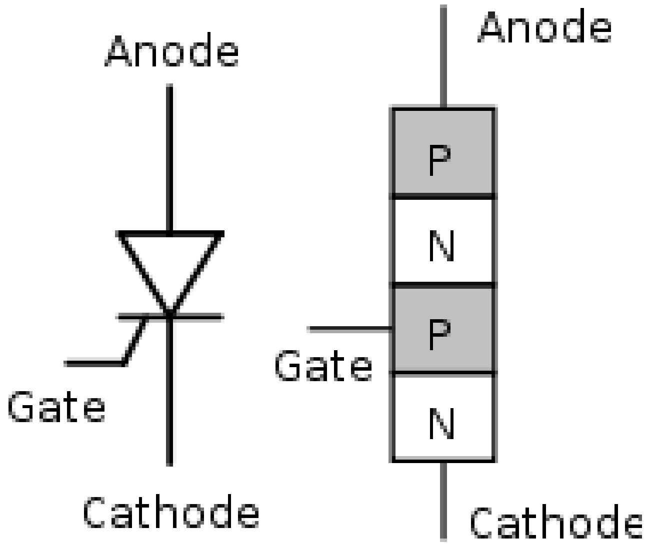
Module-3
Thyristors

Prepared By,
Dr Sathish K R
Assistant Professor
Department of EEE
ATMECE, Mysuru

Module-3

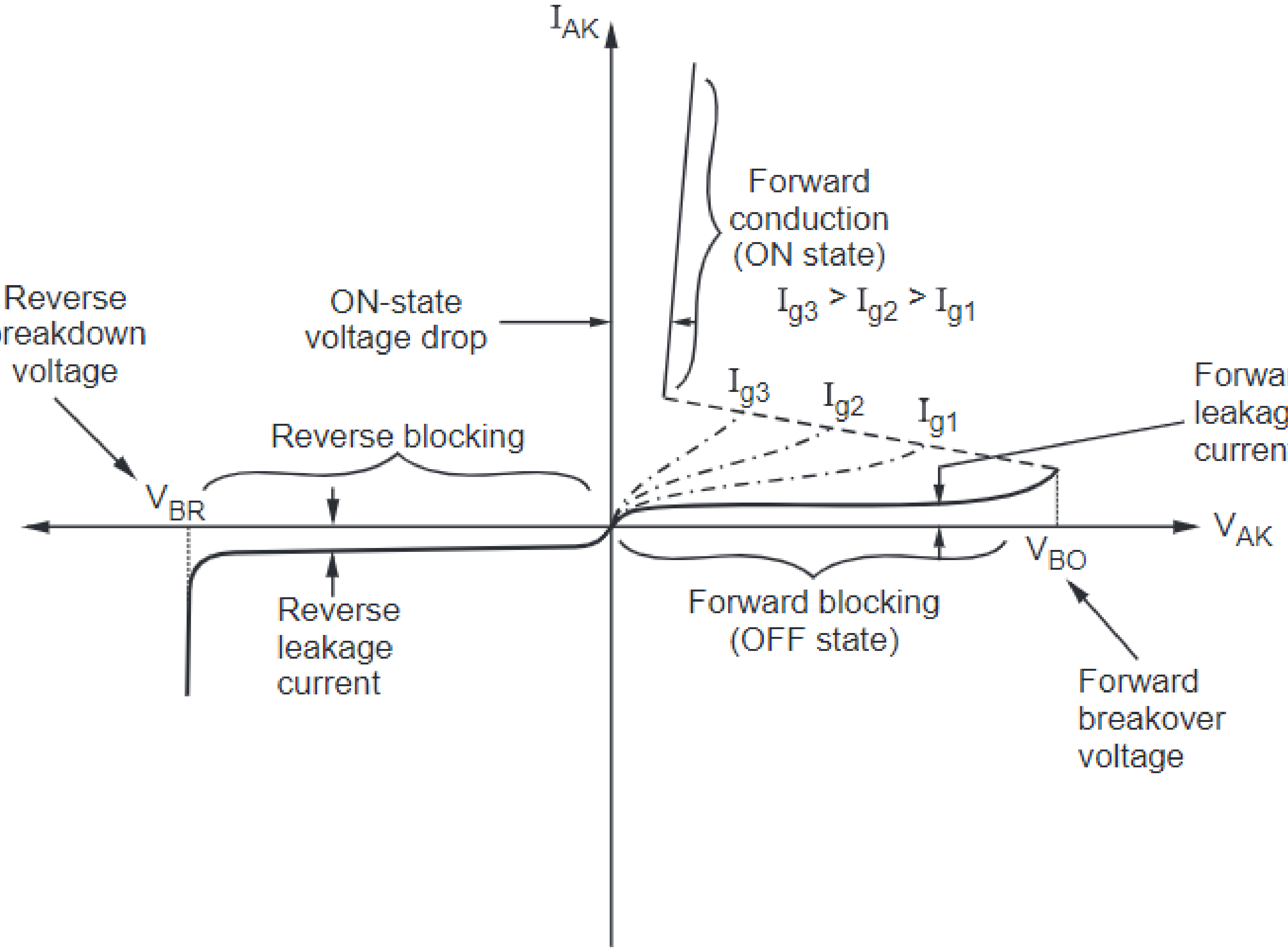
Thyristors: Introduction, Thyristor Characteristics, Two-Transistor Model of Thyristor, Thyristor Turn- On, Thyristor Turn-Off, A brief study on Thyristor Types, Series Operation of Thyristors, Parallel Operation of Thyristors, di/dt Protection, dv/dt Protection, Thyristor Firing Circuits, Unijunction Transistor.

Introduction:

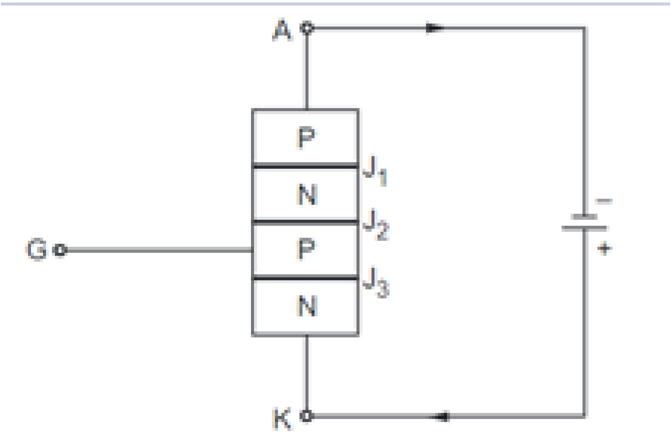


- Thyristor is a four-layer, three-joint p-n-p-n semiconductor switching device with three terminals: anode, cathode, and gate.
- The terminal connected to outer p region is called anode(A), the terminal connected to outer n region is called cathode(K) and that connected to inner p region is called the Gate(G).

Static VI Characteristics of SCR:

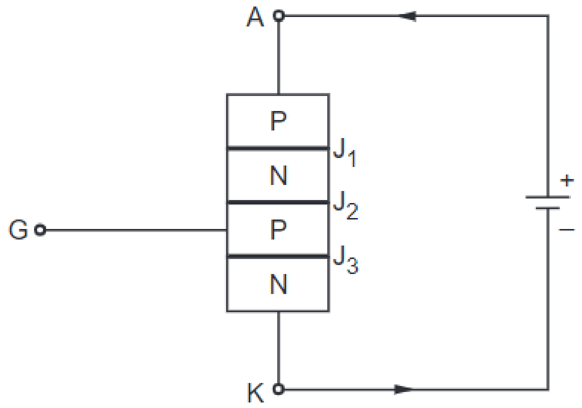


Reverse blocking mode:



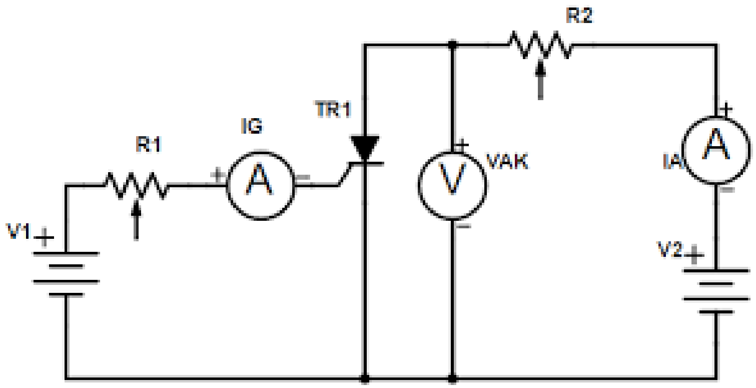
A reverse biased thyristor

Forward Blocking Mode:



Thyristor in forward biased condition

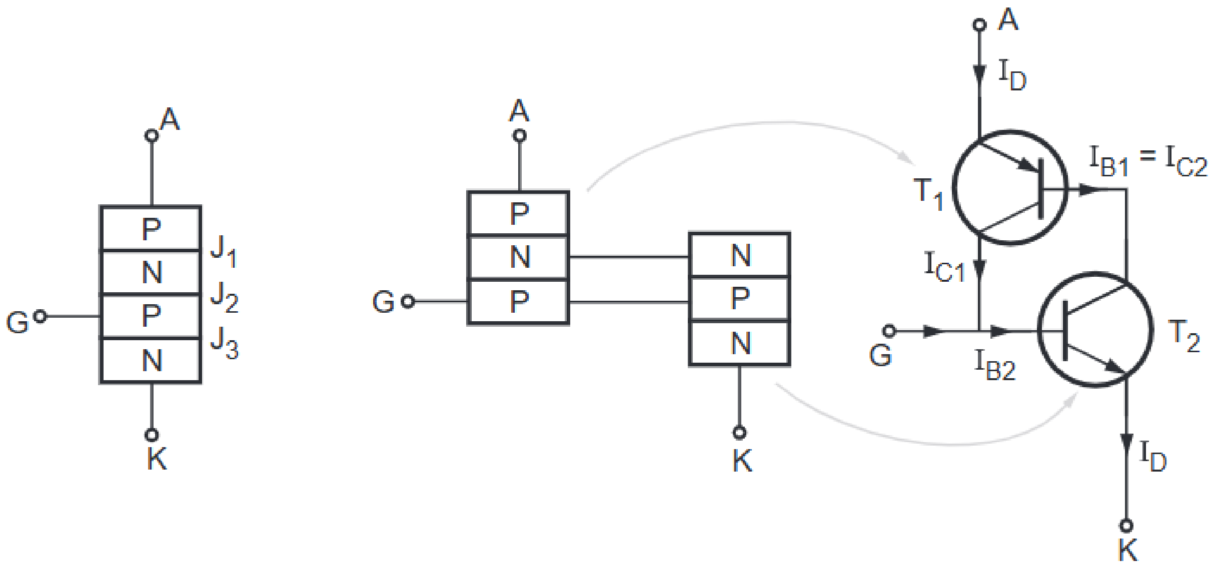
Forward Conduction Mode:



Latching Current(I_L): Latching current is the minimum forward current that flows through the thyristor to keep it in forward conduction mode (ON state) at the time of triggering if the forward current is less than the latching current thyristor doesn't turn on. Latching current is of the order of 10 to 15 milliamperes

Holding Current(I_h): Holding current is the minimum forward current that flows through the thyristor to keep it in forward conduction mode when forward current reduces below holding current thyristor turn off.

Two Transistor Model of Thyristor:



(a) Four layer structure of thyristor

(b) Middle two layers split into two separate parts

(c) Two transistor mode of the thyristor from fig (b)

A two transistor model of the thyristor

$$I_{C1} = \alpha_1 I_{E1} + I_{CO1} \quad \text{..........(1)}$$

Here $I_{E1} = I_D$ and I_{CO1} is leakage current of T_1. Similarly for T_2,

$$I_{C2} = \alpha_2 I_{E2} + I_{CO2} \quad \text{..........(2)}$$

Here $I_{E2} = I_D$ and I_{CO2} is leakage current of T_2.

Therefore equation (1) & (2) can be written as,

$$\left.\begin{aligned} I_{C1} &= \alpha_1 I_D + I_{CO1} \\ I_{C2} &= \alpha_2 I_D + I_{CO2} \end{aligned}\right\} \quad \text{..........(3)}$$

$$I_D = I_{C1} + I_{C2}$$

$$I_D = \alpha_1 I_D + I_{CO1} + \alpha_2 I_D + I_{CO2}$$

$$\therefore \quad I_D = (\alpha_1 + \alpha_2) I_D + I_{CO1} + I_{CO2}$$

$$\therefore \quad I_D = \frac{I_{CO1} + I_{CO2}}{1 - (\alpha_1 + \alpha_2)} \quad \text{.....(4)}$$

$$I_D = \frac{I_{CO}}{1 - (\alpha_1 + \alpha_2)} \quad \text{.....(5)}$$

$$I_D = \frac{I_{CO} + I_g}{1 - (\alpha_1 + \alpha_2)} \quad \text{.........(8)}$$

Thyristor Turn-on and Turn-off:

1. Gate drive: Thyristor can be turned on by applying positive gate-cathode voltage. Injected gate carriers increase the anode current and regenerative action starts. $(\alpha_1 + \alpha_2)$ approaches unit and anode current (I_D) becomes large. It is limited only by external load. Once the thyristor is turned-on, there is no need of gate drive. Hence it can be removed. Normally pulsed gate drive is applied to reduce losses in the thyristor gate.

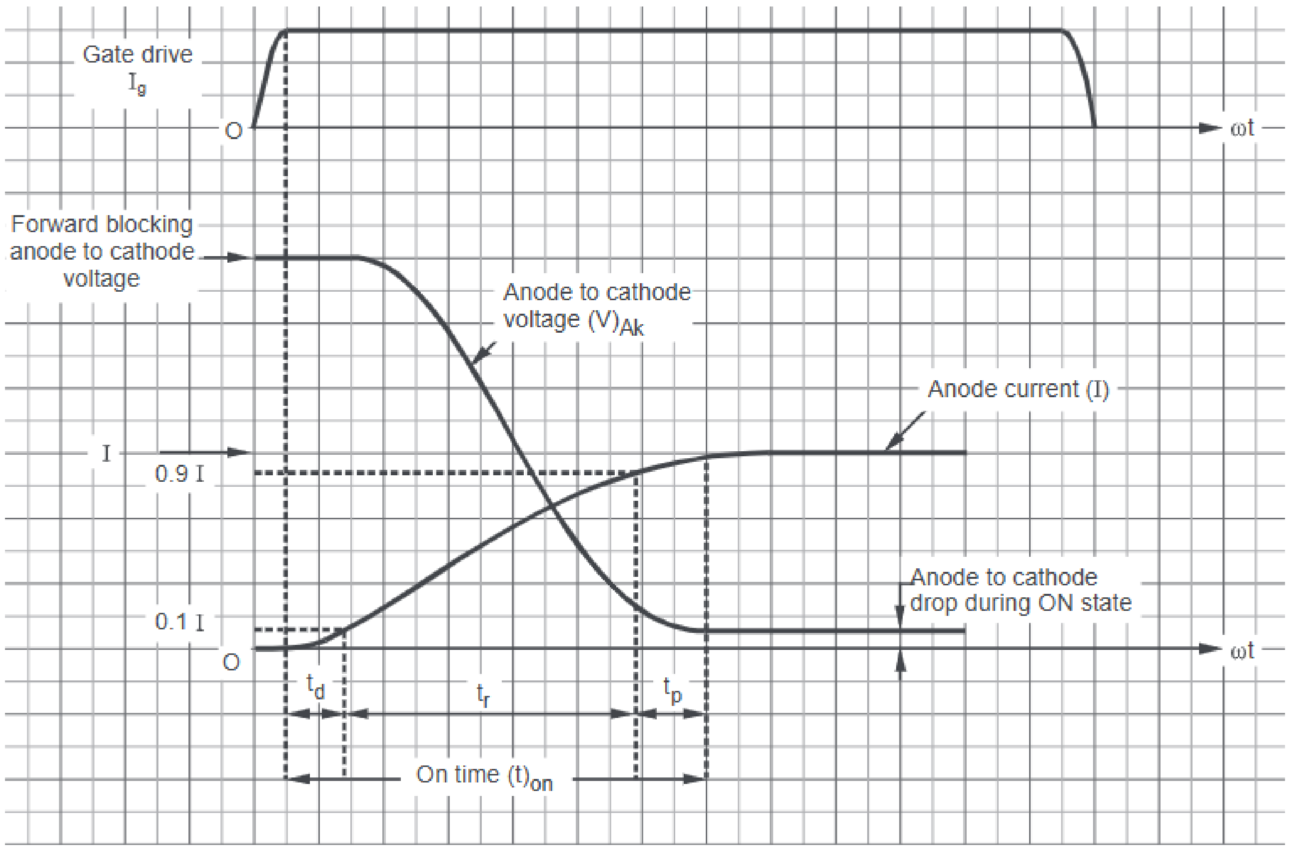
2. High forward voltage: Thyristor turns on when its anode-cathode voltage exceeds forward breakover voltage, i.e. $V_{Ak} > V_{BO}$. At these voltages, the leakage current is so high, that internal regeneration starts in the device.

3. dv/dt: Thyristor can be thought of as a capacitor in the forward biased state. When the anode-cathode voltage changes rapidly, leakage current thought the device increases due to internal capacitor. The leads to turn-on of the thyristor.

4. Light: Thyristor can be turned on by light, when it falls on gate cathode junction of the thyristor light induces electronic hole pairs and it helps to increases leakage current.

5. High temperature: Tyristor turns on due to increased temperature AT higher temperature, there are more electron-hole pairs across junctions. This inverses the leakage current and the thyristor turns on.

Turn-on Dynamic Characteristics:



Dynamic characteristics of thyristor during turn-on

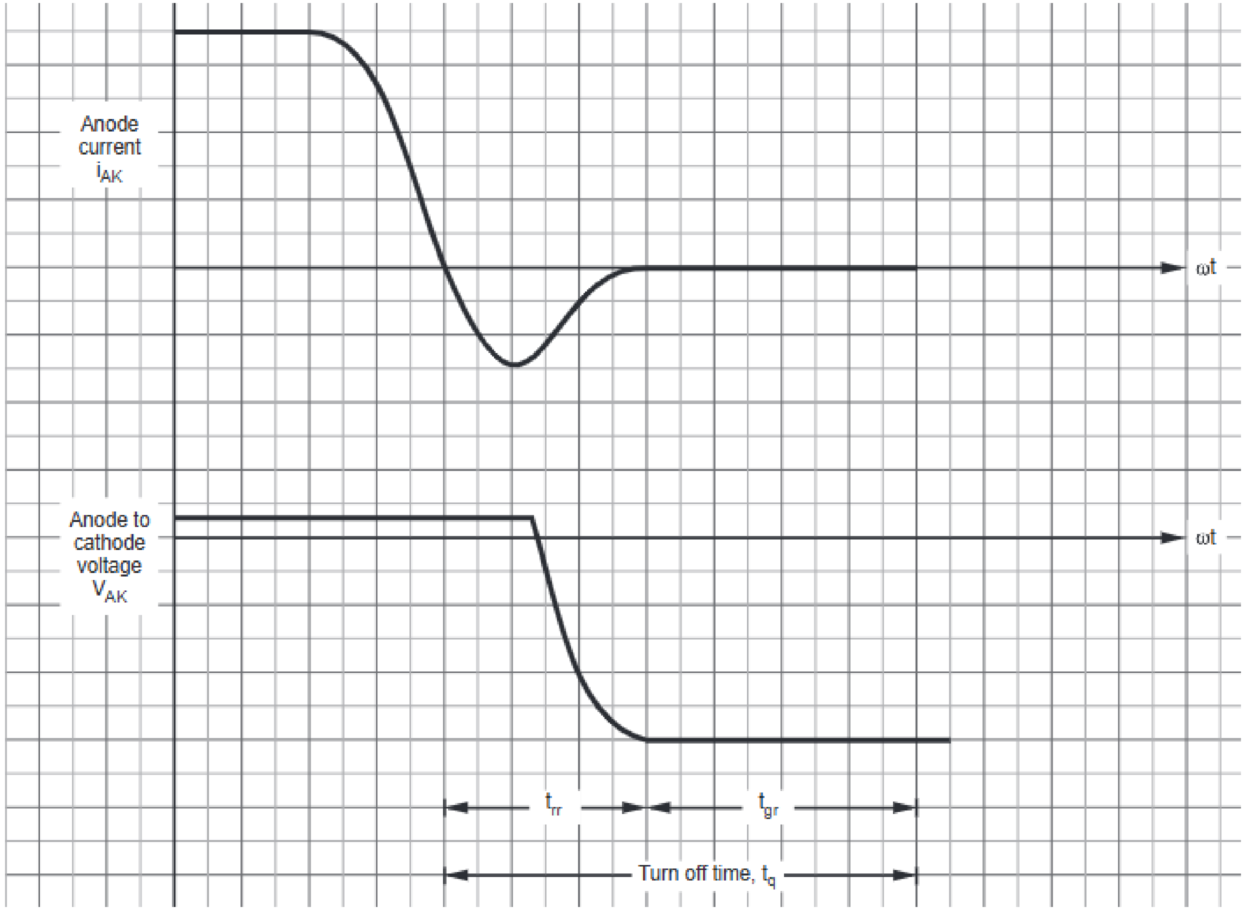
Thyristor Turn-off:

The thyristor can be turned-off, when its forward current falls below holding current. The can be done by two methods i) Natural commutation and ii) Forced commutation.

i) Natural commutation: In this type of turn-off, the supply voltage becomes zero or negative, Hence thyristor is reverse biased. Therefore it is turned-off.

ii) Forced commutation: When the supply voltage is DC, then external commutation component are used to turn-off the thriystor. The commutation components apply reverse bias across the thyristor temporarily or pass impulse of negative current. Therefore thyristor turns-off.

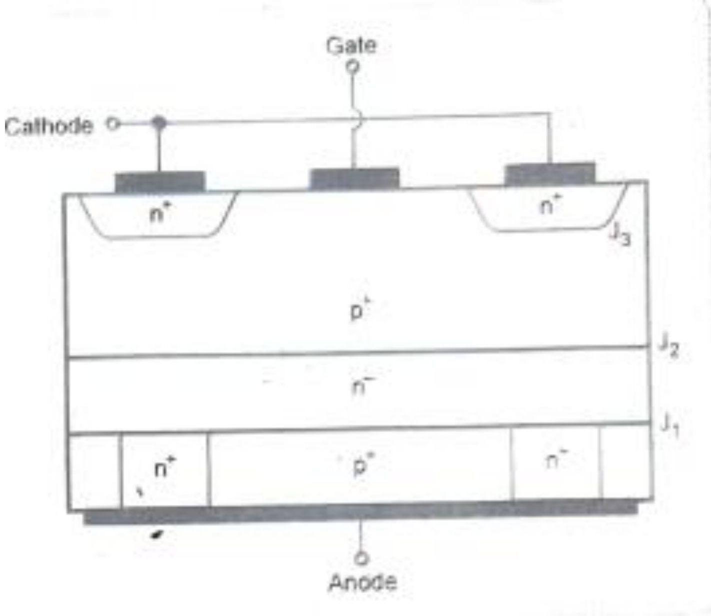
Turn-off Dynamic Characteristics:

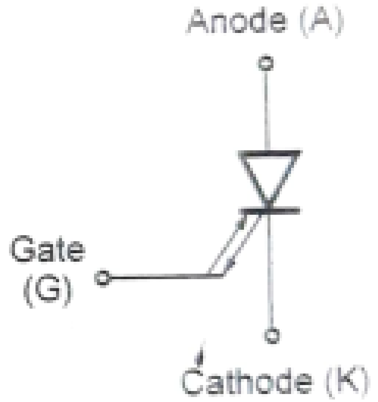


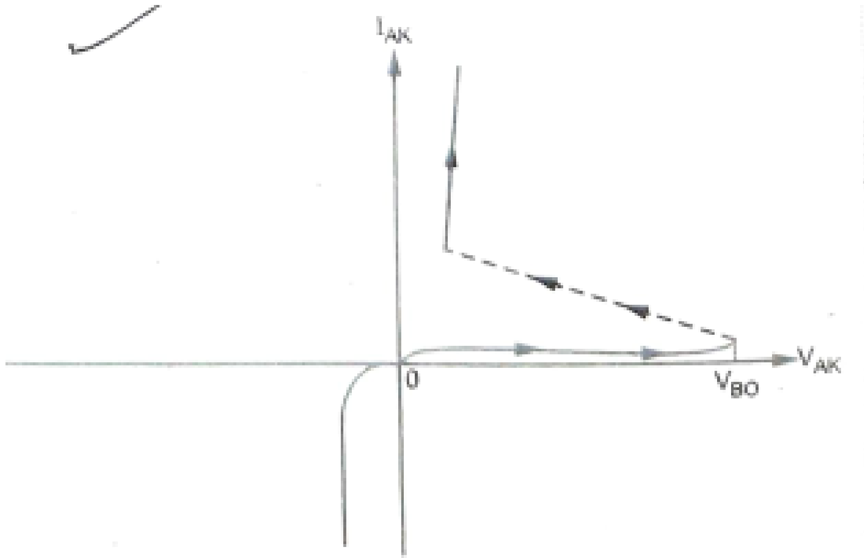
A Brief Study on Thyristor Types:

1. Gate Turn-off Thyristor (GTO)
2. Light Activated SCR (LASCR)
3. Reverse Conducting Thyristor (RCT)
4. Triac (Bidirectional Triode Thyristors
5. Diac

Gate Turn-off Thyristor (GTO):







Advantages:

1. Higher voltage blocking capability.
2. Gate has full control over the Of GTO
3. Low on-state loss.
4. High ratio of surge current to average current.
5. High on-state gain.

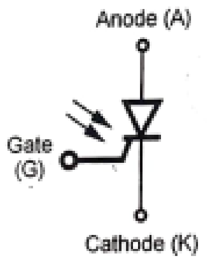
Limitations

1. GTOs require large negative gate currents for turn-off. Hence they are suitable for low-power applications.
2. Very small reverse voltage blocking capability.
3. Switching frequencies are very small.

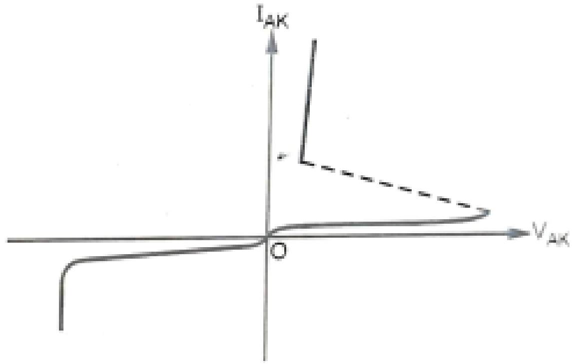
Applications

1. GTOs are suitable mainly For low power applications.
2. Induction heating and motor drives.

Light Activated SCR (LASCR):



(a) Symbol of LASCR



(b) V-I characteristics of LASCR

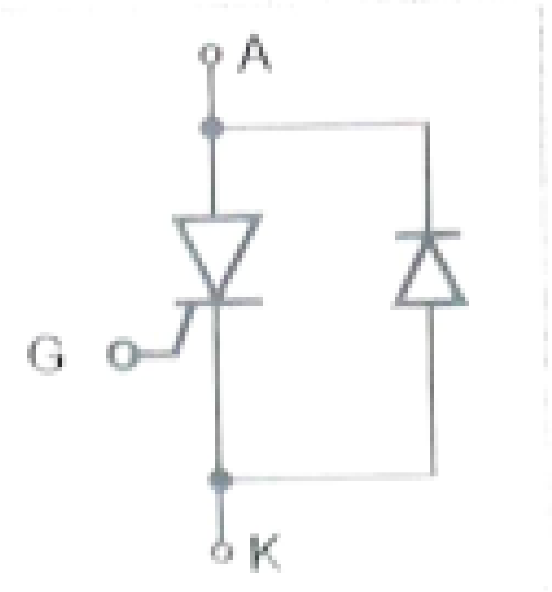
Advantages

1. It can turned-on by a beam of light. Hence isolation is provided between control circuit and SCR.
2. Because of optical triggering, effects of noise are reduced.

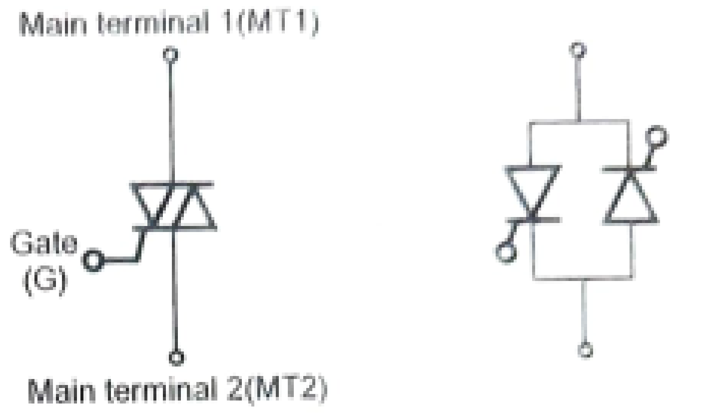
Applications

1. Used in high-power applications like HVDC transmission, VAR compensation etc.
2. Used in noise environments for better-triggering control.

Reverse Conducting Thyristor (RCT):



Triac (Bidirectional Triode Thyristors



(a)
Triac symbol

(b)
Triac equivalent circuit

Merits, Limitations and Applications of Triac:

Merits of Triac:

1. Triac is a bidirectional device, i,e it conducts in both directions.
2. Triac turns off when voltage is reversed.
3. Single gate controls conduction is both directions.
4. Triac with high voltage and current ratings are available.

Demerits if Tria:

1. Tria are latching devices like SCR. Hence, they are not suitable for DC power applications.
2. Gate has no control over the conduction once triac is turned on.
3. Triac have very small switching frequencies.

Applications of Triac:

1. AC power controllers and heater, fan etc. controller.
2. Triggering device for SCRs.

Diac:

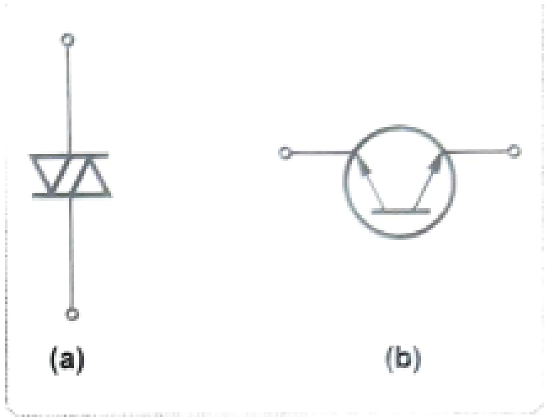
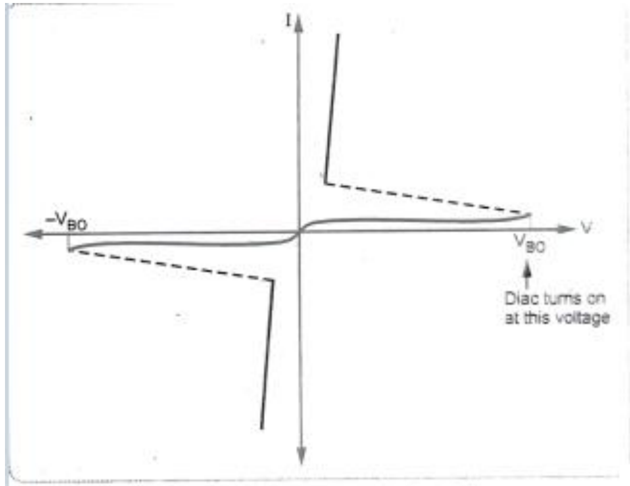


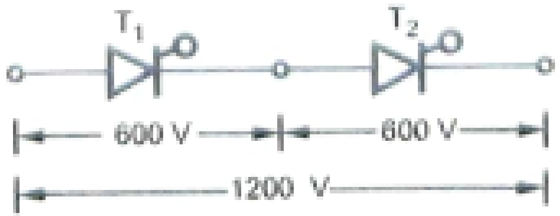
Fig (a)Two different symbols used for diac



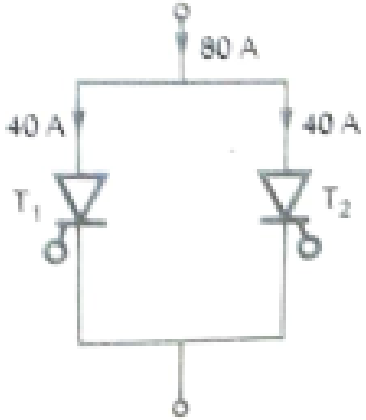
Fig(b) V-I characteristic of diac

Series and Parallel Operation of Thyristors:

Necessity of Series and Parallel Operation:



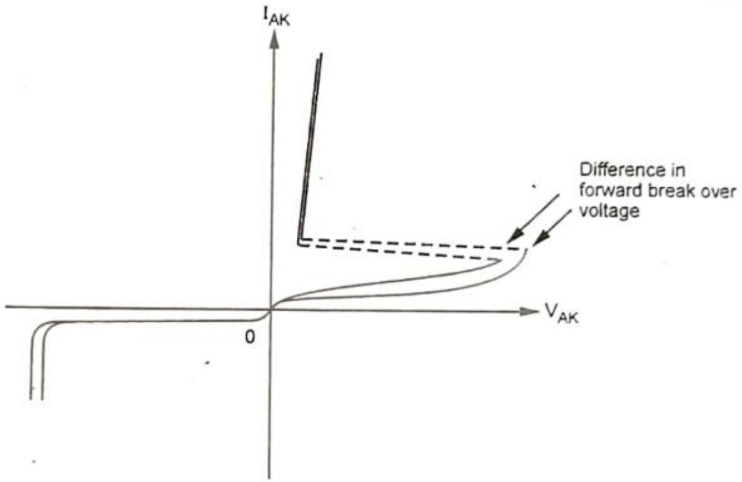
(a) Series connection



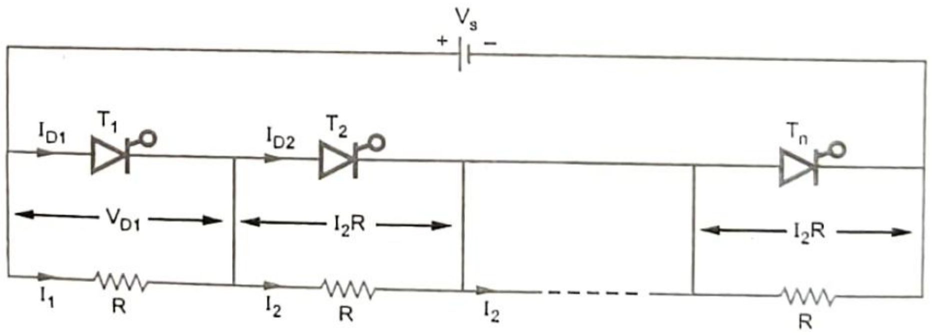
(b) Parallel connection

Series Connection of Thyristors:

Problems Encountered in Series Connection:



Equalizing Components:



$$V_s = V_{D_1} + (n-1)(I_1 - \Delta I_D)R = V_{D_1} + nI_1R - n\Delta I_D R - I_1R + \Delta I_D R$$

$$= V_{D_1} + nV_{D_1} - V_{D_1} - (n-1)\Delta I_D R = nV_{D_1} - (n-1)\Delta I_D R$$

$$V_{D_1} = \frac{V_s + (n-1)\Delta I_D R}{n} \quad \text{.......(2)}$$

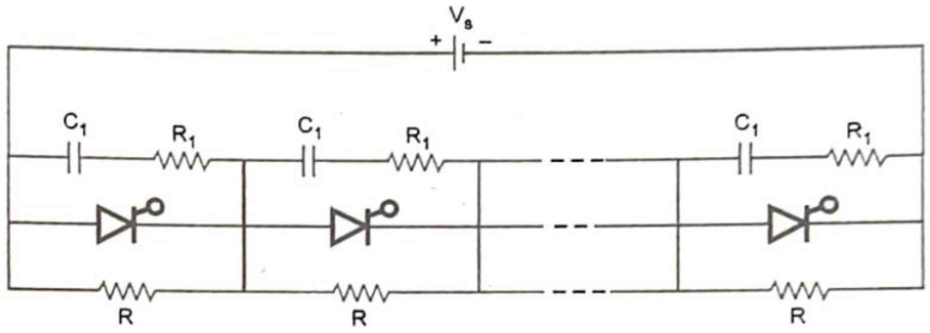
$$I_{D_1} + I_1 = I_{D_2} + I_2$$

$$I_2 = I_1 - I_{D_1} - I_{D_2} = I_1 - \Delta I_D \quad \text{..............(1)}$$

$$R = \frac{nV_{D_1} - V_s}{(n-1)\Delta I_D} \quad \text{......(3)}$$

$$V_s = I_1 R + I_2 R(n-1) = V_{D_1} + (n-1) I_2 R$$

Dynamic Equalization Circuit:



$$V = \frac{Q}{C}$$

$$\Delta V = \frac{\Delta Q}{C}$$

$$V_{D1} = \frac{V_s + (n-1)\Delta I_D R}{n}$$

$$V_{D1} = \frac{V_s + (n-1)\Delta V}{n}$$

Since $\Delta V = \frac{\Delta Q}{C_1}$,

$$V_{D1} = \frac{V_s + (n-1)\Delta Q / C_1}{n} \quad \text{........(1)}$$

$$C_1 = \frac{(n-1)\Delta Q}{nV_{D1} - V_s} \quad \text{.....(2)}$$

$$\%\,D = \left[1 - \frac{V_s}{nV_{D1}}\right] \times 100$$

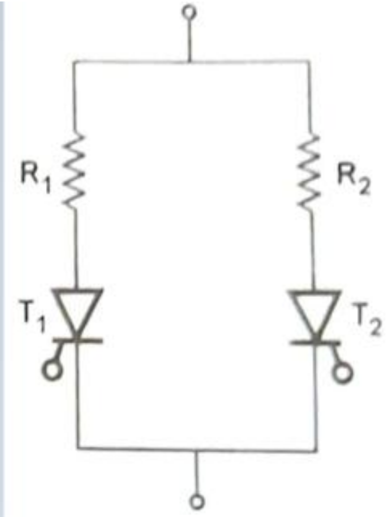
$$\%\eta = (1-D) \times 100$$

$$= \frac{V_s}{\eta V_{D1}} \times 100$$

Parallel Connection of Thyristors:

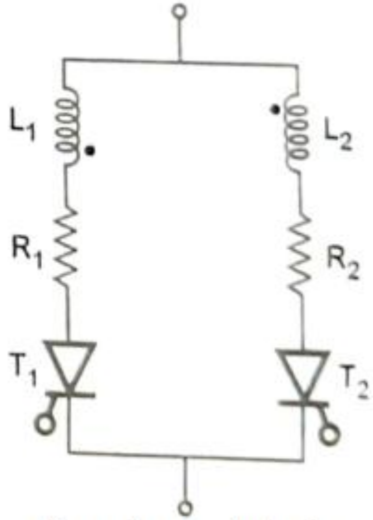
Equalizing Arrangements:

Static Current Sharing:



Static current sharing

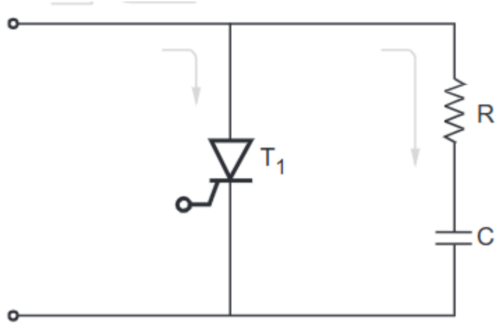
Dynamic Current Sharing:



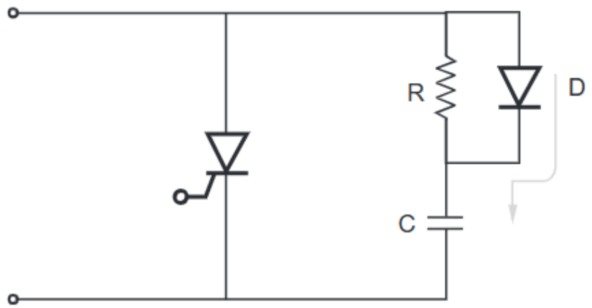
Dynamic current sharing

di/dt and dv/dt Protection:

Snubber for Protection Against dv/dt and Over Voltages:



A snubber (RC) network is used for transient voltage protection



Snubber is used for dv/dt protection

The value of capacitor is given as,

$$C = \frac{1}{2L}\left(\frac{0.564\ V_m}{\frac{dv}{dt}}\right)^2 \quad ......(1)$$

Here V_m is the peak value of supply voltage

$\frac{dv}{dt}$ is the permissible $\frac{dv}{dt}$.

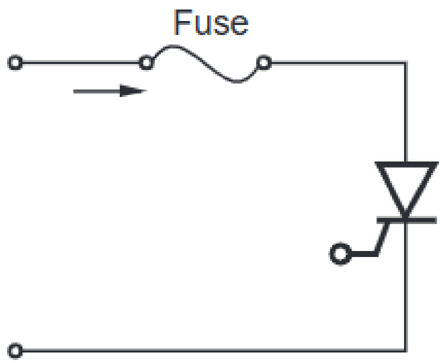
L is the source inductance.

And resistance is given as,

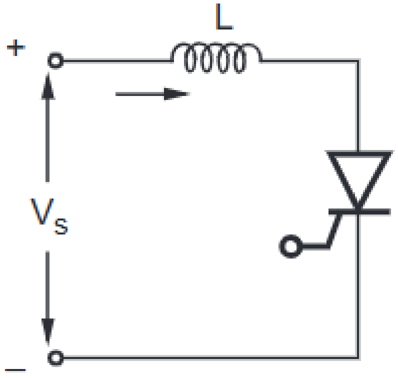
$$R = 2\sigma\sqrt{\frac{L}{C}} \quad ....(2)$$

Here σ is the damping factor. It's value is normally taken as 0.65.

Overcurrent Protection:



Fast acting fuse is used to protect thyristor against overcurrent

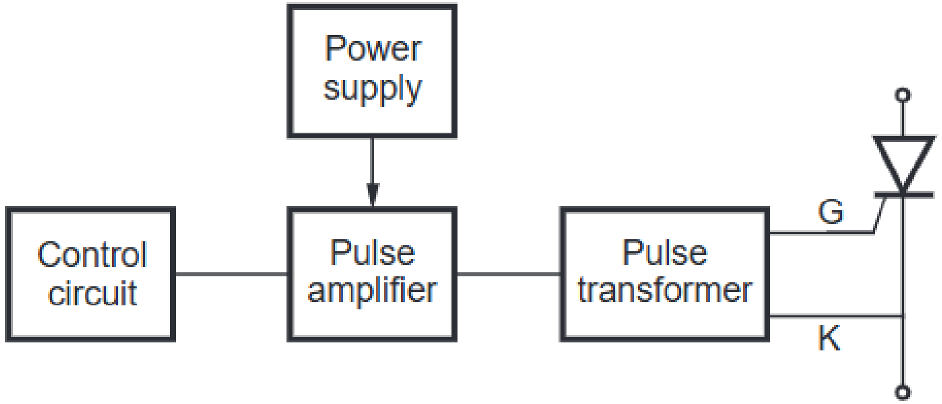


An inductance in series with the thyristor provides protection against di/dt

Firing Circuits:

1. Forward break over voltage
2. dv/dt triggering
3. Exceeding internal device temperature
4. Focusing light beam on the junction
5. Gate triggering.

Features of Firing Circuits: The triggering circuits are called firing circuits. The following features must be fulfilled by the firing circuit.



Main blocks of firing circuit

R-Firing Circuit:

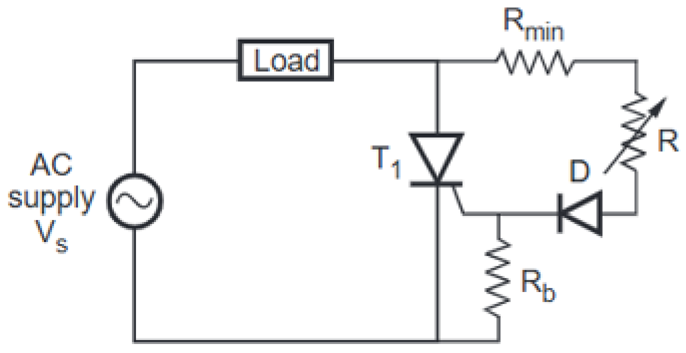


Fig. 1 R-firing circuit

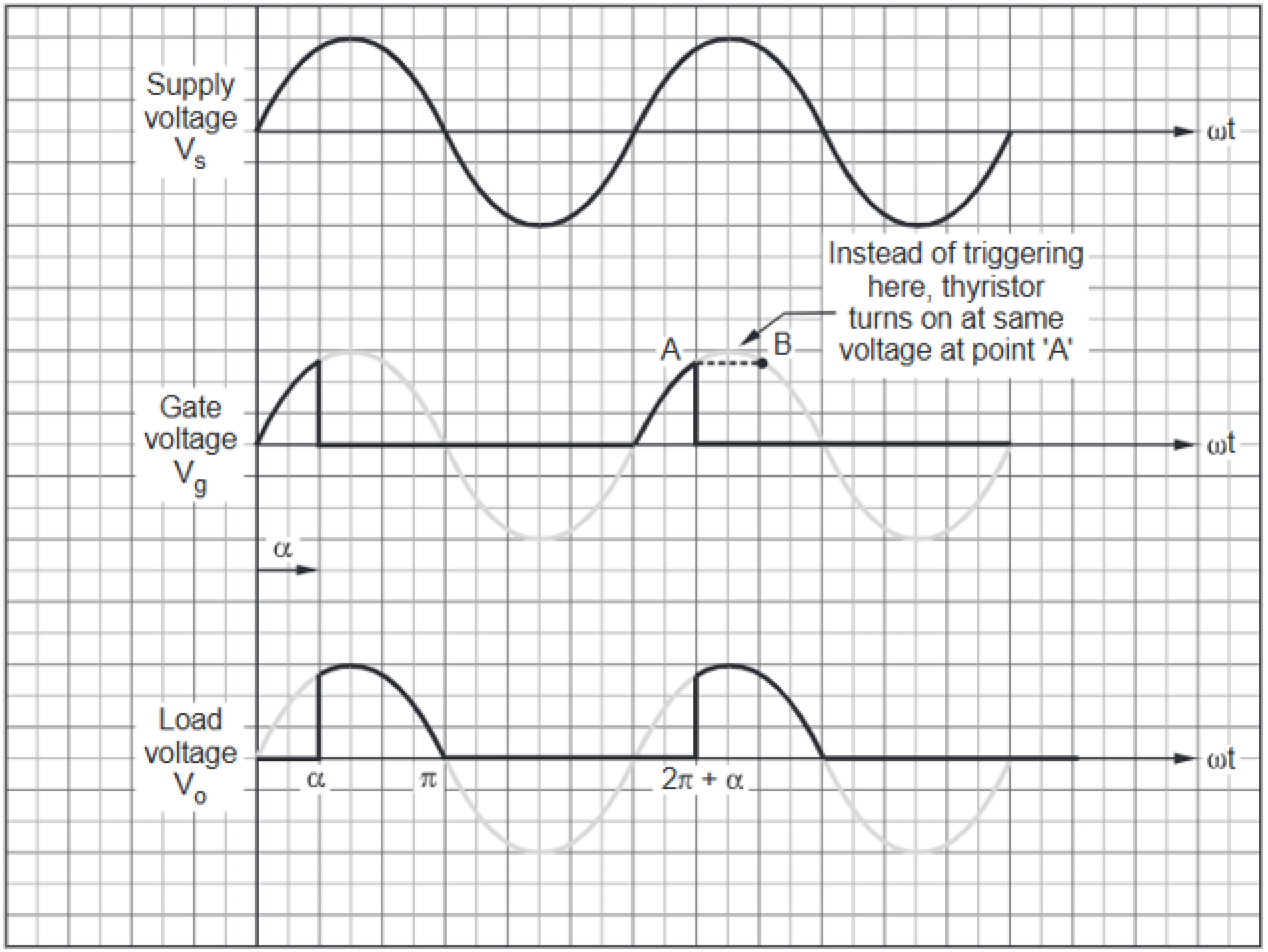


Fig. 2 Waveforms of R-firing circuit

RC Firing Circuit:

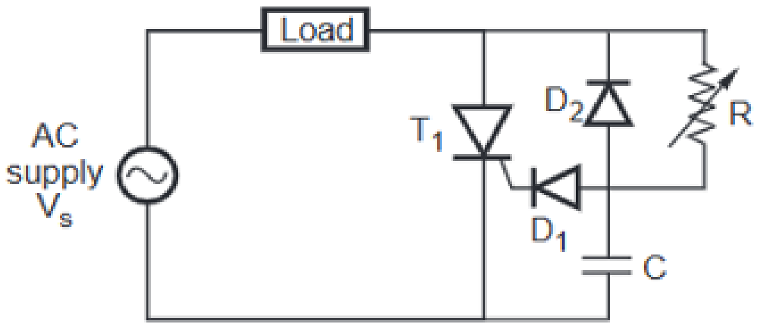


Fig. 1 RC half wave firing circuit

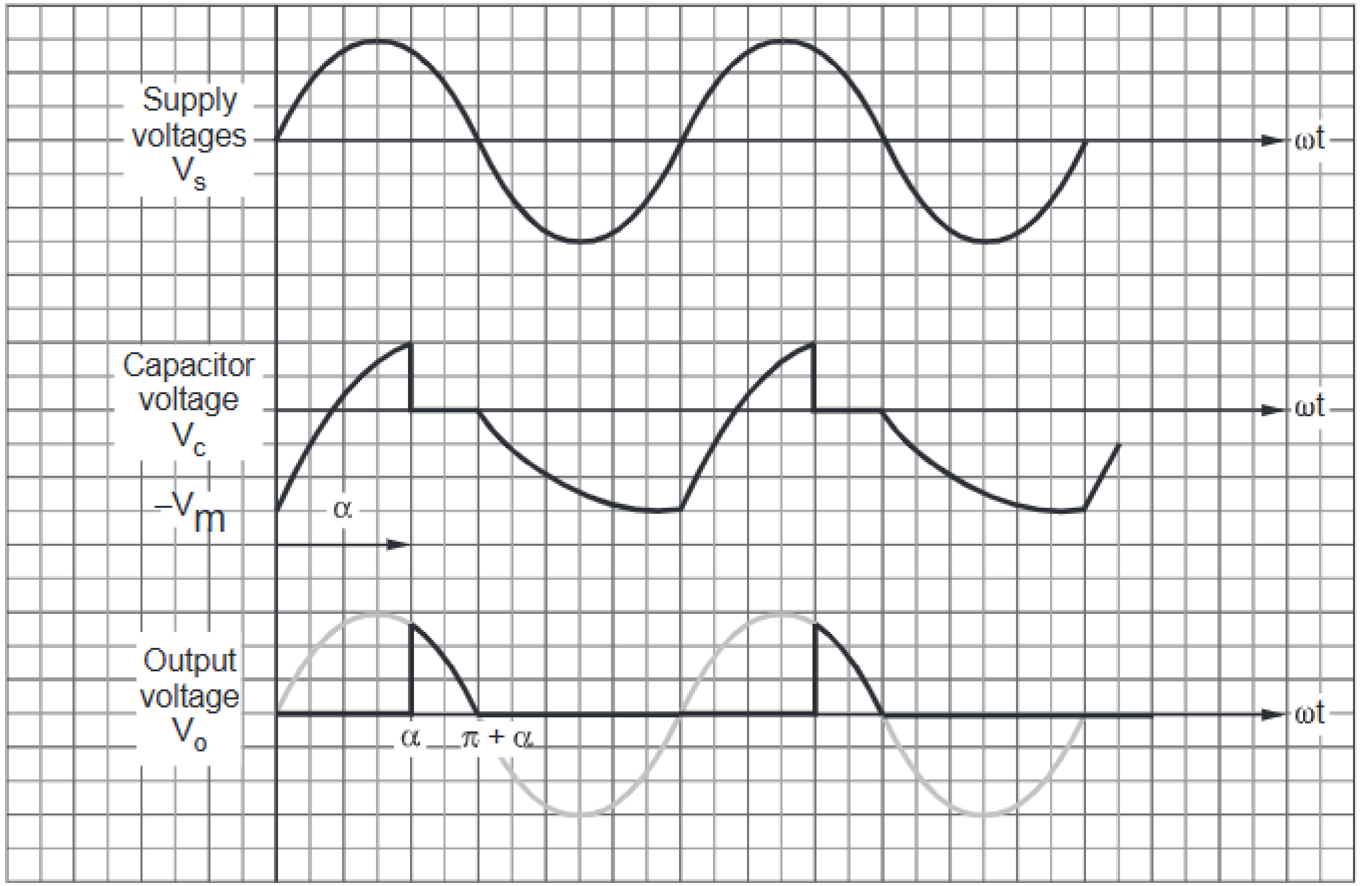


Fig. 2 Waveforms of half wave RC firing circuit

Full Wave RC-Firing Circuit:

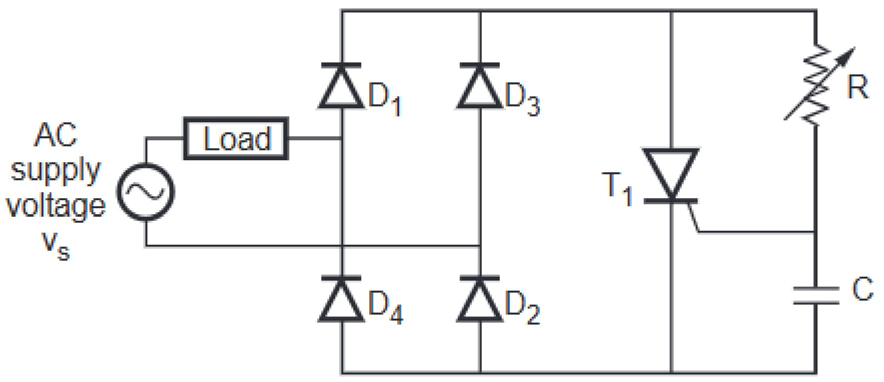


Fig. 1 Full wave RC firing circuit

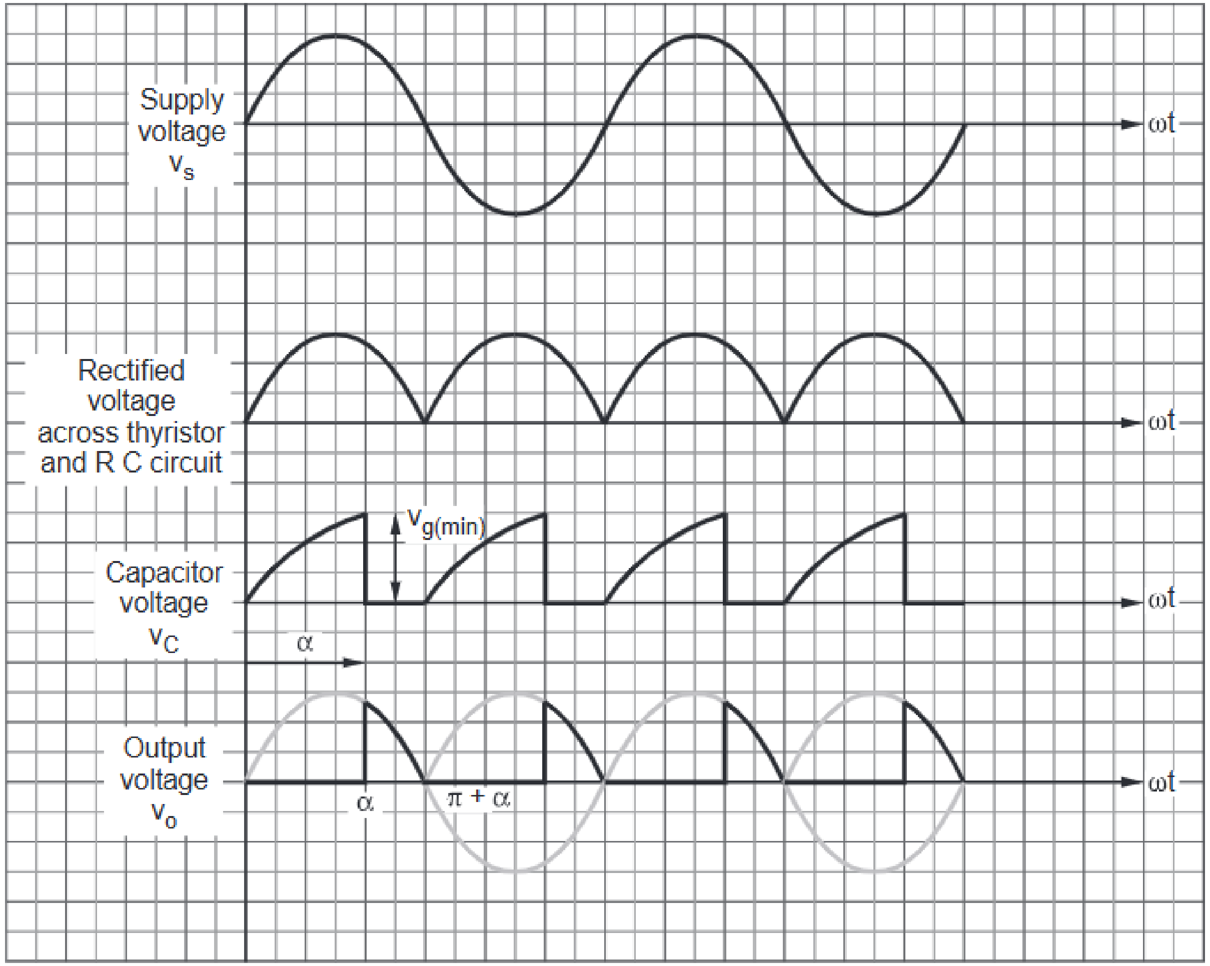


Fig.2 Waveforms of full wave RC firing circuit

UJT Triggering Circuit:

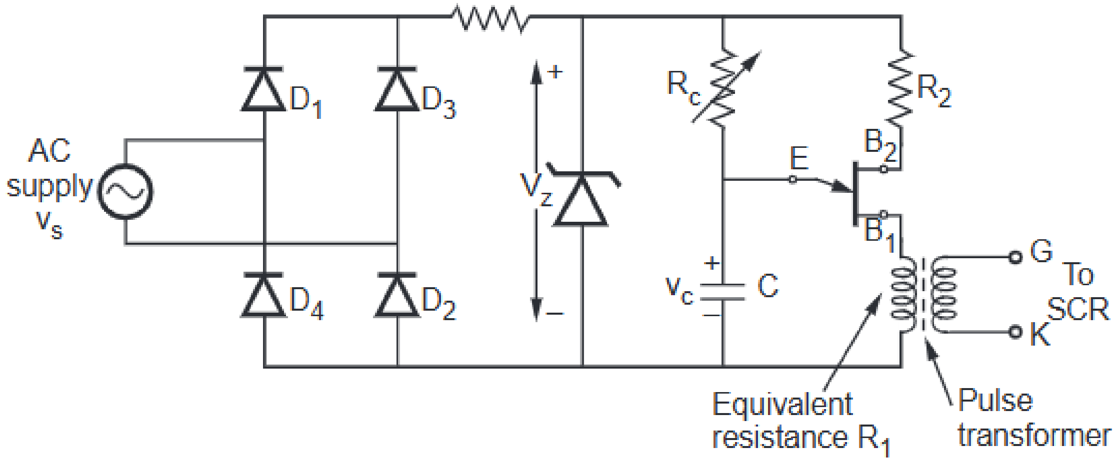


Fig. 1 UJT triggering circuit

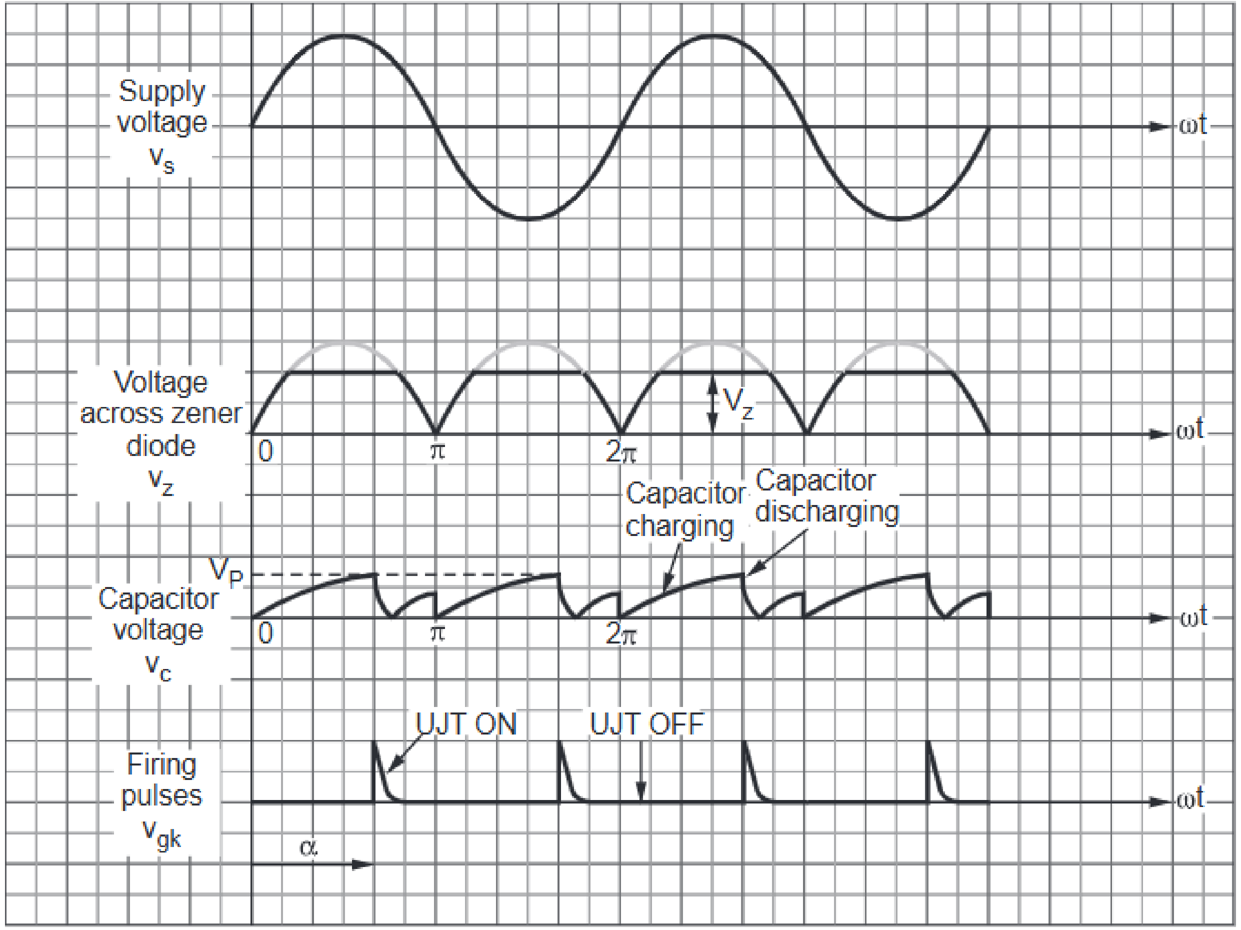


Fig. 2 Waveforms of UJT triggering circuit


thank
you