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Power Electronics

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UNIT- I

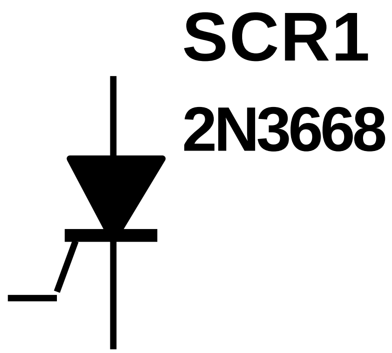
Power Switching Devices:

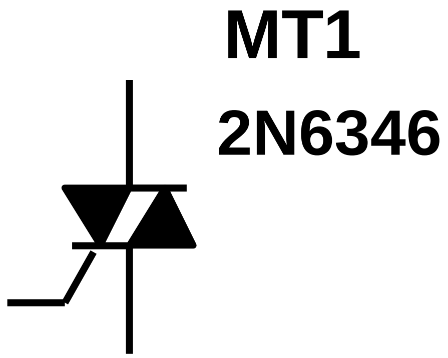
Concept of power electronics, scope and applications, types of power converters; Power semiconductor switches and their V-I characteristics - Power Diodes, Power BJT, SCR, Power MOSFET, Power IGBT; Thyristor ratings and protection, Series and parallel connections of SCRs, Two transistor analogy of SCR, methods of SCR commutation, UJT as a trigger source, gate drive circuits for BJT and MOSFETs.

Power Switching Devices

- Diodes
- Transistors
  - Power BJTs
  - Power MOSFETs
  - Insulated-Gate BJT
    - IGBT
  - Static Induction Transistors
    - SITs
- Thyristors
  - Force-Commutated
  - Line-Commutated
  - Gate Turn Off--GTO
  - Reverse-Conducting
    - RCT
  - Gate-Assisted Turn-off
    - GATI

Thyristor/Triac



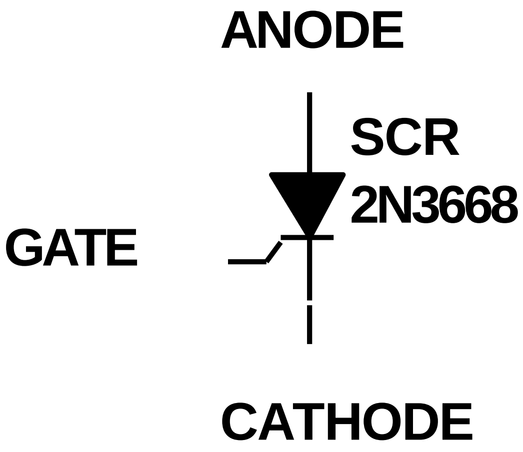


Power Electronic Circuits

- Diode Rectifiers (AC to Fixed DC)
- AC-DC Converters (Controlled Rectifiers)
- AC-AC Converters (AC Voltage Controllers)
- DC-DC Converters (DC Choppers)
- DC-AC Converters (Inverters)
- Static Switches

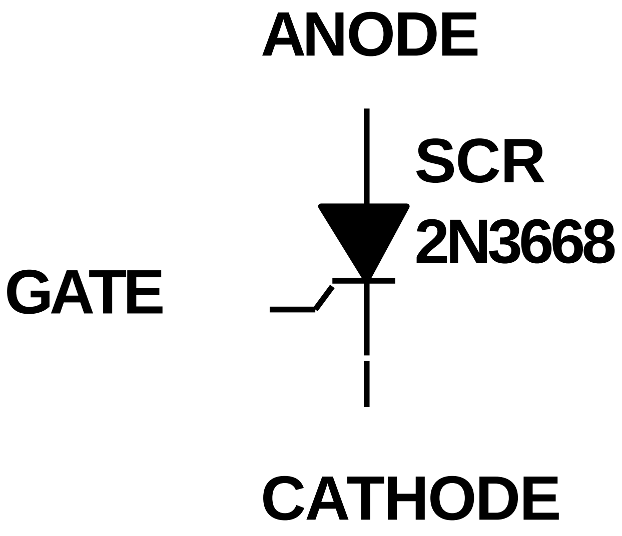
SCR / Thyristor

- Circuit Symbol and Terminal Identification



SCR / Thyristor

- Anode and Cathode terminals as conventional pn junction diode
- Gate terminal for a controlling input signal



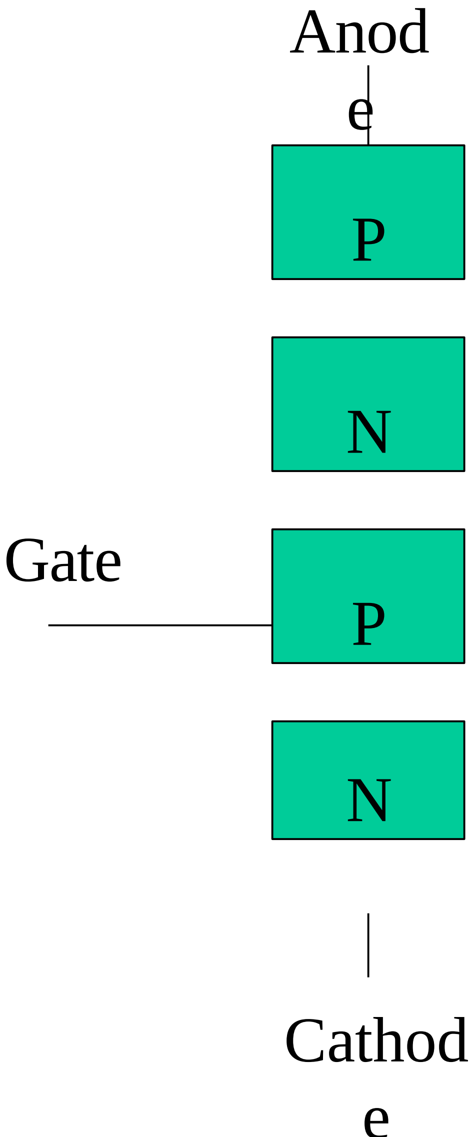
SCR/ Thyristor

- An SCR (Thyristor) is a “controlled” rectifier (diode)
- Control the conduction under forward bias by applying a current into the Gate terminal
- Under reverse bias, looks like conventional pn junction diode

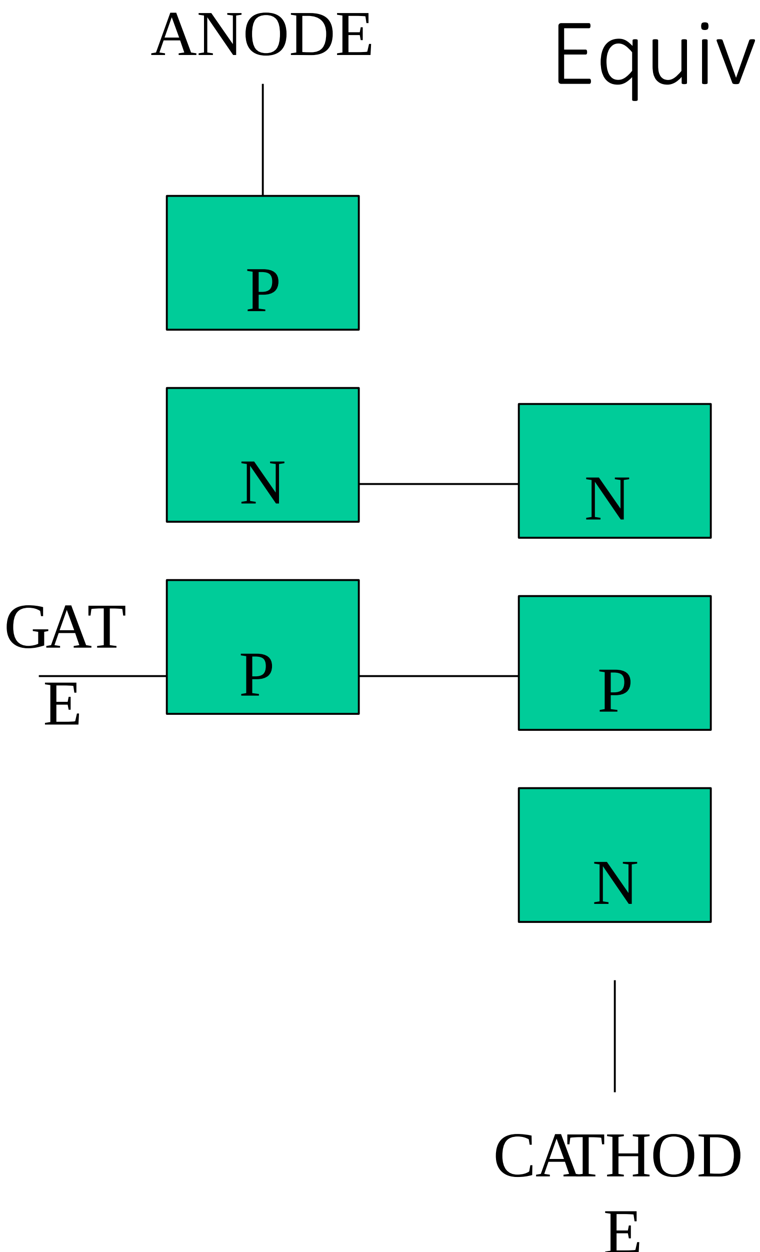
SCR / Thyristor

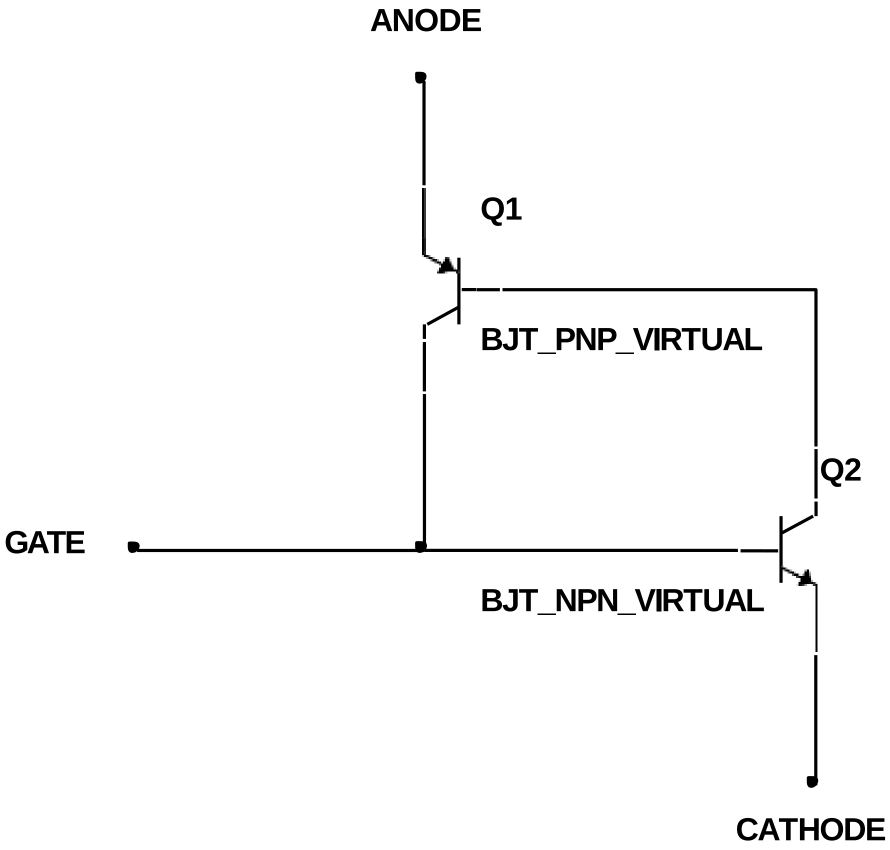
- 4-layer (pnpn) device
- Anode, Cathode as for a conventional pn junction diode

- Cathode Gate brought out for controlling input



Equivalent Circuit

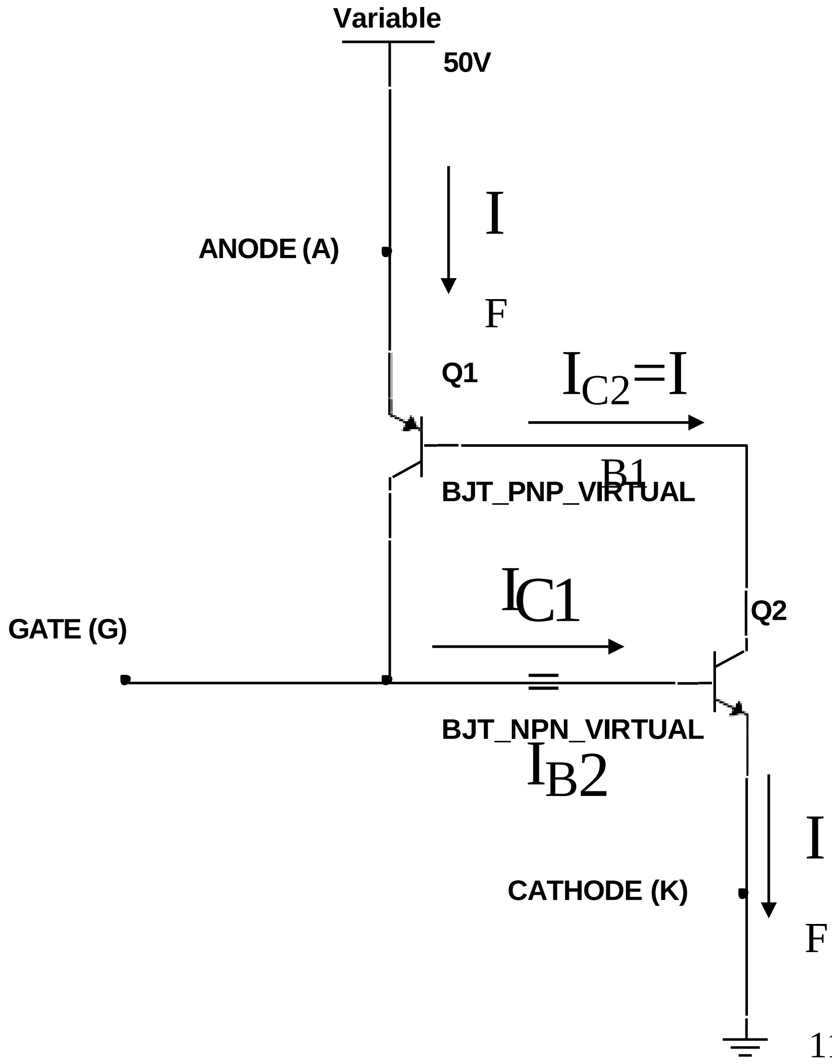




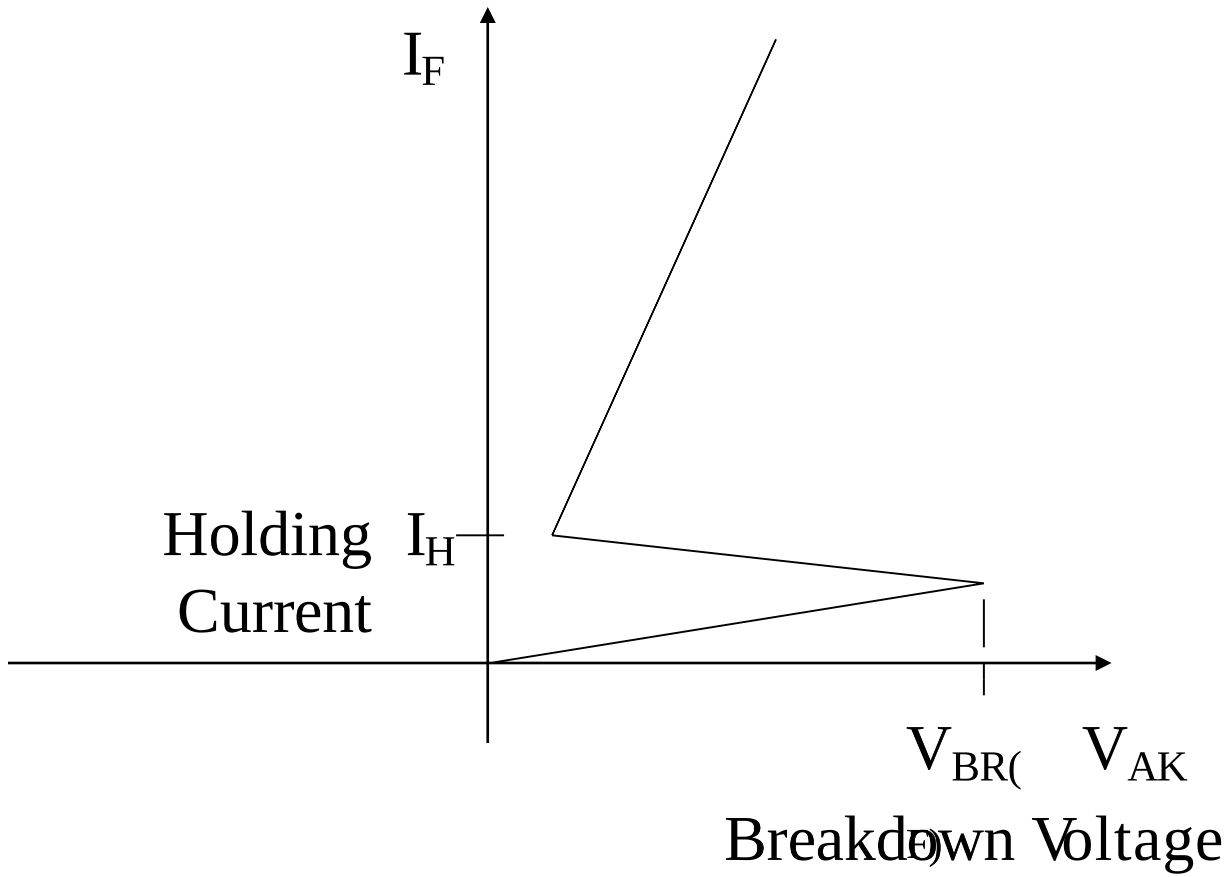
Apply Biasing

With the Gate terminal OPEN, both transistors are OFF. As the applied voltage increases, there will be a "breakdown" that causes both transistors to conduct (saturate) making $I_F > 0$ and $V_{AK} = 0$.

$V_{Breakdown} = V_{BR(F)}$



Volt-Ampere Characteristic



Apply a Gate Current

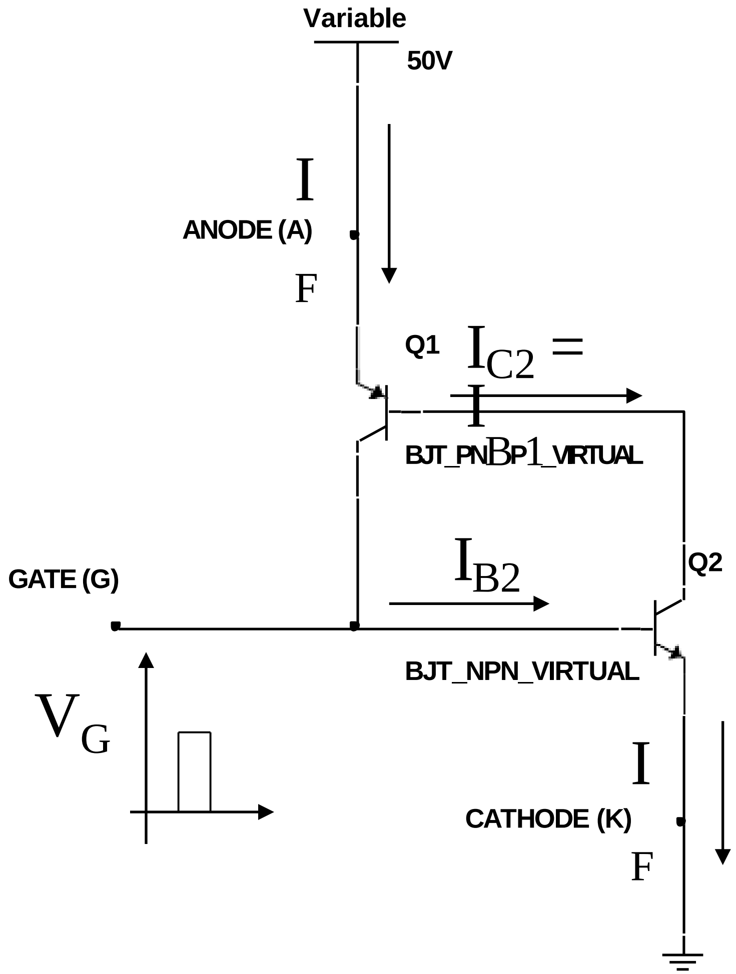
For $0 < V_{AK} < V_{BR(F)}$,

Turn Q_2 ON by applying a current into the Gate

This causes Q_1 to turn ON, and eventually both transistors SATURATE

$V_{AK} = V_{CEsat} + V_{BEsat}$

If the Gate pulse is removed, Q_1 and Q_2 still stay ON!

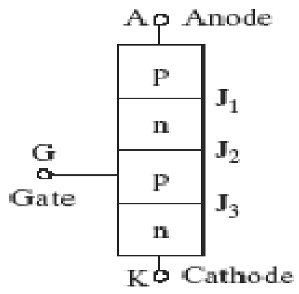


How do you turn it OFF?

- Cause the forward current to fall below the value if the “holding” current, I_H

- Reverse bias the device

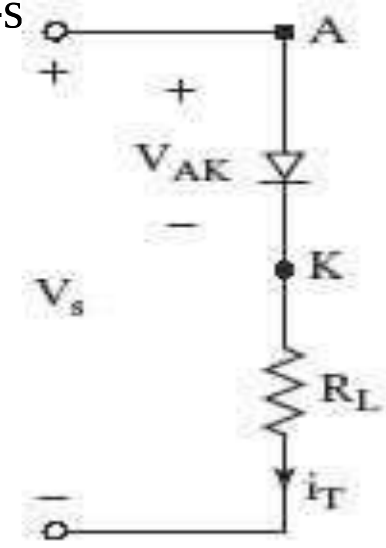
Characteristics of thyristors

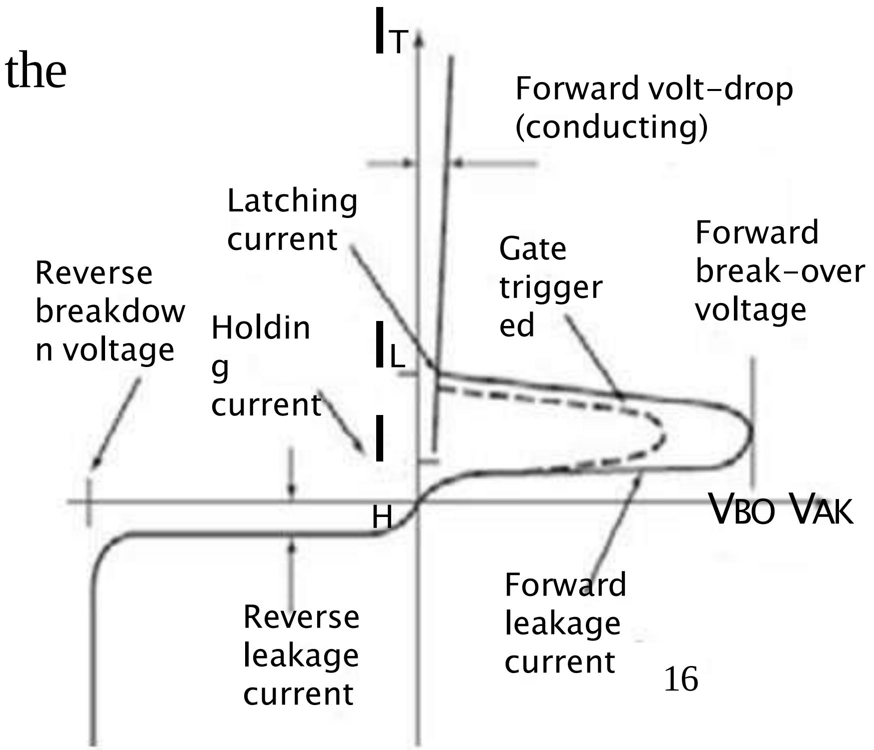


- When the anode is at a positive potential V_{AK} with respect to the cathode with no voltage applied at the gate, junctions J_1 and J_3 are forward biased, while junction J_2 is reverse biased. As J_2 is reverse biased, no conduction takes place.
- Now if V_{AK} is increased beyond the breakdown voltage V_{BO} of the thyristor, avalanche breakdown of J_2 takes place and the thyristor starts conducting.
- If a positive potential V_G is applied at the gate terminal with respect to the cathode, the breakdown of the junction J_2 occurs at a lower value of V_{AK}. By selecting an appropriate value of V_G, the thyristor can be switched into the on state suddenly.

Switching Characteristic (IV)

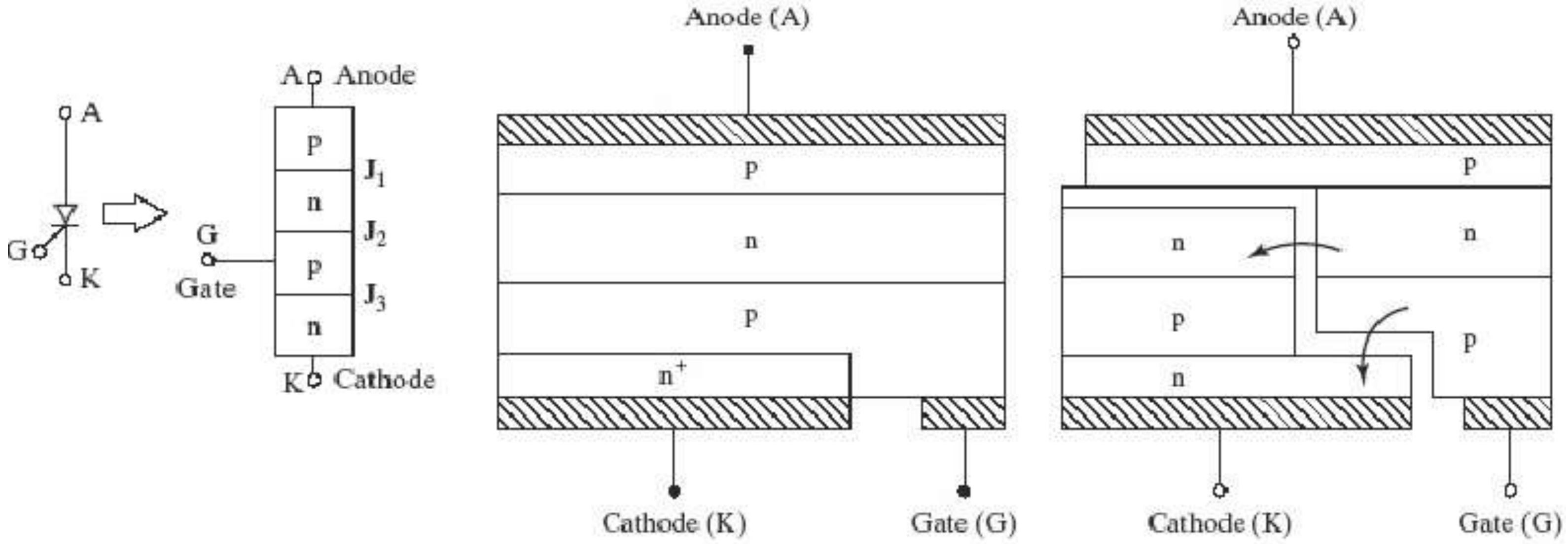
- Forward breakdown voltage V_{BO}
  - The voltage of avalanche breakdown
- Latching current I_L
  - The minimum anode current required to maintain the thyristor in the on-state immediately after it is turned on and the gate signal has been removed
- Holding current I_H
  - The minimum anode current to maintain the thyristor in the on-s
- $I_L > I_H$





Symbol and construction

The thyristor is a four-layer, three terminal semiconducting device, with each layer consisting of alternately N-type or P-type material, for example P-N-P-N. The main terminals, labeled anode and cathode, are across the full four layers, and the control terminal, called the gate, is attached to p-type material near to the cathode.

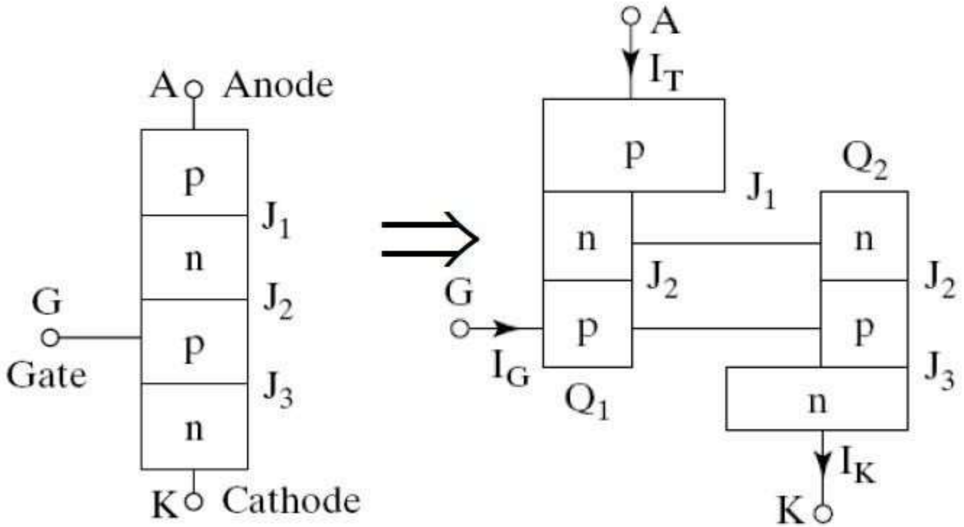


Cross section of *pnpn* structure

Split sections of *npn* and *pnp*

Different types of Thyristors

- Silicon Controlled Rectifier (SCR).
- TRIAC.
- DIAC.
- Silicon Unilateral
  in low voltage av



Construction of

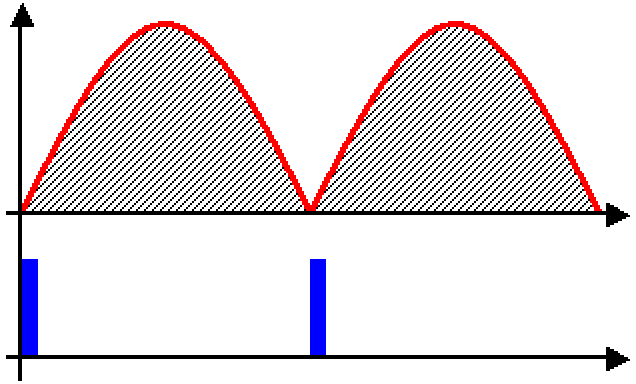
Application

- Mainly used where high currents and voltages are involved, and are often used to control alternating currents, where the change of polarity of the current causes the device to switch off automatically; referred to as Zero Cross operation.

- Thyristors can be used as the control elements for phase angle triggered controllers, also known as phase fired controllers.

Cntd…

- In power supplies for digital circuits, thyristor can be used as a sort of "circuit breaker" or "crowbar" to prevent a failure in the power supply from damaging downstream components, by shorting the power supply output to ground



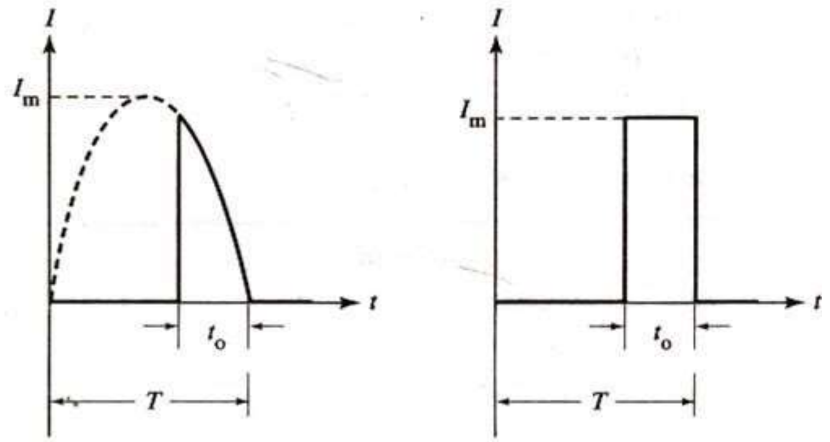
Load voltage regulated by thyristor phase control.
Red trace: load voltage
Blue trace: trigger signal.

SCR Ratings

(a) SCR Current Ratings

1 Maximum Repetitive RMS current Rating

- Average on-state current is the maximum average current value that can be carried by the SCR in its on state.
- RMS value of nonsinusoidal waveform is simplified by approximating it by rectangular waveform.
- This approximation give higher RMS value, but leaves slight safety factor.



After approximating, the RMS value of the current can be found from

$$I_{RMS} = \sqrt{\frac{I_m{}^2 t_o}{T}}$$

- Average value of pulse is

$$I_{AVE} = \frac{I_m t_o}{T}$$

- Form factor is

$$f_o = \frac{I_{RMS}}{I_{AVE}}$$

- Knowing the form factor for given waveform, RMS current can be obtained from

$$I_{RMS} = fo(I_{AVE})$$

- Maximum repetitive RMS current is given by

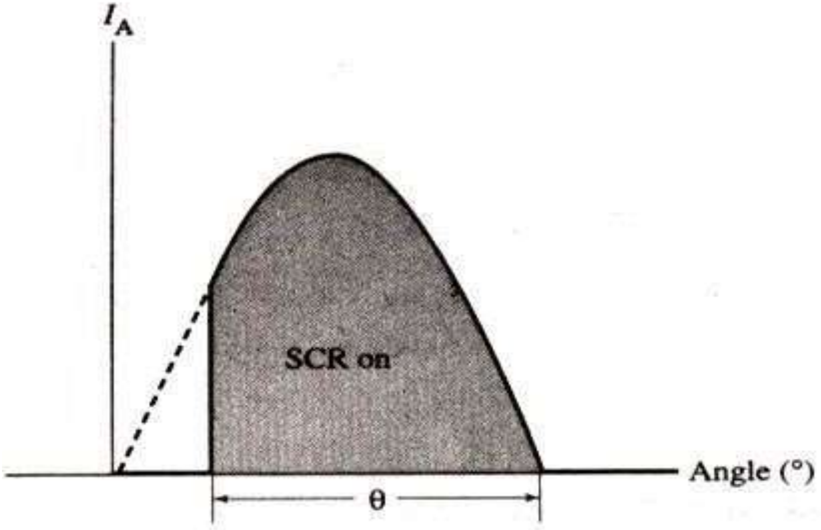
$$I_{T(RMS)} = fo(I_{T(AVE)})$$

- Conduction angle verses form factor

Conduction angle (θ)	Form factor (*f*o)
20°	5.0
40°	3.5
60°	2.7
80°	2.3
100°	2.0
120°	1.8
140°	1.6
160°	1.4
180°	1.3

Conduction Angle

- *Duration for which SCR is on*. It is measured as shown



2- *Surge Current Rating*

Peak anode current that SCR can handle for brief duration.

3 *Latching current*

Minimum anode current that must flow through the SCR in order for it to stay on initially after gate signal is removed.

4 *Holding Current*

Minimum value of anode current, required to maintain SCR in conducting state.

(b) SCR Voltage Ratings

1. Peak repetitive forward blocking voltage

   Maximum instantaneous voltage that SCR can block in forward direction.

2. Peak Repetitive Reverse Voltage

   Maximum instantaneous voltage that SCR can withstand, without breakdown, in reverse direction.

3. Non-repetitive peak reverse voltage

   Maximum transient reverse voltage that SCR can withstand.

(c) SCR Rate-of-Change Ratings

1 (di/dt rating)

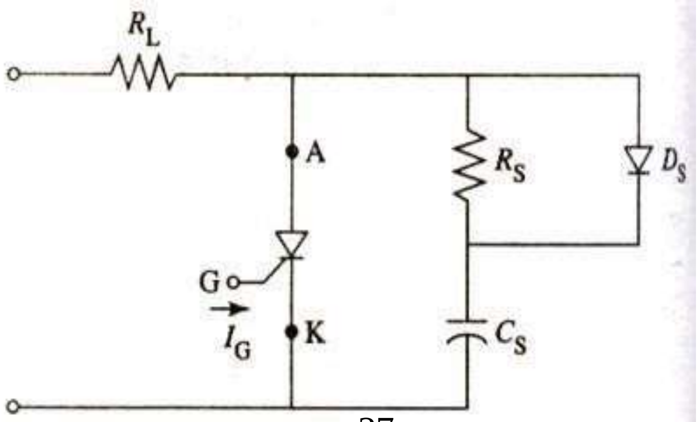
Critical rate of rise of on-state current. It is the rate at which anode current increases and must be less than rate at which conduction area increases.

To prevent damage to SCR by high di/dt value, small inductance is added in series with device. Vaue of required inductance is

$$L >= \frac{V_p}{(di/dt)_{max}}$$

2 dv/dt rating

Maximum rise time of a voltage pulse that can be applied to the SCR in the off state without causing it to fire. Unscheduled firing due to high value of dv/dt can be prevented by using RC snubber circuit.



(d) Gate Parameters

1 Maximum Gate Peak Inverse Voltage

Maximum value of negative DC voltage that can be applied without damaging the gate-cathode junction.

2 Maximum Gate Trigger Current

Maximum DC gate current allowed to turn on the device.

3 Maximum gate trigger voltage

DC voltage necessary to produce maximum gate trigger current.

4 Maximum Gate Power Dissipation

Maximum instantaneous product of gate current and gate voltage that can exist during forward-bias.

5 Minimum gate trigger voltage

Minimum DC gate-to-cathode voltage required to trigger the SCR.

6 Minimum gate trigger current

Minimum DC gate current necessary to turn SCR on.

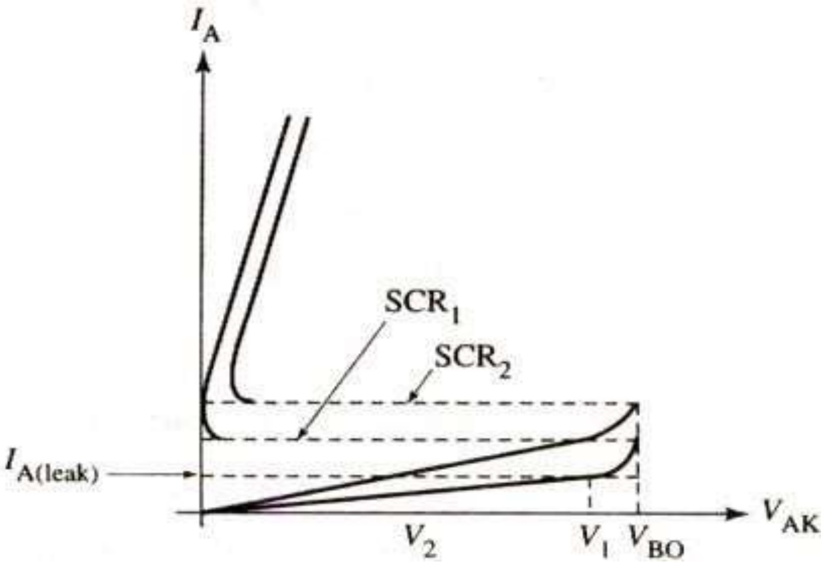
Series and Parallel SCR Connections

SCRs are connected in series and parallel to extend voltage and current ratings.

For high-voltage, high-current applications, series-parallel combinations of SCRs are used.

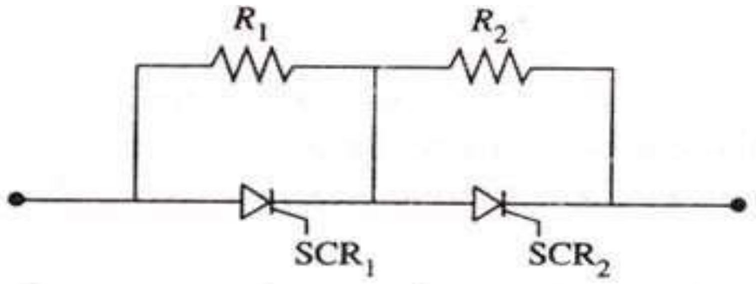
SCRs in Series

- Unequal distribution of voltage across two series SCRs.

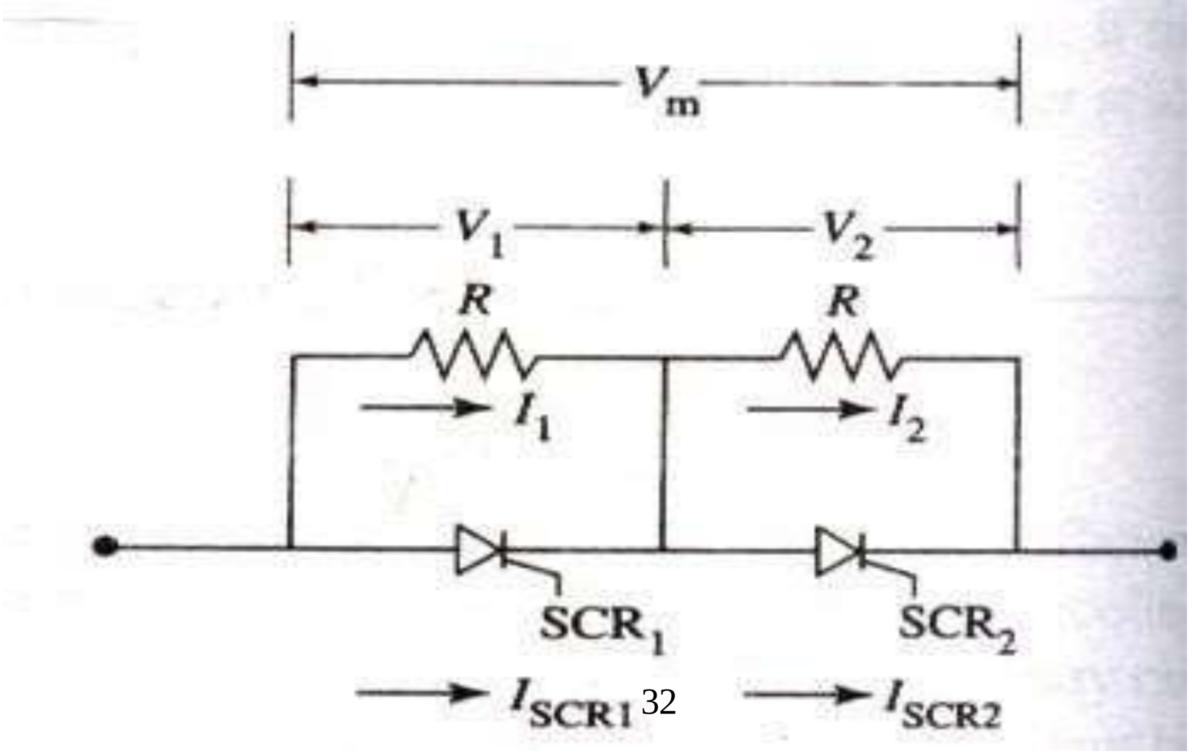


- Two SCRs do not share the same supply voltage. Maximum voltage that SCRs can block is V_1+V_2, not $2V_{BO}$.

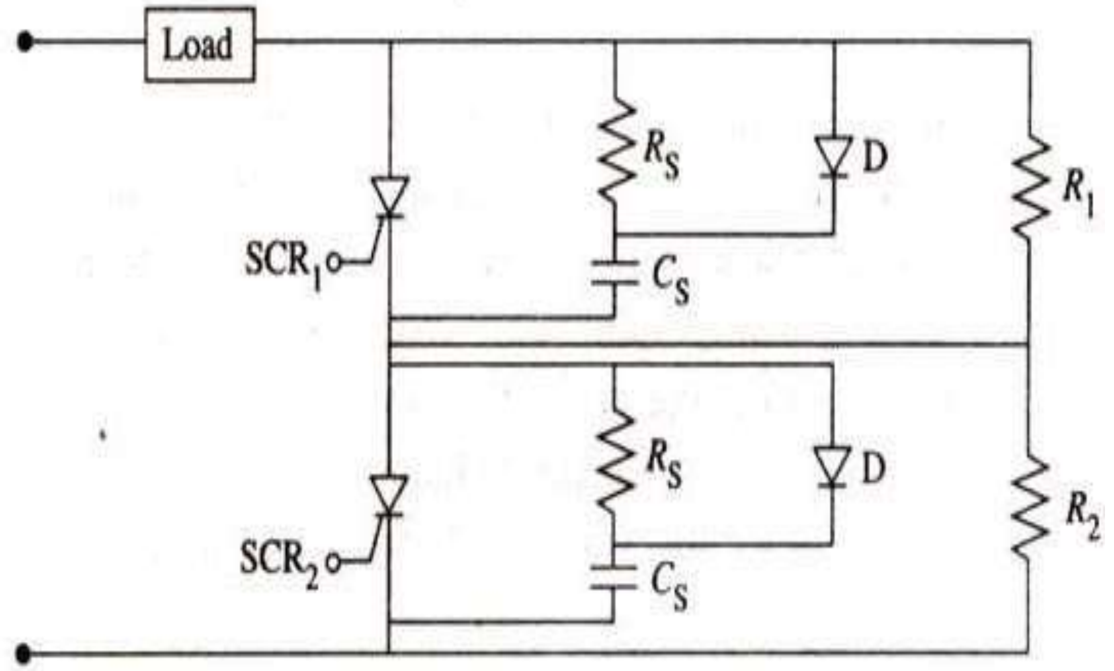
- **Resistance equalization**



- **Voltage equalization**

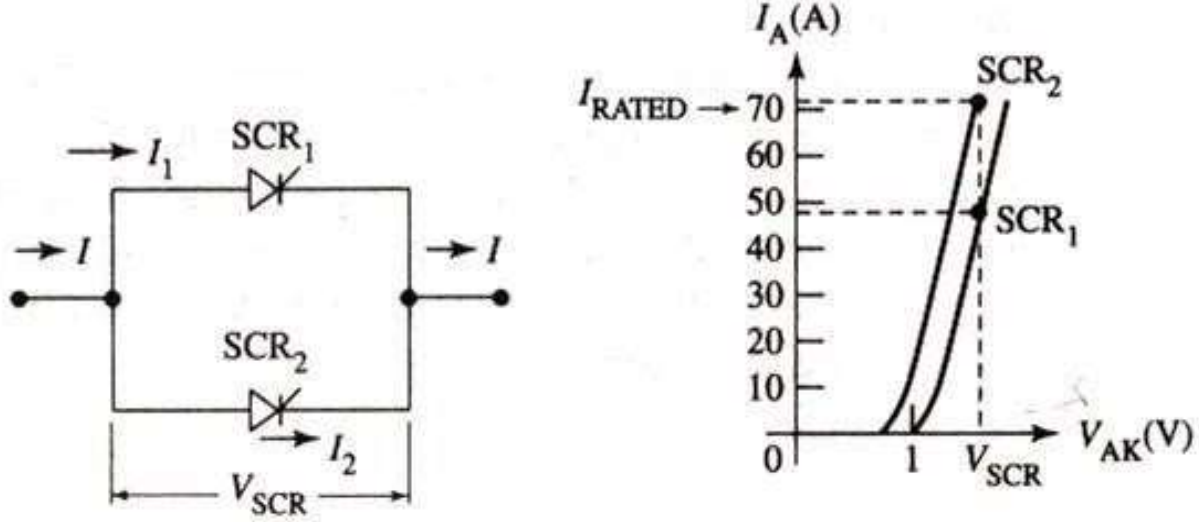


- **RC equalization for SCRs connected in series.**



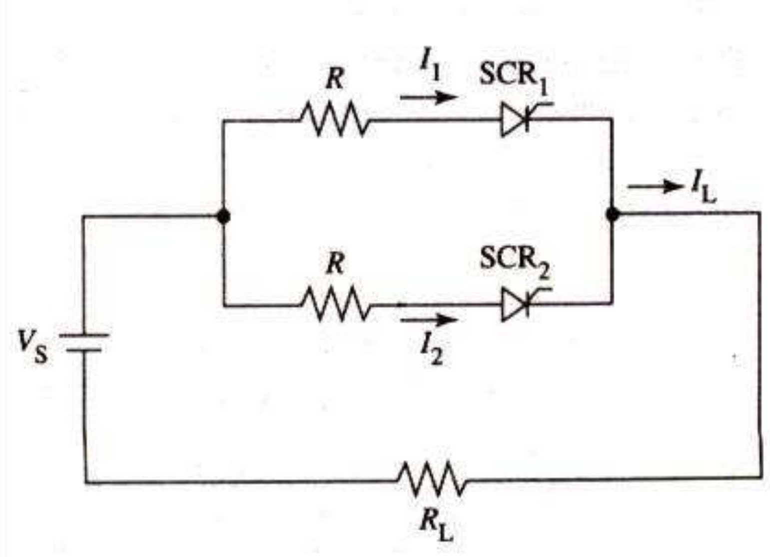
SCRs In Parallel

- Unequal current sharing between two SCRs is shown:



- Total rated current of parallel connection is I_1+I_2, not $2I_2$.

- With unmatched SCRs, equal current sharing is achieved by adding low value resistor or inductor in series with each SCR, as shown below.



- Value of resistance

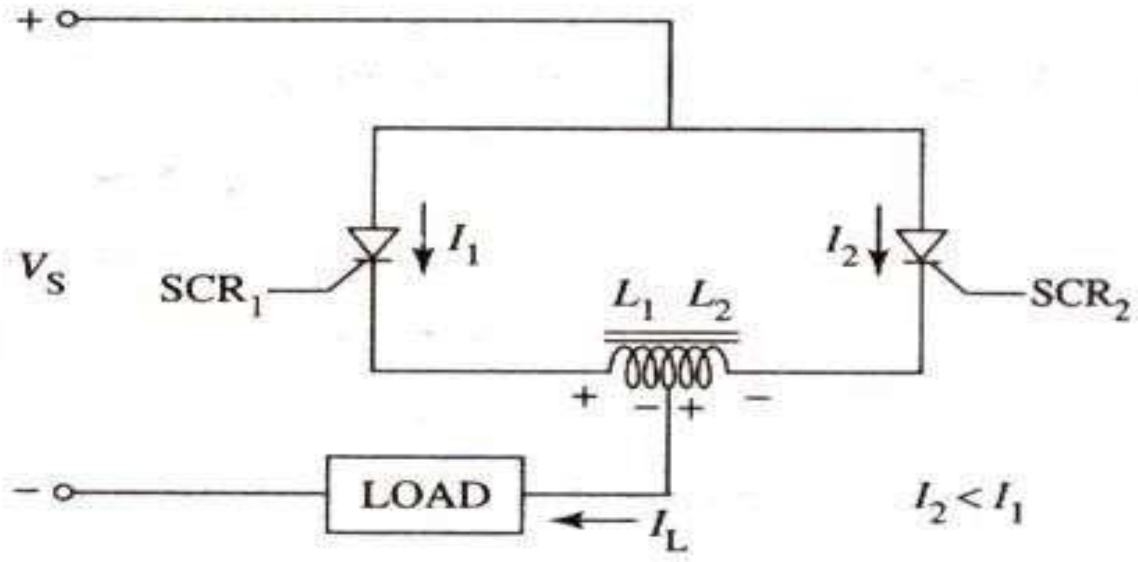
$$R = \frac{V_1 - V_2}{I_2 - I_1}$$

∘ Current sharing in SCRs with parallel reactors

Equalization using resistors is inefficient due to

- *Extra power loss*
- *Noncompansation for unequal SCR turn-on and turn-off times.*
- *Damage due to overloading*

SCRs with center-tapped reactors is shown below.



SCR Gate-Triggering Circuits

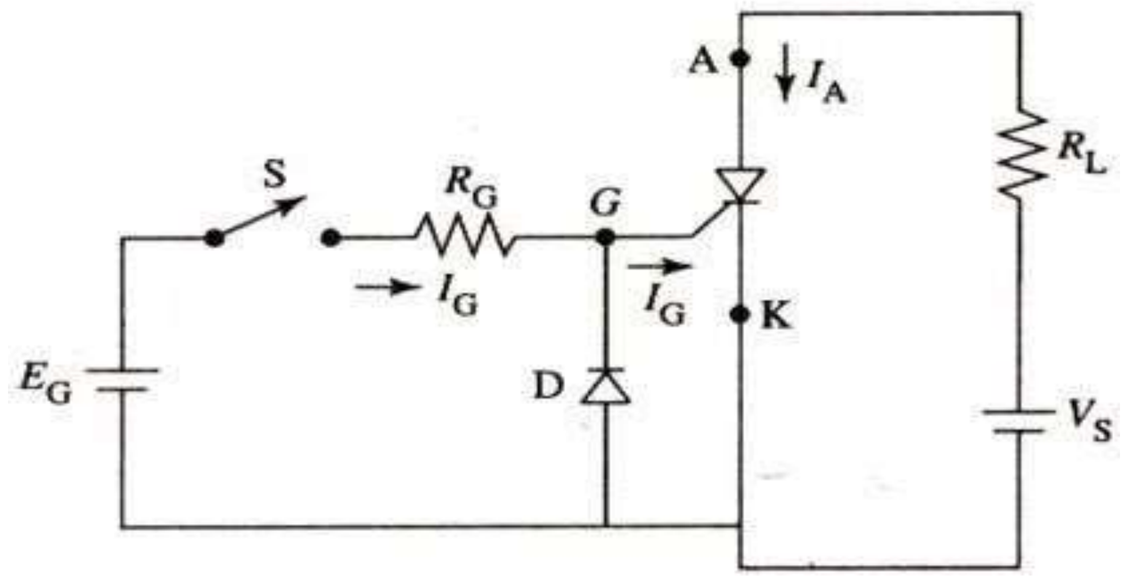
- Triggering circuits provide firing signal to turn on the SCR at precisely the correct time.
- Firing circuits must have following properties

1. Produce gate signal of suitable magnitude and sufficiently short rise time.
2. Produce gate signal of adequate duration.
3. Provide accurate firing control over the required range.
4. Ensure that triggering does not occur from false signals or noise
5. In AC applications, ensure that the gate signal is applied when the SCR is forward-biased
6. In three-phase circuits, provide gate pulses that are 120° apart with respect to the reference point
7. Ensure simultaneous triggering of SCRs connected in series or in parallel.

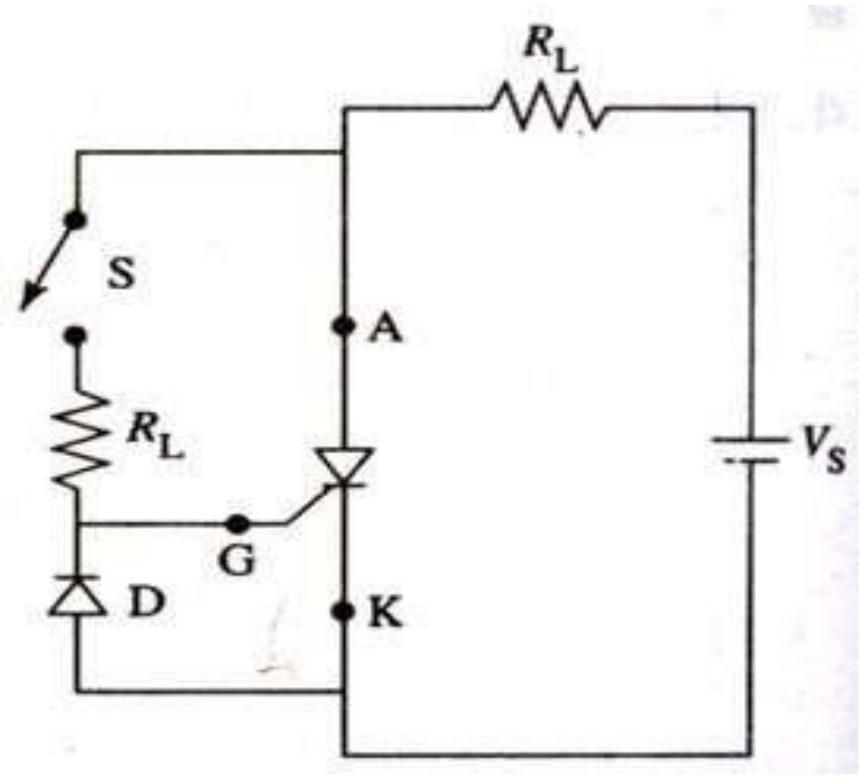
Types Of Gate Firing Signals

1. DC signals
2. Pulse signals
3. AC signals

(a) DC Gating Signal From Separate Source



DC Gating signals from Same Source



Disadvantage of DC gating Signals

1. Constant DC gate signal causes gate power dissipation

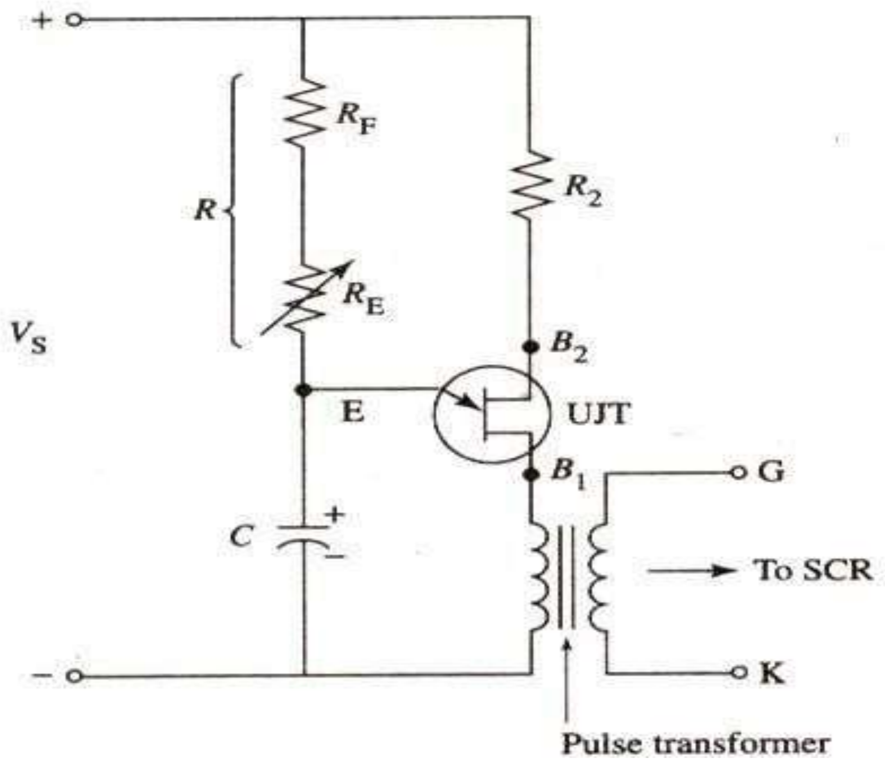
2. DC gate signals are not used for firing SCRs in AC applications, because presence of positive gate signal during negative half cycle would increase the reverse anode current and possibly destroy the device.

(2) Pulse Signals

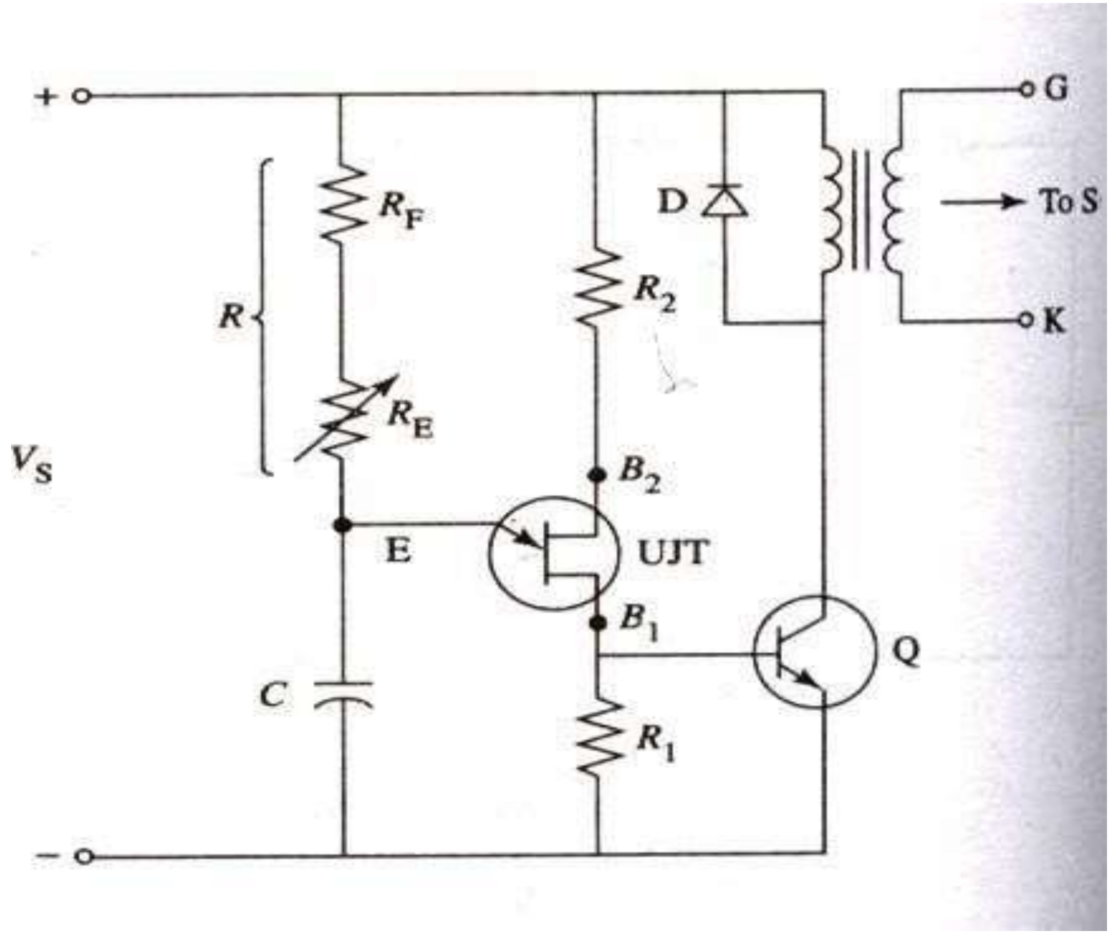
1. Instead of continuous DC signal, single pulse or train of pulses is generated.
2. It provides precise control of point at which SCR is fired.
3. It provides electrical isolation between SCR and gate-trigger circuit.

SCR trigger circuits using UJT oscillator

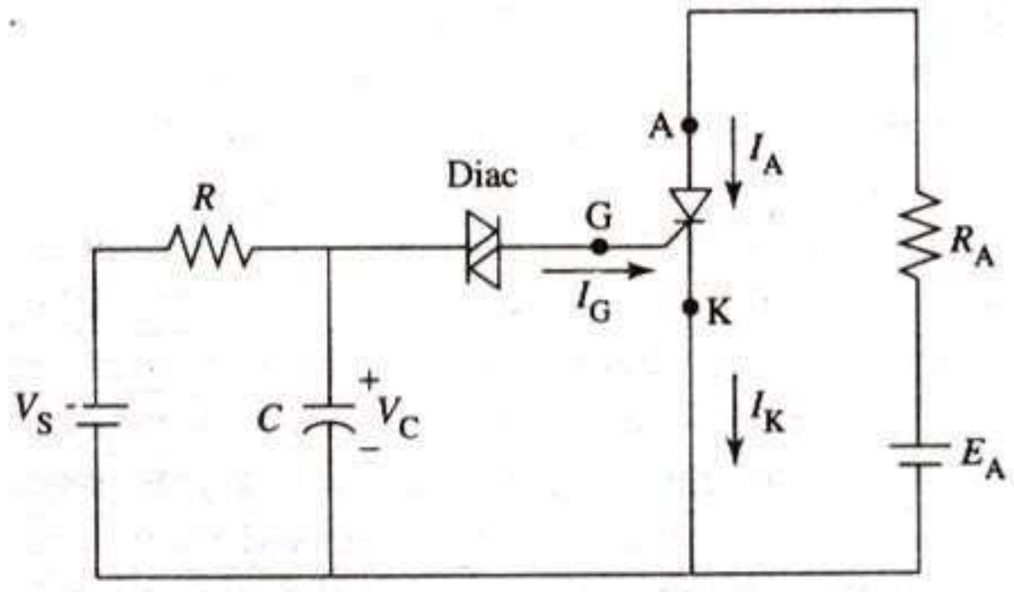
- Circuit A



Circuit B

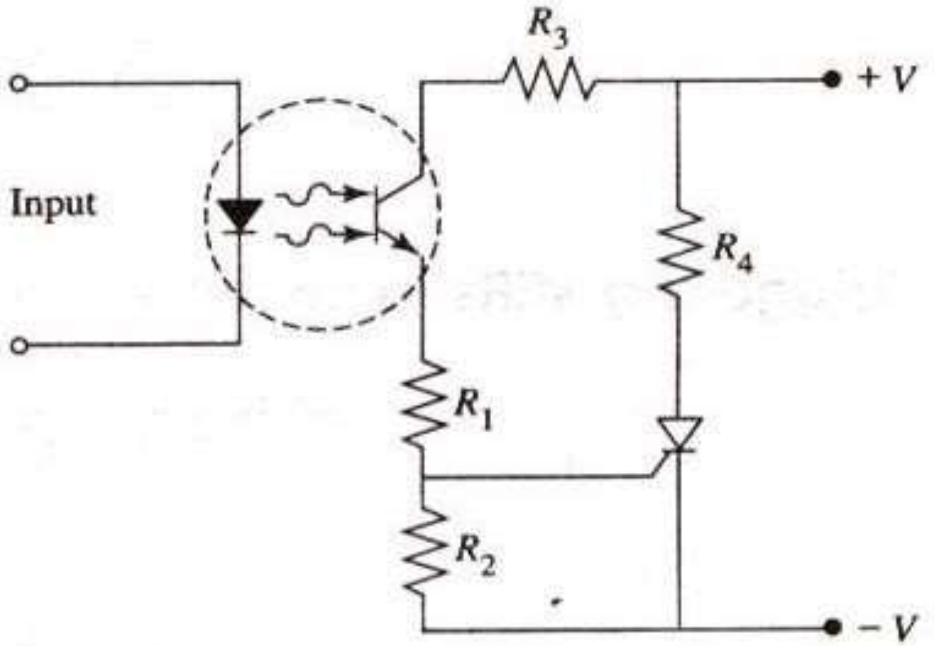


SCR trigger circuit using DIAC

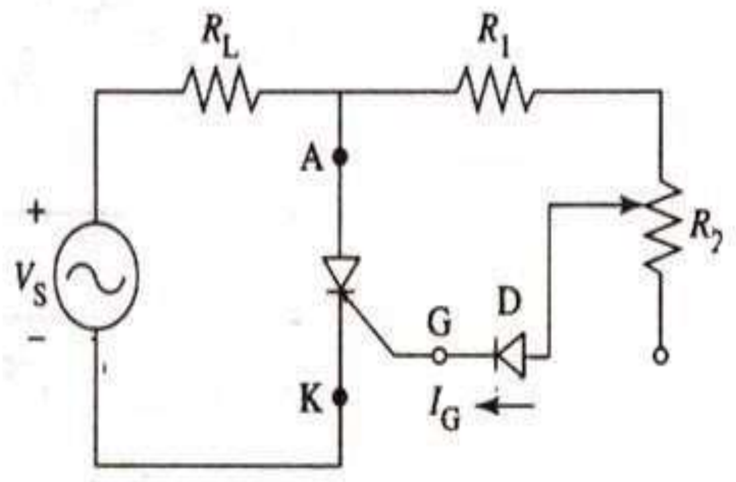


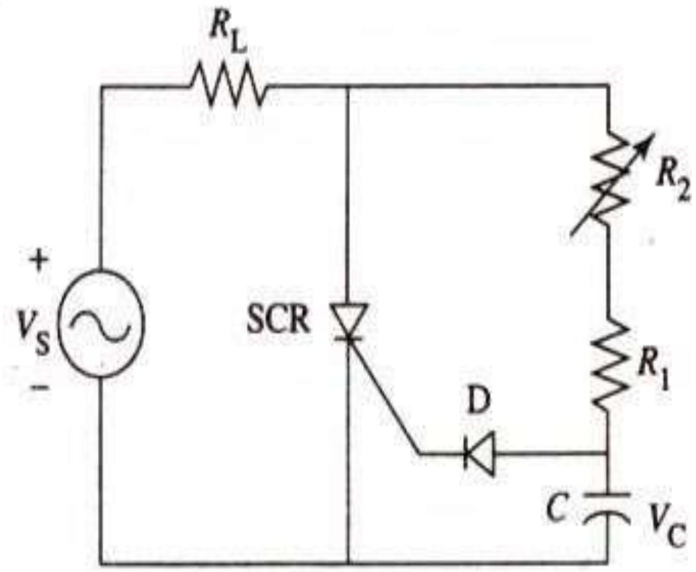
(a)

SCR trigger circuit using Optocoupler



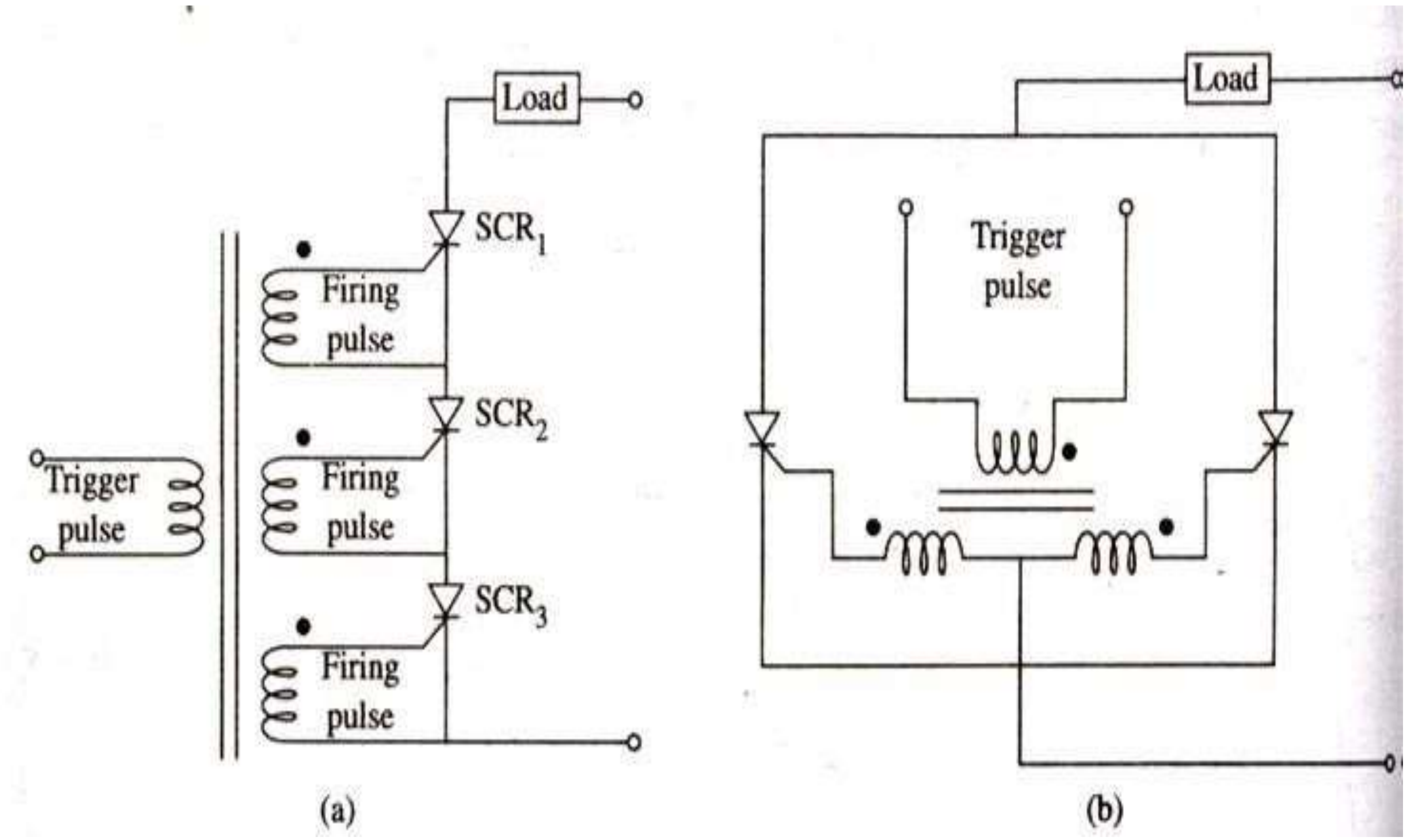
(c) AC Signals





Resistive phase control RC
phase control

Triggering SCRs in Series and in Parallel



SCR Turnoff (Commutation) Circuits

- What is Commutation?

  The process of turning off an SCR is called commutation.

  It is achieved by

1. Reducing anode current below holding current
2. Make anode negative with respect to cathode

- Types of commutation are:

1. Natural or line commutation
2. Forced commutation

SCR Turnoff Methods

1. Diverting the anode current to an alternate path

2. Shorting the SCR from anode to cathode

3. Applying a reverse voltage (by making the cathode positive with respect to the anode) across the SCR

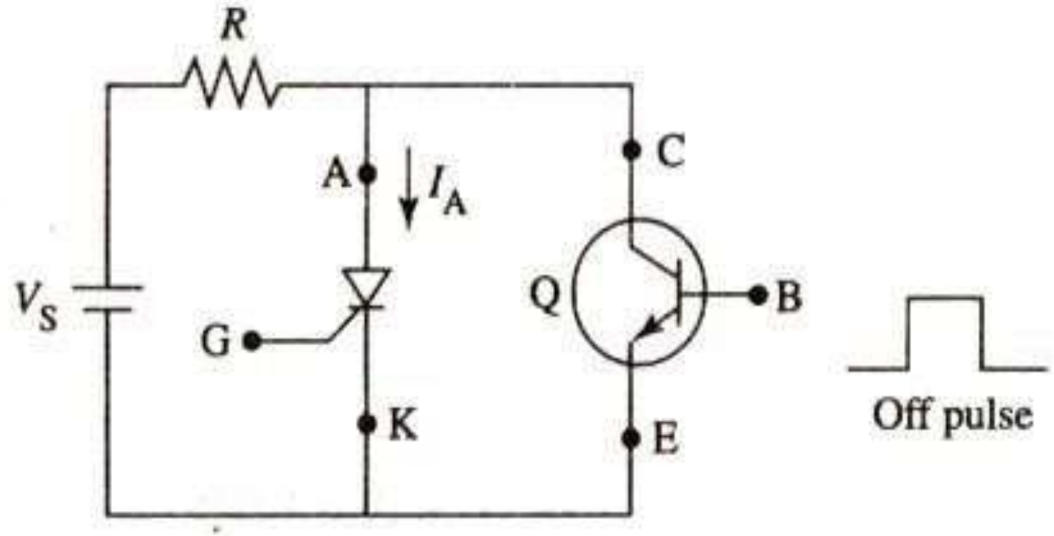
4. Forcing the anode current to zero for a brief period

5. Opening the external path from its anode supply voltage

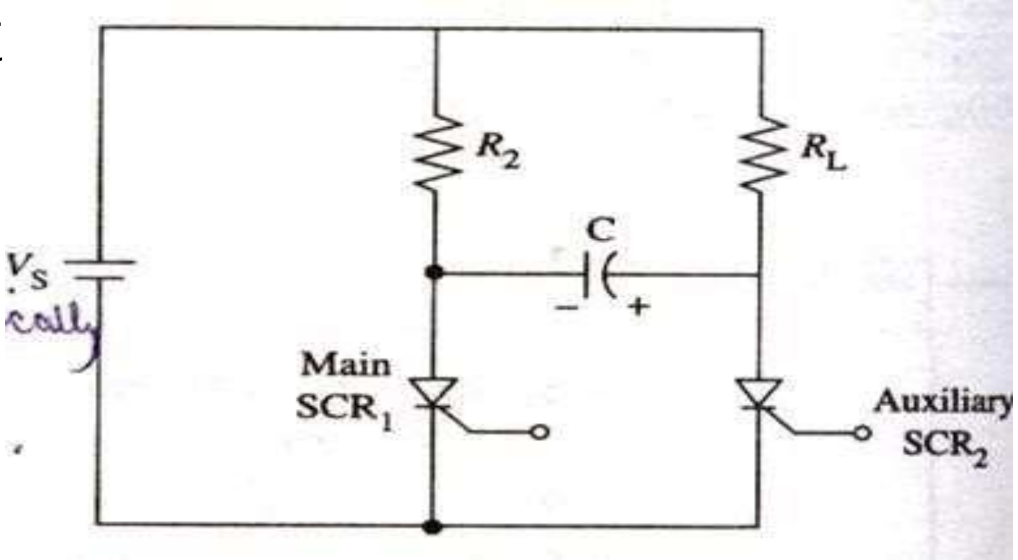
6. Momentarily reducing supply voltage to zero

(1) Capacitor Commutation

- SCR turnoff circuit using a transistor switch



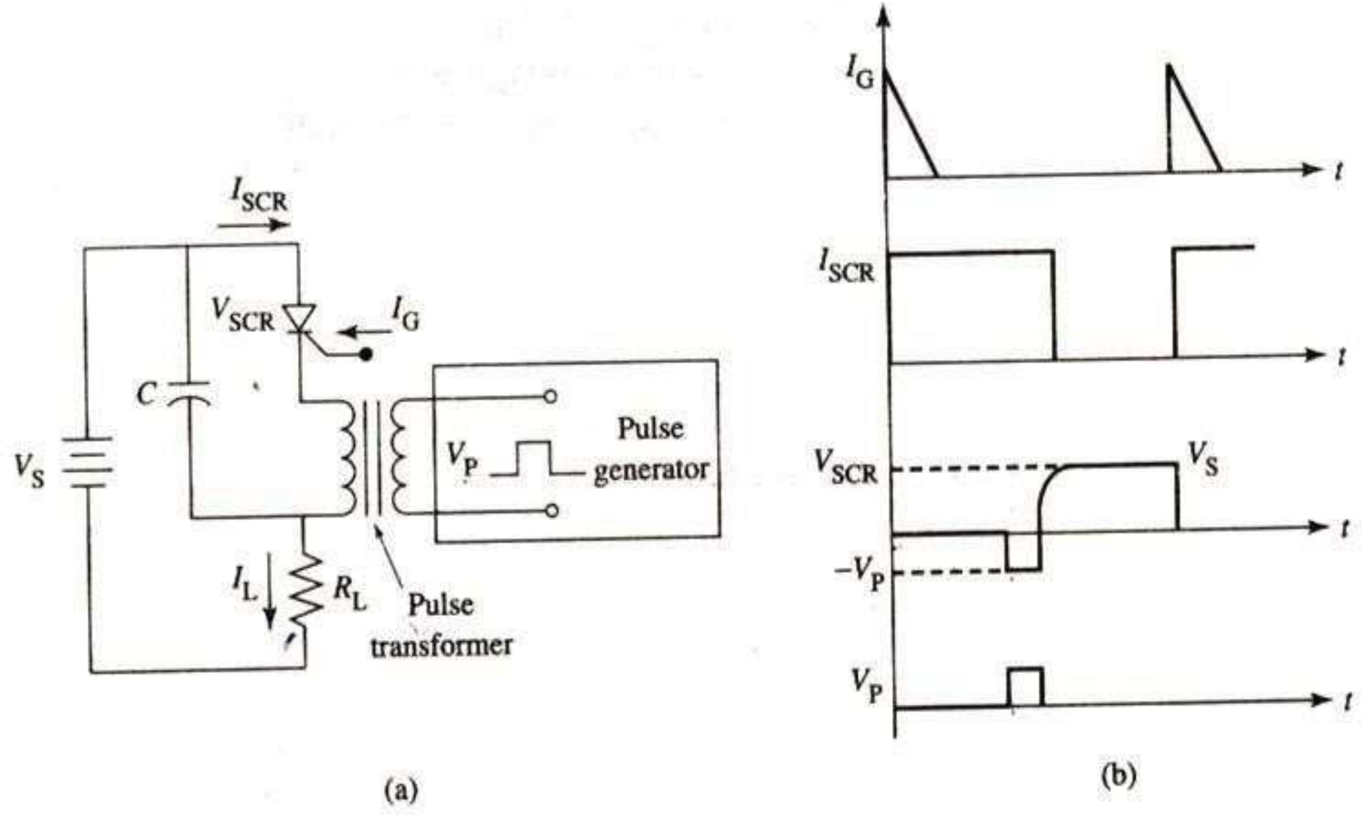
- SCR turnoff circuit using commutation capacit



- Value of capacitance is determined by:

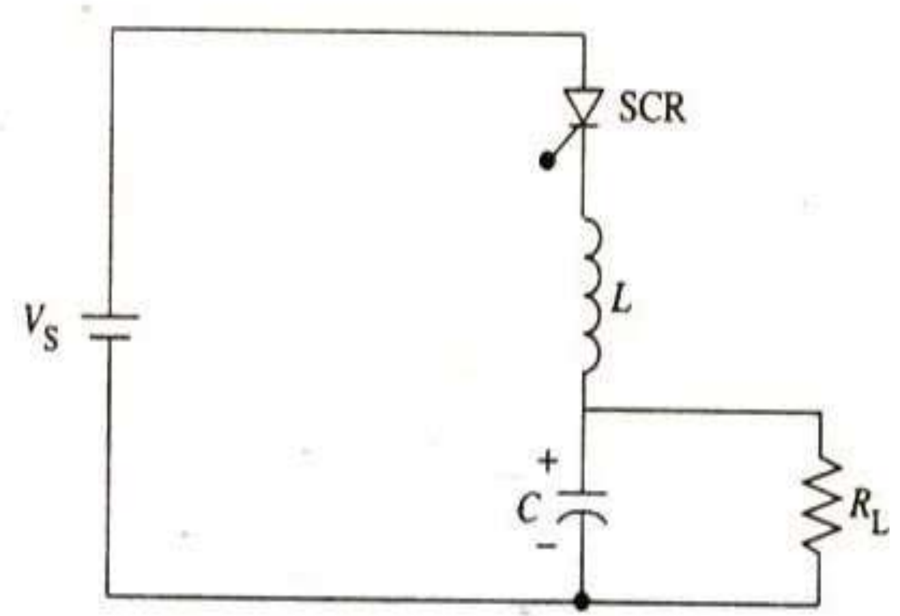
$$C >= \frac{t_{OFF}}{0.693 R_L}$$

(2) Commutation By External Source

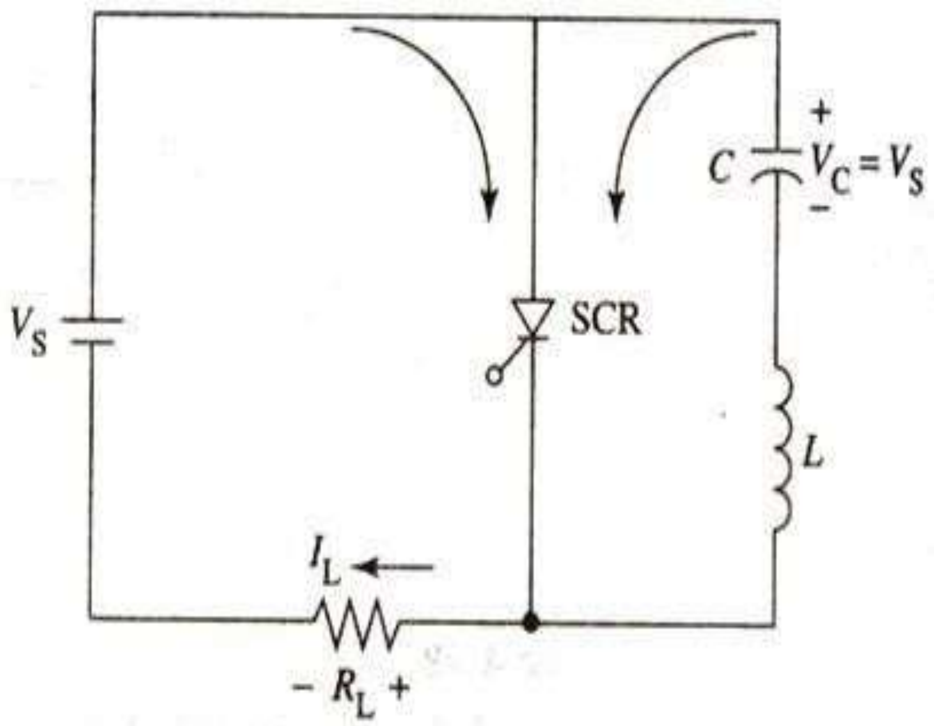


(3) Commutation by Resonance

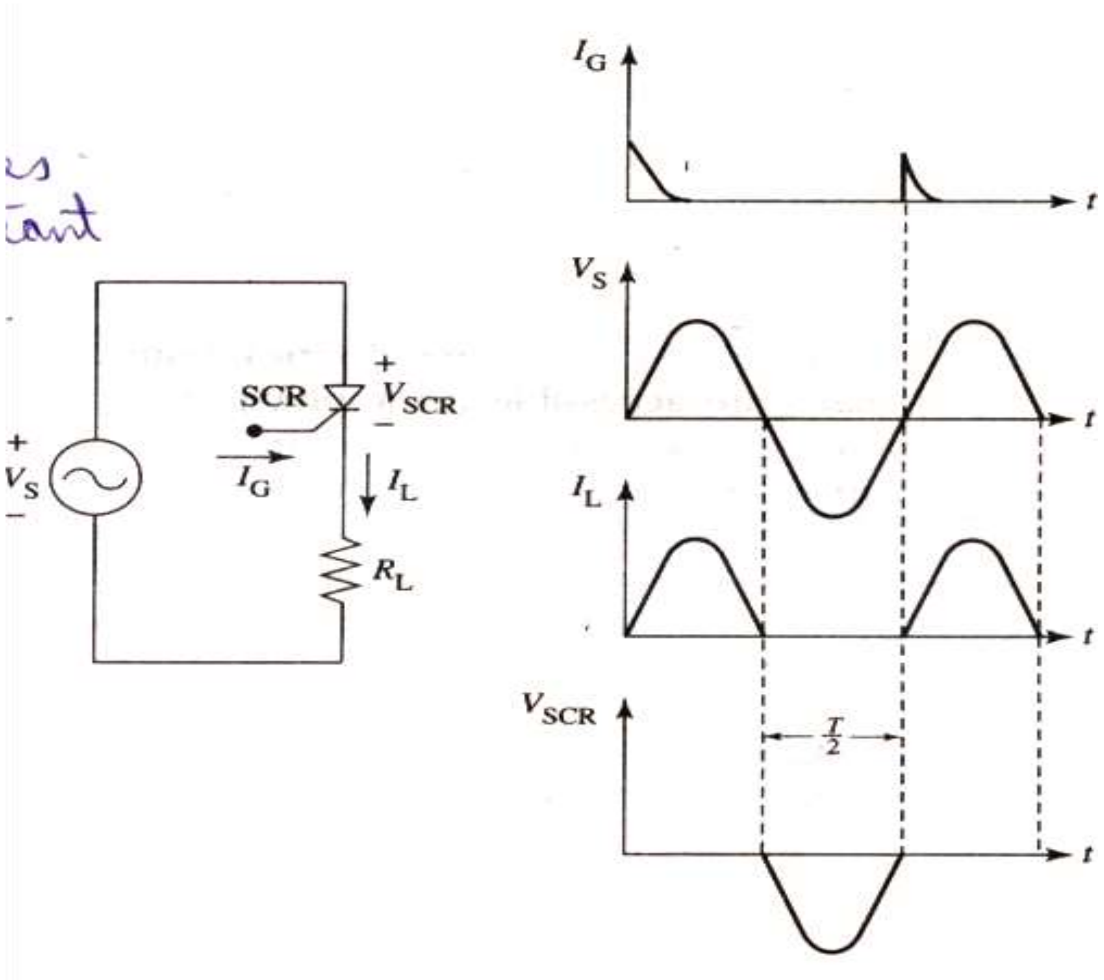
. Series resonant turnoff circuit



- Parallel resonant turnoff circuit



(4) AC line commutation



Other members of Thyristor Family

Power Semiconductor Switches

Power Diodes
2 layer device

Power Transistors
3 layer Device

Thyristors
4 layer Device

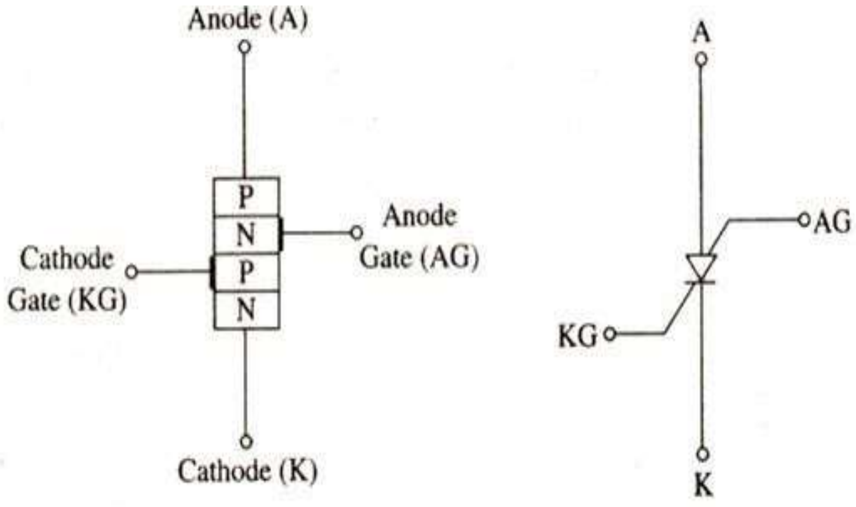
- **Thyristor devices can convert and control large amounts of power in AC or DC systems while using very low power for control.**
- **Thyristor family includes**

  1 Silicon controlled switch (SCR)
  2 Gate-turnoff thyristor (GTO)
  3 Triac
  4 Diac
  5Silicon controlled switch (SCS)
  6- Mos-controlled switch (MCT)

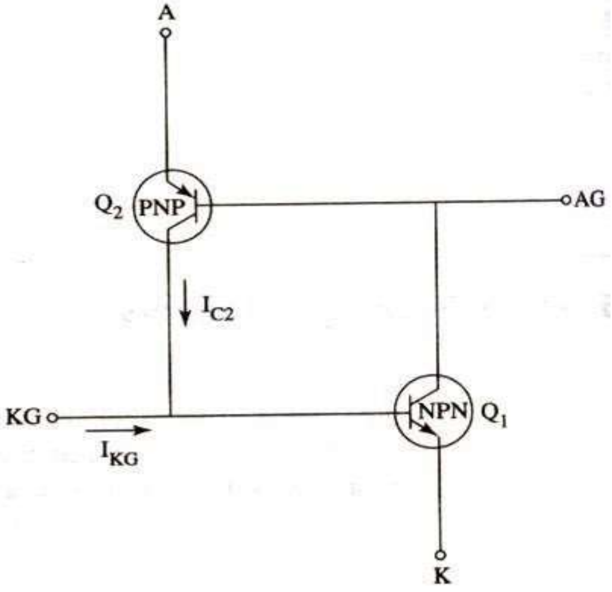
Other Types of Thyristors

1. Silicon Controlled Switch (SCS)
2. Gate Turnoff Thyristor (GTO)
3. DIAC
4. TRIAC
5. MOS-Controlled Thyristor (MCT)

1. SCS



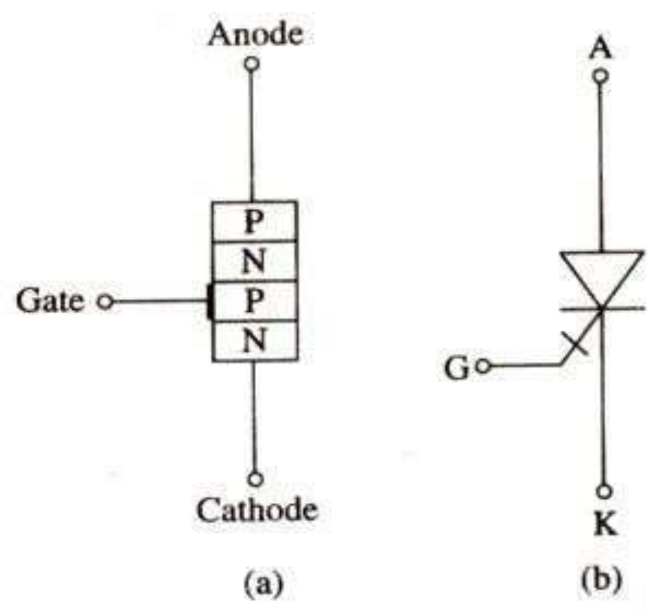
(a) (b)

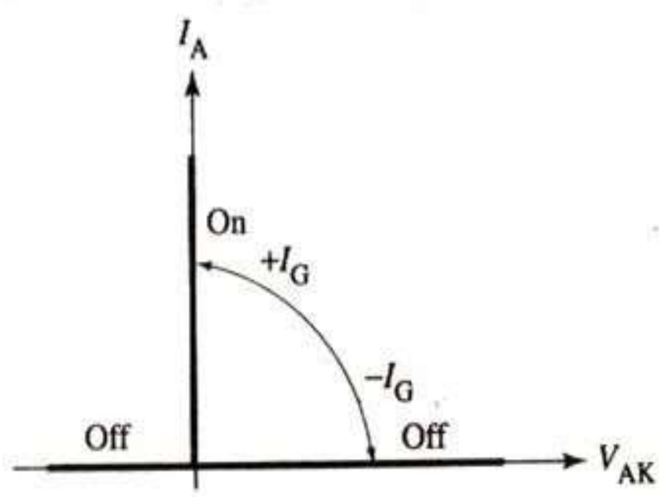


Structure
Symbol

Equivalent circuit
for SCS

(2) GTO

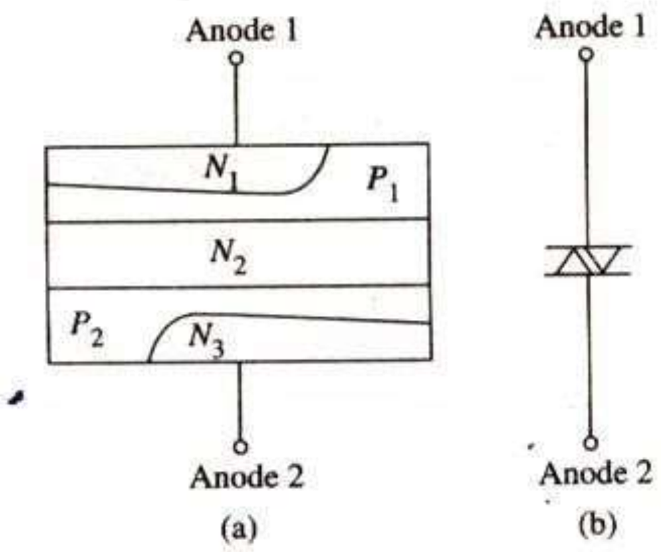


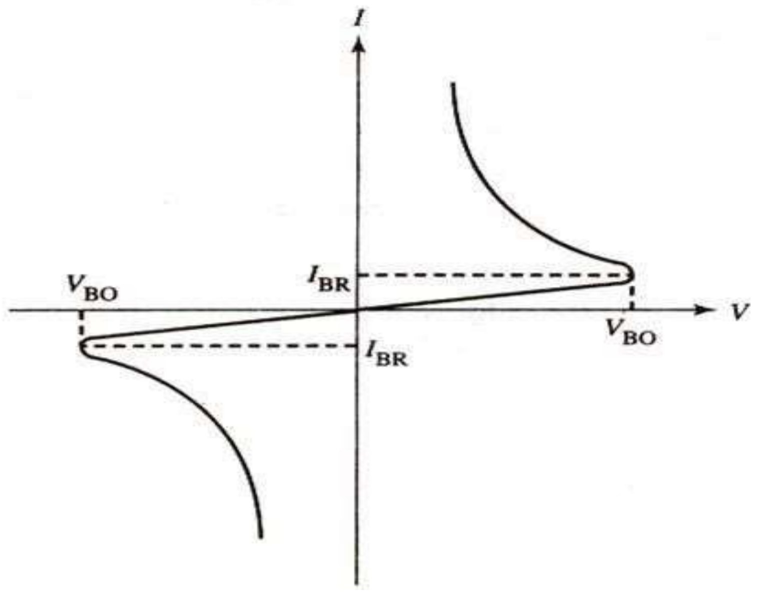


Structure
Symbol

GTO Ideal VI
characteristiccs

(3) DIAC

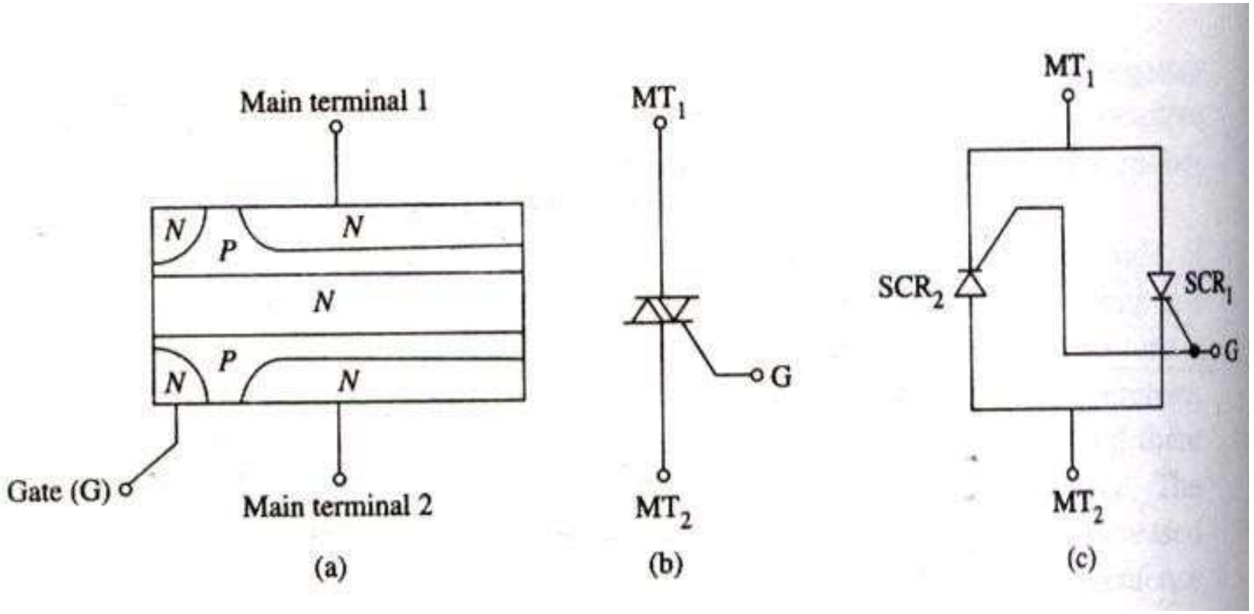




Structure
Symbol

VI characteristics
of diac

(4) Triac



Structure Symbol SCR
equivalent circuit

Triac VI characteristics