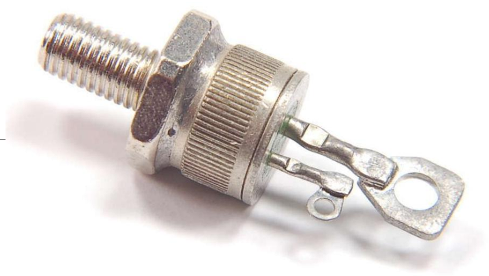
Power Electronics

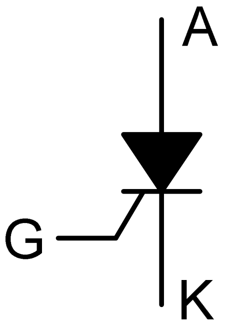
SILICON CONTROLLED RECTIFIERS

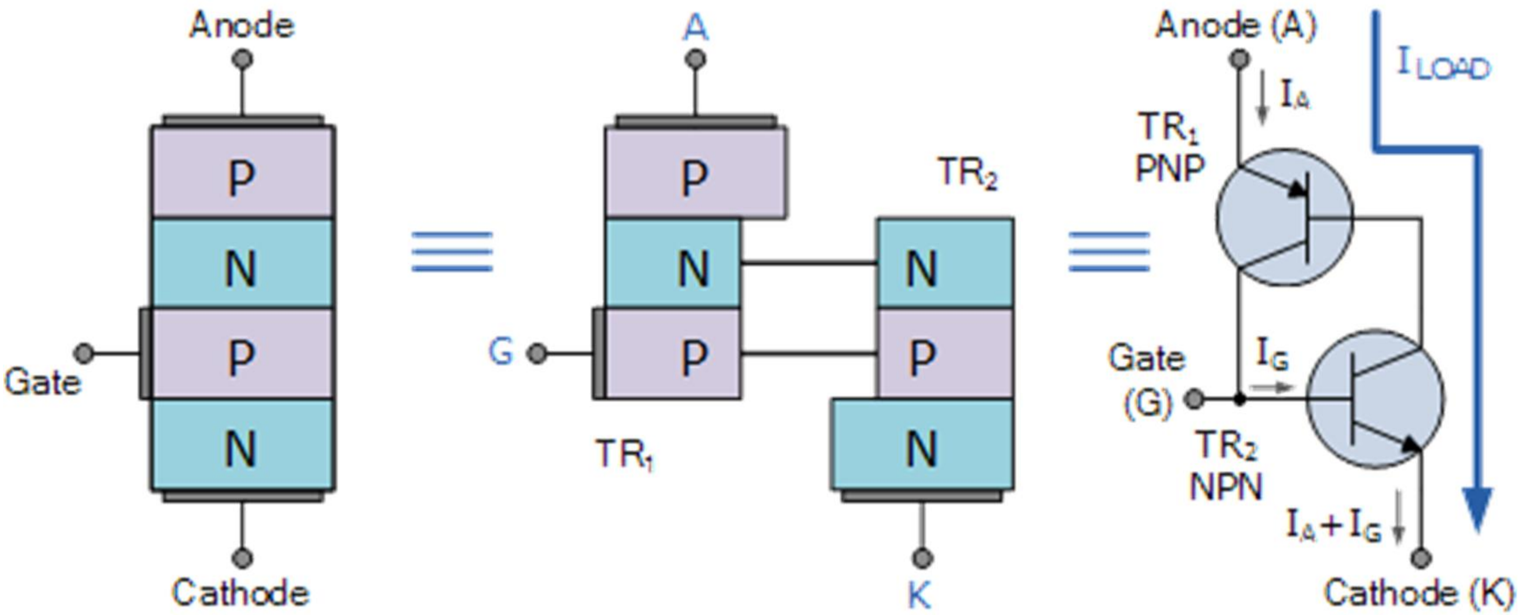
2018

Dr. Francis M. Fernandez

Silicon Controlled Rectifier (SCR)



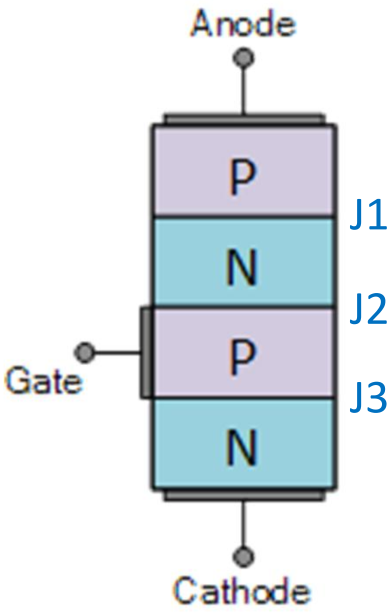




SCR operating modes

1. Forward blocking mode
   - When a positive voltage is applied to the anode of the SCR with respect to the cathode, and with zero gate current, the junction J_2 will be reverse biased and therefore the device will not conduct. This is **the forward blocking mode** of SCR.

2. Reverse blocking mode
   - When the cathode of SCR is made positive with respect to the anode, the junctions J_1 and J_3 will be reverse biased and therefore the device will not conduct. This is **the reverse blocking mode** of SCR.



SCR operating modes

3. Forward Conduction Mode

- An SCR will go into forward conduction mode in two ways:
  a) without gate current, the anode voltage is increased beyond a certain level called breakover voltage V_{BO}
  b) A gate current is applied so that the SCR starts conducting
- Once the SCR starts conducting, no gate current is needed to maintain the anode current.

Latching and Holding current

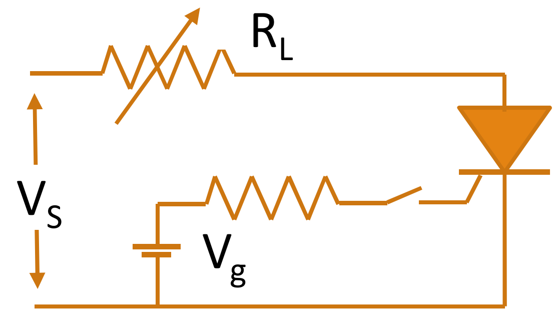
Latching current

- The minimum **anode current** required to maintain the ON condition even after removal of the gate current is the latching current.
- Typ value: 25 mA

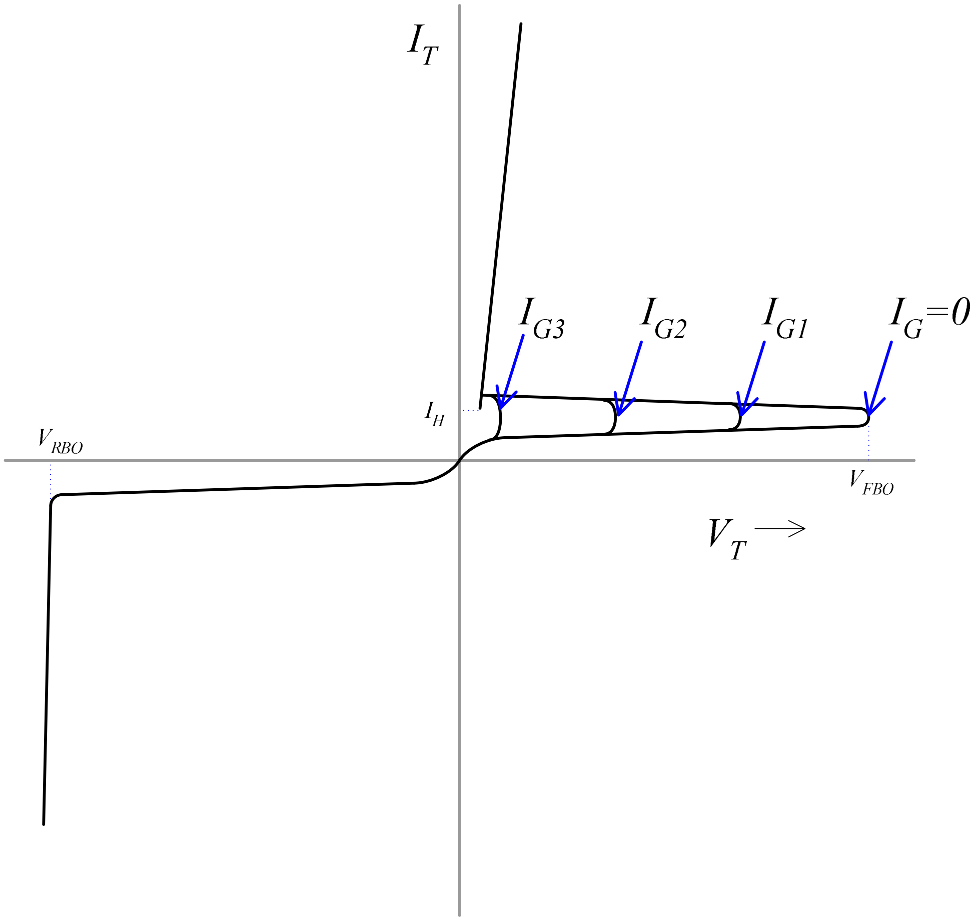
Holding current

- The minimum **anode current** below which the SCR will go to forward blocking state is the holding current.
- Typ value: 10 mA

Latching current > Holding current

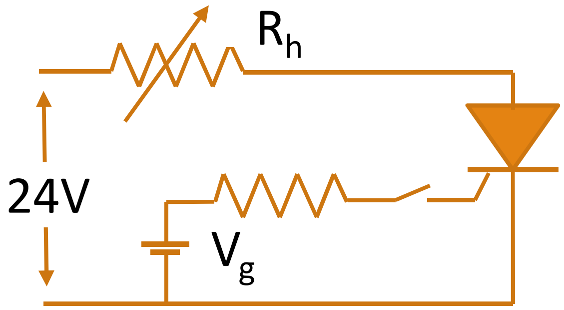


SCR Characteristics



$I_{G3} > I_{G2} > I_{G1} > I_{G0}$

Problem



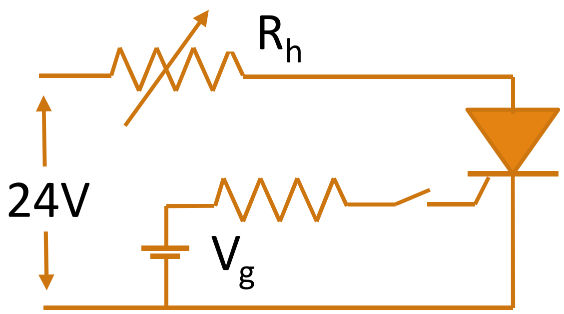
For the given circuit, a gate pulse is applied with R_h = 1200 ohms

a) Will the SCR turn on?
b) If the answer is "no" what is the condition to effect a turn on?
c) After turn on how can the SCR be turned off?

Assumptions:

Latching current = 24 mA
Holding current = 10 mA
Forward on state voltage = 0V

Solution



Current throgh the SCR when it is conducting = $\frac{24\ \mathrm{V}}{1200\ \Omega} = 20\ \mathrm{mA}$

This current is less than the latching current; so the SCR will not turn on

Maximum value of load resistance = $\frac{24\ \mathrm{V}}{24\ \mathrm{mA}} = 1000\ \Omega$

To ensure proper turn on, the load resistance (R_h) should be 1000 ohms or less

To turn off the SCR, the current should be brought down to below 10 mA by reducing the supply voltage of increasing the load resistance (R_h)

SCR Turn On Methods

1. Forward Voltage Triggering
2. Gate Triggering
3. Radiation Triggering (Light Triggering)
   - Light falling on the junction created electron-hole pairs and leads to current flow.
   - This principle if used in the following devices:
     - Light activated SCR (LASCR)
     - Light activate silicon controlled switch(LASCS)
4. Thermal Triggering (Temperature Triggering)
   - Width of depletion layer decreases with rise in junction temperature. If the anode is at near break-over voltage and the if the temperature rises, the device may start conducting.
   - This is an undesirable triggering
5. dv/dt Triggering

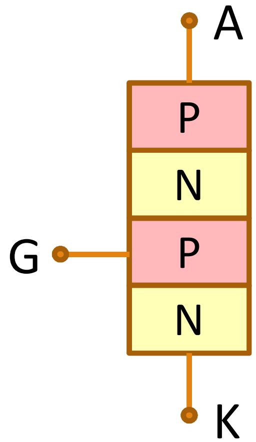
SCR Turn On Methods

5. dv/dt Triggering

- The reverse biased junction of the SCR may have a capacitance across it. When a sudden voltage is applied, the device may turn on due to the capacitance charging current

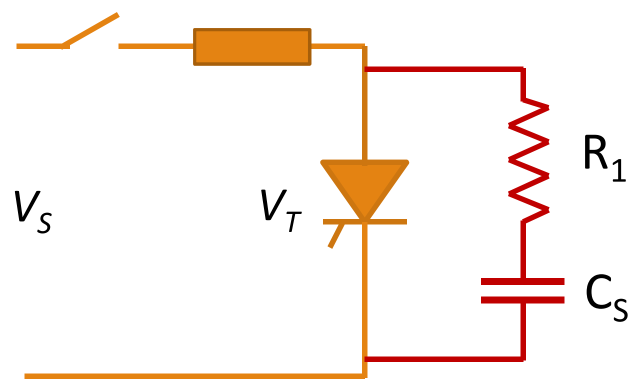
$$i_J = \frac{d}{dt}(Q_J) = \frac{d}{dt}(C_J V) = V\frac{d}{dt}C_J + C_J\frac{d}{dt}V$$

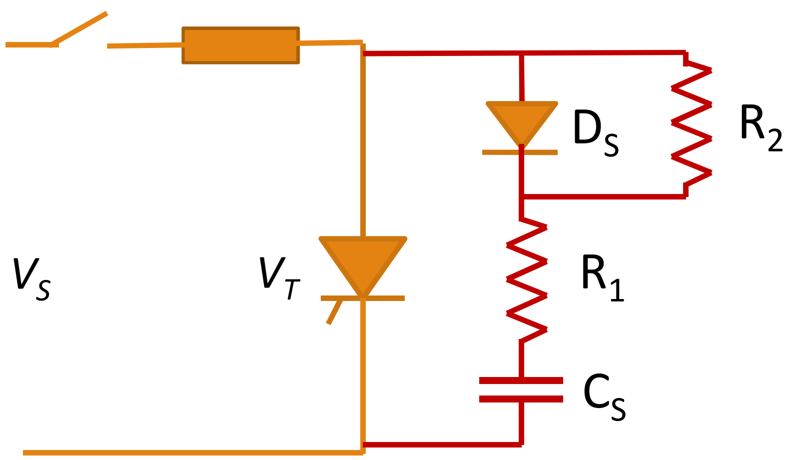
- This is an undesirable triggering
- Typical limit for *dv/dt* is 10-20 V/μs



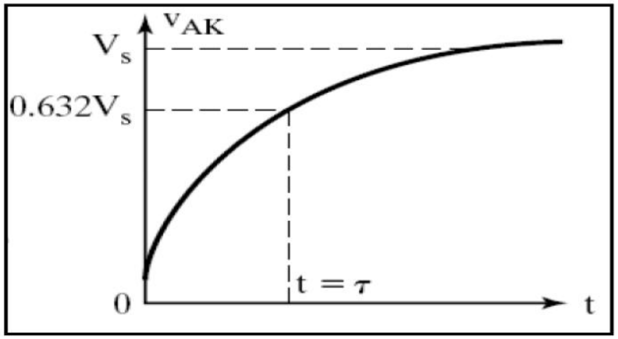
Snubber Circuit

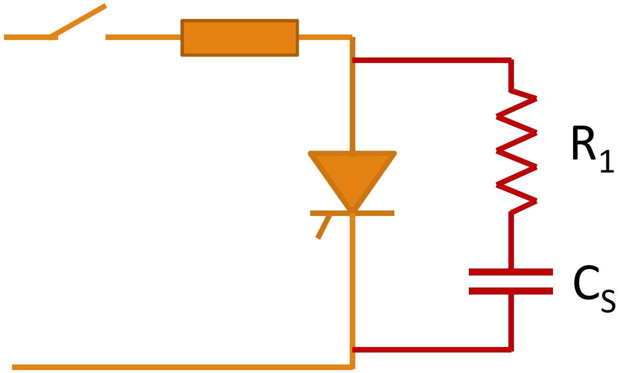
- A Snubber Circuit may be used to eliminate the dv/dt turn on problem
- A suitable RC network forms the snubber circuit





Design of Snubber Circuit





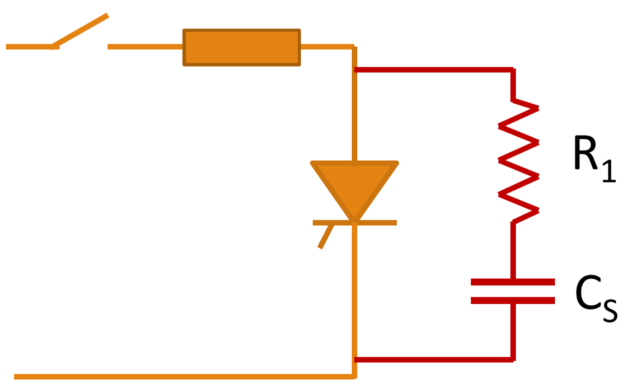
$$V_T = V_S\left(1 - e^{-t/\tau_S}\right) \Rightarrow At \;\; t = \tau_S, \quad V_T = 0.632\,V_S \Rightarrow \frac{dv}{dt} = \frac{0.632\,V_S}{\tau_S} = \frac{0.632\,V_S}{R_1 C_S}$$

$$\boxed{\frac{dv}{dt} = \frac{0.632\,V_S}{R_1 C_S}}$$

$Also \;\; \boxed{R_1 = \frac{V_S}{I_{TD}}}$ $\quad where, \; I_{TD}$ is the maximum discharge current of SCR

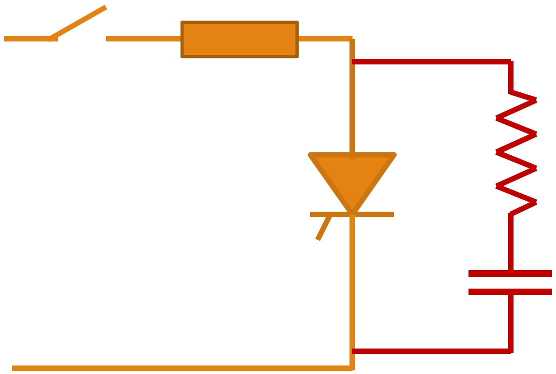
Problem

A SCR is to operate in a circuit where the supply voltage is 200 VDC. The dv/dt should be limited to 100 V/ µs. Series R and C are connected across the SCR for limiting dv/dt. The maximum discharge current from C into the SCR, if and when it is turned ON is to be limited to 100 A. Using an approximate expression, obtain the values of R and C.



Solution

$$R_1 = \frac{V_S}{I_{TD}} = \frac{200}{100} = 2\Omega$$



Select 2.2 ohms

$$\frac{dv}{dt} = \frac{0.632\,V_S}{R_1 C_S} \Rightarrow \frac{100}{10^{-6}} = \frac{0.632 \times 200}{2.2 \times C_S}$$

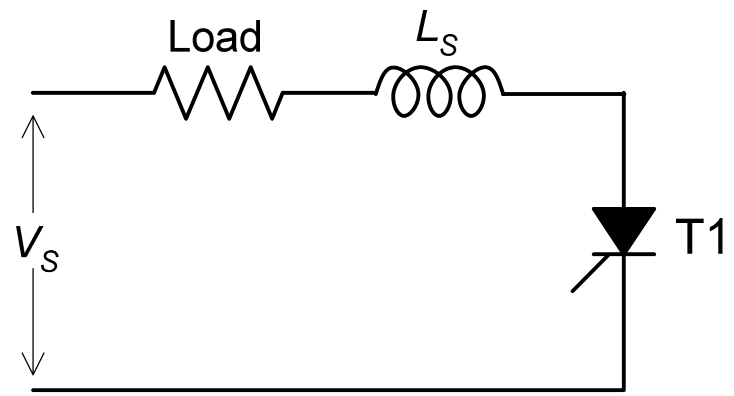
$$C_S = \frac{0.632 \times 200 \times 10^{-6}}{2.2 \times 100} = 0.575\,\mu F$$

Select 0.68 µF

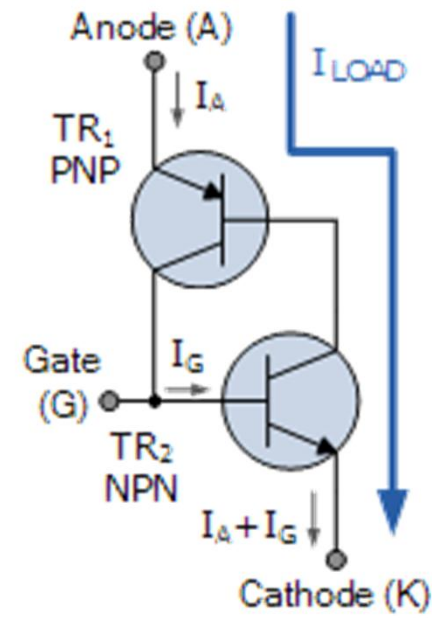
di/dt Rating

- Critical rate of rise of current is the maximum rate of rise of anode current in the ON state that the device can safely withstand.
- If the rate of rise if faster than the spreading velocity of carriers across the junction, hot spots may develop and damage the device.
- Specified for the highest value of junction temperature.
- Typical di/dt ratings are in the range of 50-800 A/µs
- Protection provided with a series inductor.

$$\frac{di}{dt} = \frac{V_s}{L_s}$$



Two Transistor Analogy



Eber Moll equation: $I_C = \alpha I_E + I_{CBO}$

For TR$_1$: $I_{C1} = \alpha_1 I_A + I_{CBO1}$

For TR$_2$: $I_{C2} = \alpha_2 I_K + I_{CBO2}$

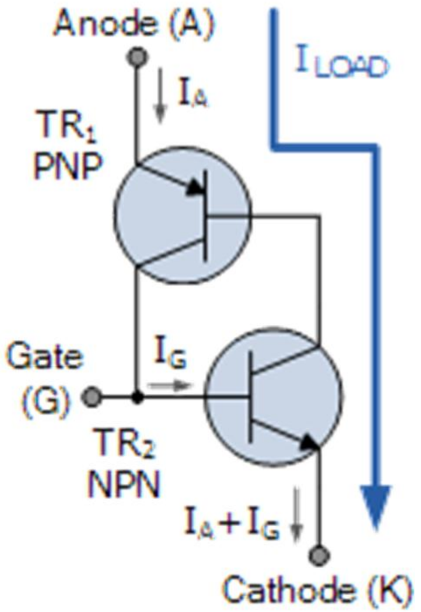
$I_A - I_{C1} - I_{C2} = 0$

$$I_A = I_{C1} + I_{C2}$$
$$= \alpha_1 I_A + I_{CBO1} + \alpha_2 I_K + I_{CBO2}$$

For gating signal $I_K = I_G + I_A$

$$I_A = \alpha_2 (I_G + I_A) + \alpha_1 I_A + I_{CBO1} + I_{CBO2}$$

Two Transistor Analogy Contd.



$$I_A = \alpha_2(I_G + I_A) + \alpha_1 I_A + I_{CBO1} + I_{CBO2}$$

$$I_A - \alpha_1 I_A - \alpha_2 I_A = \alpha_2 I_G + I_{CBO1} + I_{CBO2}$$

$$I_A(1 - (\alpha_1 + \alpha_2)) = \alpha_2 I_G + I_{CBO1} + I_{CBO2}$$

$$I_A = \frac{\alpha_2 I_G + I_{CBO1} + I_{CBO2}}{1 - (\alpha_1 + \alpha_2)}$$

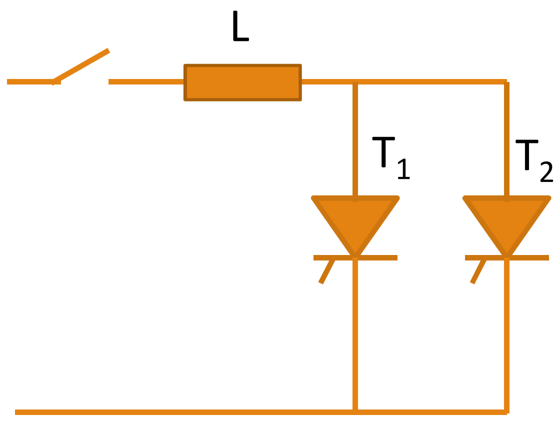
$(\alpha_1 + \alpha_2)$ is called the loop gain

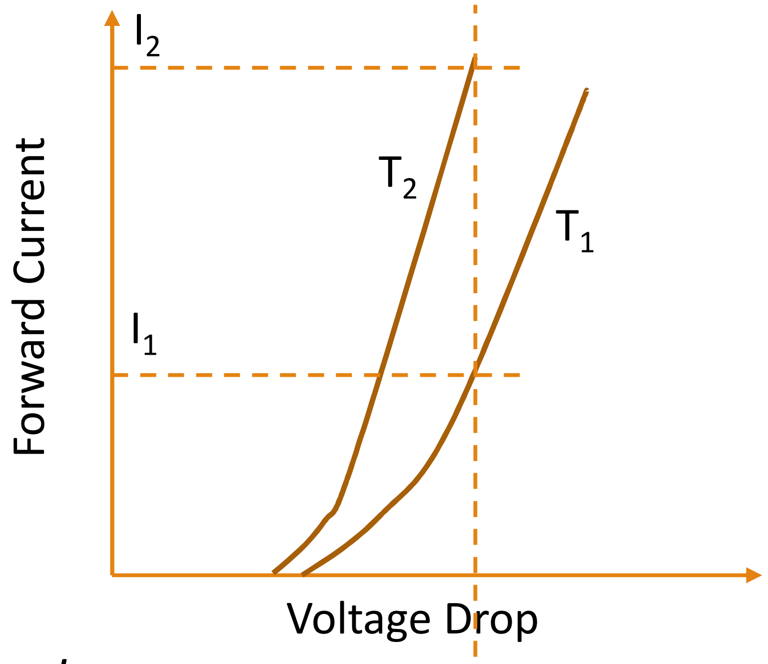
When $(\alpha_1 + \alpha_2) = 1$, I_A becomes very high.

Here, I_A is limited by the external resistance (Load)

Parallel operation of SCRs

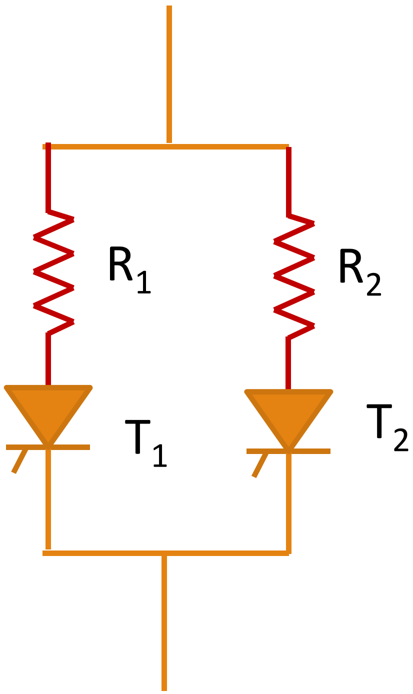
- Parallel operation is needed when the load current is more than device rating
- Should be done carefully if the VI characteristics are different





$$I = I_1 + I_2$$

Proper Current Sharing



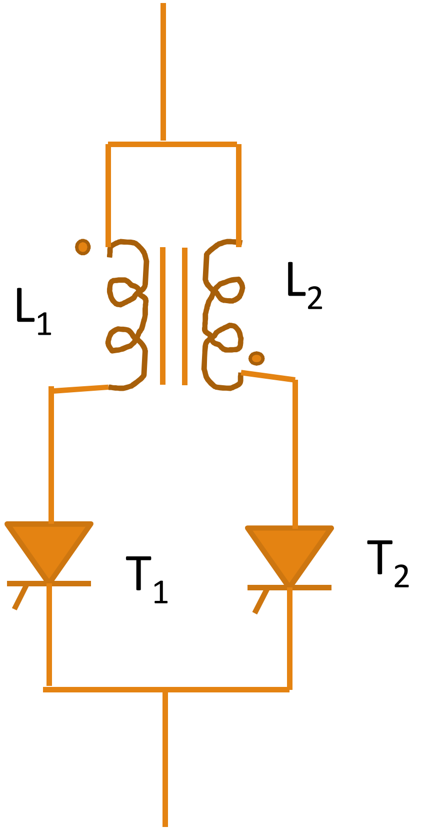
Current sharing using series resistance

$$R_1 + R_{T1} = R_2 + R_{T2}$$

The SCRs should turn on simultaneously

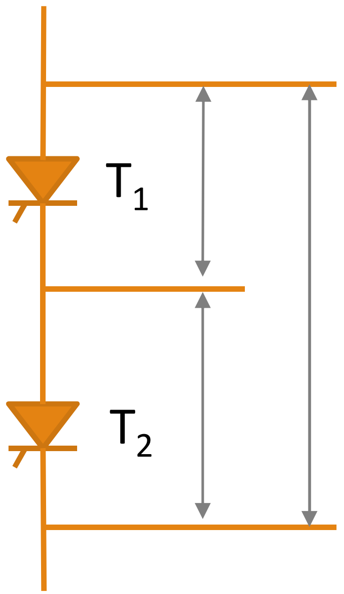
- SCRs are mounted symmetrically on the heat sink to reduce difference of inductance of conducting paths
- Series resistance connected in gate circuit

Proper Current Sharing



Current Sharing using magnetically coupled series reactance

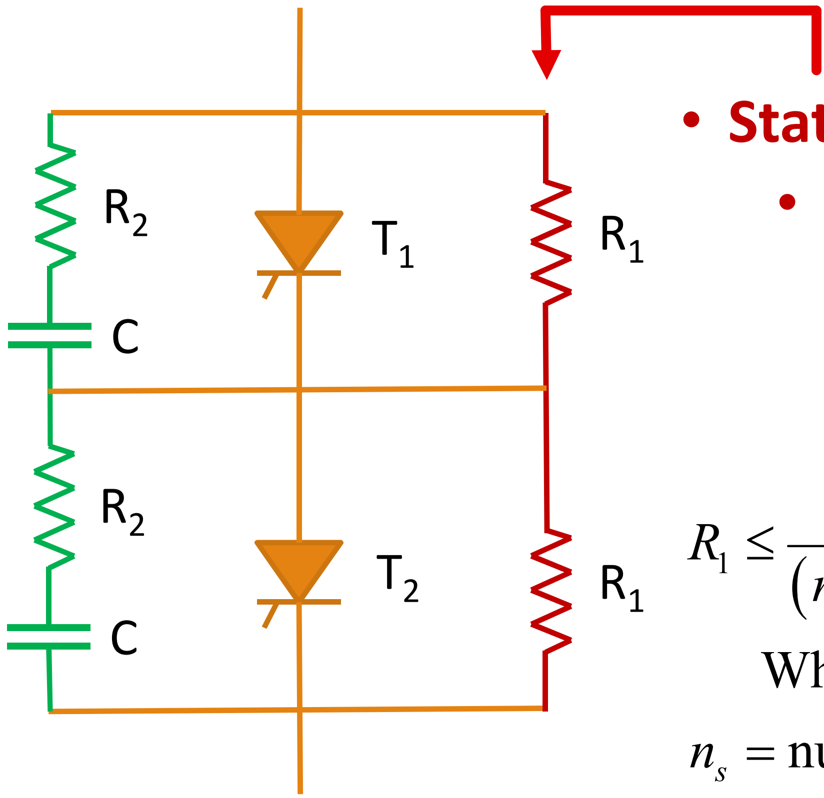
Series Operation of SCRs



- SCR with higher resistance will have larger voltage drop across it
- Results in unequal distribution of voltages
- String efficiency reduces

$$String\ Efficiency = \frac{Actual\ voltage\ rating\ of\ the\ string}{Voltage\ rating\ of\ one\ SCR \times Number\ of\ SCRs}$$

Voltage Equalisation



- **Static Equalisation**
  - A uniform voltage distribution in steady state can be achieved by connecting a suitable resistance (same value) across each SCR

$$R_1 \leq \frac{n_s \cdot E_D - E_s}{(n_s - 1)(I_{b\max} - I_{b\min})}$$

Where

n_s = number of devices

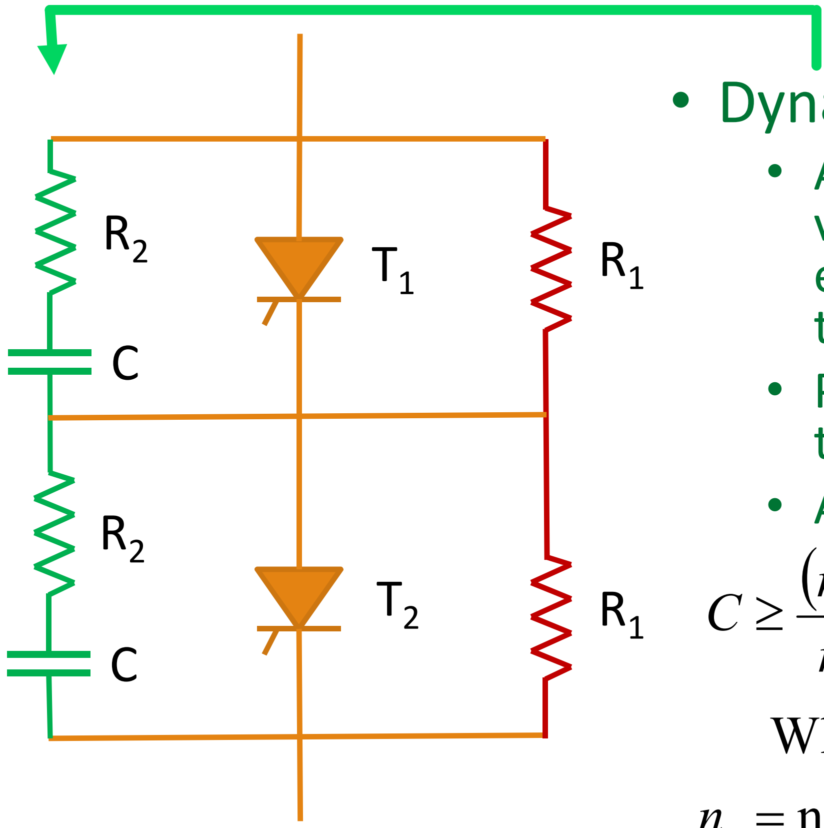
E_D = maximum permissible breakdown voltage

E_s = string voltage

I_b = device blocking current

$$Power\ dissipated,\ P_R = \frac{E^2}{R}$$

Voltage Equalisation



- Dynamic Equalisation
  - A simple resistor used for static voltage equalization cannot maintain equal voltage distribution under transient conditions
  - Parallel connected RC network does the dynamic compensation
  - Also acts as snubber circuit

$$C \geq \frac{(n_s - 1)\Delta Q_{\max}}{n_s \cdot E_D - E_s}$$

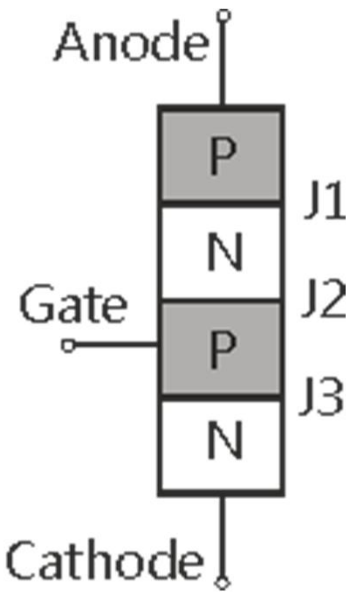
Where

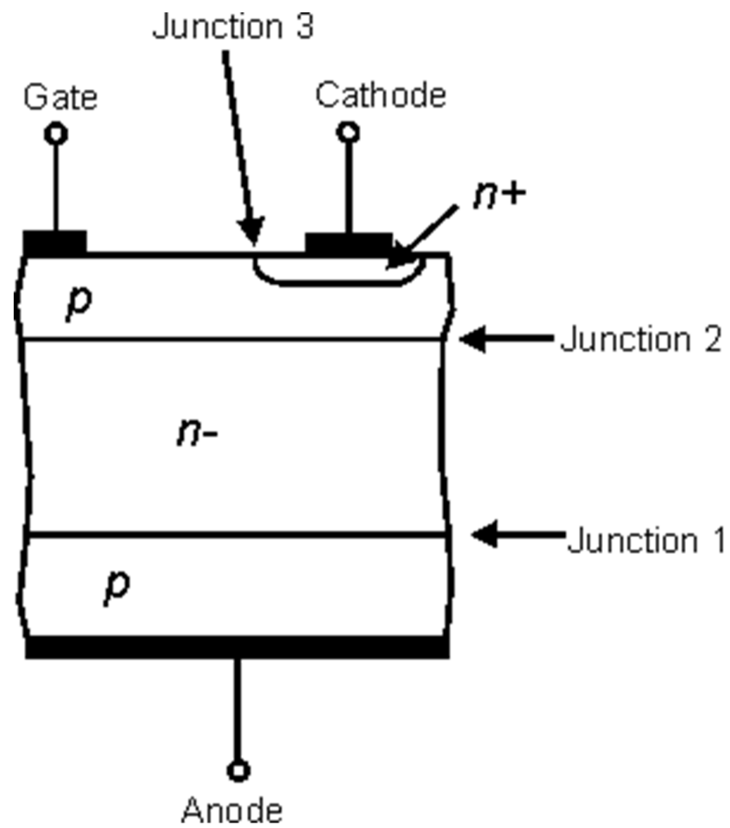
n_s = number of devices

E_D = maximum permissible breakdown voltage

$\Delta Q_{\max}$ = maximum difference between reverse recovery charge of SCRs of the same type

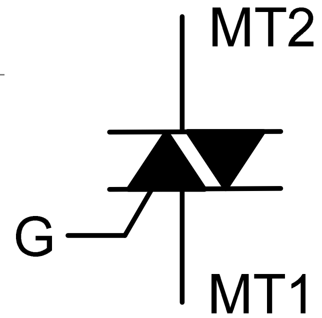
Structure of SCR



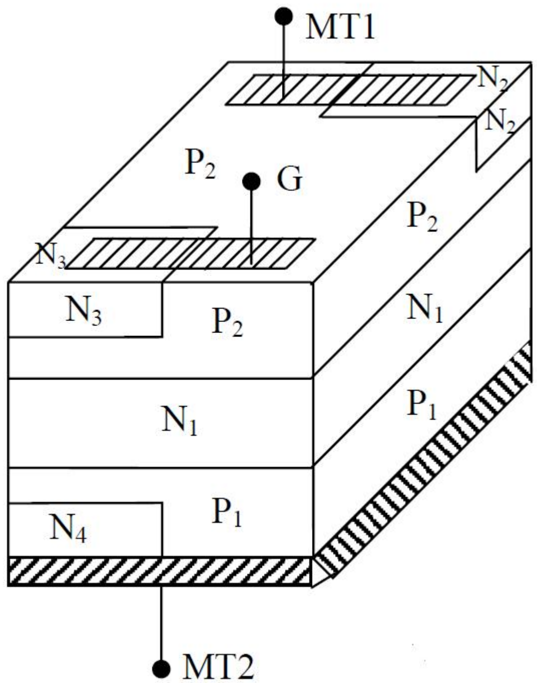


TRIAC

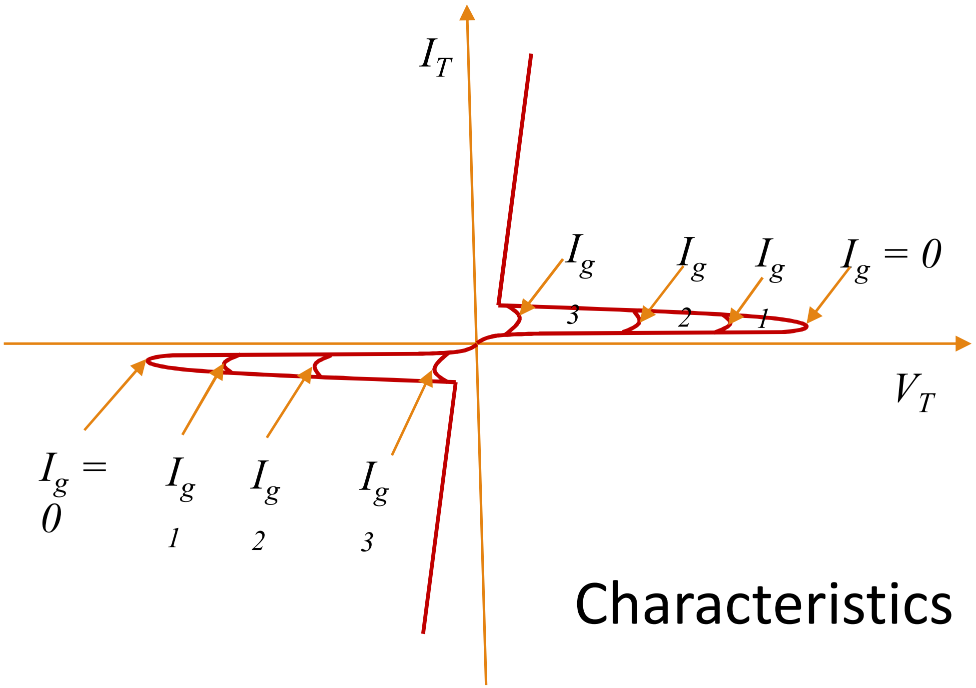
- Conducts in both half cycles of AC supply voltage
- Has two **main terminals** and a **gate**



Symbol

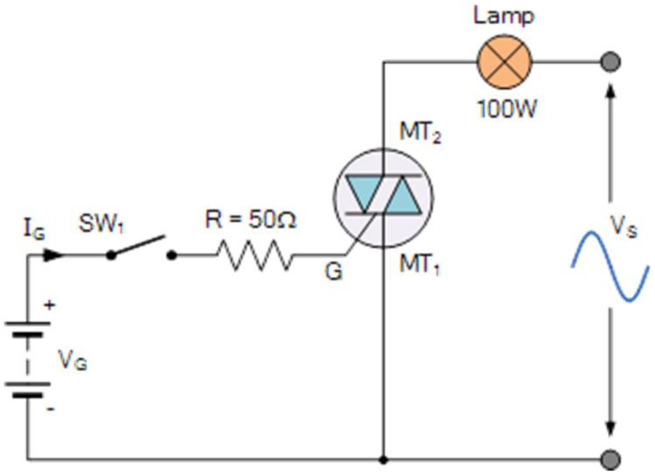


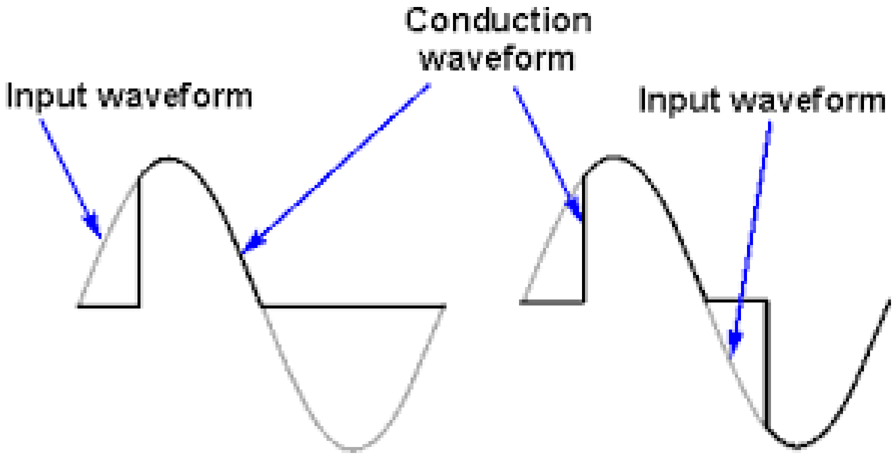
Internal Structure



Characteristics

Triac Circuit & Waveforms





SCR

TRIAC