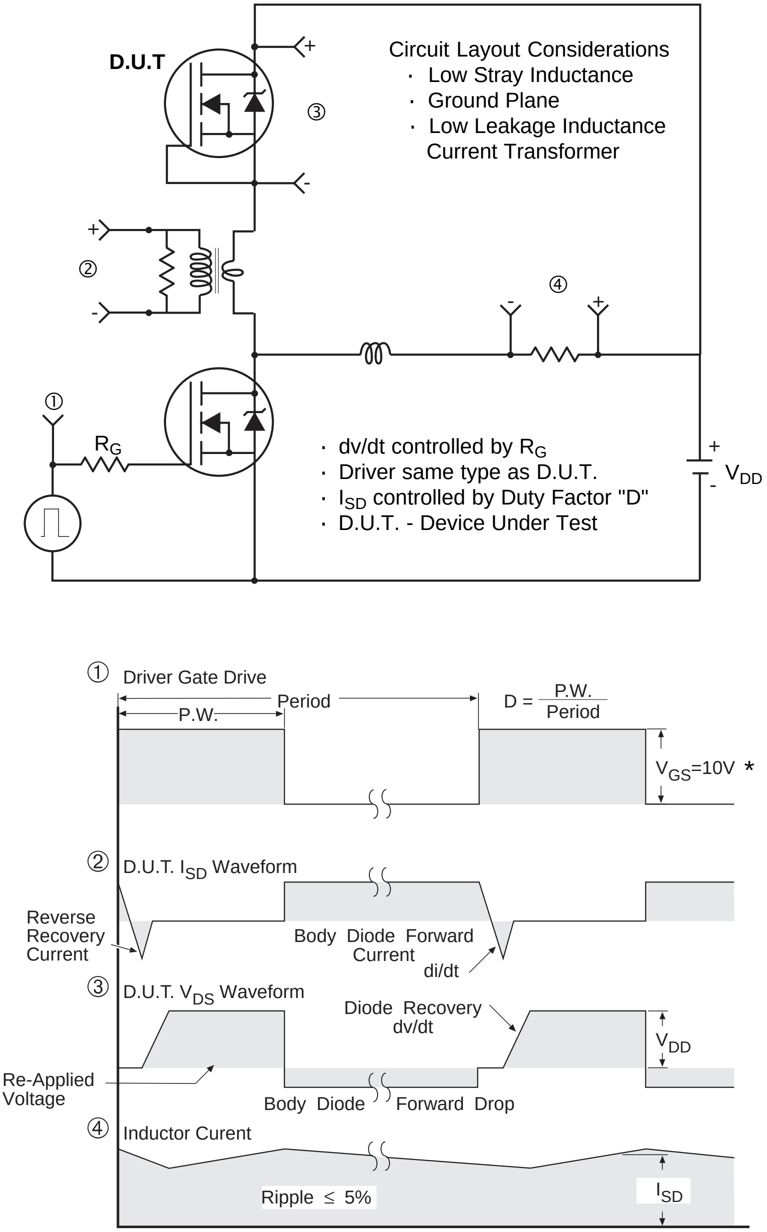


Fig 13b. Gate Charge Test Circuit

Peak Diode Recovery dv/dt Test Circuit



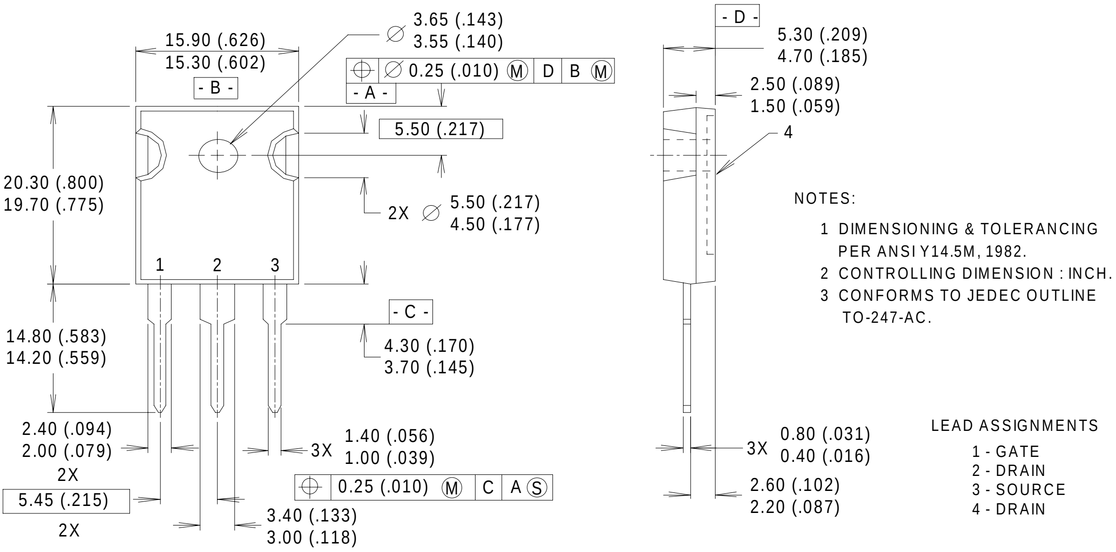
* V_{GS} = 5V for Logic Level Devices

Fig 14. For N-Channel HEXFETS

Package Outline

TO-247AC Outline

Dimensions are shown in millimeters (inches)



NOTES:

1 DIMENSIONING & TOLERANCING PER ANSI Y14.5M, 1982.
2 CONTROLLING DIMENSION : INCH.
3 CONFORMS TO JEDEC OUTLINE TO-247-AC.

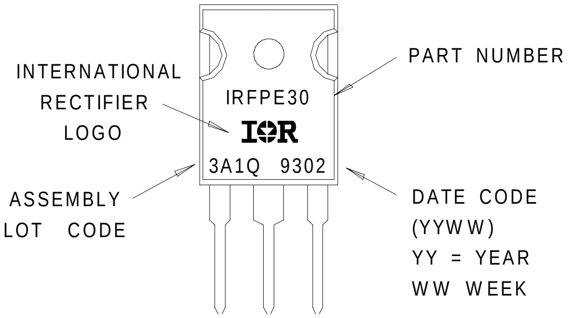
LEAD ASSIGNMENTS

1 - GATE
2 - DRAIN
3 - SOURCE
4 - DRAIN

Part Marking Information

TO-247AC

EXAMPLE : THIS IS AN IRFPE30
WITH ASSEMBLY
LOT CODE 3A1Q



Data and specifications subject to change without notice.

International
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