Power Electronics (EC0606)

Unit-1

B.Tech (Electronics and Communication)

Semester-VI

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Learning Objectives

– Identify the function of electronics switches, hence to select a proper switching for certain applications.

– To become familiar with the power electronics system.

Introduction

- Generally, the electrical engineering field may be divided into three areas of specialization:

✓ Electronics
✓ Power
✓ Control

- Electronics essentially deals with the study of semiconductor devices and circuits for the processing of information at low power levels.
- The Power area deals with both rotating and static equipment for the generation, transmission, distribution, and utilization of vast quantities of electrical power.
- The control area deals with the stability and response characteristics of closed loop system using feedback on either a continuous or sampled data basis.

- Power electronics deals with the use of electronics for the control and conversion of large amount of electrical power.

Introduction

- Power electronics refers to control and conversion of electrical power by power semiconductor devices wherein these devices operate as switches.
- silicon-controlled rectifiers, abbreviated as SCRs, led to the development of a new field of application called the power electronics.
- Before SCRs, mercury-arc rectifiers were used for controlling electrical power, but such rectifier circuits were part of industrial electronics and the scope for applications of mercury-arc rectifiers was limited.
- The application spread to many fields such as drives, power supplies, aviation electronics, high frequency inverters and power electronics.

introduction

- Power electronics relates to the control and flow of electrical energy.

- Control is done using electronic switches, capacitors and control systems.

- Scope of power electronics: milliWatts $\Rightarrow$ gigaWatts

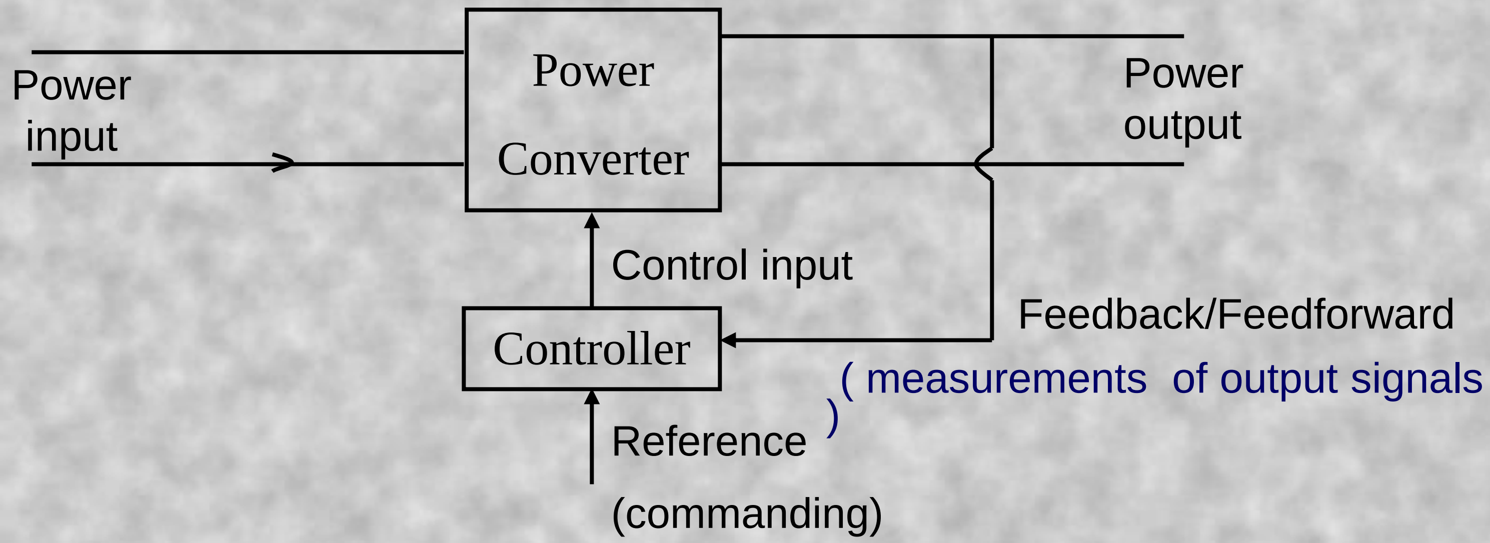
- Power electronics is a growing field due to the improvement in switching technologies and the need for more and more efficient switching circuits.

introduction

- Power Electronics (definition): it is the electronics applied to conversion and control of electric power.

- The primary task of power electronics is to process and control the flow of electric energy by supplying voltages and currents in a form that is optimally suited for user loads.

Power electronics System

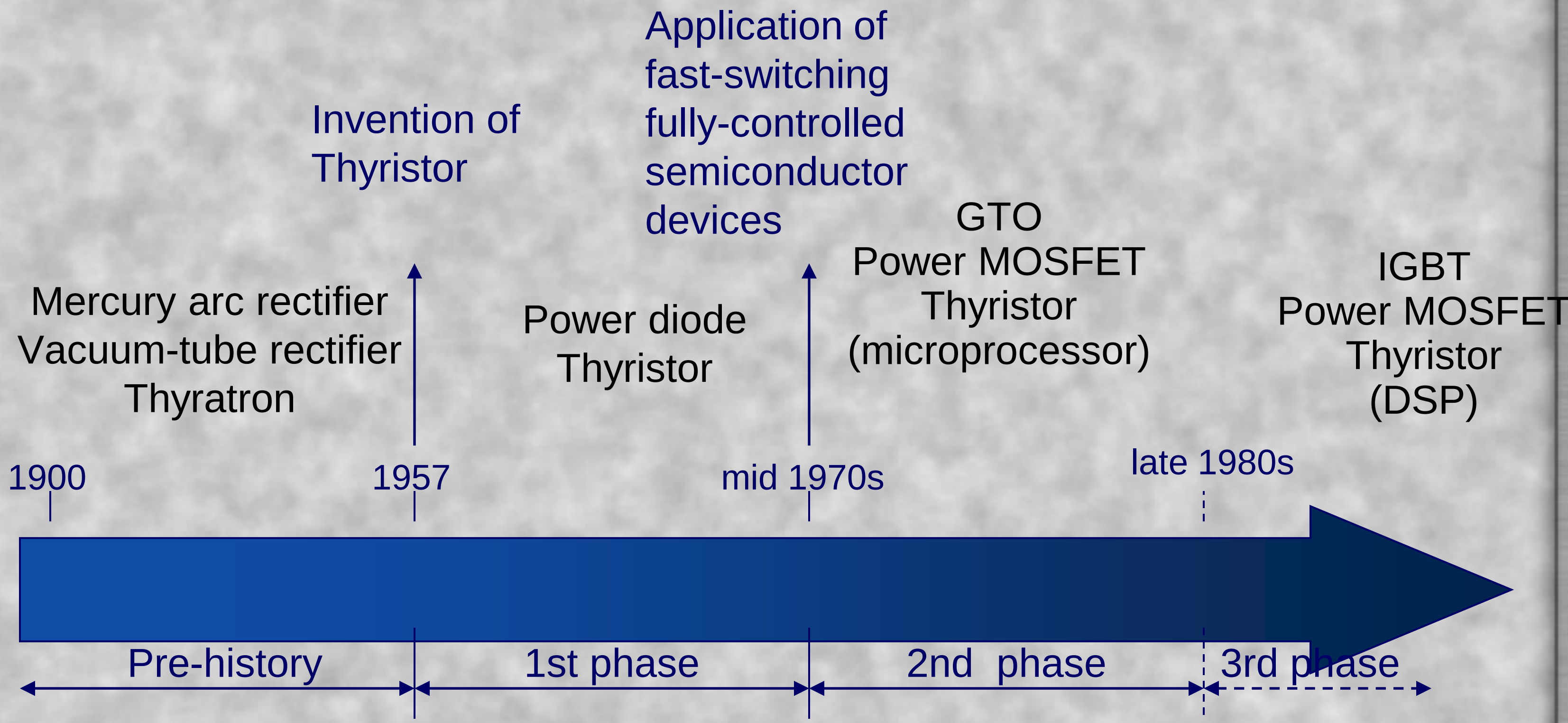


- Power modulators converts electrical energy of the source as per the requirement of the load.
- Power converter along with its controller including the corresponding measurement and interface circuits, is also called power electronic system.

Classification of power converters

Power Output & Power Input	DC	AC
AC	AC to DC converter (Rectifier)	AC to AC converter (AC controller or Cycloconverter or frequency converter)
DC	DC to DC converter (Chopper)	DC to AC converter (Inverter)

History



- The thread of the power electronics history precisely follows and matches the break-through and evolution of power electronic devices

Applications

- Industrial
- Transportation
- Utility Systems
- Power supplies for all kinds of electronic equipment
- Residential and home appliances
- Space technology
- Other applications

Industrial applications

- Motor drives
- Electrolysis
- Electroplating
- Induction heating
- Welding
- Arc furnaces and ovens
- Lighting

Transportation

- Trains & locomotives
- Subways
- Trolley buses
- Electric vehicles
- Automotive electronics
- Ship power systems
- Aircraft power systems

Utility systems applications

- High-voltage dc transmission(HVDC)
- Custom power & power quality control
- Supplemental energy sources :

  wind, photovoltaic, fuel cells
- Energy storage systems

Residential and home appliances

- Lighting
- Heating
- Air conditioning
- Refrigeration & freezers
- Cooking
- Cleaning
- Entertaining

Power supplies for electronic equipment

- Telecommunications
- Computers
- Office equipment
- Electronic instruments
- Portable or mobile electronics

Applications

- Heating and lighting control
- Induction heating
- Uninterruptible power supplies (UPS)
- Fluorescent lamp ballasts: Passive; Active
- Electric power transmission
- Automotive electronics
- Electronic ignitions
- Motor drives
- Battery chargers
- Alternators
- Energy storage
- Electric vehicles
- Alternative power sources: Solar; Wind; Fuel Cells
- And more!

Power semiconductor devices (Power switches)

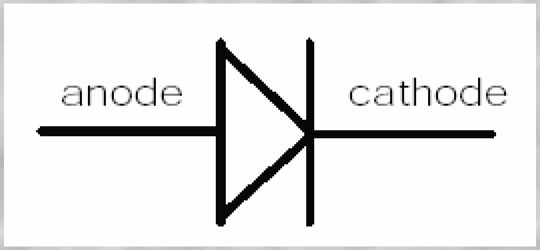
- Can be categorized into three groups:

– **Uncontrolled: Diode**

– **Semi-controlled: Thyristor (SCR)**

– **Fully controlled: Power transistors e.g. BJT,**MOSFET, IGBT, GTO, IGCT

Diodes & SCR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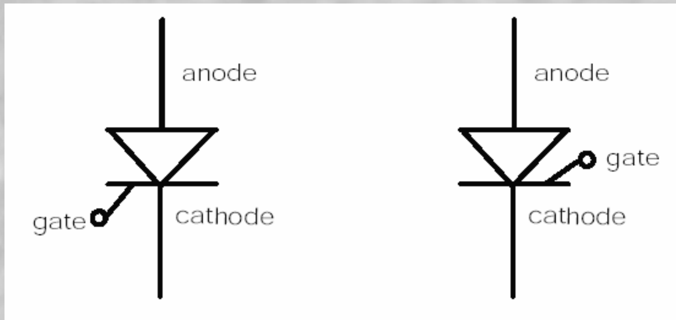
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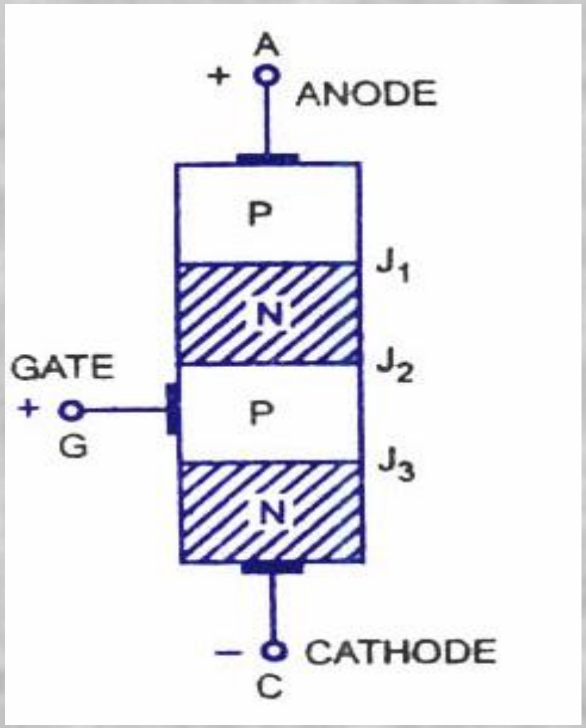
A
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Modes of Operation

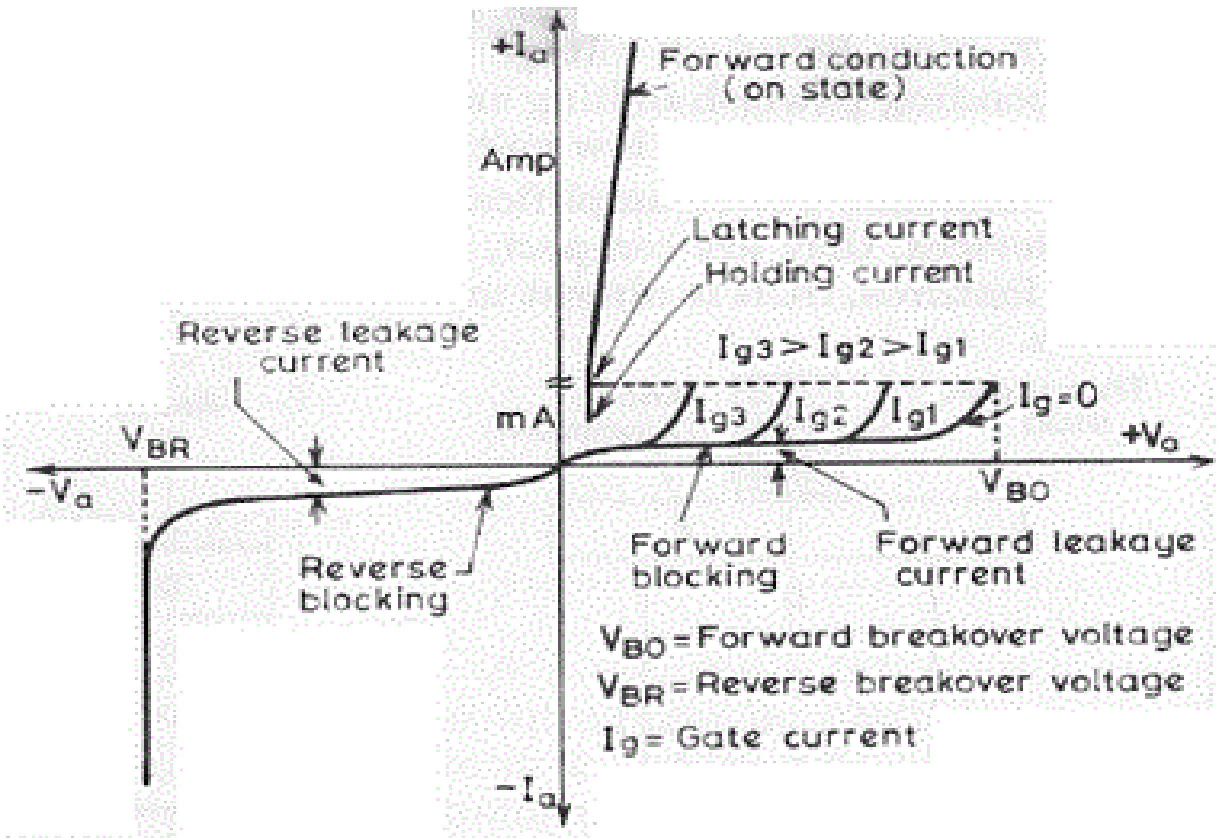
- There are three modes of operations of SCR

1) Forward biased operation

    a) Forward Blocking or Off-state condition
    b) Conducting State or ON-state condition

2) Reverse Biased operation

Static Characteristics



V-I characteristics of thyristor.

- Latching Current: once the SCR is conducting forward current that is greater than minimum value, called latching current. the gate signal is no longer required to maintain the device in its ON state.
- Holding Current: The SCR will return to its original forward blocking state if the anode current falls below a low level, called holding current.

NOTE 1: Latching current is associated with turn on process and holding current with turn-off process.
NOTE 2: holding current is usually lower than, but very close to the latching current.

Latching current should be greater than holding current

Break over Voltage:

These are the anode to cathode voltage across the SCR after that SCR will be in ON state without applying any gate signal to gate terminal.

NOTE: The forward break over voltage is generally higher than the reverse break over voltage.

Higher the gate current gives lower forward break over voltage

Important Points

- The forward anode current of a thyristor must be more than its latching current to latch into the conduction state; otherwise, the device reverts to the blocking condition as the anode to cathode voltage falls.

- IF the forward anode current is reduced below its holding current, the device becomes unlatched and remain in Off State.

- Once a thyristor conducts, it behaves like a conducting diode and there is no control over the device. That is, the device cannot be turned Off by another positive or negative gate pulse. So we can say that it is a semi control device.

Turn on methods of a Thyristor

- A thyristor can be switched from no conducting to conducting state in several ways described as follows:

1. Forward Voltage Triggering
2. Thermal Triggering (Temperature Triggering)
3. Radiation Triggering (Light Triggering)
4. dv/dt Triggering.
5. Gate Triggering
   - ✔ D.C. Gate triggering
   - ✔ A.C. Gate triggering
   - ✔ Pulse Gate triggering

Forward Voltage Triggering

- When anode to cathode forward voltage is increased , the reverse biased junction will have an avalanche breakdown at the voltage called forward break over voltage $V_{BO.}$
- At this voltage, a thyristor changes from OFF state to ON state
- The forward voltage drop across the SCR during the ON state is of the order of 1 to 1.5 V and increases slightly with the load current

Thermal triggering

- Like other semiconductors, the width of the depletion layer of a thyristor decreases on increasing the junction temperature.
- When the voltage applied between the anode & cathode is very near to its breakdown voltage, the device can be triggered by increasing its junction temperature.
- This method of triggering device by heating is also known as temperature triggering process

Radiation Triggering

- As the name suggests, the energy is imparted by radiation.
- Thyristor is bombarded by energy particles such as neutrons or photons.
- With the help of this external energy . Electron-hole pairs are generated in the device, thus increasing the number of charge carriers.
- This leads to the instantaneous flow of current within the device and triggering of the device.
- Examples of this type of triggering : LASCR & LASCS

dv/dt Triggering.

- Junction J1 & J3 are in FW bias with the forward voltage across anode and cathode, where as J2 becomes in reversed biased.
- This reversed bias Junction J2 has the characteristics of a capacitor due to charges existing across the junction.
- if forward voltage suddenly applied, charging current will flow tending to turn the device ON.
- If the voltage impressed across the device is denoted by V, the charge by Q and the capacitance by C_j then

$$i_c = \frac{dQ}{dt} = \frac{d}{dt}\left(C_j V\right) = C_j \frac{dV}{dt} + V \frac{dC_j}{dt}$$

- The rate of change of junction capacitance may be negligible as the junction capacitance is almost constant.

$$i_c = C_j \frac{dV}{dt}$$

- Therefore, if the rate of change of voltage across the device is large, the device may be turn-on even through the voltage appearing across the device is small

Gate triggering

- This is the most commonly used method for triggering the SCRs.
- By applying the positive signal at the gate terminal of the device, it can be triggered much before the specified break over voltage.
- The conduction period of the SCRs can be controlled by varying the gate signal.
- For the gate triggering, a signal is applied between the gate and cathode of the device.
- Three types of signals can be used for this purpose
  1. D.C. Gate signals
  2. A.C. Gate signals
  3. Pulse Gate Signals

D.C. Gate triggering

- In this type of triggering, a d.c. voltage of proper magnitude and polarity is applied between the gate and cathode of the device in such a way that the gate becomes positive with respect to the cathode.
- When the applied voltage is sufficient to produce the gate current, the device starts conducting.
- Drawback:
  - ✔ Both the power and control circuits are DC and there is no isolation between this two.
  - ✔ A continuous DC signal has to be applied, at the gate causing more gate power loss

A.C. Gate Triggering

- A.C. source is most commonly used for the gate signal in all application of thyristor control adopted for AC applications.
- This scheme provides the proper isolation between the power and control circuits.
- the firing angle control is obtained very conveniently by changing the phase angle of the control signal.
- The gate drive is maintained for one half cycle after the device is ON, and a reverse voltage is applied between the gate and cathode during the negative half cycle.
- Drawback:
  - ✔ A separate transformer is required to step down the AC supply, which adds to the cost.

Pulse Gate triggering

- This is the most popular method for triggering the Device. In this method, the gate drive consists of single pulse appearing periodically or a sequence of high frequency pulses.
- This is also known as carrier frequency gatting.
- A pulse transformer is used for isolation.
- Advantage:
  - ✔ There is no need of applying continuous signals and hence the gate losses are very much reduced.
  - ✔ Electrical isolation is also provided between the main device and gatting signals.

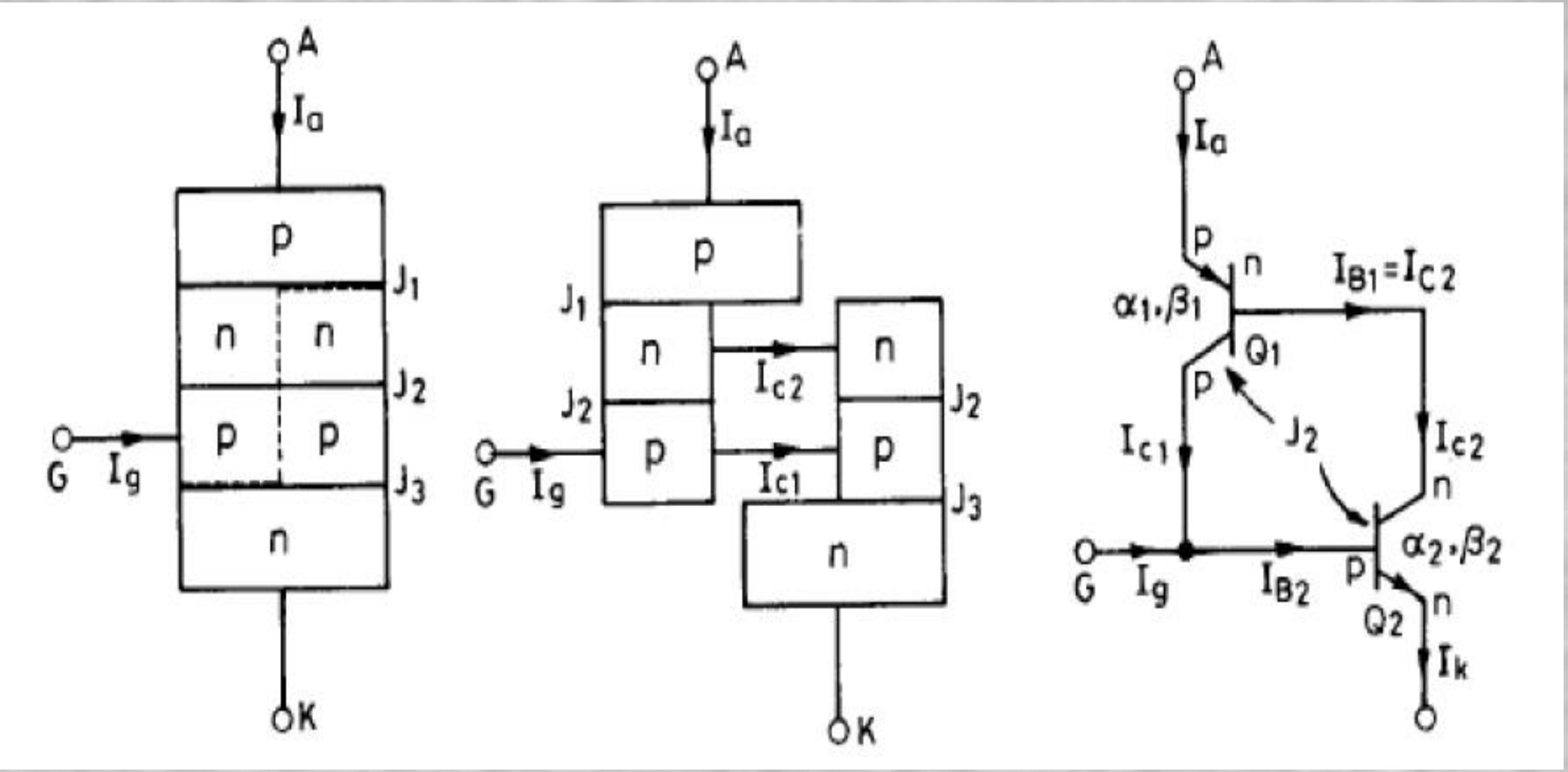
Two-Transistor model of Thyristor

- Since Thyristor is a Latching device so the regenerative or Latching action due to positive feedback can be demonstrated by using a two transistor model of SCR.

- A thyristor can be considered as two complementary transistors, one is pnp -transistor Q1 and other is npn – transistor Q2.

- The circuit representation of the two-transistor model of a thyristor is shown in diagram.

Diagram



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Ia
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J1
n
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J2
p
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J3
n
G
Ig
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G
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Ic1
J3
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K
A
Ia
p
n
IB1=IC2
α1,β1
Q1
p
J2
Ic1
Ic2
n
α2,β2
G
Ig
IB2
p
n
Q2
Ik

Contd.

- In the off state of a transistor, collector current I_C is related to emitter current I_E as-

$$I_C = \alpha I_E + I_{CBO} \quad \ldots(1)$$

- where α is the common-base current gain and I_{CBO} is the common base leakage current of collector-base junction of a transistor with emitter open.
- For transistor Q_1 in diagram, emitter current I_E = anode current I_a and collector current I_c is I_{c1}. Therefore for transistor Q_1,

$$I_{C1} = \alpha_1 I_a + I_{CBO1} \quad \ldots(2)$$

where α_1 = common–base current gain of Q_1

and I_{CBO1} = common–base leakage current of Q_1.

Contd.

- Similarly for transistor Q_2, collector current I_{C2} is given by

$$I_{C2} = \alpha_2 I_k + I_{CBO2} \quad \ldots(3)$$

where α_2 = common–base current gain of Q_2

I_{CBO2} = common–base leakage current of Q_2

and I_k = emitter current of Q_2.

- The sum of the two collector currents given by equations (2) and (3) is equal to the anode current I_a.

$$I_a = I_{C1} + I_{C2} \quad \ldots(4)$$

-

$$I_a = \alpha_1 I_a + I_{CBO1} + \alpha_2 I_k + I_{CBO2} \quad (5)$$

Contd.

- $$I_a = \alpha_1 I_a + I_{CBO1} + \alpha_2 (I_a + I_g) + I_{CBO2}$$

$$I_a = \frac{\alpha_2 I_g + I_{CBO1} + I_{CBO2}}{1 - (\alpha_1 + \alpha_2)} \quad .(7)$$

where $I_k = (I_a + I_g)$

- It is clear from eq. (7), that $\alpha_1 + \alpha_2 \rightarrow 1$ causes the thyristor to turn on i.e. the anode current reaches a high value or the SCR starts conducting.

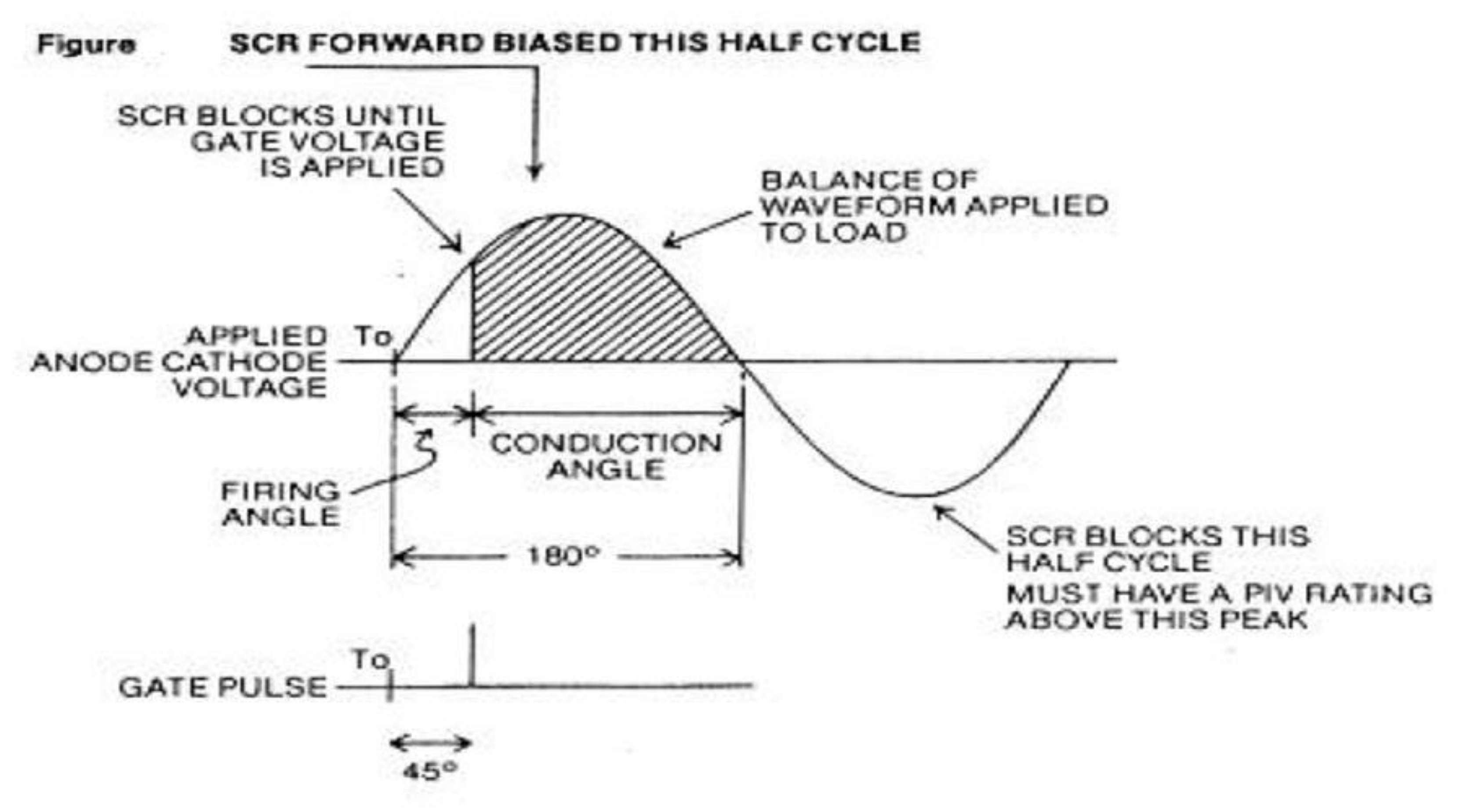
- α_1 varies with I_a (emitter current) and α_2 varies with $I_a + I_g$. If I_g is increased, this increases I_a, which further increases α_1 and α_2. This will in turn increase I_a. This is a regenerative or positive feedback effect.

Phase Control of SCR

- In SCR Phase Control, the firing angle, or point during the half-cycle at which the SCR is triggered, determines the amount of current which flows through the device as well as from the load.

- It acts as a high-speed switch which is open for the first part of the cycle, and then closes to allow power flow after the trigger pulse is applied.

Firing angle



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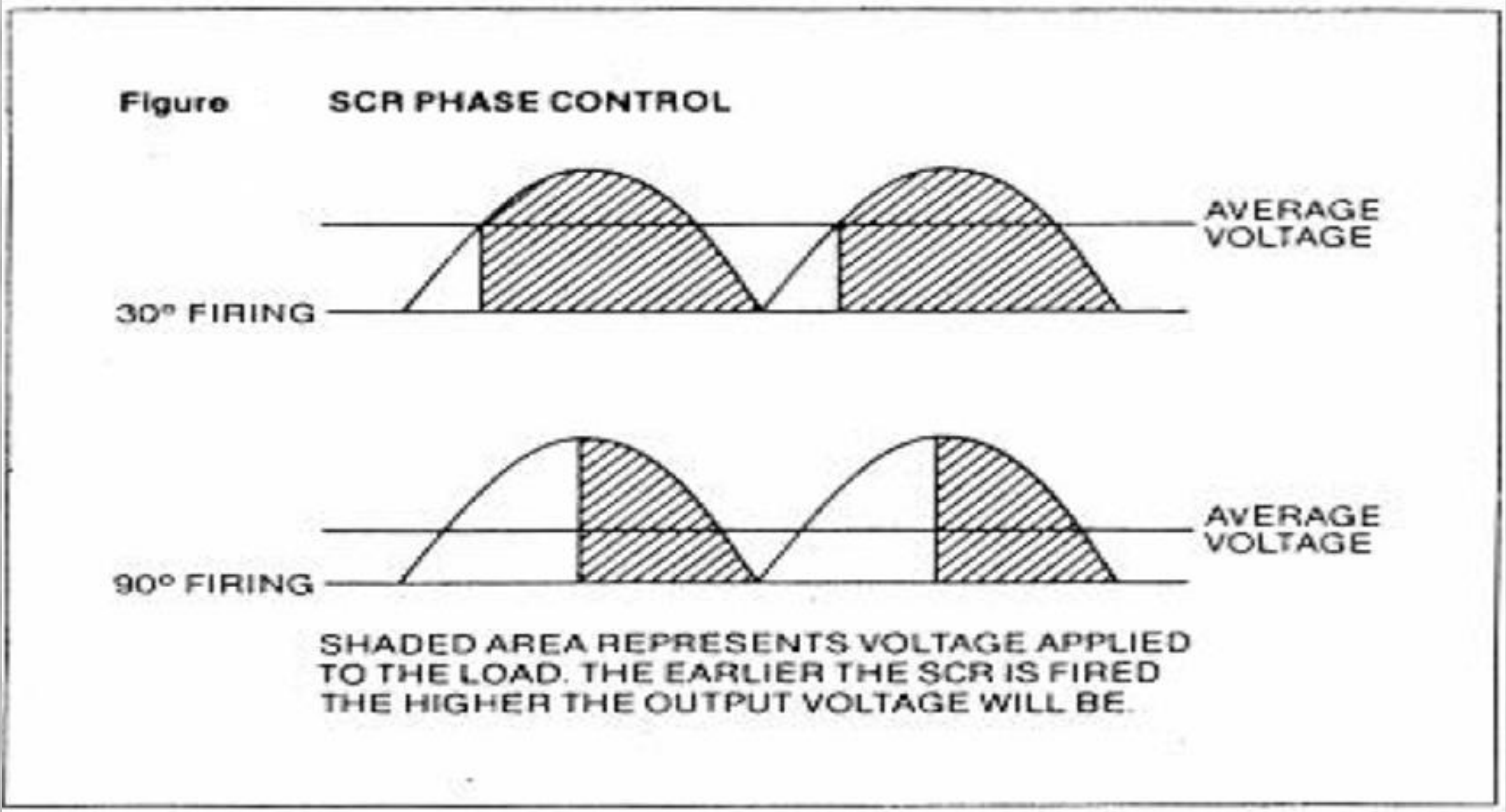
- Figure shows an AC waveform being applied with a gating pulse at 45 degrees. There are 360 electrical degrees in a cycle; 180 degrees in a half-cycle.

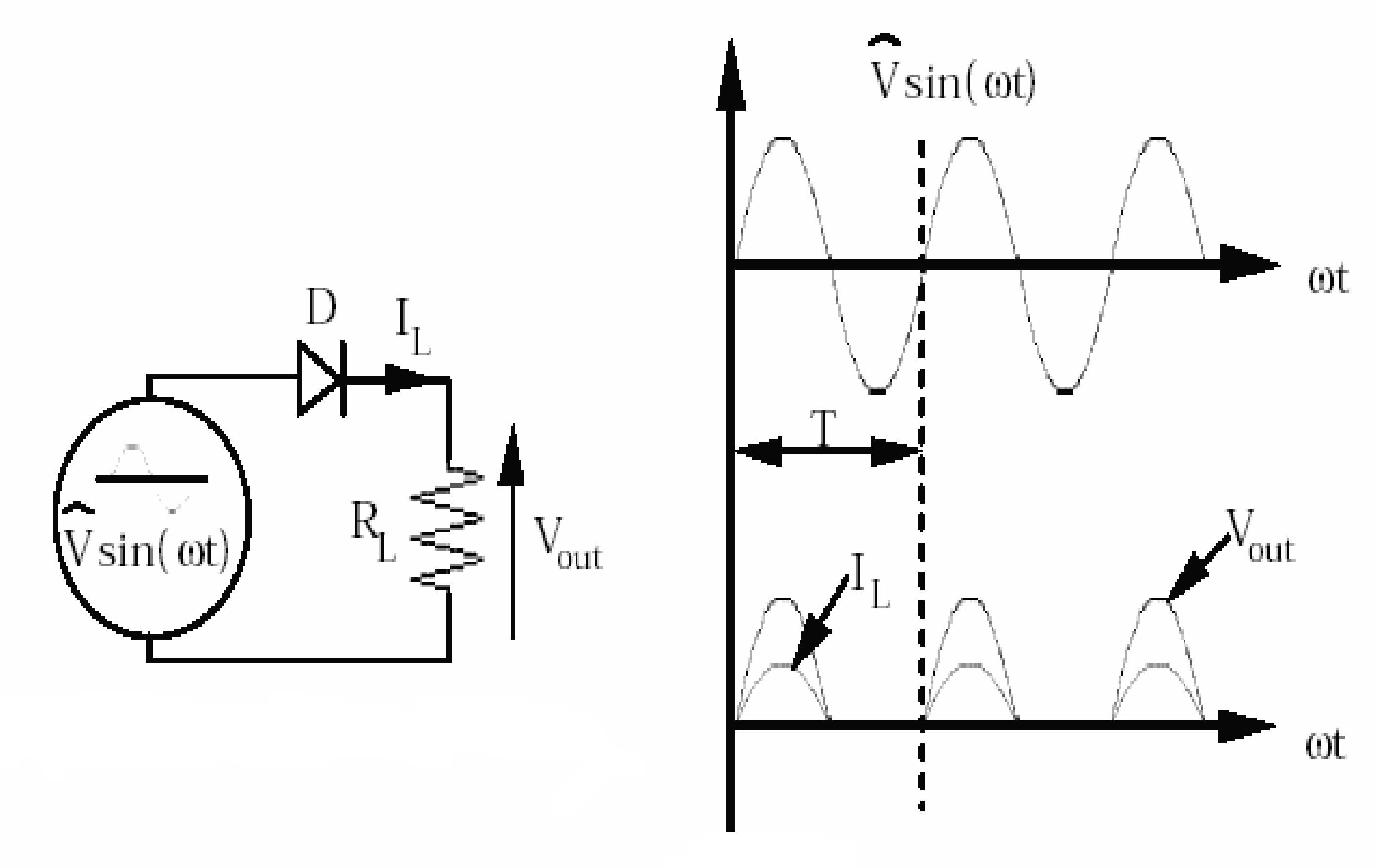
- The number of degrees from the beginning of the cycle until the SCR is gated ON is referred to as the *firing angle.*

- The number of degrees that the SCR remains conducting is known as the *conduction angle*.

output voltage applied to the load



AC to DC Conversion: Half-Wave Rectifier



Importance of Free-Wheeling Diode

- A "freewheeling diode" is put into a circuit to protect the switching device from being damaged by the reverse current of an inductive load.

✔ This diode serves two main functions

1. To protect/prevent the switching device from being damaged by the reverse current of an inductive load.
2. It transfers load current away from the main rectifier, there by allowing all of its thyristors to regain their blocking states.

Note: with freewheeling diode, thyristor will not be able to conduct beyond 180.

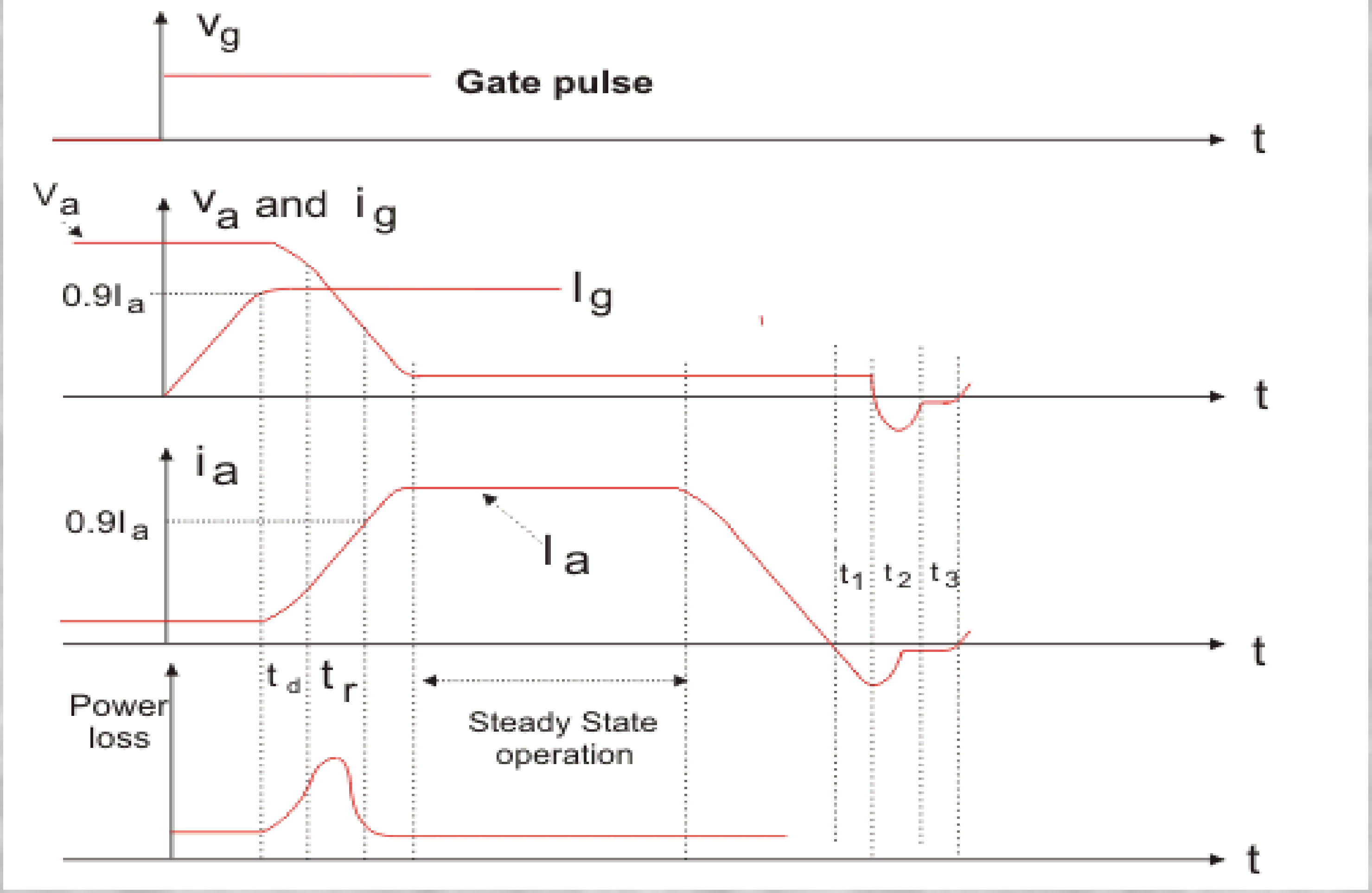
Dynamic turn-ON switching Characteristics

- The static characteristics gives no indication as to the speed at which the SCR is capable of being switched from the forward blocking voltage to the conducting state and vice-versa.

- However transition from one state to another state does not take place instantaneously, it takes a finite period of time.

- Total turn on time is subdivided into three distinct periods, called the delay time, rise time and spread time.

Dynamic turn-ON switching Characteristics



- Delay Time: This is the time between the instant at which the gate current reaches 90% of its final value and the instant at which the anode current reaches 10% of its final value.
- It can also be defined as the time during which anode voltage falls from Va to 0.9 Va, where Va is the initial value of the anode voltage.

- Rise Time: this is the time required for the anode current to rise from 10 to 90% of its final value.

- It can also be defined as the time required for the forward blocking off state voltage to fall from 0.9 to 0.1 of its initial value.

- Spread time: the spread time is the time required for the forward blocking voltage to fall from 0.1 to its value to the on state voltage drop (1 to 1.5 V).
- Turn –On time: this is the sum of the delay time, rise time, spread time. This is typically of the order of 1 to 4 micro-sec, depend upon the anode circuit parameters and gate signal.

Turn-off characteristics

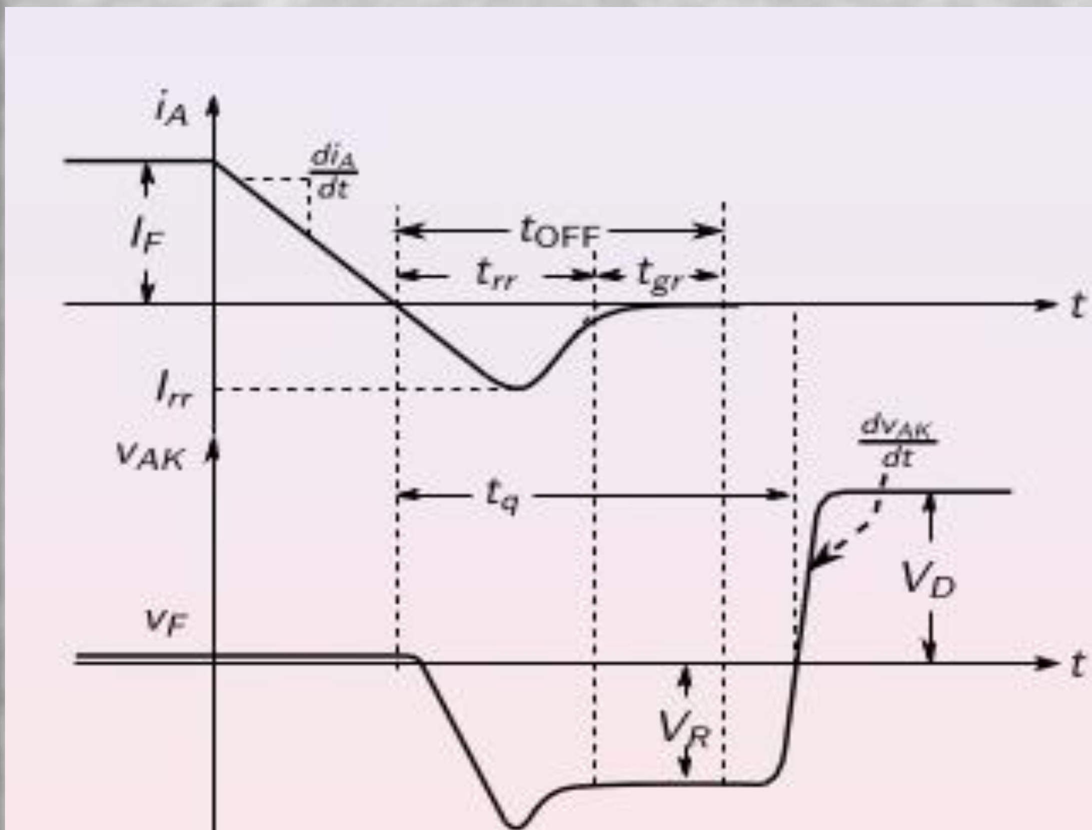
- Once the SCR starts conducting , the gate has no control on it and device can be brought back to the blocking state only by reducing the forward current to a level below that of the holding current
- However, if a forward voltage is applied immediately after reducing the anode current to zero, it will not block the forward voltage and will start conducting again, although it is not triggered by a gate pulse.
- Therefore, it is necessary to keep the device reverse biased for a finite period before a forward anode voltage can be reapplied.

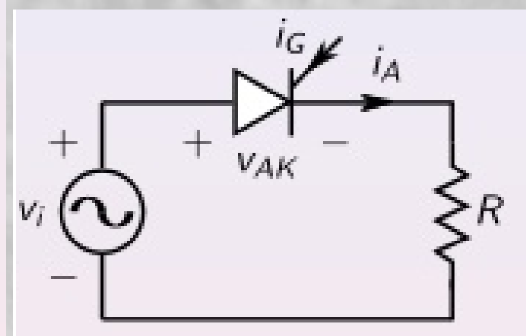
- The Turn off time of the thyristor is defined as the minimum time interval between the instant at which the anode current becomes zero, and the instant at which the device is capable of blocking the forward voltage.

- The turn off time is divided into two time intervals: The reverse recovery time & gate recovery time.

Process of turn off thyristors is also called as commutation

Turn-off characteristics





- At the instant t_1, the anode forward current becomes zero. During the reverse recovery time, t_1 to t_3, the anode current flows in the reverse direction.
- At the instant t_2, a reverse anode voltage is developed and reverse recovery current continuous to decrease.
- At t3, because of the junction J2, the thyristor is not able to block a forward voltage.
- Total turn off time: ?

Thyristors having large turn off time are called as slow switching device or phase control type thyristors.

Thyristors having low turn off time are called as fast switching device or inverter control type thyristors.

Commutation

- The term commutation means the transfer of current from one path to another.
- In thyristors, this term is used to describe process of transferring current from one thyristor to another.
- As we know, it is not possible for a thyristor to turn itself off, the current in which it is connected must reduce the thyristor current zero to enable it to turn off.
- Two methods: natural commutation and forced commutation

Natural Commutation

- The simplest the most widely used method of commutation makes use of the alternating, reversing nature of ac voltages.
- In ac circuits, the current always passes through zero every half cycle
- As the current passes through natural zero, a reverse voltage will simultaneously appear across the device, This can turn-off the device
- This process is known as *natural commutation* since no external circuits are required for this purpose.
- This method may use ac main supply voltages, the line commutated converters and inverters come under this category

Forced Commutation

- In case of DC circuits for switching of the thyristors, the forward current should be forced to zero by means of some external circuits.
- This process is called *forced commutation* and the external circuit is required for it are known as *commutation circuits.*
- The components which constitute the commutating circuits are called as *commutating components*.
- The method of commutation is based on the arrangement of the commutation components in the manner at which zero current is obtained in the SCR.

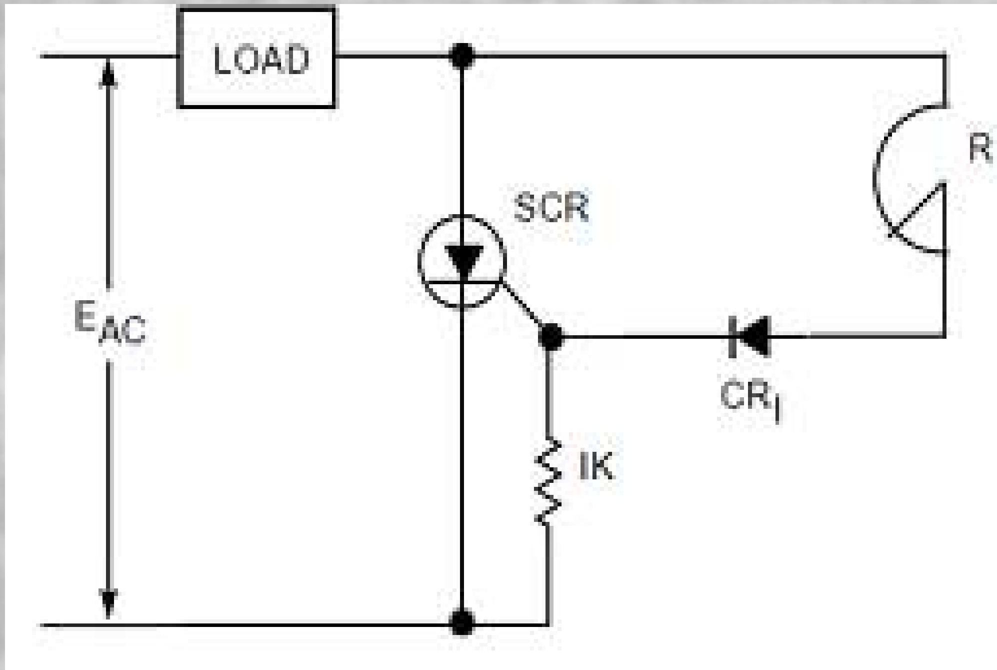
Triggering of an SCR

- There are two simple methods for varying the trigger angle of SCR. Instead of using a gate pulse to trigger an SCR, the gate current is supplied by an ac source of voltage Vs through Resistors and Diode.

- As Vs goes positive, the SCR becomes forward biased from A-K, it will not conduct (VL=0) until its gate current exceeds Ig (min).

- The positive Vs also forward biases the diode and it causes the flow of gate current.

- The gate current increases as Vs increases, when Ig reaches a value equal to Ig(min), the SCR turns on and VL goes to equal Vs (approximately).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CR_I
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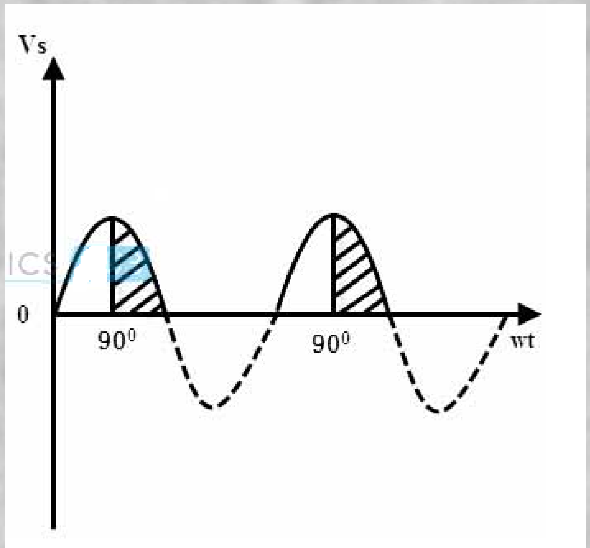

Vs
0
90⁰
90⁰
wt

- The SCR remains on and VL=Vs until Vs decreases to the point where the load current is below the SCR holding current. this usually occurs very close to the point until Vs=0 and begins to go negative.

- The SCR now turns OFF and remains OFF, while Vs goes negative (reversed biased) that means now SCR act as a open switch, the load voltage becomes zero during this period.

- The purpose of diode in this circuit is to prevent the gate-cathode reverse bias from exceeding peak gate voltage during the negative half cycle of Vs.

- The same sequence is repeated when Vs goes positive again.

- Advantages:

✔ R- triggering circuits are very simple to construct.

✔ Hence, most Economical circuits.

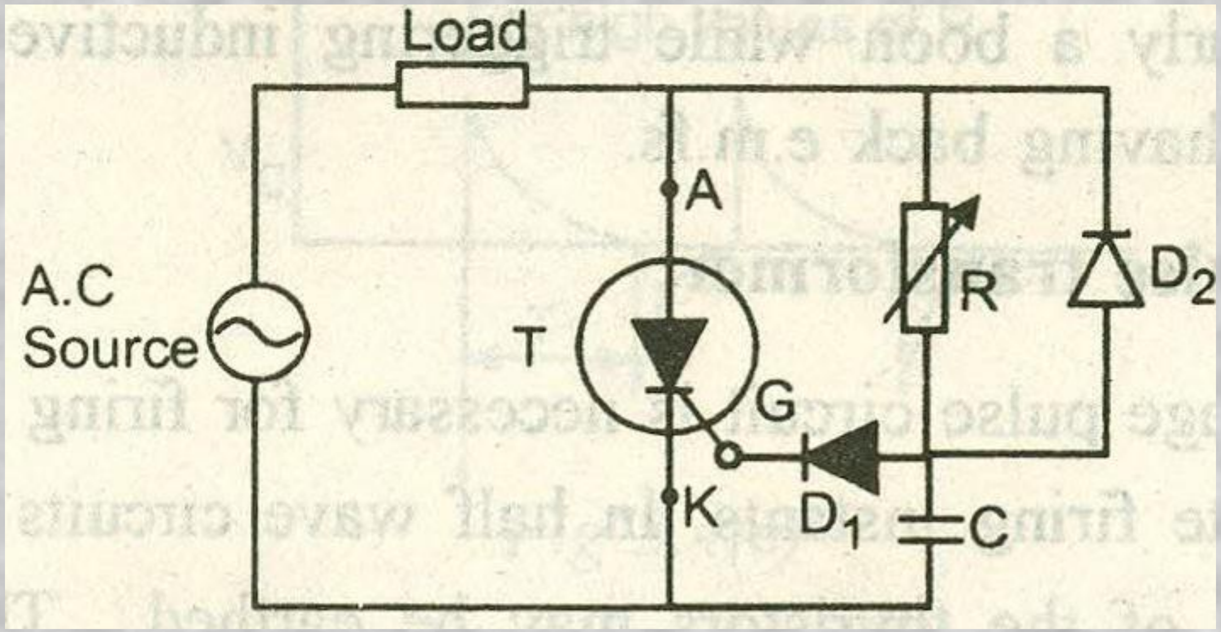
- Disadvantages

✔ Triggering angle can be varied up to an approximate 90 degree.

✔ Due to the use of only one SCR, this is a half wave controlled circuit.

✔ No isolation between gate and anode circuit.

RC triggering



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- A large variation in the value of firing angle can be obtained by changing the phase and amplitude of the gate current. by varying Rv , the firing angle can be controlled from 0 to 180.
- In the negative half cycle , capacitor charges through diode D2 with lower plate positive to peak supply voltage (Vmax).
- This capacitor voltage remains constant at –Vmax until supply voltage attains zero value.
- As the SCR anode voltage passes through zero and becomes positive , capacitor C begins to charge through Rv, from the initial Value –Vmax.

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- When the capacitor charges to positive voltage equal to gate trigger voltage V_{gt} (=$V_{g(min)}$+V_{d1}), SCR is triggered and after this, the capacitor holds to a small positive voltage.
- During negative half cycle, the d1 prevents the breakdown of the gate to cathode junction.

Contd..

- Advantages:

✓ RC- triggering circuits are easy to design & economical.

✓ Firing angle can be varied from 0 to 180.

- Disadvantages

✓ Value of alpha will depend on RC time constant which is temperature dependent.

✓ No isolation between gate and anode circuit.

- R- Triggering circuit uses an SCR with $I_{g(\min)} = 0.1mA$ and $V_{g(\min)} = 0.5V$. The diode is silicon and the peak amplitude of the input is 24 V. Determine the conduction angle for $R_V = 100K\Omega$ and $R_{\min} = 10K\Omega$.

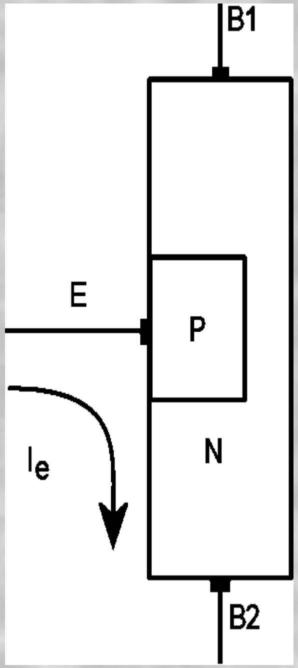
UJT

A uni-junction transistor (UJT) is an electronic semiconductor device that has only **one junction.**

The UJT has **three terminals**: an emitter (E) and two bases (B1 and B2).

The base is formed by lightly doped n-type bar of silicon. Two ohmic contacts B1 and B2 are attached at its ends.

The emitter is of p-type and it is heavily doped. The resistance between B1 and B2, when the emitter is open-circuit is called interbase resistance (R_{BB} or r'_{BB}).



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- UJT is another solid state three terminal device that can be used in gate pulse, timing circuits and trigger generator applications to switch and control either thyristors and triacs for AC power control type applications.
- Like diodes, unijunction transistors are constructed from separate P-type and N-type semiconductor materials forming a single (hence its name Uni-Junction) PN-junction within the main conducting N-type channel of the device.
- Although the *Unijunction Transistor* has the name of a transistor, its switching characteristics are very different from those of a conventional bipolar or field effect transistor as it can not be used to amplify a signal but instead is used as a ON-OFF switching transistor.

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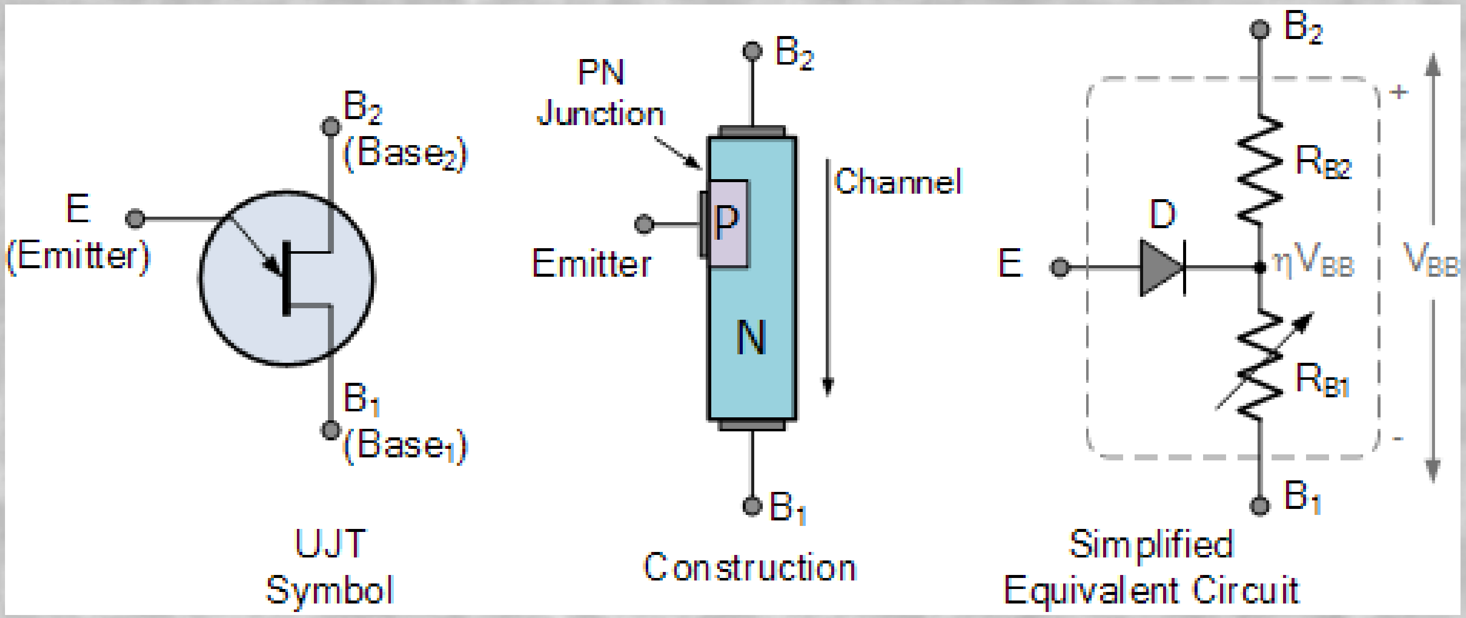
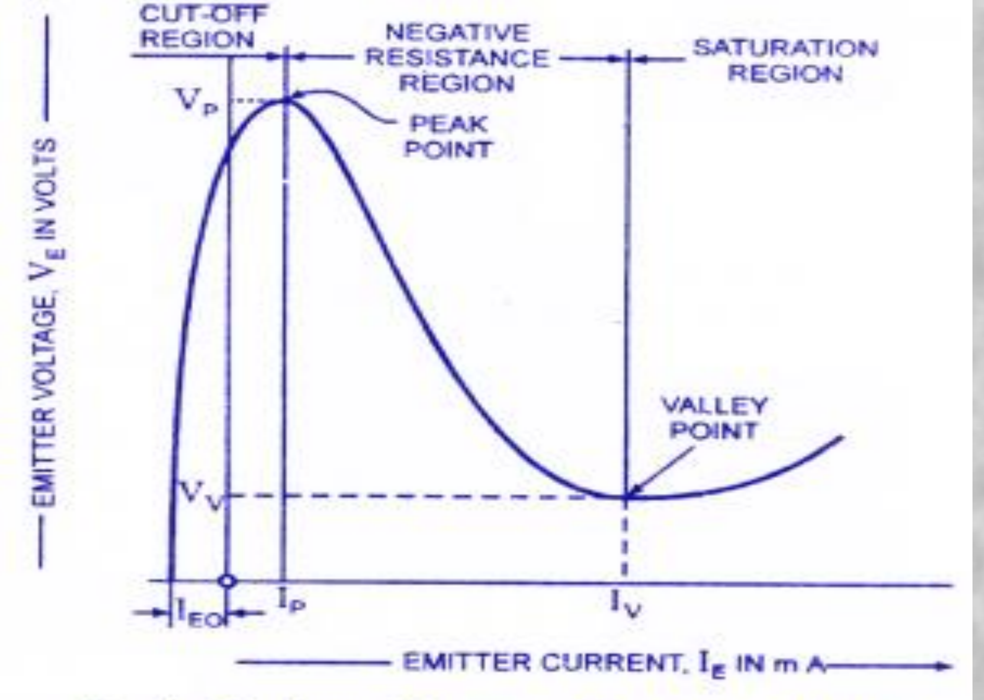


When the emitter diode is reversed biased, only a very small amount of emitter current flows. Under this condition RB1 is at its normal high value. this is UJT's OFF state.

When the emitter diode becomes forward biased, R_{B1} drops to a very low value, so that the total resistance between E and B1 becomes very low, allowing emitter current to flow rapidly. This is the ON state of UJT

UJT Characteristics

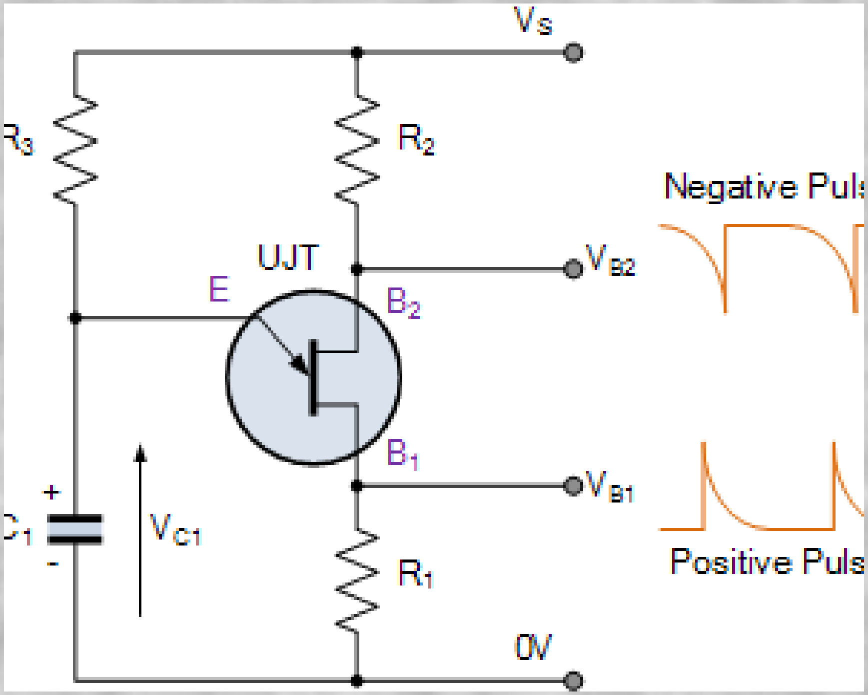
- Values of intrinsic standoff ratio is typically in the range from 0.5 to 0.8.
- What is the relationship in between Vp and V_{BB} ?



Static Emitter-Characteristic For a UJT

UJT Applications

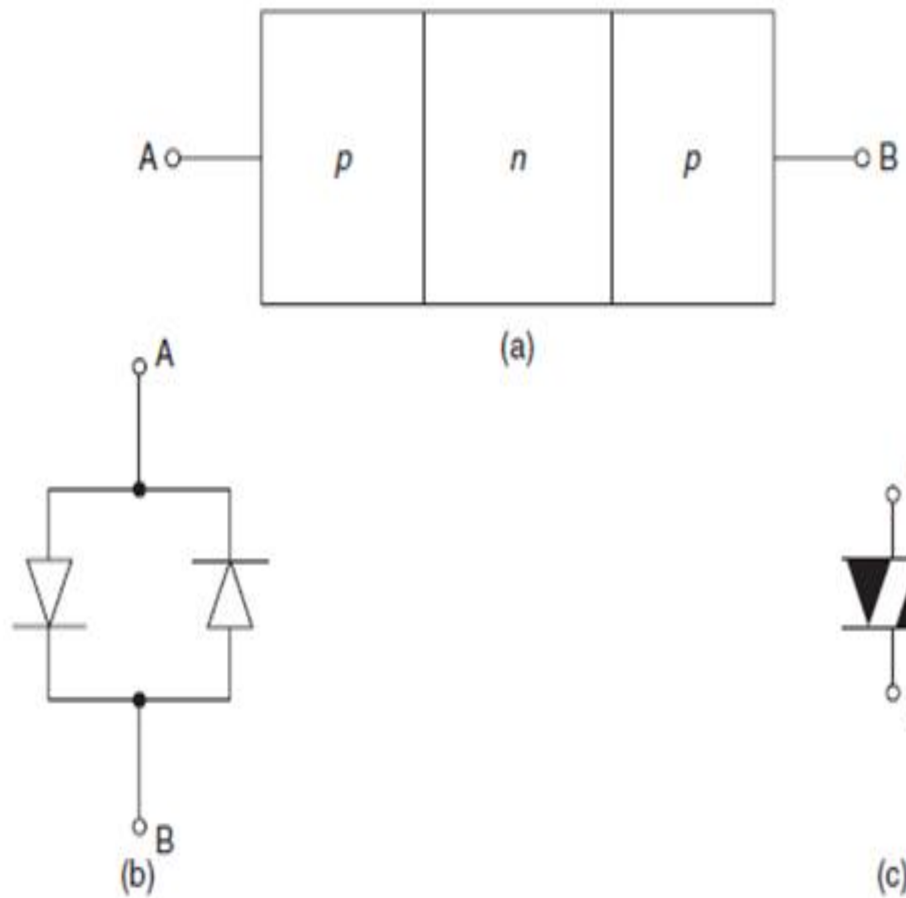
UJT is often used as a trigger device for SCR and TRIACs. Other applications include non sinusoidal oscillators, saw tooth generators, phase control, and timing circuits.



- The data sheet for a 2N2646 Unijunction Transistor gives the intrinsic stand-off ratio **η** as 0.65. If a 100nF capacitor is used to generate the timing pulses, calculate the timing resistor required to produce an oscillation frequency of 100Hz.
- Find the peak voltage for UJT, if intrinsic stand-off ratio **η** as 0.78 and supply voltage is 20 V.

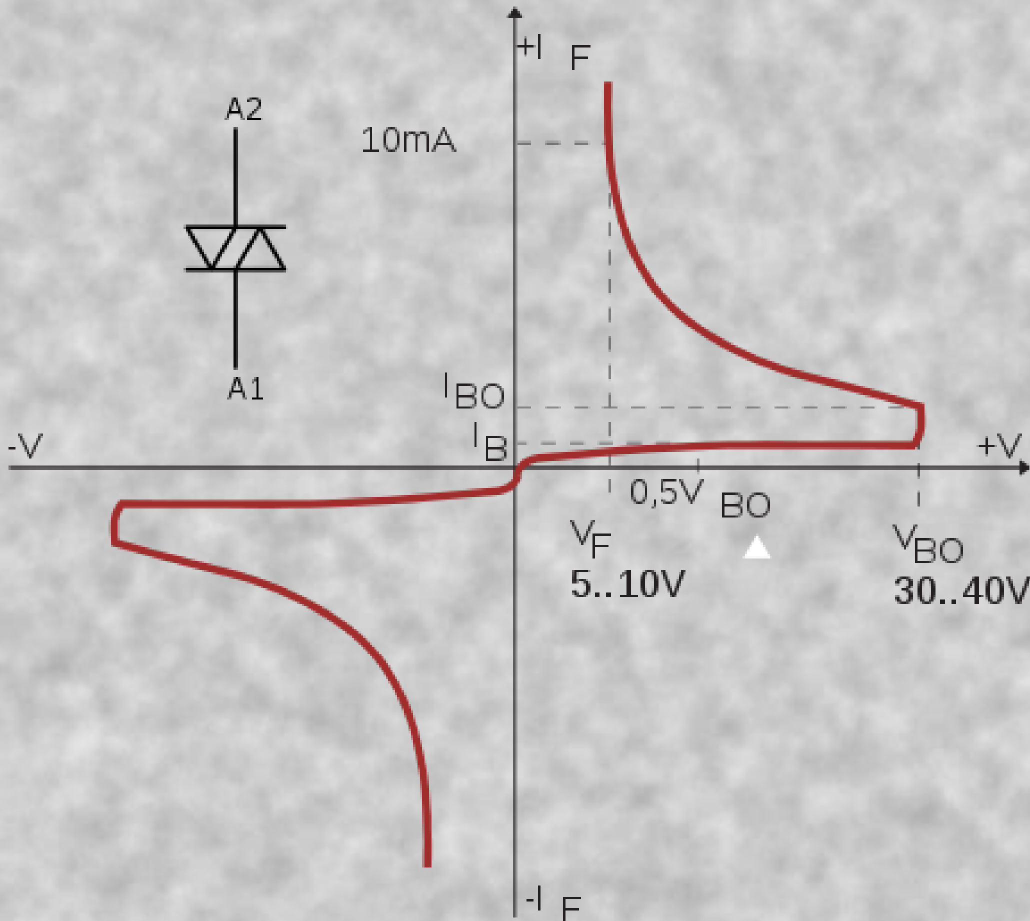
Diac

- The DIAC is a combination of two diodes. Diodes being unidirectional devices, conduct current only in one direction.
- If bidirectional (ac) operation is desired, two diodes may be joined in parallel facing different directions to form the DIAC.
- Because DIACs are bidirectional devices, their terminals are not labeled as anode and cathode but as A1 and A2 or *main terminal* M_{T1} and M_{T2}.



(a) Basic structure of the DIAC (b) Equivalent circuit of the DIAC (c) Symbol of the DIAC

Diac Characteristics

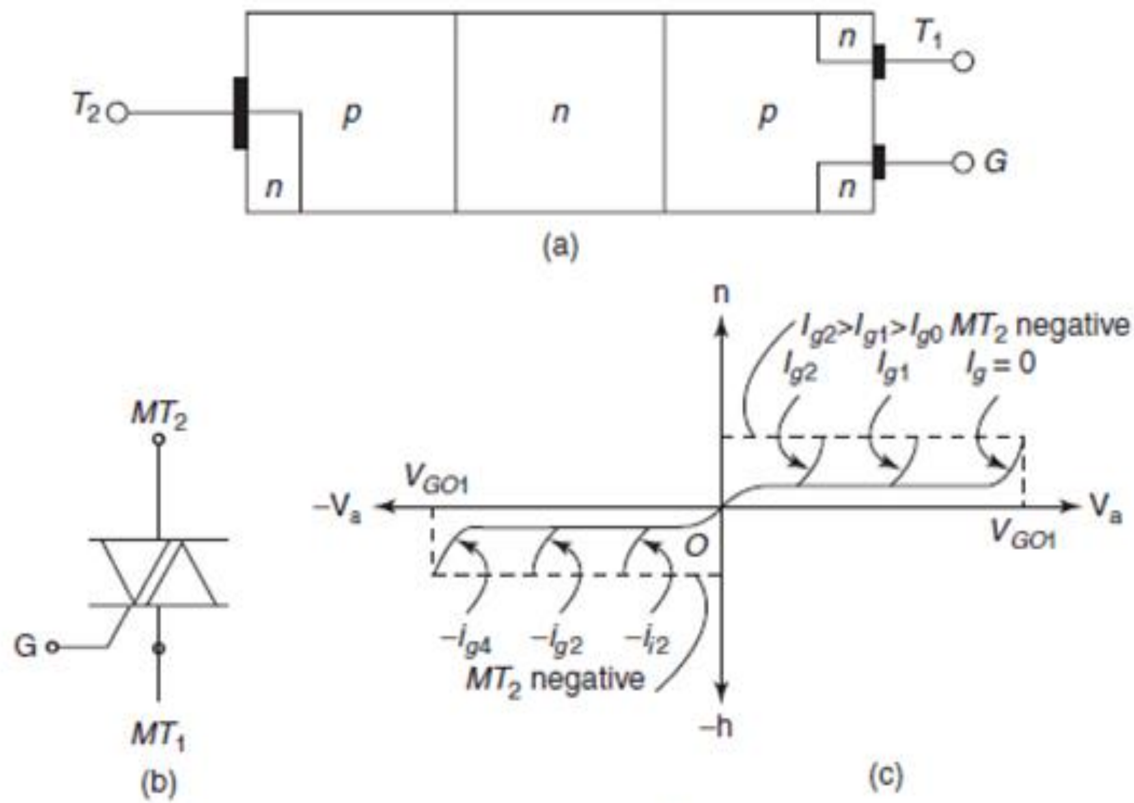


Applications

- Diac is mainly used as a triggering device for triacs.
- Various matched diac-triac pair can be used in different types of control circuits, like light dimmers, heat control, etc.

Triac

- The term TRIAC is derived by combining the first three letters of the word “TRIODE” and the word “AC”.
- A TRIAC is capable of conducting in both the directions. The TRIAC, is thus, a bidirectional thyristor with three terminals. It is widely used for the control of power in ac circuits.



(a) Structure of TRIAC (b) Circuit symbol (c) Static I—V characteristics

- ***The TRIAC has the following advantages:***

  (i) They can be triggered with positive- or negative-polarity voltage.

  (ii) They need a single heat sink of slightly larger size.

  (iii) They need a single fuse for protection, which simplifies their construction.

  (iv) In some dc applications, the SCR has to be connected with a parallel diode for protection against reverse voltage, whereas a TRIAC may work without a diode, as safe breakdown in either direction is possible

- *The TRIAC as a bidirectional thyristor has various applications. Some of the popular applications of the TRIAC are as follows:*

  (i) In speed control of single-phase ac series or motors.

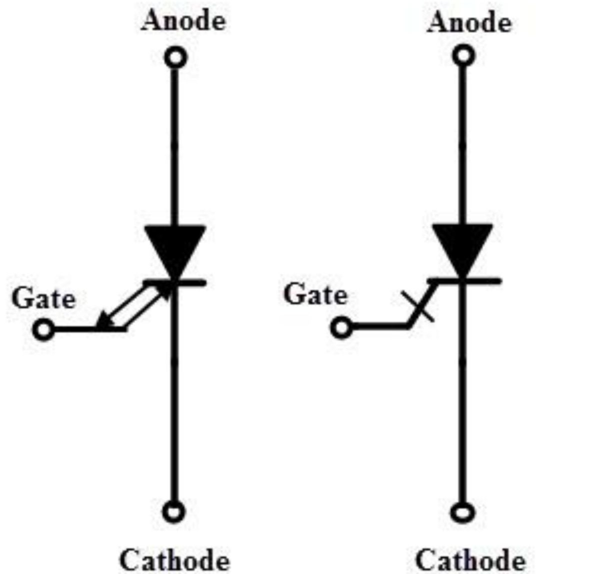
  (ii) In food mixers and portable drills.

  (iii) In lamp dimming and heating control.

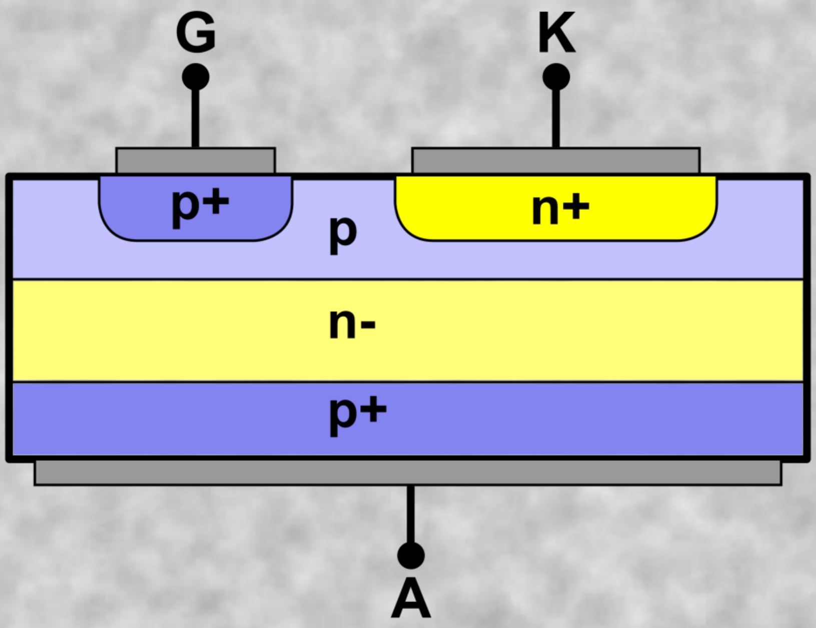
GTO

- The Gate turn off thyristor (GTO) is a four layer PNPN power semiconductor switching device that can be turned on by a short pulse of gate current and can be turned off by a reverse gate pulse.
- This reverse gate current amplitude is dependent on the anode current to be turned off.
- There is no need for an external commutation circuit to turn it off. So inverter circuits built by this device are compact and low-cost.
- The device is turned on by a positive gate current and it is turned off by a negative gate cathode voltage.

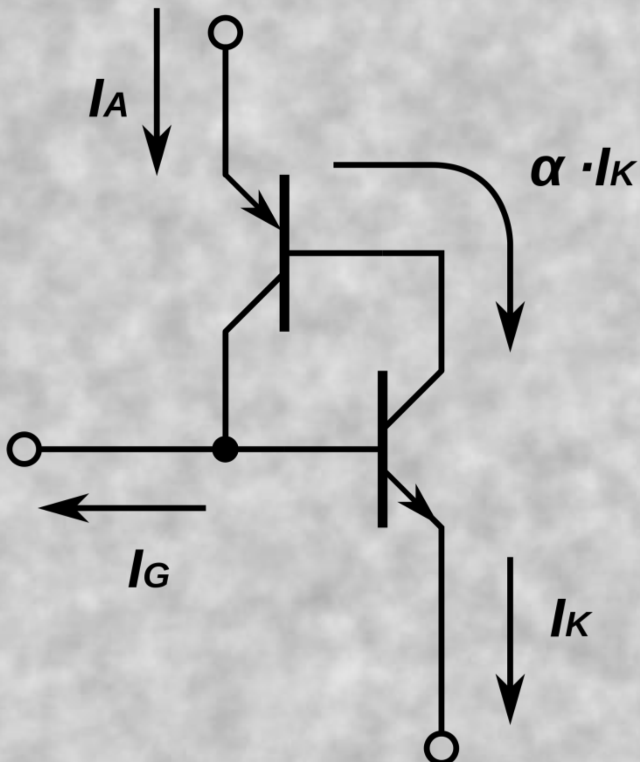
Symbol & Structure of GTO



Gate Turn-Off Thyristor Symbols



GTO



With –ve gate drive, IB2↓

$I_{B2} < I_{C2}/_{\beta 2}$…….(1)

β2=α2/(1-α2) &
β1=α1/(1 -α1)

IC1= IGN+ IB2
during turn-off
IB2= IC1– IGN=α1.IE1– IGN
IB2=α1.Ia– IGN

IC2=IB1=IE1-IC1
IC2=Ia-α1Ia
IC2=Ia(1-α1)

βoff=α2/(α1+α2- 1)

Advantages

- High blocking voltage capabilities
- High over current capabilities
- exhibits low gate currents
- fast and efficient turn off
- better static and dynamic dv/dt capabilities

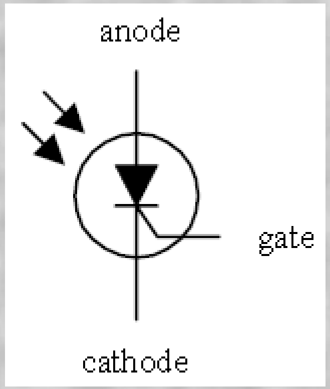
Disadvantages

Compared to a conventional SCR, the device has the following disadvantages

- Magnitude of latching, holding currents is more. The latching current of the GTO is several times more as compared to conventional thyristors of the same rating.
- On state voltage drop and the associated loss is more.
- Due to multi cathode structure of GTO, triggering gate current is higher than that required for normal SCR.
- Gate drive circuit losses are more. Its reverse voltage blocking capability is less than the forward voltage blocking capability.

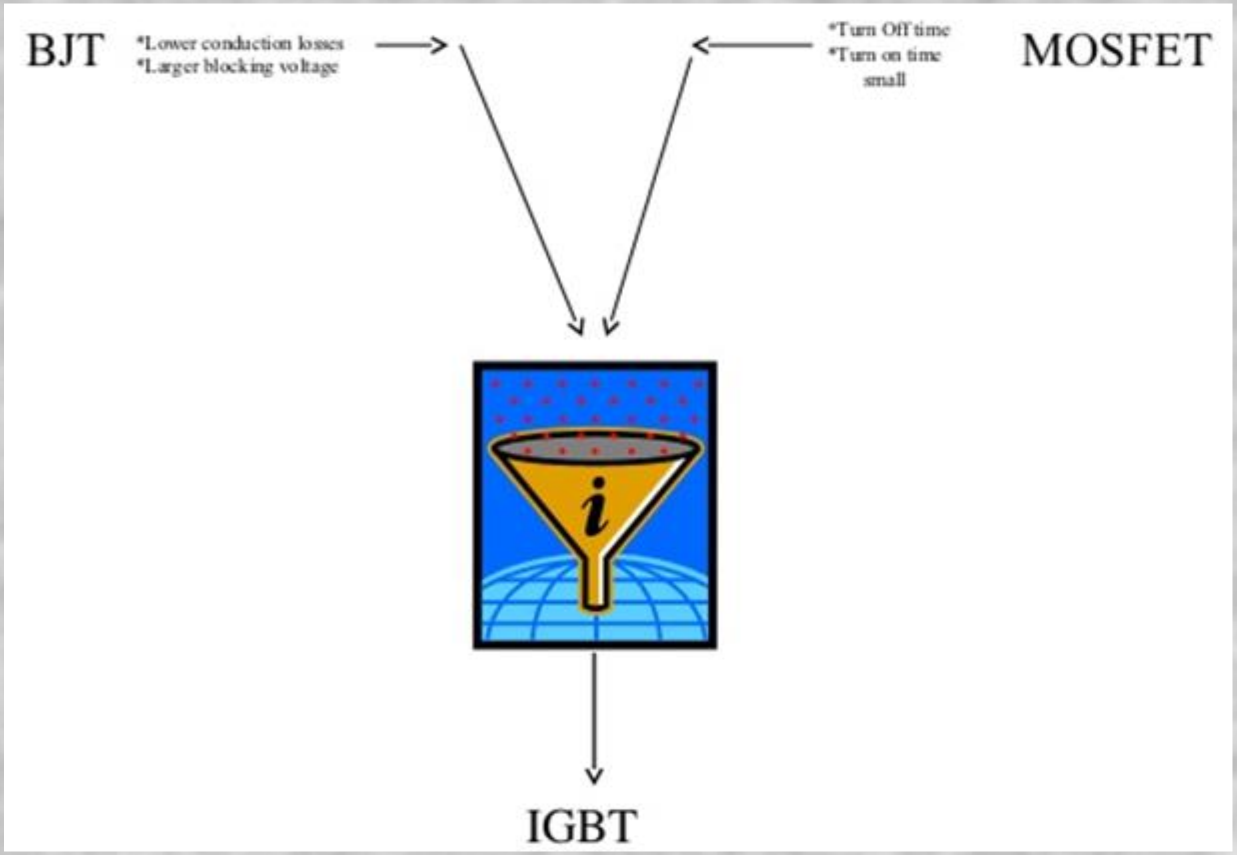
LASCR

- This device is turned on by direct radiation of light on the silicon wafer.
- Electron –hole pair which are created due to the radiation produce triggering current under the influence of electric fields
- The gate structure is designed to provide sufficient gate sensitivity for triggering from practical light sources
- Once the LASCR is triggered to the ON state , it behaves like a normal SCR
- The LASCR will stay ON even if the light disappears.



- HVDC
- It offers isolation between gate and anode circuit.

IGBT



BJT
*Lower conduction losses
*Larger blocking voltage
*Turn Off time
*Turn on time
small
MOSFET
IGBT

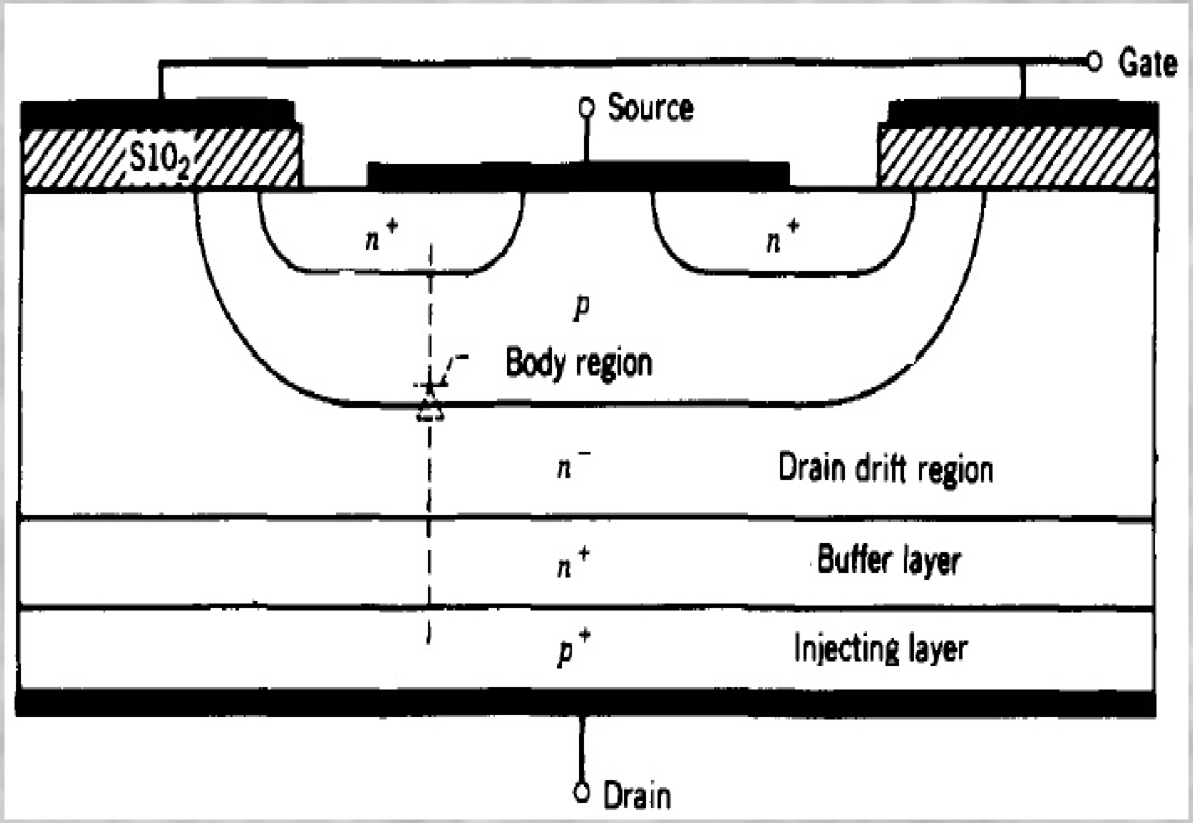
Contd…

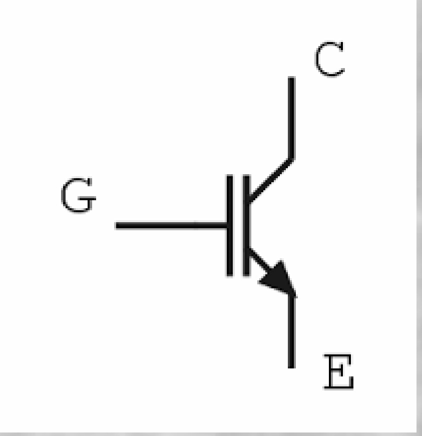
- IGBT combines the best qualities of power MOSFET & BJT.

- It has input characteristics of MOSFET & an output characteristics of BJT. These means it has high input impedance & low on-state loss.

- An IGBT is a voltage controlled device similar to MOSFET, however it’s turn-off time period is slightly greater.

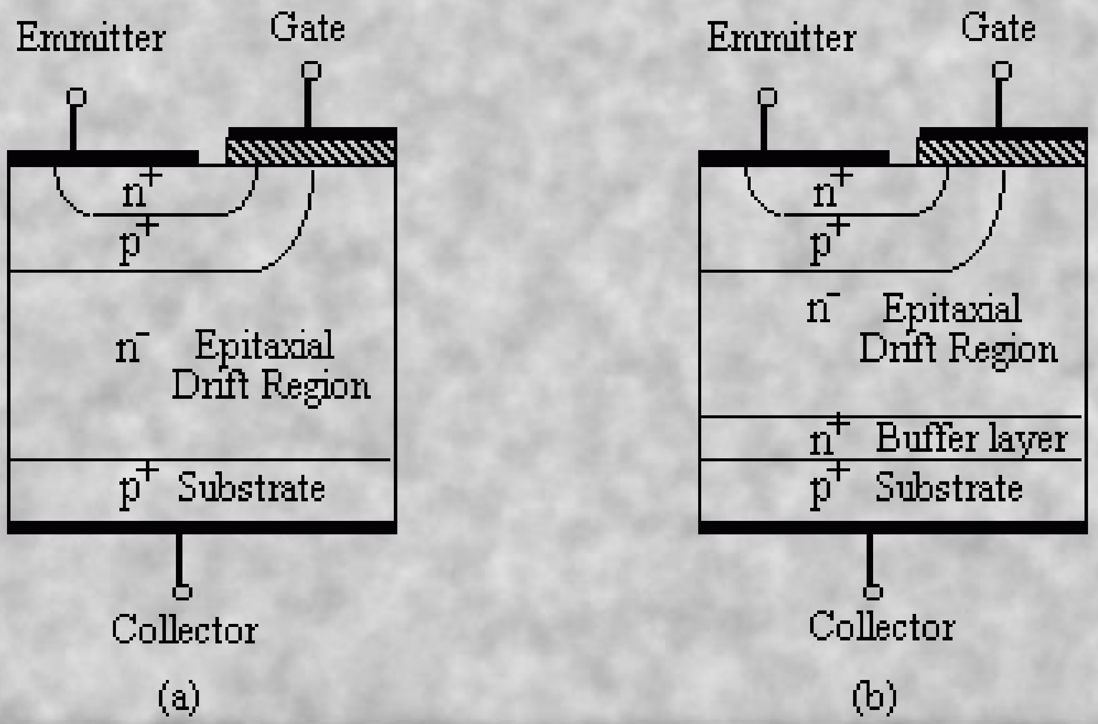
Structure & Symbol of IGBT





Symmetric & Asymmetric IGBTs

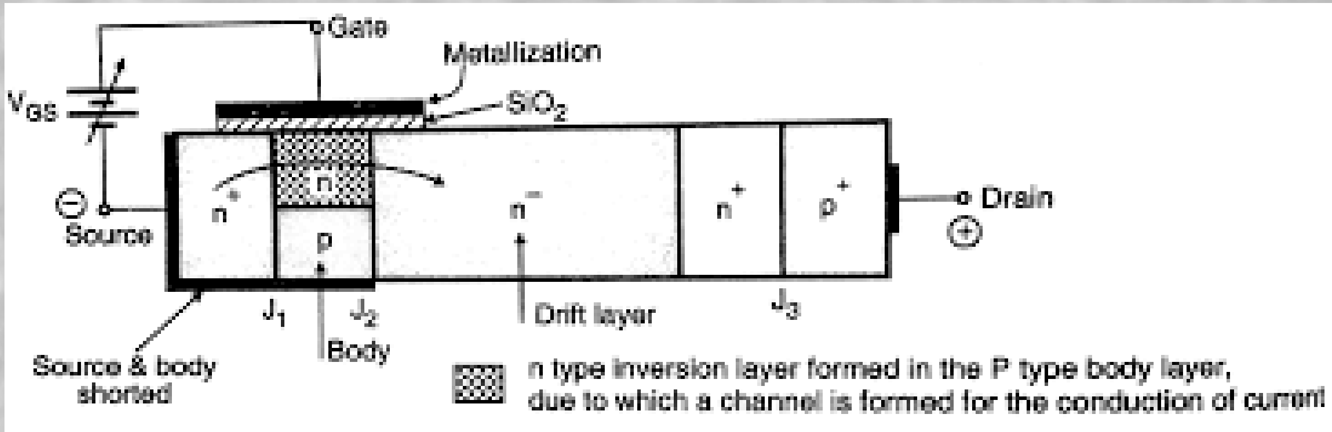
IGBTs are classified on the basis of n^+ buffer layer. They are
(a) Symmetric IGBTs (Non-Punch through IGBTs)
(b) Asymmetric IGBTS (Punch Through IGBTs)



Operation of IGBT

The operation principle of an IGBT is similar to that MOSFET. It can be divided into two parts as follows:

(a) Creation of an Inversion Layer
(b) Conducting Modulation



(a) : Creation of an inversion layer

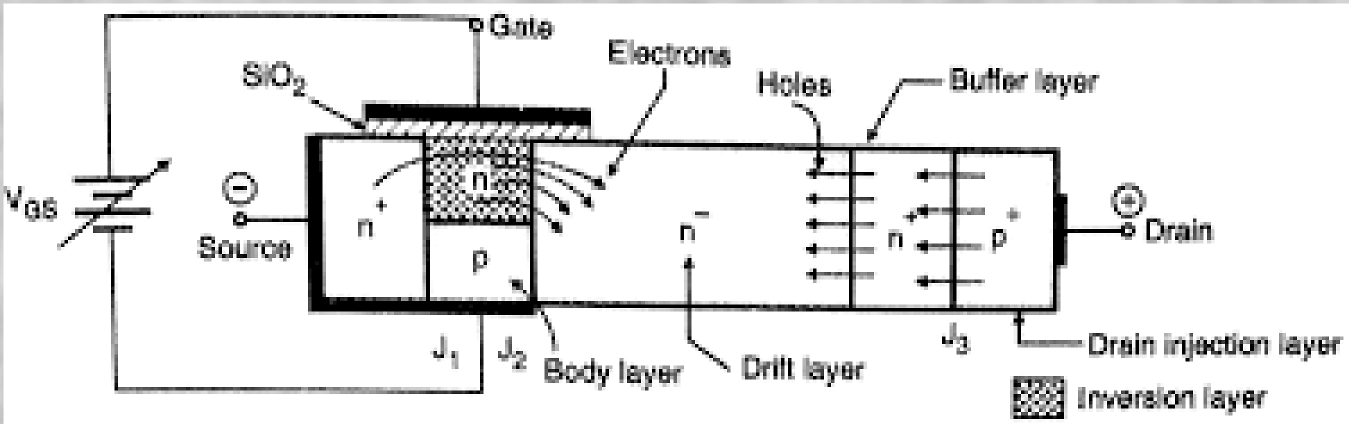
- The operation of an IGBT is based on the principle of creation of an inversion layer.
- When gate to source voltage (Vgs) greater than Vgs(th) is applied, n type inversion layer is created.
- Due to the information of n-type of layer in the p-type body layer, a channel (n+ n n-) is formed which helps to establish the current as shown in figure.

Operation of IGBT

As shown in the figure Junction J3 is forward biased when the forward voltage is applied between the collector & the emitter.

Due to the creation of inversion layer, electrons from the emitter are injected into the n- drift layer via n+ n n- channel.

As the junction J3 is already forward biased, it will inject holes in the n+ buffer layer

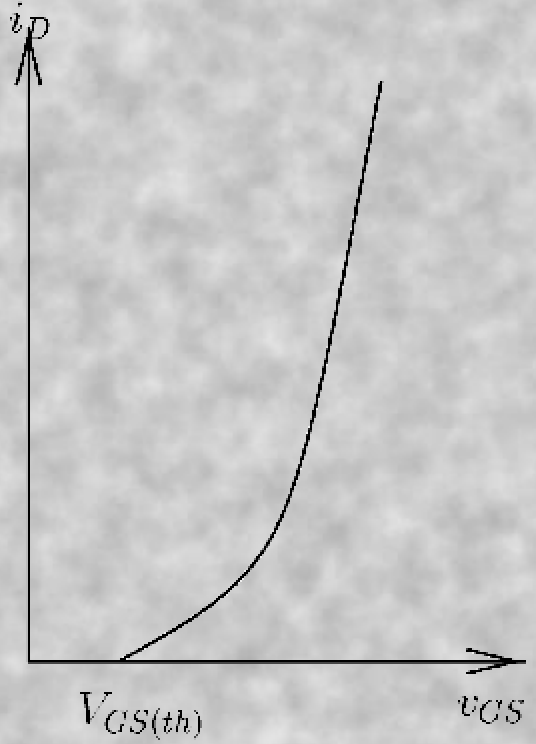


(b) : Conductivity modulation in IGBT

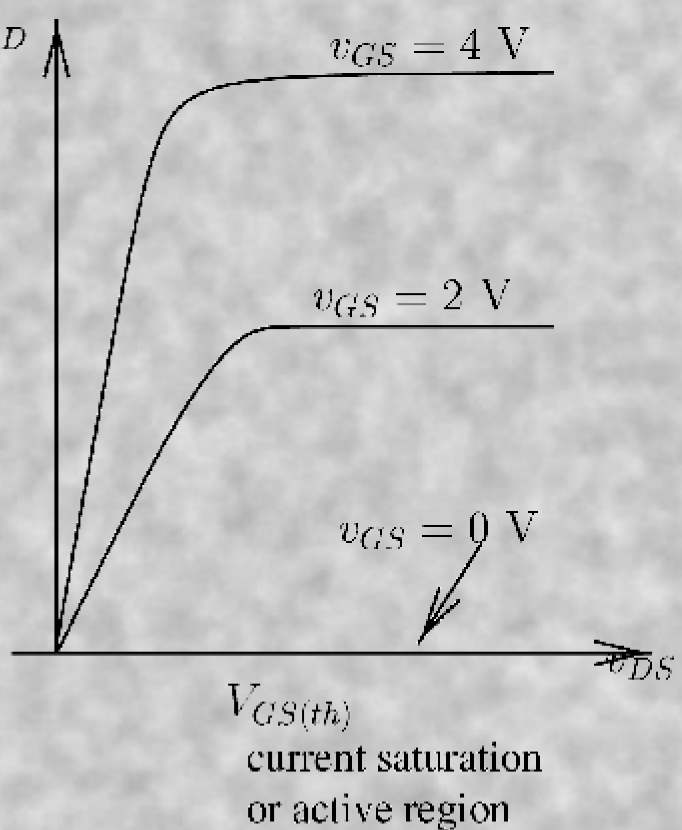
- This way, double injection takes place into the n- drift region from both sides as shown in figure.
- This increases the conductivity of the drift region and reduces the resistance to its minimum.
- In this way, the conductivity modulation reduces the on sate voltage across the IGBT.

- There is no conductivity modulation of drift layer in MOSFET. Therefore, the on-state resistance and hence the on-state power loss is high in MOSFET.
- However in IGBTs the conductivity modulation of the drift layer reduces the on-state resistance and hence the on-state power loss.
- Hence, the on-state power losses in IGBT are less than MOSFET.

Characteristics of IGBT



(a) Transfer Characteristics



(b) Output Characteristics

Series & Parallel operation

- Nowadays, SCRs are available of ratings up to 10 KV & 3 KA. But sometimes we face demand, more than these ratings. In this case combination of more than one SCRs is used.
- **Series connection of SCRs** meets high voltage demand and **parallel connection of SCRs** meets high current demand.
- These series and parallel connection of SCR will work efficiently if all SCRs are fully utilized. Although all SCRs in a string are of same rating, their V-I characteristics differ from one another

Series Operation of SCR

- When we consider a series connection of thyristors, we mean thyristors of the same class to be connected in series.
- Like any other semiconductor device, characteristics properties of two thyristors of same make and rating are never same and this leads to the following two major problems during series connection of the devices.
    1) Unequal distribution of voltage across devices and
    2) Difference in reverse recovery characteristics

Need for Equalising Network

- Due to the difference in blocking currents, junction capacitance, delay times, forward-voltage drops as well as reverse recovery time for individual SCRs, external voltage equalisation networks and special considerations in gatting circuit design are required.
- Equalising Network Design:
    1. Static Equalising Network
    2. Dynamic Equalising Network

Triggering of series connected thyristors

- Series operation of thyristors takes place satisfactory only if all the thyristors are fired at the same instant.

- Even differences of few microseconds in the gate pulses to different thyristors can have a major influence on the voltage sharing in series operation

Triggering of series connected thyristors

- The following are the primary methods in common use of triggering series connected SCRs:

1. Simultaneous triggering.
2. Sequential triggering.
3. Optical triggering.

Simultaneous triggering

- In this type of triggering, all the thyristors are triggered simultaneously and independently with the help of pulse transforming.
- hence, this method is also known as independent or individual firing method.
- Most of the trigger pulse transformers are provided with two secondary windings and these can be used for two series connected SCRs.

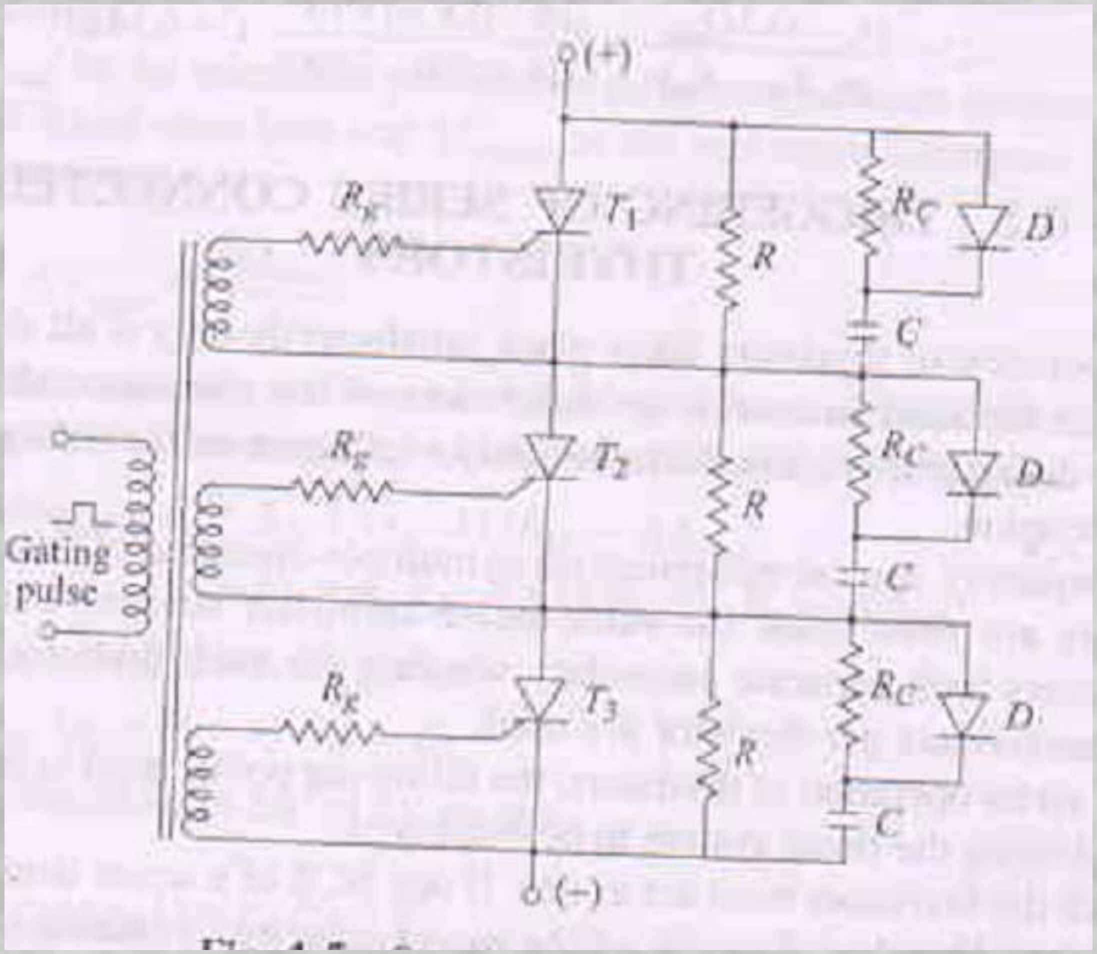
Simultaneous triggering

- For more than two SCRs, special triggering transformer has got to be made with sufficient number of secondaries.
- The main triggering pulse is applied to the primary of the transformer and each of the secondary winding is connected to the individual gates of respective SCRs.
- Triggering requirements may differ quite widely between individual SCRs.

Simultaneous triggering

- To equalize the gate current in each SCR, a resistor is connected in series with the secondary winding for swamping out any difference in a gate-cathode impedance of individual units.

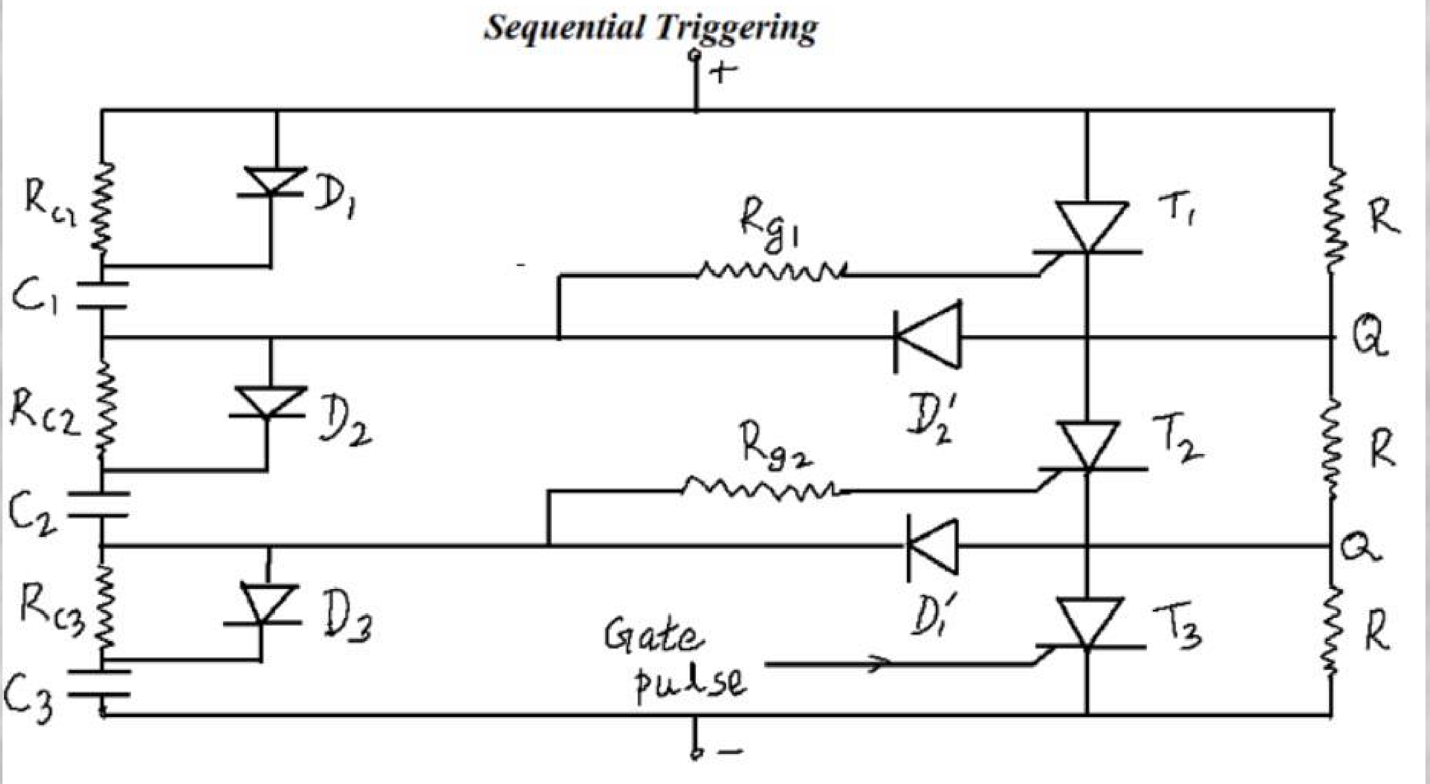
Simultaneous triggering



Sequential triggering

- In this technique, one “master” SCR is triggered, and as its forward blocking voltage collapse, a gate signal is thereby applied to the “slave” SCR. Hence, this method is also called slave-triggering method.

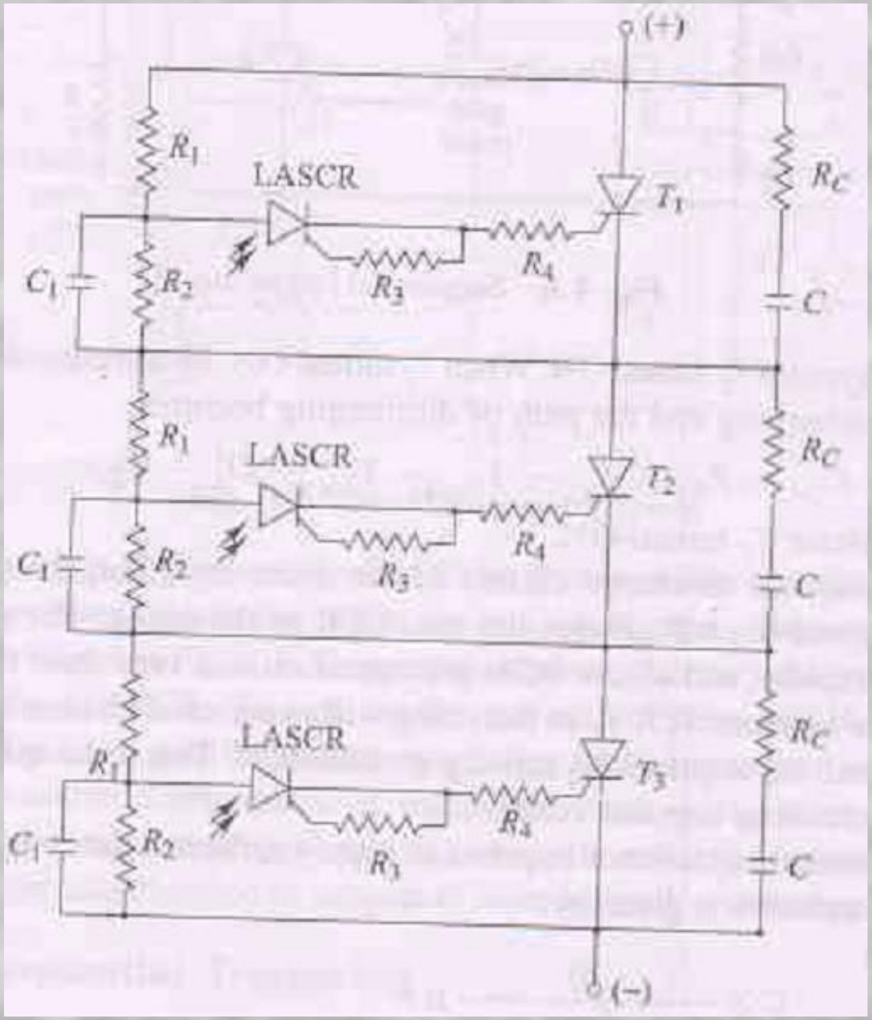
Sequential triggering



Optical triggering

- In this technique, LASCR is connected in the gate circuit of each SCRs.
- Simultaneous triggering of SCRs is achieved by triggering LASCR.
- Therefore, this method provides the required gate isolation along with simultaneous turn-on when a single light source is used to turn on all LASCRs.

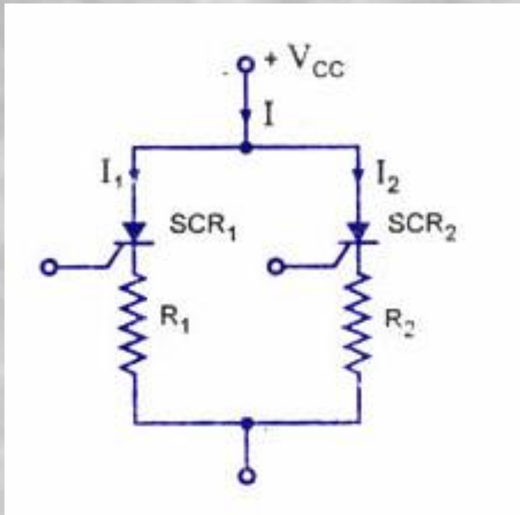
Optical triggering

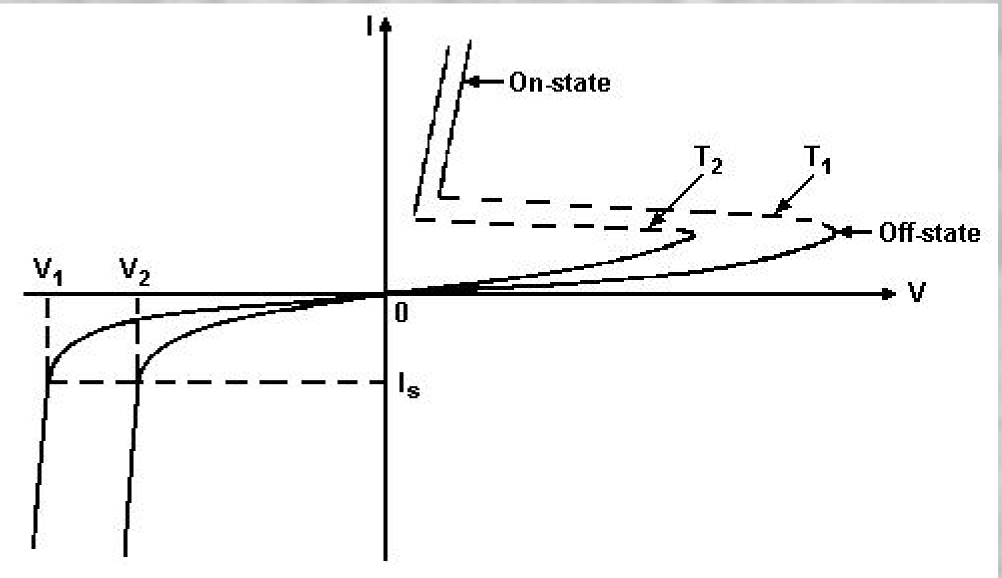


Parallel operation of Thyristors

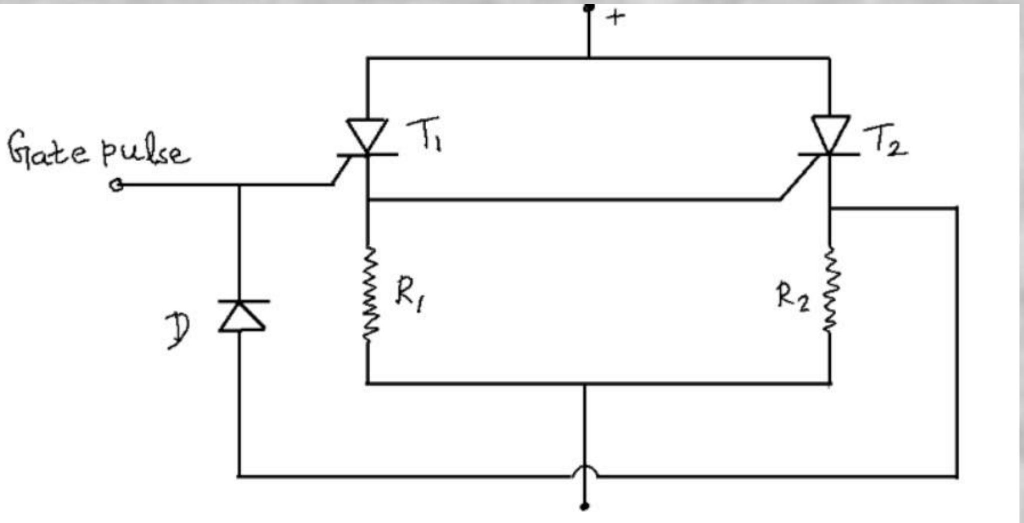
- With parallel thyristors, all thyristors must act as one and so the firing system employed must be highly reliable.
- The essential requirement for triggering SCRs connected in parallel is to use a common pulse generator for all.

Parallel operation of Thyristors





Parallel operation of Thyristors



The very simplest method of triggering of thyristors in parallel is shown in the figure.

Here, when thyristor T1 is triggered, the voltage drop in R1 will trigger thyristor T2.

Contd..

Diode D is necessary when one of the SCRs tends to turn-off due to the current through it failing to a value lower than holding current value.

Because of the presence of diode D, thyristor T1 will be retriggered whenever current in T2 increases and T1 is not being triggered.

T1 will be triggered by the voltage drop in R2.

String Efficiency

- These series and parallel connection of SCR or Thyristor will work efficiently if all SCRs are fully utilized.
- Although all SCRs in a string are of same rating, their V-I characteristics differ from one another.
- This leads to unequal voltage or current division among them. Hence every SCR is not fully utilized.
- So the efficiency of string is always less than 100% according to the given expression

$$String\ efficiency = \frac{V_{oi}\ or\ actual\ current\ rating\ of\ the\ whole\ string}{nos\ of\ SCR\ in\ the\ string\ \times V_{oi}\ or\ current\ rating\ of\ individual\ SCR}$$

String Efficiency

- We can say that string efficiency is a term that is used for measuring the degree of utilization of SCR in string (Series/Parallel).
- In practice, this ratio is less than one.
- To obtain highest possible string efficiency, the SCRs connected in string must have identical characteristics. *(Since, SCRs of the same rating and specifications do not have identical characteristics, unequal current /voltage sharing is bound to occur for all SCRs in string. Hence, the string efficiency can never be equal to one)*

- A thyristor string is formed by the series & parallel connection of thyristors. The voltage and current ratings of the string are 6KV and 1 KA respectively. Available thyristors have the voltage & current ratings of 1.2 KV and 1 KA, respectively. The string efficiency is 90% for both the series & parallel connections.

Calculate the number of thyristors to be connected in series & parallel.

Derating

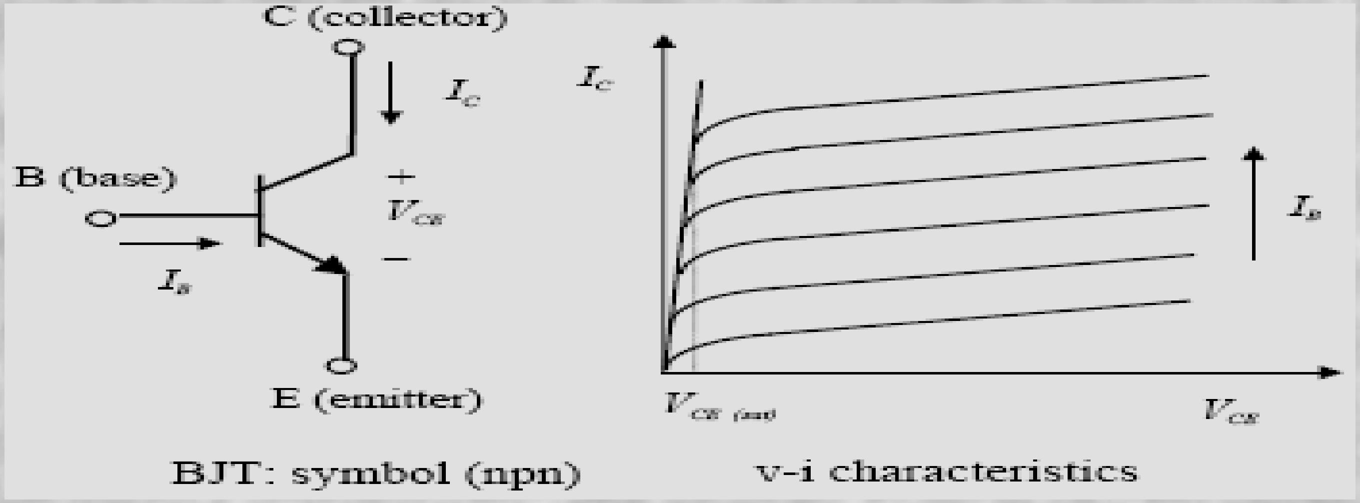
- Several methods/networks used for voltage & current equalization in series & Parallel connected thyristors, respectively.
- Although, the differences in voltages/current will be reduced, these methods do not entirely eliminate these differences.
- Therefore, in order to improve the reliability of the series/parallel string, an extra unit may be added so that the voltage/current applied to each device will be lower than its normal rating.

Cont…

- This phenomenon increases the reliability of the string, but reduces the utilization of each SCR. Thus string efficiency decreases. Reliability of string is measured by derating factor (DRF) which is given by the expression

DRF = 1 – string efficiency

Bipolar Junction Transistor (BJT)



- Ratings: Voltage: V_{CE}<1000, Current: I_C<400A. Switching frequency up to 5kHz. Low on-state voltage: $V_{CE(sat)}$: 2-3V.
- Low current gain (β). Need high base current to obtain reasonable I_C . **(Current driven).** Expensive and complex base drive circuit.
- Not popular in new products.

BJT Conduction

- The level of I_B in the active region just before saturation must be

$$I_{B_{max}} > \frac{I_{c\,sat}}{\beta_{dc}}$$

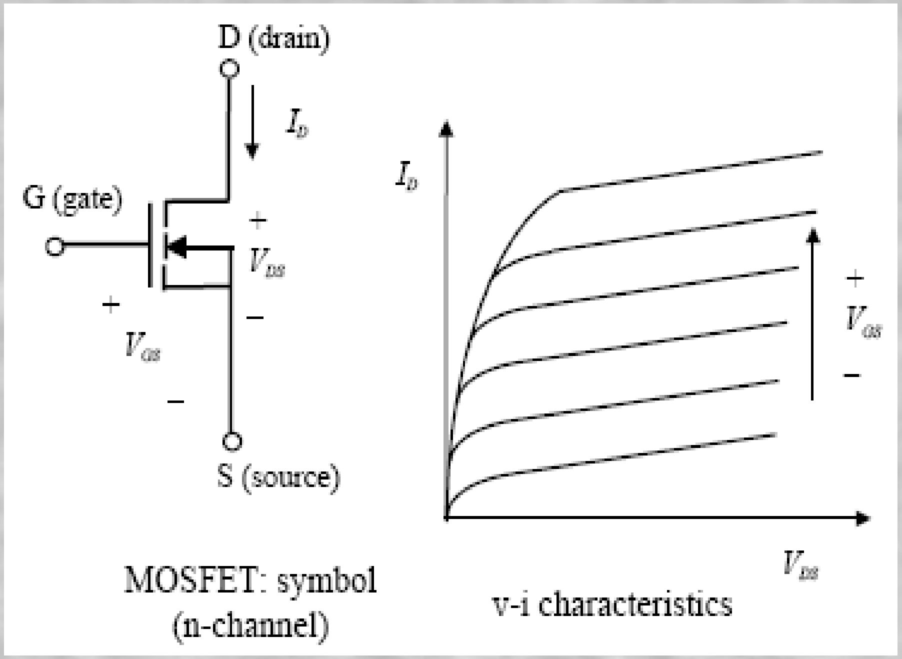
- At saturation, the current I_C is quite high and the voltage V_{CE} very low. The resistance across the terminals determined by

$$R_{sat} = \frac{V_{CE\,sat}}{I_{C\,sat}}$$

Saturation conditions and the resulting terminal resistance

Cutoff conditions and the resulting terminal resistance

Metal Oxide Silicon Field Effect Transistor (MOSFET)



- Ratings: Voltage V_{DS}<500V, current I_{DS}<300A. **(Voltage driven)**
- Very fast device: >100KHz. For some low power devices (few hundred watts) may go up to MHz range.

MOSFET characteristics

- Turning on and off is very simple. Only need to provide V_{GS} =+15V to turn on and 0V to turn off. Gate drive circuit is simple.
- Basically low voltage device. High voltage device are available up to 600V but with limited current. Can be paralleled quite easily for higher current capability.
- Internal (dynamic) resistance between drain and source during on state, $R_{DS(ON)}$, limits the power handling capability of MOSFET. High losses especially for high voltage device due to $R_{DS(ON)}$.
- Dominant in high frequency application (>100kHz). Biggest application is in switched-mode power supplies.