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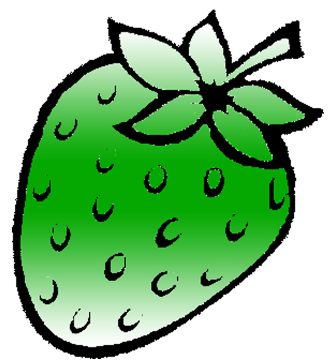

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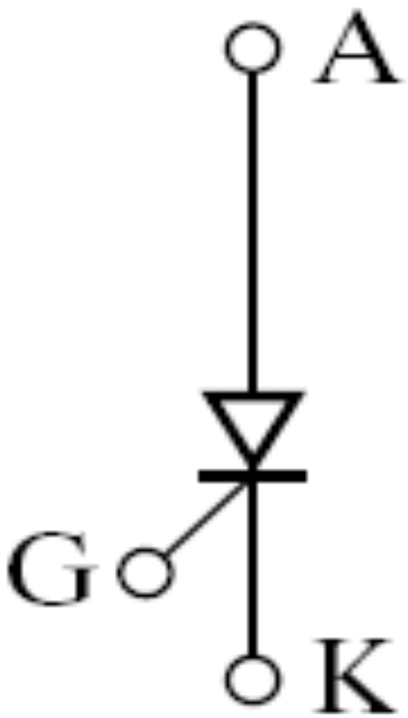
Unit 5

Silicon Controlled Rectifier

Contents

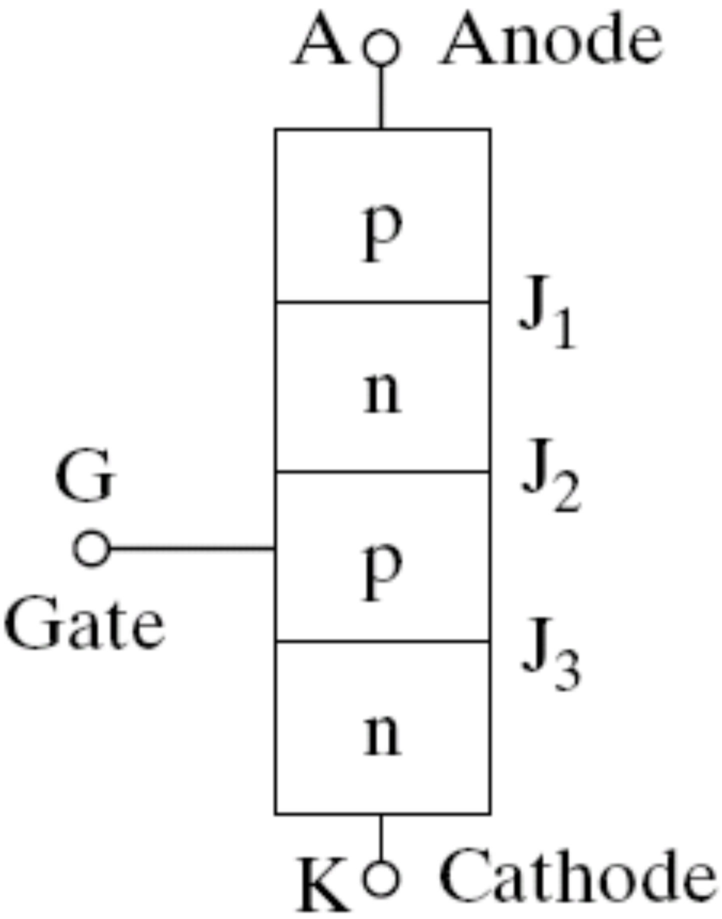
- Construction
- Working
- Characteristic
- Two transistor Analogy
- Controlled Rectifier

SCR



Symbol of
Silicon Controlled Rectifier

Device Operation



Simplified model of a thyristor

Working

- Forward Blocking State (OFF state)

  SCR is Forward Biased, i.e. anode is positive w.r.t cathode $V_{AK} < V_{BO}$

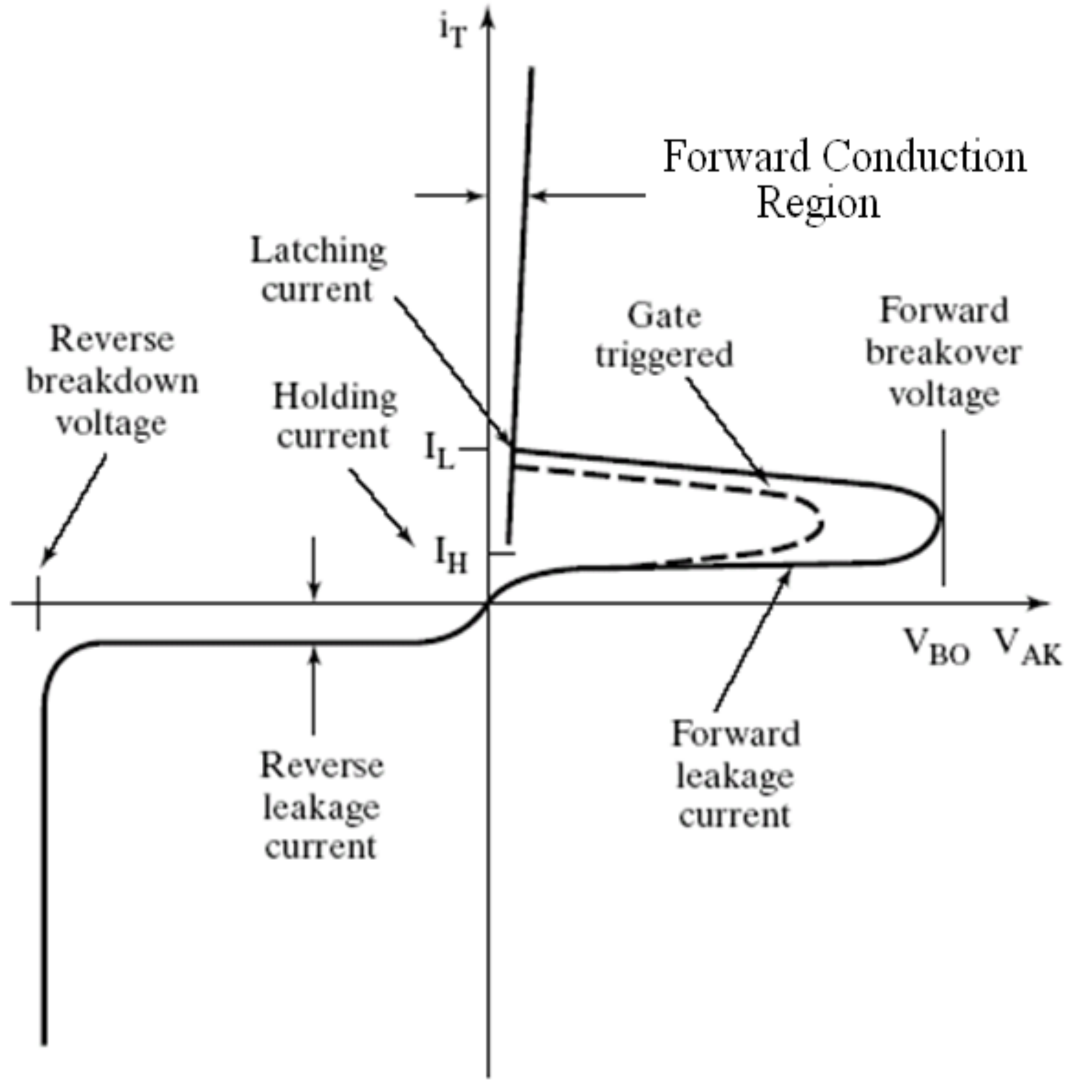
- Forward Conduction State (ON state)

  SCR is Forward Biased, i.e. anode is positive w.r.t cathode $V_{AK} > V_{BO}$

- Reverse Blocking State (OFF state)

  SCR is reverse biased, cathode is Positive w.r.t anode

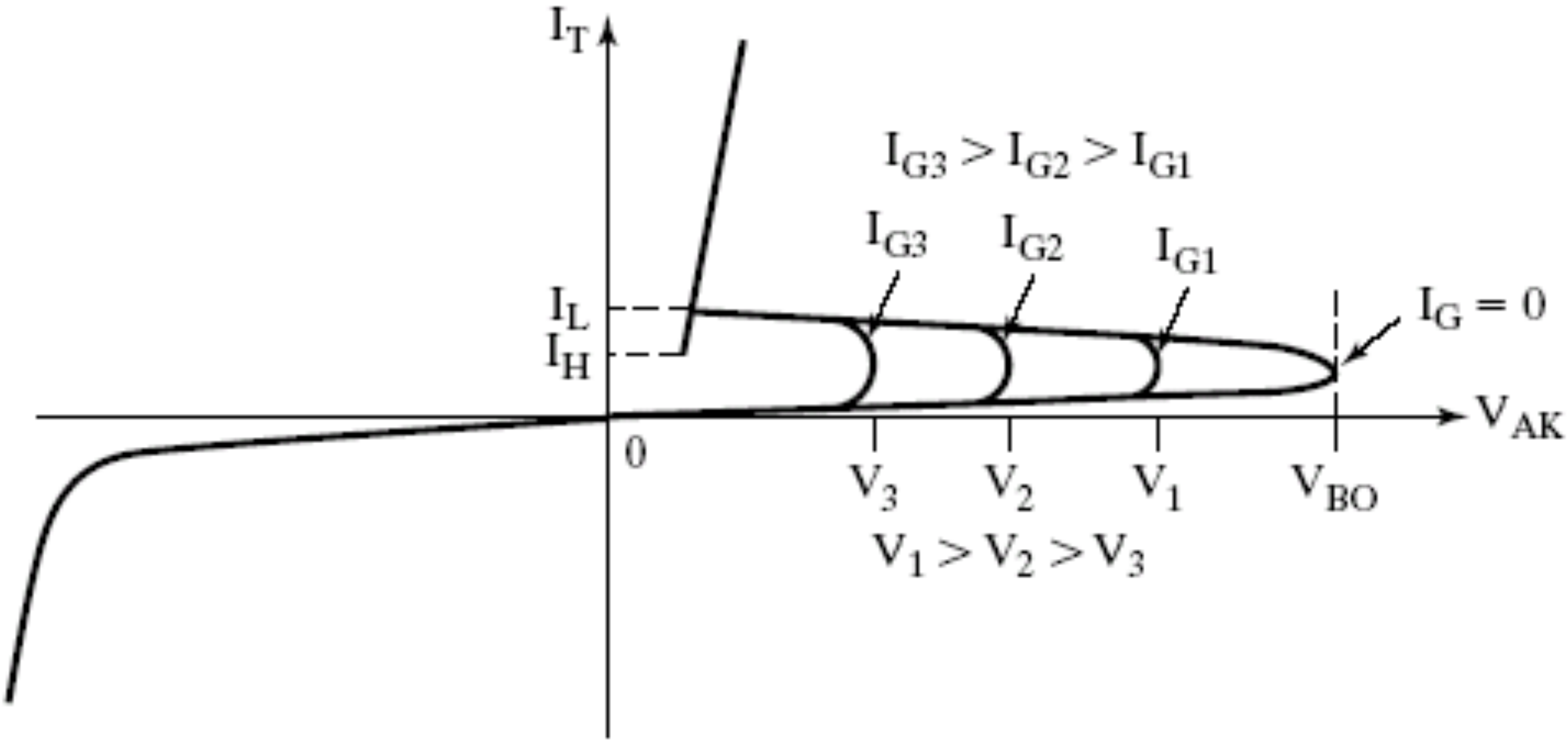
V-I Characteristics



Effect of Gate Signal

- Thyristor turns on before $V_{BO.}$
- The forward voltage V_{AK} at which the thyristor turns ON depends on the gate current magnitude.
- Higher the gate current , lower is the forward breakover voltage V_{BO} .

Effects of gate current



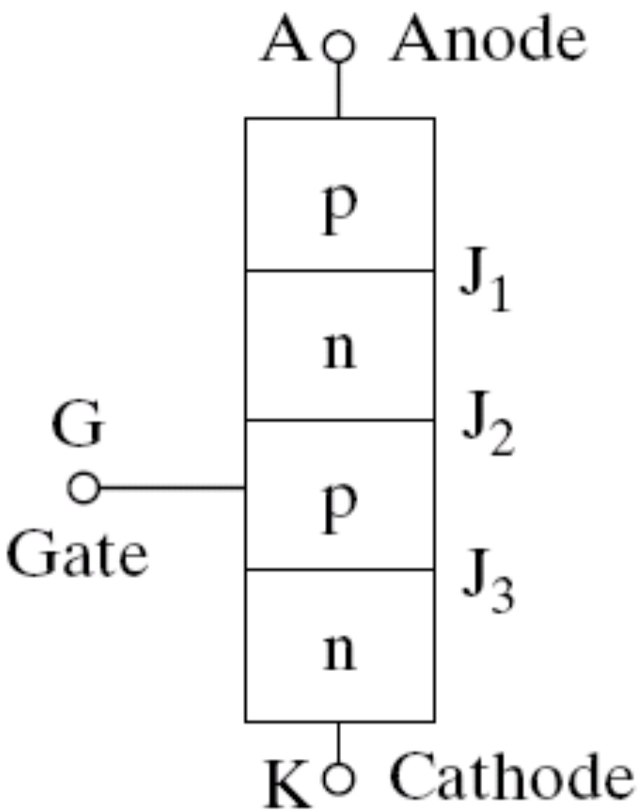
Latching Current

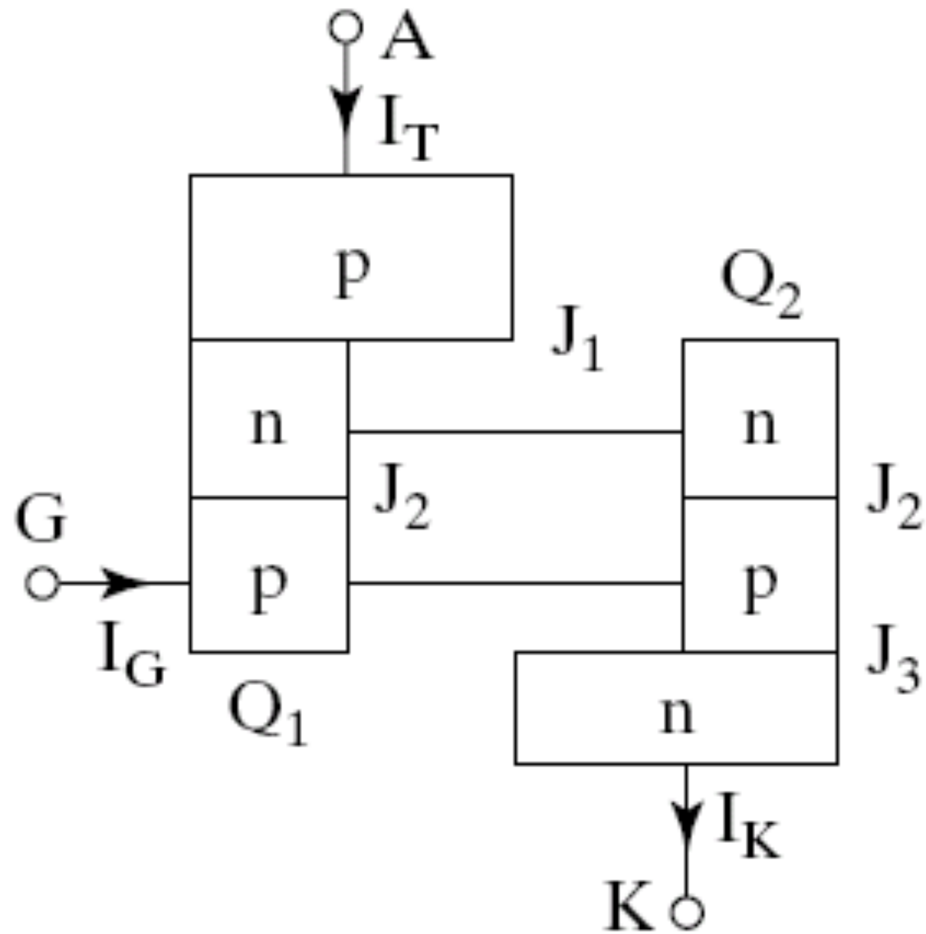
- Latching current is the minimum anode current that must flow through the SCR in order to latch it into ON state.
- Once $I_a > I_{latch}$ the SCR does not turn OFF even if the gate signal is removed.

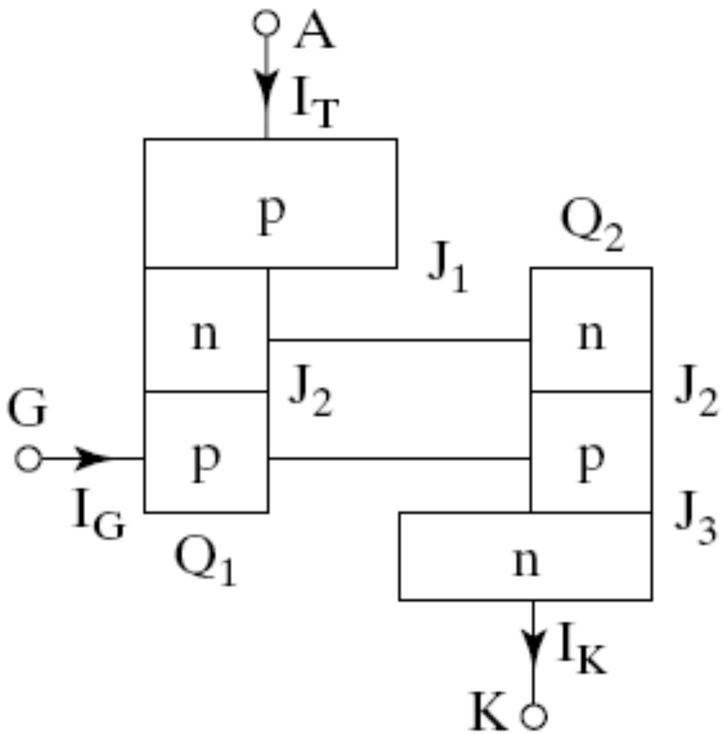
Holding Current

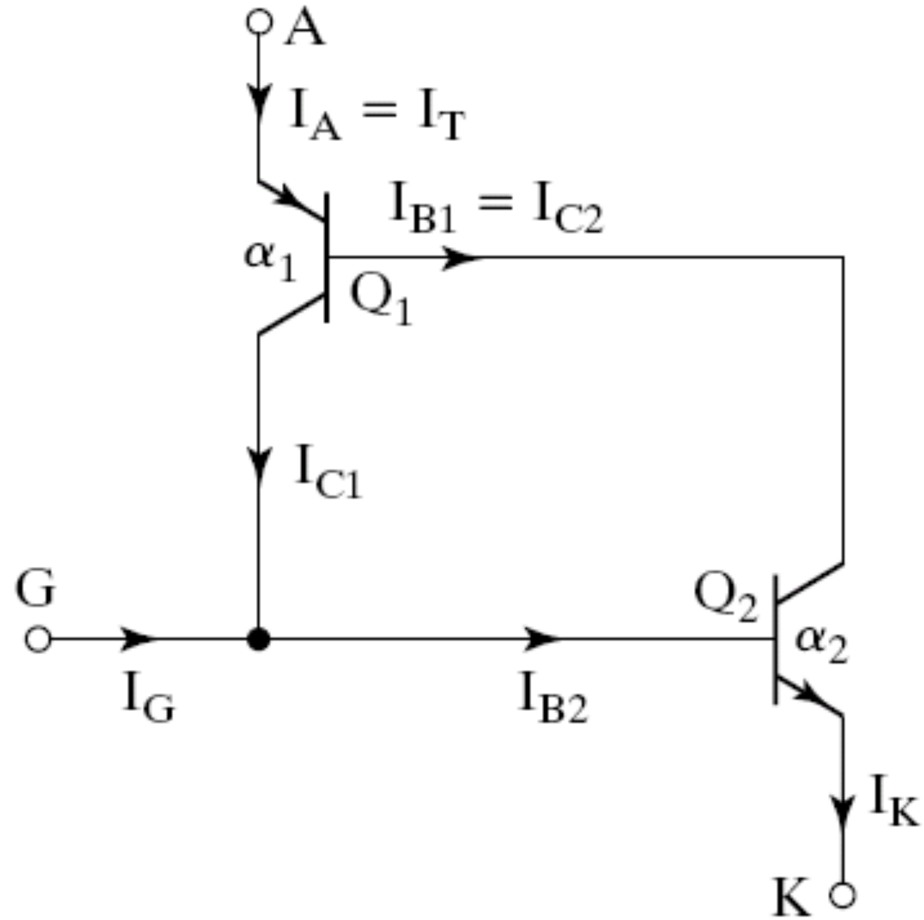
- Holding current I_h is the minimum anode current that must flow through the SCR in order to ‘hold’ it in ON state.
- Once SCR is on, it will go into OFF state only if the anode current falls below the minimum level called the HOLDING CURRENT (I_h)

Two Transistor Model of SCR






A
I_T
p
n
p
n
p
n
J_1
J_2
J_2
J_3
Q_2
Q_1
G
I_G
I_K
K


A
$I_A = I_T$
$I_{B1} = I_{C2}$
α_1
Q_1
I_{C1}
G
I_G
I_{B2}
Q_2
α_2
I_K
K

Derivation of anode current equation

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

The general transistor equations are,

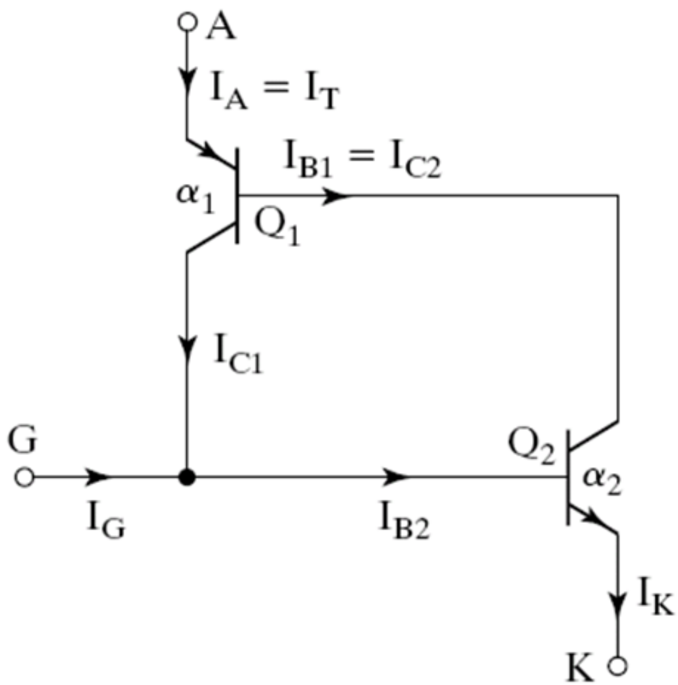
$$I_C = \beta I_B + (1+\beta) I_{CBO}$$

$$I_C = \alpha I_E + I_{CBO}$$

$$I_E = I_C + I_B$$

$$I_B = I_E (1-\alpha) - I_{CBO}$$

Applying the Eqns to the Transistor analogy



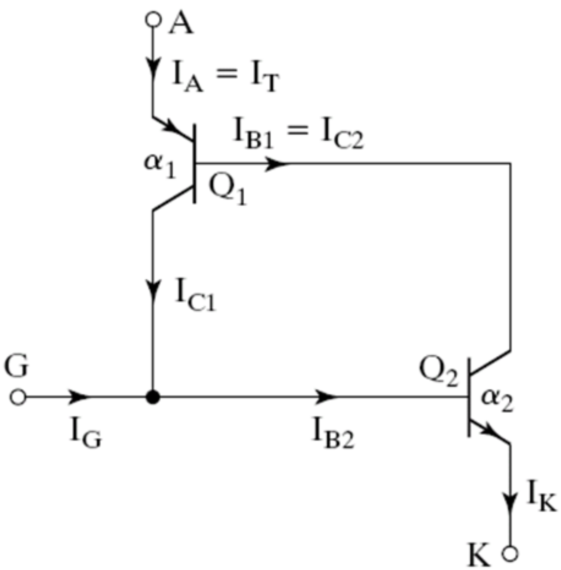
We have the following relations for T1 and T2

$$I_{C1} = \alpha_1 I_{e1} + I_{co1} \quad \text{—— (1)}$$

$$I_{C2} = \alpha_2 I_{e2} + I_{co2} \quad \text{—— (2)}$$

where α_1, α_2 are the common base current gain

I_{co1}, I_{co2} are the reverse leakage currents of the reverse biased jn J_2



for Tx. $T_1 \longrightarrow \quad I_{b1} = I_{e1} - I_{c1}$

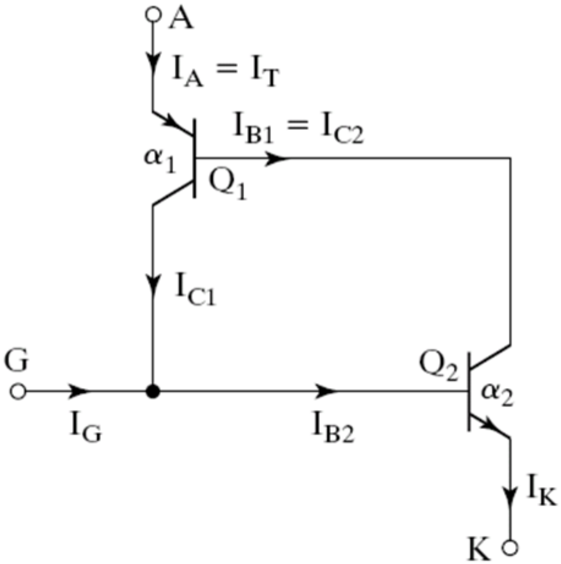
Sub. $I_{c1} = \alpha_1 I_{e1} + I_{co1}$

$I_{b1} = I_{e1} - \alpha_1 I_{e1} - I_{co1}$

$I_{b1} = (1-\alpha_1) I_{e1} - I_{co1}$ ———— (A)

From fig. (a) $I_a = I_{e1}$.

$\therefore I_{b1} = (1-\alpha_1) I_a - I_{co1}$



For $T_x \cdot T_2 \rightarrow I_{C2} = \alpha_2 I_{e2} + I_{CO2}$

From Fig (a) $I_{e2} = I_K$.

$$\therefore I_{C2} = \alpha_2 I_K + I_{CO2} \quad \text{—— (B)}$$

Since $I_{B1} = I_{c2}$

Equating eqn A and B we get

$$(1-\alpha_1) I_a - I_{CO1} = \alpha_2 I_K + I_{CO2} \quad \text{—— (C)}$$

From Fig it is seen that

$I_K = I_a + I_g$ sub, in eqn C

$$(1-\alpha_1) I_a - I_{CO1} = \alpha_2 (I_a + I_g) + I_{CO2}$$

$$(1-\alpha_1-\alpha_2) I_a = \alpha_2 I_g + I_{CO1} + I_{CO2}$$

$$[1-(\alpha_1+\alpha_2)]\, I_a = \alpha_2 I_g + I_{CO1} + I_{CO2}$$

$$I_a = \frac{\alpha_2 I_g + I_{CO1} + I_{CO2}}{[1-(\alpha_1+\alpha_2)]}$$

Assuming the leakage currents of T1 and T2 are negligible

$$\boxed{I_a = \frac{\alpha_2 I_g}{1-(\alpha_1+\alpha_2)}}$$

Significance of the anode current eqn.

$$I_a = \frac{\alpha_2 I_g}{1-(\alpha_1+\alpha_2)}$$

- Turn ON condition of SCR (Regenerative action) $\{(\alpha_1+\alpha_2) \geq 1\}$.

- As long as $(\alpha_1 + \alpha_2) < 1$, that is the current gains of both the transistors are small , anode current remains quite low (µA) and SCR is in BLOCKING STATE

- When $(\alpha_1 + \alpha_2) \geq 1$, REGENERATIVE ACTION begins and device goes from OFF to ON state.

- This turn on condition of SCR

i.e. $\{(\alpha_1+\alpha_2) \geq 1\}$.

can be satisfied by the following ways

1. By raising temperature (Thermal triggering)
2. By applying high voltage (forward voltage triggering)
3. By increasing the gate current

The Controlled Rectifier

- The controlled rectifier is the converter that changes the constant ac input to variable dc output.

- The ac input may be a single or three-phase supply

- Some rectifiers are based on semi controlled switching devices (mainly SCRs) others are based on fully controlled switching devices

Controlled Rectifier Applications

Using controlled rectifiers is the basic way to obtain variable voltage dc supply, which has many practical applications, such as:

- To supply variable speed dc motors
- For high voltage DC transmission systems
- Battery chargers
- Other applications require controlled current: e.g. electric arc welding

Single Phase Full Wave Controlled Rectifier

Rectification: is a process of converting AC to DC .

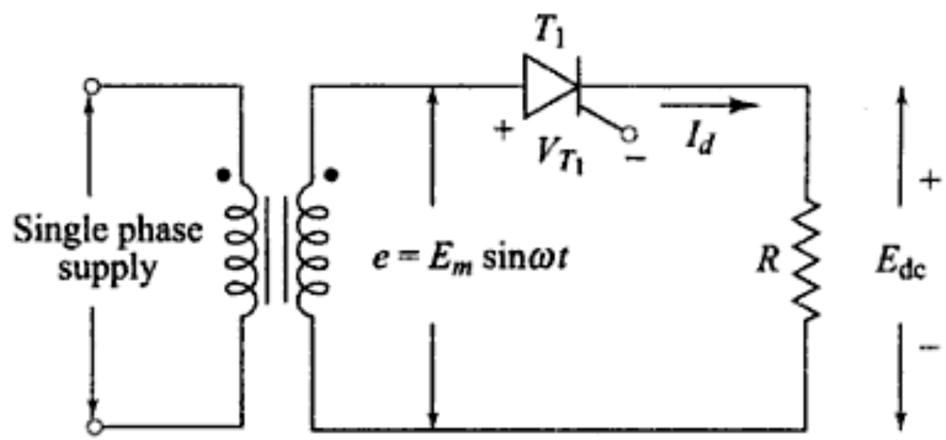
1. Uncontrolled Rectifier: uses only diodes and the dc output is fixed in amplitude by the amplitude of the AC supply.

2. Fully Controlled Rectifiers: There use thyristors as rectifying elements and the dc output voltage is a function of
   - The amplitude of the AC voltage applied
   - Output Voltage can be adjusted depending on yhe point of the AC input voltage at which the thyristor is triggered (α)

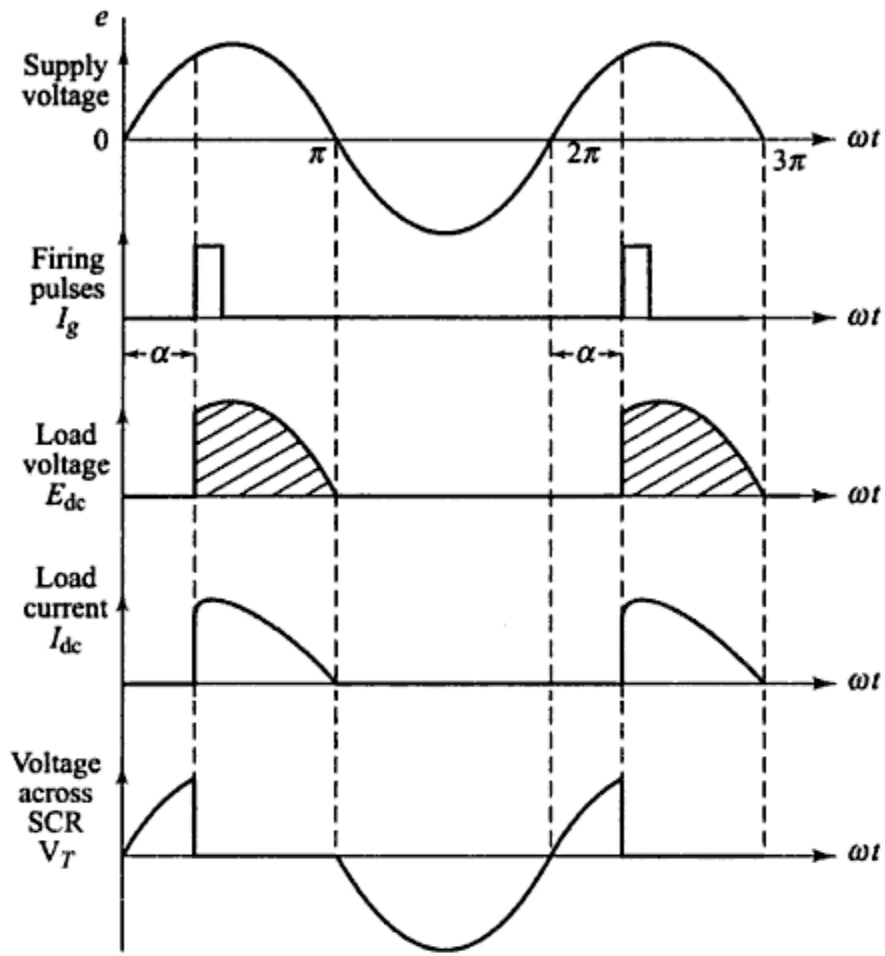
3. Half Controlled Rectifiers: There use thyristors and diodes as rectifying elements and allow a more limited control over the dc o/p voltage level.

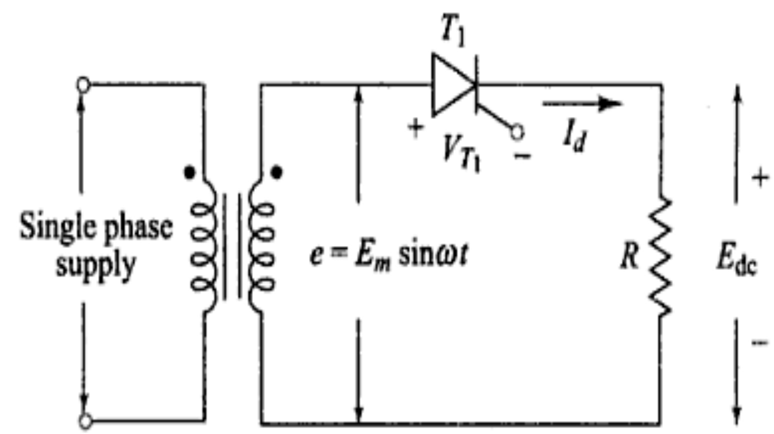
Single Phase
Half Wave Controlled Rectifier

Half Wave Controlled Rectifier with Resistive Load



Waveforms for a half-wave circuit





Voltage and Current Relations

(a) ***Average Load Voltage***

$$E_{dc} = \frac{E_m}{2\pi}[1 + \cos\alpha].$$

where E_m is the peak value of the a.c. input voltage

The maximum output voltage is obtained when $\alpha = 0$.

$$E_{dcmax} = \frac{E_m}{\pi}$$

(b) ***Average load current*** With resistive load, the average load current is directly proportional to the average load voltage divided by the load resistance:

$$\therefore \qquad I_d = \frac{E_m}{2\pi R}[1+\cos\alpha]$$

(c) ***RMS load voltage*** The RMS load voltage for a given firing angle α is given by

$$E_{\text{rms}} = E_m \left[\frac{\pi-\alpha}{4\pi} + \frac{\sin 2\alpha}{8\pi}\right]^{1/2}$$

For firing angle $\alpha = 0$, $E_{\text{rms}} = \dfrac{E_m}{2}$

Equations to be remembered

Average Load Voltage $E_{dc} = \frac{E_m}{2\pi}[1+\cos\alpha].$

Average load current $I_d = \frac{E_m}{2\pi R}[1+\cos\alpha]$

RMS load voltage $E_{rms} = E_m \left[\frac{\pi-\alpha}{4\pi} + \frac{\sin 2\alpha}{8\pi}\right]^{1/2}$

Single Phase
Full Wave Controlled Rectifier

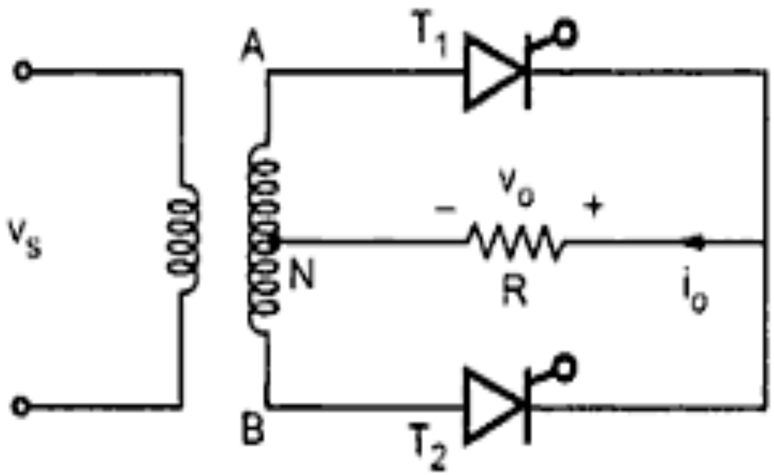
There are two basic configurations of full wave controlled rectifiers.

(1) Midpoint Converters

(2) Bridge Converters

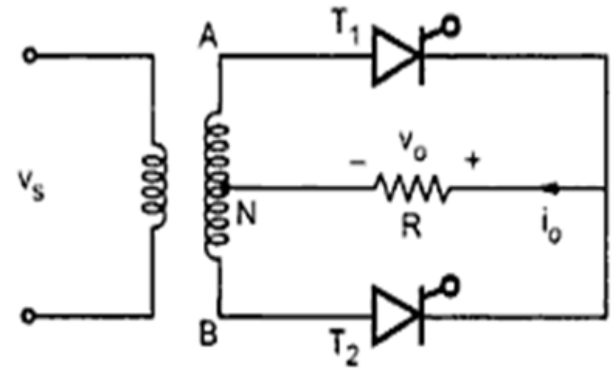
Full Wave Midpoint Converter (M-2 Converter)

The full wave converter rectifies both, positive as well as negative half cycles of the supply.

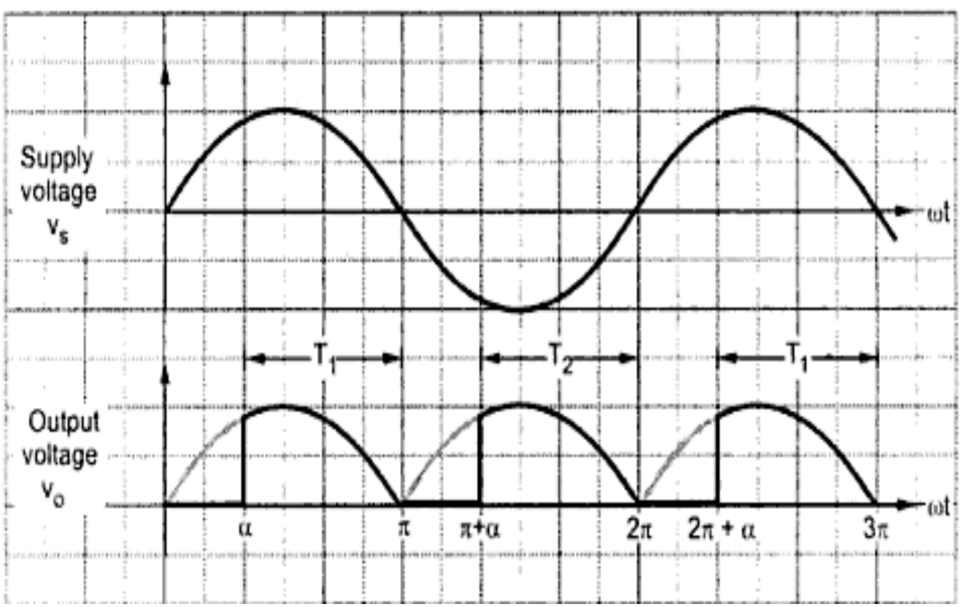


Circuit diagram of full wave mid point converter

Waveforms



T1
A
vs
vo
N
R
io
B
T2



Supply voltage vs
ωt
T1
T2
T1
Output voltage vo
ωt
α
π
π+α
2π
2π + α
3π

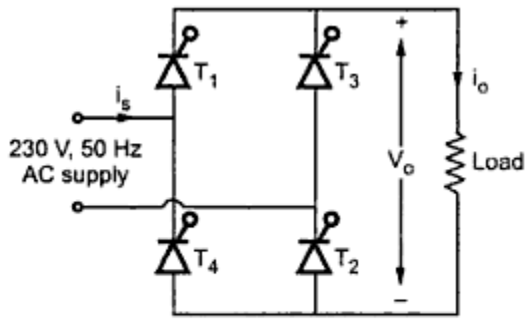
Mathematical Analysis

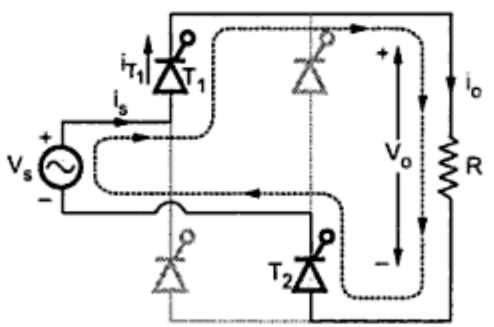
Average Load Voltage $E_{dc} = \frac{E_m}{\pi}[1 + \cos\alpha].$

Average load current $I_d = \frac{E_m}{\pi R}[1 + \cos\alpha]$

RMS load voltage $E_{rms} = E_m \left[\frac{\pi - \alpha}{2\pi} + \frac{\sin 2\alpha}{4\pi}\right]^{1/2}$

Fully Controlled Bridge Rectifier with Resistive Load





Conduction of T_1 and T_2 in positive half cycle of the supply.
Dotted line shows path of current flow