7. BIAS COMPENSATION

Compensation techniques are used to reduce the drift (change) of the operating point. Sometimes for excellent bias and thermal stabilisation both stabilisation as well as compensation techniques are used.

The compensation techniques are discussed as follows

a) Diode Compensation for instability due to V_{BE} Variation

- For Germanium transistor, changes in I_{co} with temperature contribute more problem than for silicon transistor. On the other hand, in a silicon transistor, the changes of V_{BE} with temperature possess significantly to the changes in I_c.
- Thus a diode may be used as compensation element for variation in V_{BE} or I_{CO}. In this case the diode is kept forward biased by the source V_{DD} and R_d. If the diode is of the same material as the transistor, then the voltage V_D across the diode has same temperature coefficient as V_{BE} of the transistor.

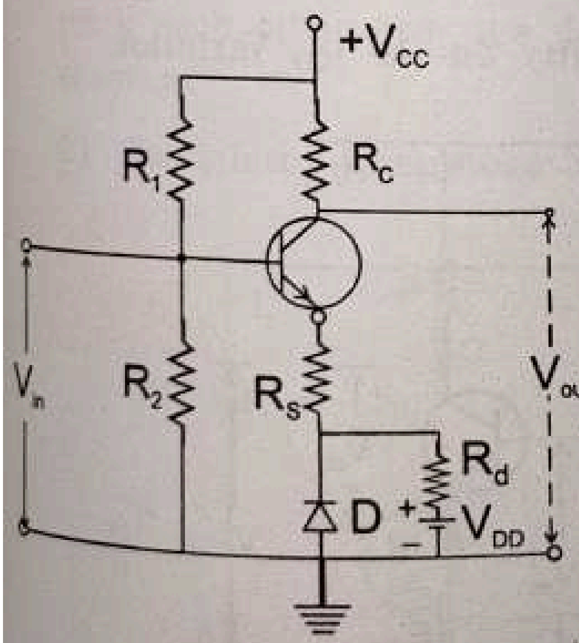


Figure 9(a) Self-bias with Stabilisation and Compensation

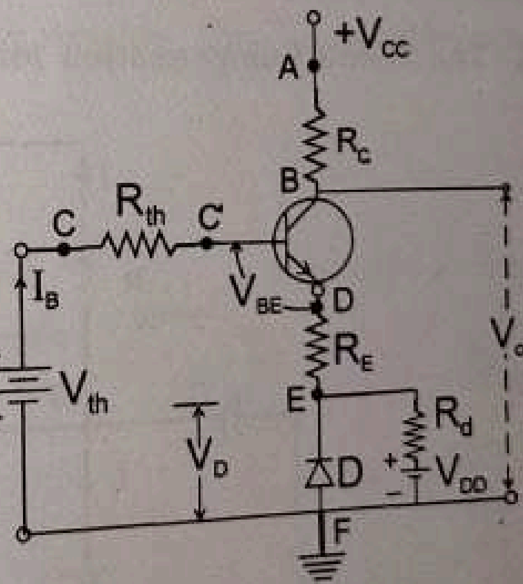


Figure 9(b) Thevenin's Equivalent Circuit

Applying Kirchhoff's voltage law to the base circuit in figure 9 [CC'DEFC]

$$V_{TH} = I_B R_{TH} + V_{BE} + I_E R_E - V_{DD} \quad (1)$$

$$= I_B R_{TH} + R_E(I_B + I_C)$$

$$V_{TH} - V_{BE} + V_D = I_B R_{TH} + R_E(I_B + I_C)$$

$$V_{TH} - V_{BE} + V_D = R_E I_C + (R_{TH} + R_E) I_B$$

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

or $$I_B = \frac{I_C - (1+\beta) I_{CO}}{\beta} \qquad (2)$$

thus $$V_{TH} - V_{BE} + V_D = R_E I_C + (R_{TH} + R_E)\left(\frac{I_C - (1+\beta) I_{CO}}{\beta}\right)$$

or $$\beta[V_{TH} - (V_{BE} - V_D)] = \beta R_E I_C + (R_{TH} + R_E) I_C - (1+\beta) I_{CO}(R_{TH}+R_E)$$

or $$\beta[V_{TH} - (V_{BE} - V_D)] + (1+\beta) I_{CO}(R_{TH}+R_E) = I_C[\beta R_E + R_{TH} + R_E]$$

$$\therefore \quad I_C = \frac{\beta\left[V_{TH} - (V_{BE} - V_D)\right] + (1+\beta) I_{CO}(R_{TH} + R_E)}{R_{TH} + (1+\beta) R_E} \qquad (3)$$

Since the variation in V_{BE} with temperature is the same as the variation in V_D with temperature hence $(V_{BE} - V_D)$ remains constant so I_C remains constant inspite of the variation in V_{BE}.

b) The Diode Compensation for instability due to I_{CO} Variation

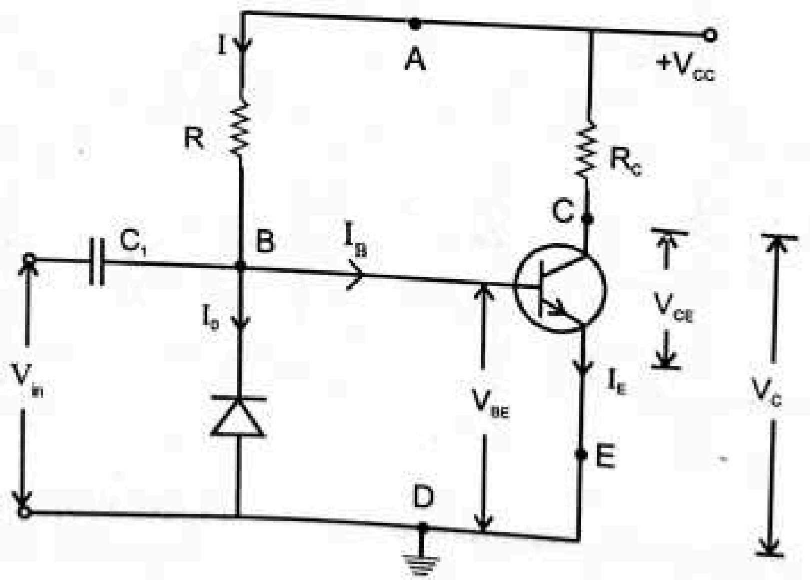


Figure 10 Diode Compensation

Figure 10 shows the circuit of a transistor amplifier with diode D used for compensation of variation in I_{co}. The diode D and the transistor are of the same type and the same material. So the reverse saturation current I_{co} of the diode will increase with temperature at the same rate as the transistor collector saturation current I_{co}.

Apply KVL to the base or input circuit (ABDA)

$$V_{CC} = I.R + V_{BE} \quad \text{or} \quad I = \frac{V_{CC} - V_{BE}}{R} \simeq \frac{V_{CC}}{R} \quad \because V_{CC} >> V_{BE}$$

The diode D is reverse biased by V_{BE}, we know that in case of Ge transistor V_{BE} is 0.3 volt. So the current through D is the reverse saturation current.

Now $I_B = I - I_0$

We know $I_C = \beta I_b + (1+\beta)I_{CO}$ (5)

hence $I_C = \beta(I - I_0) + (1+\beta)I_{CO}$

If $\beta >> 1$, $I_C = \beta I - \beta I_0 + \beta I_{CO}$ (6)

In this equation 'I' is almost constant and if I_O of diode 'D' and I_{CO} of transistor track each other over the desired temperature, then I_C remains essentially constant.

C) Thermistor Compensation

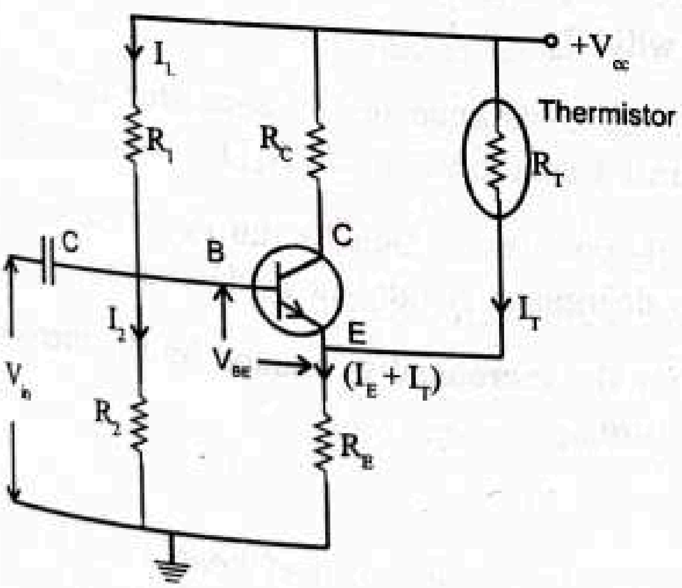


Figure 11 Thermistor Compensation

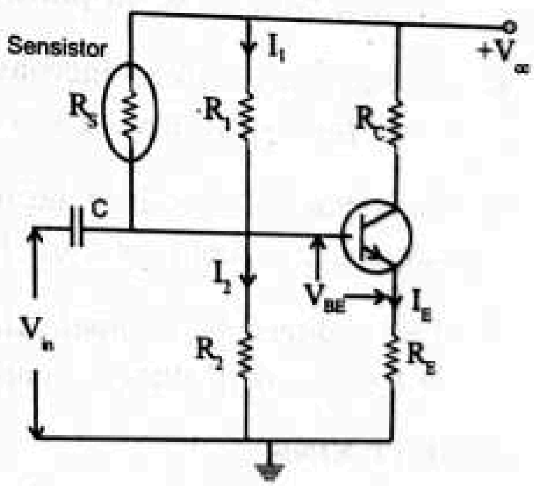


Figure 12 Sensistor Compensation

circuit

8.3 PRINCIPLE OF OPERATION AND CHARACTERISTICS OF VARACTOR DIODE

The varactor, also called a varicap, tuning or voltage variable capacitor diode, is also a junction diode with a small impurity dose at its junction, which has the useful property that its junction or transition capacitance is easily varied electronically.

When any diode is reverse biased, a depletion region is formed, as seen in Fig. 8.4(a). The larger the reverse bias applied across the diode, the width of the depletion layer "W" becomes wider. Conversely, by decreasing the reverse bias voltage, the depletion region width "W" becomes narrower. This depletion region is devoid of majority carriers and acts like an insulator preventing conduction between the N and P regions of the diode, just like a dielectric, which separates the two plates of a capacitor. The varactor diode with its symbol is shown in Fig. 8.4(b).

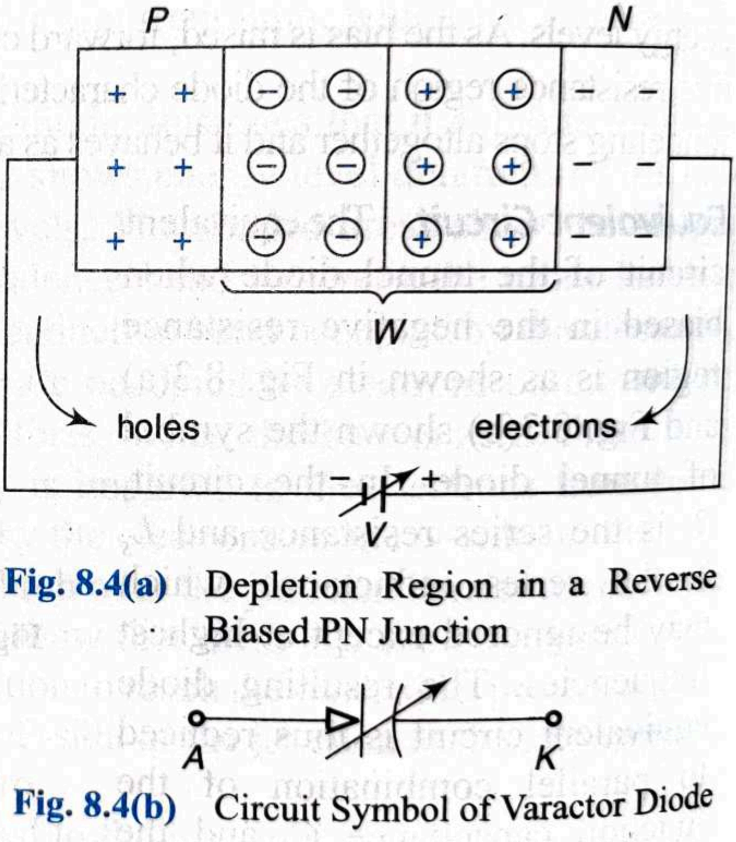


Fig. 8.4(a) Depletion Region in a Reverse Biased PN Junction

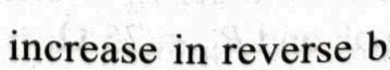
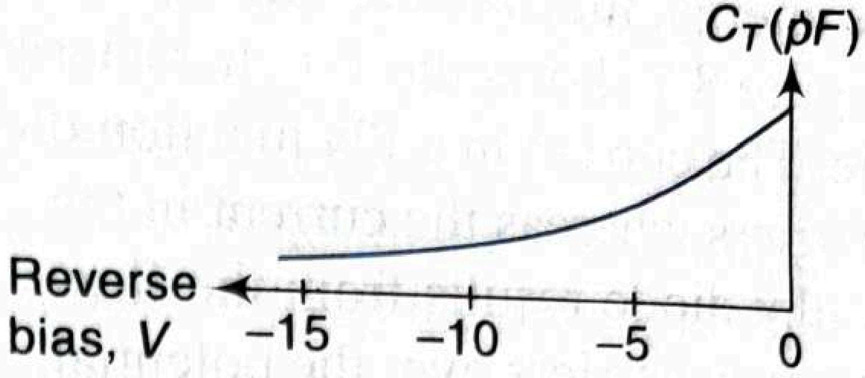


Fig. 8.4(b) Circuit Symbol of Varactor Diode

As the capacitance is inversely proportional to the distance between the plates $\left(C_T \propto \frac{1}{W}\right)$, the transition capacitance C_T varies inversely with the reverse voltage as shown in Fig. 8.5. Consequently, an increase in reverse bias voltage will result in an increase in the depletion region width and a subsequent decrease in transition capacitance C_T. At zero volt, the varactor depletion region W is small and the capacitance is large at approximately 600 pF. When the reverse bias voltage across the varactor is 15 V, the capacitance is 30 pF.



(b)

Fig. 8.5 Characteristics of Varactor Diode

The varactor diodes are used in FM radio and TV receivers, AFC circuits, self adjusting bridge circuits and adjustable bandpass filters. With improvement in the type of materials used and construction, varactor diodes find application in tuning of LC resonant circuit in microwave frequency multipliers and in very low noise microwave parametric amplifiers.

8.5 PRINICIPLE OF OPERATION OF SILICON CONTROLLED RECTIFIER (SCR)

Thyristor, in general, is a semiconductor device having three or more junctions. Such a device acts as a switch without any bias and can be fabricated to have voltage ratings of several hundred volts and current ratings from a few amperes to almost thousand amperes. The family of thyristors consists of PNPN diode (Shockley diode), SCR, LASCR, TRIAC, DIAC, GTO etc.

8.5.1 PNPN Diode (Shockley Diode)

As shown in Fig. 8.8, it is a four layer PNPN silicon device with two terminals. When an external voltage is applied to the device in such a way that anode is positive with respect to cathode, junctions J_1 and J_3 are forward biased and J_2 is reverse biased. Then the applied voltage appears across the reverse biased junction J_2. Now the current flowing through the device is only reverse saturation current.

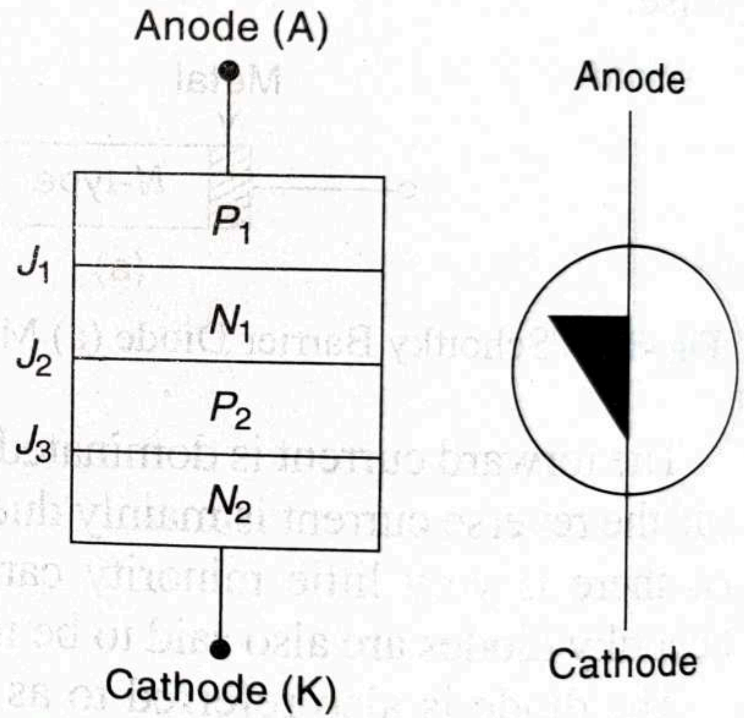


Fig. 8.8 PNPN Diode: (a) Basic Structure and (b) Circuit Symbol

However, as this applied voltage is increased, the current increases slowly until the so called firing or breakover voltage (V_{BO}) is reached. Once firing takes place, the current increases abruptly and the voltage drop across the device decreases sharply. At this point, the diode switches over from 'OFF' to 'ON' state. Once the device is fired into conduction, a minimum amount of current known a *holding current*, I_H, is required to flow to keep the device in ON state. To turn the device OFF from ON state, the current has to be reduced below I_H by reducing the applied voltage close to zero, i.e. below *holding voltage*, V_H. Thus the diode acts as a switch during forward bias condition. The characteristic curve of a PNPN diode is shown in Fig. 8.9.

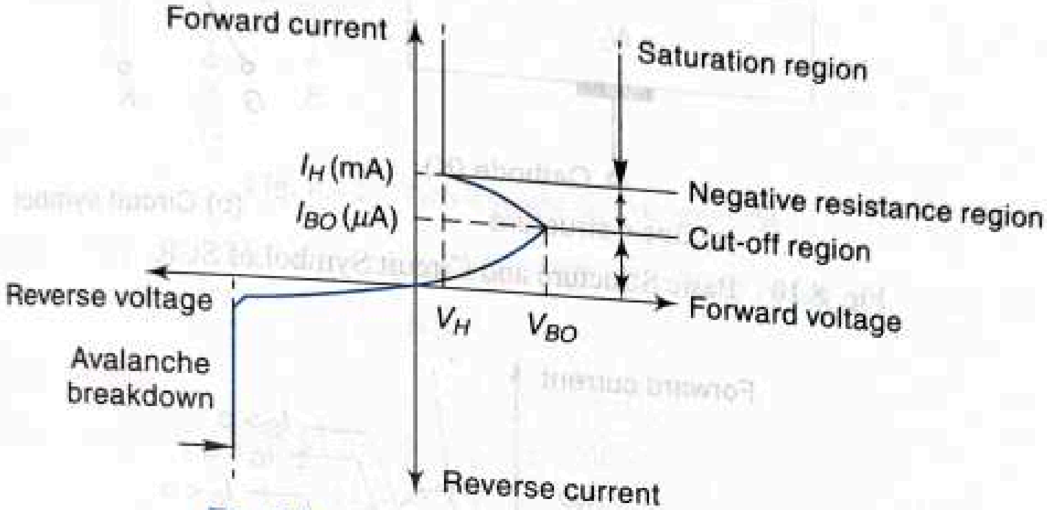


Fig. 8.9 Characteristic Curve of PNPN Diode

8.5.2 SCR (Silicon Controlled Rectifier)

The basic structure and circuit symbol of SCR is shown in Fig. 8.10. It is a four layer three terminal device in which the end P-layer acts as anode, the end N-layer acts as cathode and P-layer nearer to cathode acts as gate. As leakage current in silicon is very small compared to germanium, SCRs are made of silicon and not germanium.

Characteristics of SCR The characteristics of SCR are shown in Fig. 8.11. SCR acts as a switch when it is forward biased. When the gate is kept open, i.e. gate current $I_G = 0$, operation of SCR is similar to PNPN diode. When $I_G < 0$, the amount of reverse bias applied to J_2 is increased. So the breakover voltage V_{BO} is increased. When $I_G > 0$, the amount of reverse bias applied to J_2 is decreased thereby decreasing the breakover voltage. With very large positive gate current breakover may occur at a very low voltage such that the characteristics of SCR is similar to that of ordinary PN diode. As the voltage at which SCR is switched 'ON' can be controlled by varying the gate current I_G, it is commonly called as controlled switch. Once SCR is turned ON, the gate loses control, i.e. the gate cannot be used to switch the device OFF. One way to turn the device OFF is by lowering the anode current below the holding current I_H by reducing the supply voltage below holding voltage V_H, keeping the gate open.

SCR is used in relay control, motor control, phase control, heater control, battery chargers, inverters, regulated power supplies and as static switches.

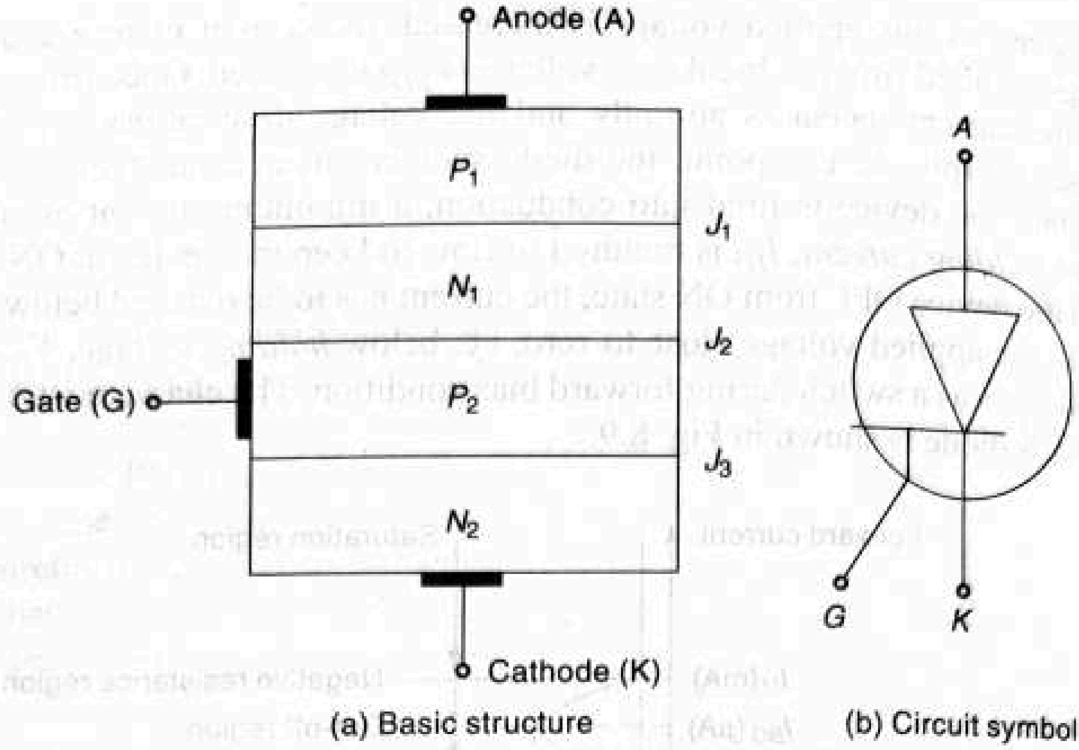


Fig. 8.10 Basic Structure and Circuit Symbol of SCR

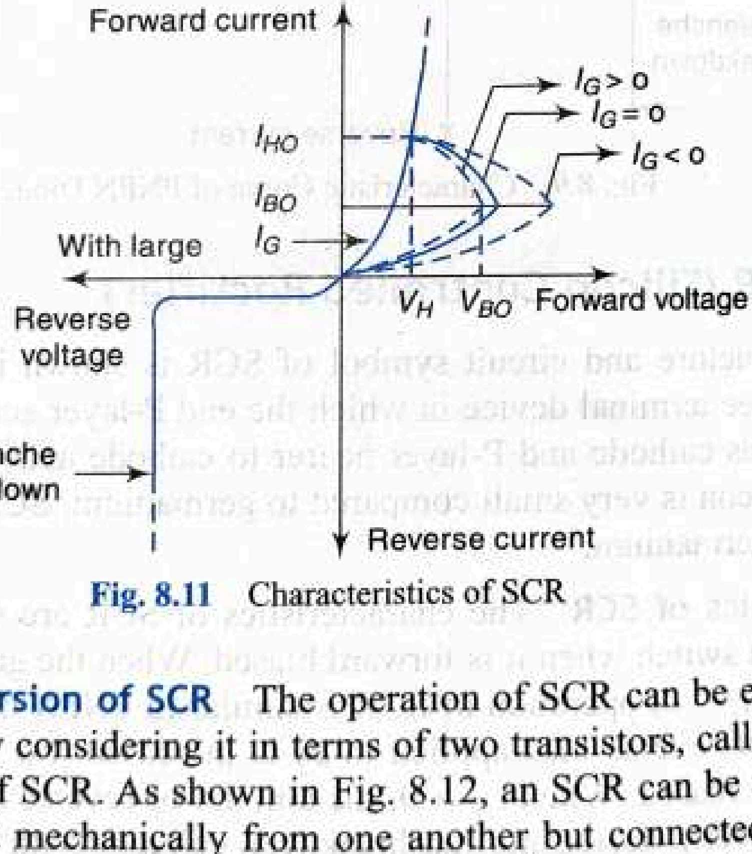


Fig. 8.11 Characteristics of SCR

Two transistor version of SCR The operation of SCR can be explained in a very simple way by considering it in terms of two transistors, called as the two transistor version of SCR. As shown in Fig. 8.12, an SCR can be split into two parts and displaced mechanically from one another but connected electrically. Thus the device may be considered to be constituted by two transistors T_1 (PNP) and T_2 (NPN) connected back to back.

Assuming the leakage current of T_1 to be negligibly small, we obtain

$$I_{b1} = I_A - I_{e1} = I_A - \alpha_1 I_A = (1 - \alpha_1) I_A \tag{8.1}$$

Also, from the Fig. 8.12, it is clear that

$$I_{b1} = I_{C2} \tag{8.2}$$

and

$$I_{C2} = \alpha_2 I_K \tag{8.3}$$

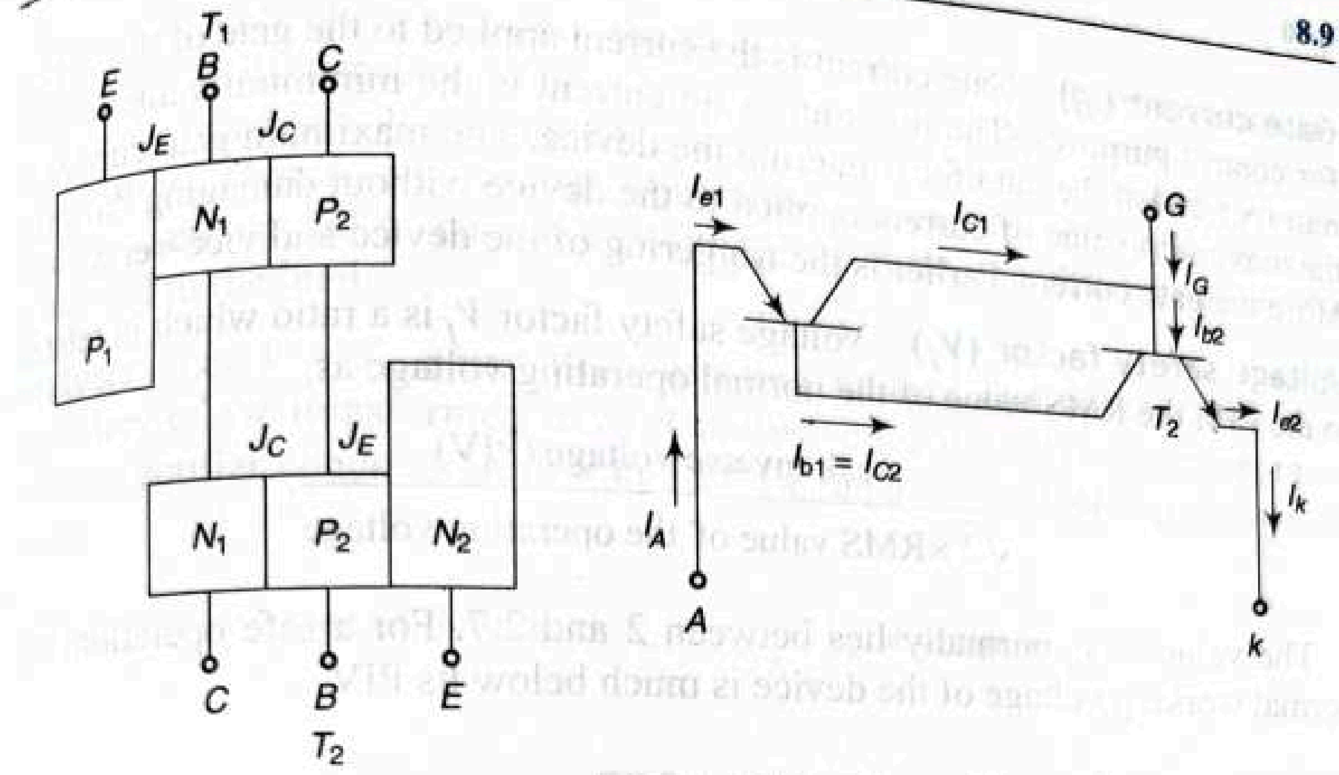


Fig. 8.12 Two Transistor Version of SCR

Substituting the values given in Eqs (8.2) and (8.3) in Eq. (8.1), we get

$$(1 - \alpha_1)\, I_A = \alpha_2 I_K \tag{8.4}$$

We know that
$$I_K = I_A + I_G \tag{8.5}$$

Substituting Eq. (8.5) in Eq. (8.4), we obtain

$$(1 - \alpha_1)\, I_A = \alpha_2 (I_A + I_G)$$

i.e.
$$(1 - \alpha_1 - \alpha_2)\, I_A = \alpha_2 I_G$$

i.e.
$$I_A = \left[\frac{\alpha_2 I_G}{1 - (\alpha_1 + \alpha_2)} \right] \tag{8.6}$$

Equation (8.6) indicates that if $(\alpha_1 + \alpha_2) = 1$, then $I_A = \infty$, i.e. the anode current I_A suddenly reaches a very high value approaching infinity. Therefore, the device suddenly triggers into ON state from the original OFF state. This characteristic of the device is known as its *regenerative action*.

The value of $(\alpha_1 + \alpha_2)$ can be made almost equal to unity by giving a proper value of positive current I_G for a short duration. This signal I_G applied at the gate which is the base of T_2 will cause a flow of collector current I_{C2} by transferring T_2 to its ON state. As $I_{C2} = I_{b1}$, the transistor T_1 will also be switched ON. Now, the action is regenerative since each of the transistors would supply base current to the other. At this point even if the gate signal is removed, the device keeps on conducting, till the current level is maintained to a minimum value of holding current.

8.5.3 Thyristor Ratings

Latching current (I_L) Latching current is the minimum current required to latch ... ON state. ... rent to hold with time, dV/dt.

Fig. 8.16 Light Activated SCR

8.6 PRINCIPLE OF OPERATION OF SEMICONDUCTOR PHOTODIODE

Silicon photodiode is a light sensitive device, also called *photodetector*, which converts light signals into electrical signals. The construction and symbol of a photodiode are shown in Fig. 8.17. The diode is made of semiconductor PN junction kept in a sealed plastic or glass casing. The cover is so designed that the light rays are allowed to fall on one surface across the junction. The remaining sides of the casing are painted to restrict the penetration of light rays. A lens permits light to fall on the junction. When light falls on reverse biased PN photodiode junction, hole-electron pairs are created. The movement of these hole-electron pairs in a properly connected circuit results in current flow. The magnitude of the photocurrent depends on the number of charge carriers generated and hence, on the illumination of the diode element. This

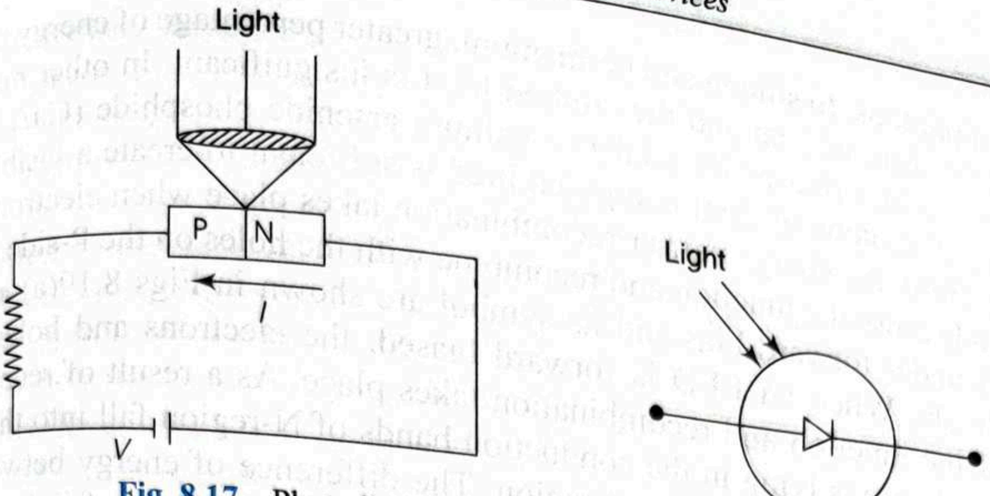


Fig. 8.17 Photodiode (a) Construction, and (b) Symbol

current is also affected by the frequency of the light falling on the junction of the photodiode. The magnitude of the current under large reverse bias is given by

$$I = I_S + I_o\,(1 - e^{V/\eta V_T})$$

Where I_0 = reverse saturation current
I_S = short-circuit current which is proportional to the light intensity
V = voltage across the diode
V_T = volt equivalent of temperature
η = parameter, 1 for Ge and 2 for Si.

The characteristics of a photodiode are shown in Fig. 8.18. The reverse current increases in direct proportion to the level of illumination. Even when no light is applied, there is a minimum reverse leakage current called *dark current*, flowing through the device. Germanium has a higher dark current than silicon, but it also has a higher level of reverse current.

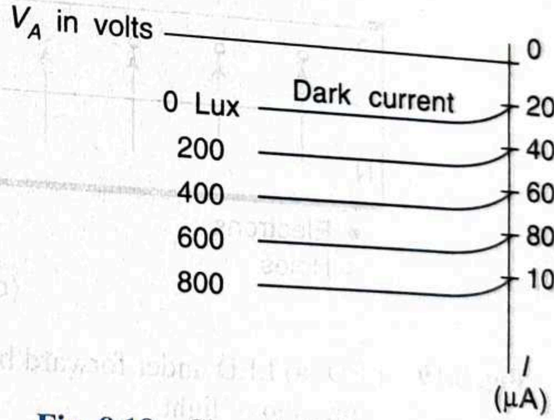


Fig. 8.18 Characteristics of Photodiode

Photodiodes are used as light detectors, demodulators and encoders. They are also used in optical communication system, high speed counting and switching circuits. Further, they are used in computer card punching and tapes, light operated switches, sound track films and electronic control circuits.

8.7 LIGHT EMITTERS

8.7.1 Light Emitting Diode (LED)

The Light Emitting Diode (LED) is a PN junction device which emits light when forward biased, by a phenomenon called electroluminescence. In all semiconductor PN junctions, some of the energy will be radiated as heat and some in the form of photons. In silicon and germanium, greater percentage of energy is given out in the form of heat and the emitted light is insignificant. In other materials such as gallium phosphide (GaP) or gallium arsenide phosphide (GaAsP), the number of photons of light energy emitted is sufficient to create a visible light source. Here, the charge carrier recombination takes place when electrons from the N-side cross the junction and recombine with the holes on the P-side.

LED under forward bias and its symbol are shown in Figs 8.19(a) and (b), respectively. When an LED is forward biased, the electrons and holes move towards the junction and recombination takes place. As a result of recombination, the electrons lying in the conduction bands of N-region fall into the holes lying in the valence band of a P-region. The difference of energy between the conduction band and the valance band is radiated in the form of light energy. Each recombination causes radiation of light energy. Light is generated by recombination of electrons and holes whereby their excess energy is transferred to an emitted photon. The brightness of the emitted light is directly proportional to the forward bias current.

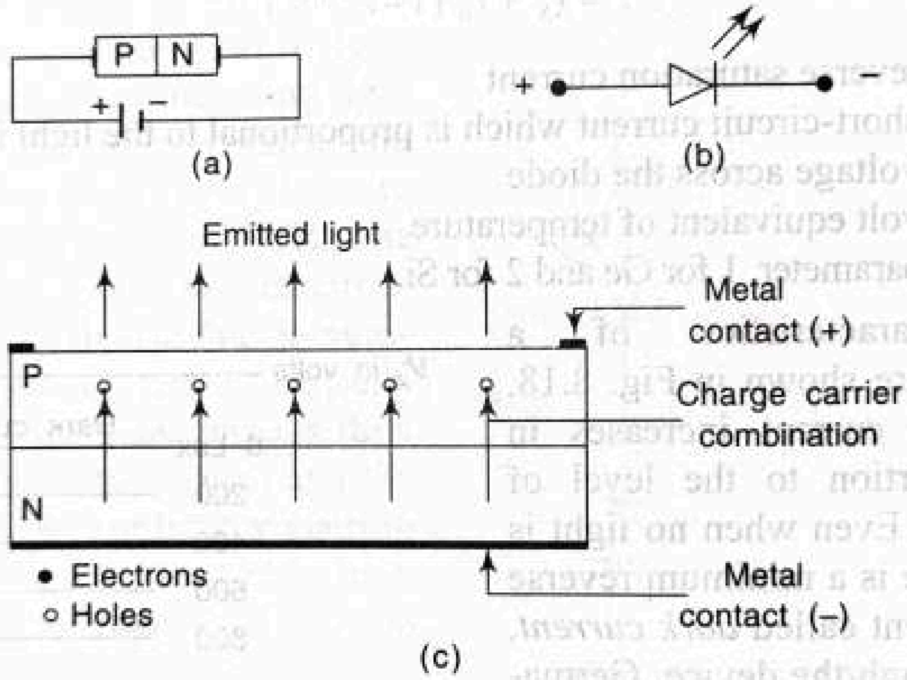


Fig. 8.19 LED (a) LED under forward bias, (b) Symbol, and (c) Recombinations and emission of light.

Figure 8.19(c) shows the basic structure of an LED showing recombination of carriers and emission of light. Here, an N-type layer is grown on a substrate and a P-type is deposited on it by diffusion. Since carrier recombination takes place in the P-layer, it is kept uppermost. The metal anode connections are made at the outer edges of the P-layer so as to allow more central surface area for the light to escape. LEDs are manufactured with domed lenses in order to reduce the reabsorption problem. A metal (gold) film is applied to the bottom of the substrate for reflecting as much light as possible to the surface of the device and also to provide cathode connection. LEDs are always encased to protect their delicate wires.

The efficiency of generation of light increases with the increases in injected current and with a decrease in temperature. The light is concentrated near the junction as the carriers are available within a diffusion length of the junction.