the transistor and cause wastage of supply power. Moreover, a higher zero signal I_C will reduce the value of collector resistance R_C for the given V_{CC} and so reduction in voltage gains.

Example 11.31. Draw the circuit of a common-emitter amplifier with emitter bias (or self bias). Derive relation for stability factor $S = \dfrac{\delta I_C}{\delta I_{CO}}$ for such a circuit.

In the above circuit, let V_{CC} = 20 V, R_E = 1 kΩ and β = 100 for silicon transistor. Design the values for different resistors in the circuit so that S = 10 and I_C = 2 mA.

Solution: Given that V_{CC} = 20 V; R_E = 1,000 Ω; β = 100; S = 10; I_C = 2 mA

$$\text{Base current, } I_B = \frac{I_C}{\beta} = \frac{2 \times 10^{-3}}{100} = 20 \times 10^{-6}\,\text{A}$$

$$\text{Emitter current, } I_E = I_B + I_C$$
$$= 20 \times 10^{-6} + 2 \times 10^{-3} = 2.02\ \text{mA}$$

From Eq. (11.21)

$$S = \frac{1+\beta}{1+\beta\dfrac{R_E}{R_{Th}+R_E}}$$

$$\therefore 10 = \frac{1+100}{1+100\times\dfrac{1,000}{R_{TH}+1,000}} \quad \text{or} \quad R_{TH} = 9,989\ \Omega$$

$$V_{TH} = I_B R_{TH} + V_{BE} + I_E R_E$$
$$= 20 \times 10^{-6} \times 9,889 + 0.7 + 2.02 \times 10^{-3} \times 1,000$$
$$= 2.918\ \text{V}$$

$$R_1 = R_{TH} \times \frac{V_{CC}}{V_{TH}} = \frac{9,889 \times 20}{2.918} = 67.8\ \text{k}\Omega\ \textbf{Ans.}$$

$$\text{and } R_2 = \frac{V_{Th} \times R_1}{V_{CC} - V_{TH}} = \frac{2.918 \times 67.8 \times 10^3}{20 - 2.918} = 11.6\ \text{k}\Omega\ \textbf{Ans.}$$

11.7. BIAS COMPENSATION

During the discussion made for various biasing methods for providing stability to the operating point we have seen that self bias (or potential divider bias) and collector-to-base bias circuits provide better operating point stability but in both arrangements the stabilization is provided due to negative feedback action of the circuit. Although the negative feedback improves the operating point stability but it also reduces drastically the amplification of the signal. In certain applications, the loss in the signal gain may be intolerable and in such cases it is better to use compensating techniques in order to reduce the drift of the operating point. Sometimes both stabilization and compensation techniques are used for providing excellent bias and thermal stabilization. In compensation techniques temperature-sensitive devices such as diodes, transistors, thermistors, sensistors etc. are used to provide compensation for variations in currents.

11.7.1. Diode Compensation For Variations in Base-Emitter Voltage V_{BE}.

A circuit utilizing the self-bias stabilization and diode compensation is shown in Fig. 11.37. The Thevenin's equivalent circuit is given in Fig. 11.38. The diode is kept forward biased by the source V_{DD} and resistor R_D. The diode employed is of the same material and type as the transistor and as a consequence the voltage across the diode has the same temperature coefficient (–2.5 mV per °C) as V_{BE} of the transistor.

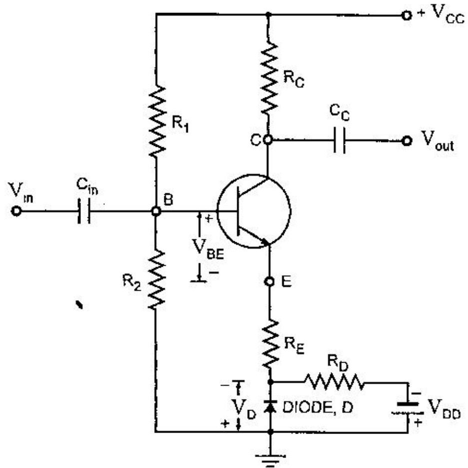

Fig. 11.37. ***Stabilization Circuit Using Self Bias and Diode Compensation Techniques***

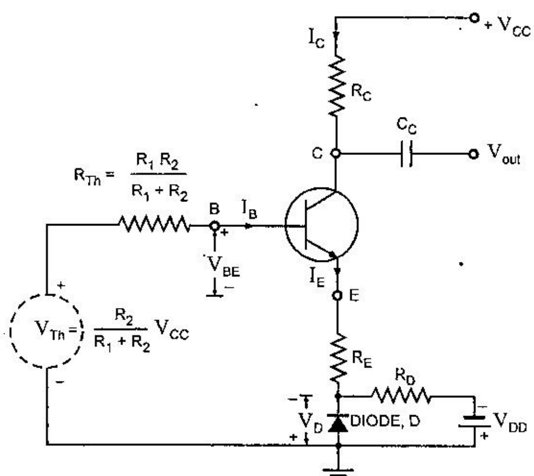

Fig. 11.38. ***Simplified Equivalent Circuit of Circuit Shown in Fig. 11.37***

Applying Kirchhoff's voltage law to the base portion of the circuit shown in Fig. 11.38, we have

$$V_{Th} = I_B R_{Th} + V_{BE} + I_E R_E - V_D$$
$$= I_B R_{Th} + V_{BE} + (I_B + I_C) R_E - V_D \qquad \because I_E = I_B + I_C$$
$$= I_B (R_{Th} + R_E) + I_C R_E + V_{BE} - V_D$$
$$= \left[\frac{I_C - (1+\beta) I_{CO}}{\beta}\right](R_{Th} + R_E) + I_C R_E + V_{BE} - V_D \qquad \because I_C = \beta I_B + (1+\beta) I_{CO}$$

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

or Collector current,

$$I_C = \frac{\beta\left[V_{Th} - (V_{BE} - V_D) + (1+\beta) I_{CO} (R_{Th} + R_E)\right]}{R_{Th} + (1+\beta) R_E} \qquad \text{...(11.36)}$$

Since variations in V_{BE} and V_D are the same due to temperature variation, so $(V_{BE} - V_D)$ remains unchanged in above Eq. (11.36) and collector current I_C, therefore, becomes insensitive to variations in V_{BE}. In practice, the compensation of V_{BE} as explained above is not perfect but it is sufficiently effective to take care of a great part of transistor drift due to variations in V_{BE}.

11.7.2. Diode Compensation For Variations in I_{CO}. We have seen that in silicon transistors the variations in base-emitter voltage V_{BE} due to temperature variations contribute significantly towards collector current variations. On the other hand, in case of germanium transistors, changes in reverse saturation current I_{CO} with temperature variations result in more serious problem in collector current stability. The circuit using diode compensation for a germanium transistor is given in Fig. 11.39. The diode D used in circuit is of the same material and type as the transistor. So the reverse saturation current of transistor I_{CO} and that of the diode, I_0 will increase at the same rate with the increase in temperature.

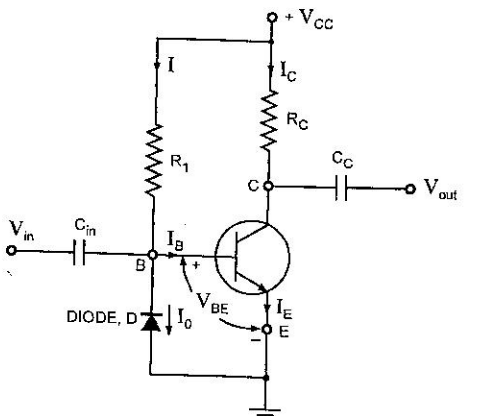

Fig. 11.39. *Circuit Using Diode Compensation For a Germanium Transistor*

From circuit diagram shown in Fig. 11.39.

$$I = \frac{V_{CC} - V_{BE}}{R_1} \simeq \frac{V_{CC}}{R_1} = \text{constant}$$

$\because$ V_{BE} is negligibly small in comparison with V_{CC}.

Since diode is reverse-biased by base-emitter voltage V_{BE} (0.3 V in case of Ge transistor), the current through diode is the reverse saturation current I_0.

Now base current $I_B = I - I_0$

Substituting $I_B = (I - I_0)$ in equation of collector current,

$$I_C = \beta I_B + (1 + \beta) I_{CO} \text{ we have}$$

Collector current, $I_C = \beta I - \beta I_0 + (1 + \beta) I_{CO}$ ...(11.37)

From Eq. (11.37) it is obvious that if $\beta >> 1$ and if I_0 of diode and I_{CO} of transistor track each other over the desired temperature range, then collector current I_C remains essentially constant.

11.7.3. Thermistor Compensation. Circuit using thermistor compensation in a self-bias CE amplifier is shown in Fig. 11.40. The thermistor R_T has a negative temperature coefficient (resistance decreasing exponentially with increasing temperature T). The thermistor R_T is used in the circuit to minimize the increase in collector current due to variations in I_{CO}, V_{BE} or β with temperature. With the increase in temperature, the resistance of the thermistor decreases and consequently current supplied to the emitter resistance R_E through R_T increases. The voltage drop across emitter resistance R_E is in the direction to reverse-bias the transistor. Thus the temperature sensitivity of R_T acts as to compensate the increase in collector current I_C due to rise in temperature T.

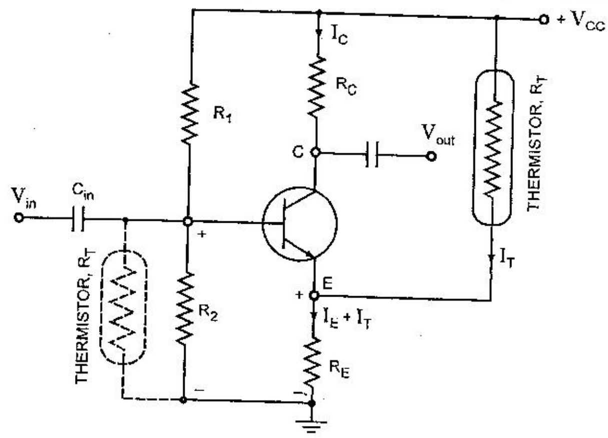

Fig. 11.40. *Circuit Using Thermistor Compensation in a Self-Biased CE Amplifier*

The thermistor can also be placed, as an alternative, in the base circuit across R_2 instead of in collector circuit, as shown dotted in the Fig. 11.40. With the increase in temperature T, voltage drop across R_T decreases and thus the forward-biasing base voltage decreases. As a result collector current I_C decreases and thus increase in I_C due to increase in temperature is compensated for.

11.7.4. Sensistor Compensation. Instead of a thermistor, it is possible to use a temperature-sensitive resistor with a positive temperature coefficient such as metal or *sensistor*. The sensistor has a temperature coefficient of resistance of 0.007 per °C (over the range from – 60°C to 150°C). Sensistor is a heavily doped semiconductor. The sensistor may be placed either in parallel with R_1, as illustrated in Fig. 11.41 or in parallel with R_E, as shown dotted in Fig. 11.41. Sensistor can also be placed in place of R_E rather than in parallel with R_E. With the increase in temperature, the resistance of the sensistor R_S increases and so the resistance of parallel combination $(R_S \parallel R_1)$. As a result the voltage drop across R_2 decreases thereby decreasing the net forward emitter bias. Thus collector current I_C decreases compensating increase in collector current due to increase in I_{CO}, β or V_{BE} because of temperature rise.

The same result is obtained if the sensistor R_S is placed in parallel with (or in place of) emitter resistor R_E.

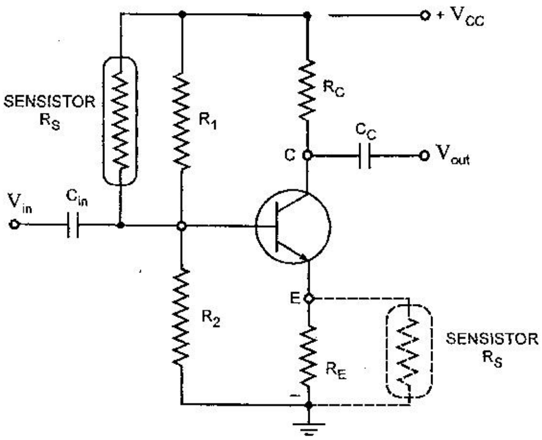

Fig. 11.41. ***Circuit Using Sensistor Compensation in Self-Biased CE Amplifier***

11.8. THERMAL RESISTANCE

With power transistors, a designer often uses a heat sink to get a higher power rating for the transistor. As already mentioned the heat sink allows the internally generated heat to escape more easily from the transistor. This reduces the junction temperature, equivalent to increasing the maximum power rating. *Thermal resistance*, θ, is the resistance to heat flow between two temperature points. Heat flows from the transistor case to the heat sink and on to the surrounding air. As this heat flows from the case to the heat sink, it encounters thermal resistance θ_{CS}. When the heat flows from sink to the surrounding air, it encounters thermal resistance θ_{SA}. As a guide, θ_{CS} is from 0.2 to 1°C per watt and θ_{SA} is from 1 to 100°C per watt, depending on the size of the heat sink, number of fins, finish, and other factors.

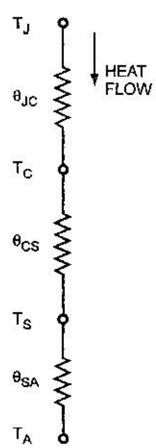

Fig. 11.42. ***Thermal Resistance***

The transistor power dissipation P_D is the same as the rate at which heat flows out of transistor. In thermodynamics, the rate of heat flow is analogous to current, thermal resistance to resistance, and temperature difference to voltage.

If T_1 and T_2 are the temperatures of two points, then by Ohm's law concept

$$P_D = \frac{T_1 - T_2}{\theta} \qquad \text{...(11.38)}$$

or $\theta = (T_1 - T_2)/P_D$

Total thermal resistance between the casing and surroundings

$$\theta_{CA} = \theta_{CS} + \theta_{SA}$$

and $\theta_{JA} = \theta_{CA} + \theta_{JC}$ in °C/W or °C/mW

and $$P_D = \frac{T_J - T_A}{\theta_{JA}} \qquad \text{...(11.39)}$$

where T_J is the junction temperature, T_A is the ambient temperature and θ_{JA} is the thermal resistance between junction and surrounding air.

Example 11.32. A power transistor has a thermal resistance of 200°C/watt. Find the maximum permissible power dissipation for the maximum junction temperature of 95°C and the ambient temperature of 25°C.
When a heat sink is used with the above transistor, the value of θ is reduced to 50°C/W. Determine the maximum permissible power dissipation.

Solution : *Without heat sink,* $T_{J\,max} = 95°C$; $T_A = 25°$, $\theta_{JA} = 200°C/watt$, so

$$\text{Power dissipation, } P_D = \frac{T_{J\,max} - T_A}{\theta_{JA}} = \frac{95-25}{200}$$

$= 0.35$ W or 350 mW **Ans.**

With heat sink, θ_{JA} becomes, 50°C/W, so

$$\text{New power dissipation } P_D = \frac{95-25}{50} = 1.4 \text{ W} \quad \textbf{Ans.}$$

Thus with the use of heat sink, permissible power dissipation is increased 4 times as compared to that when no heat sink is used.

11.9. CONDITION FOR THERMAL STABILITY

The condition required to avoid the thermal runaway is given below :

The rate at which heat is released at the collector junction must not exceed the rate at which the heat can be dissipated under steady-state condition

$$i.e. \quad \frac{\partial P_C}{\partial T_j} < \frac{\partial P_D}{\partial T_j} \qquad \text{...(11.40)}$$

where P_C is the heat released at collector and P_D is the maximum power dissipated.

From Eq. (11.39)

$$T_j - T_A = \theta_{jA} P_D$$

Differentiating above equation w.r.t. T_j we have

$$1 = \theta_{jA} \frac{\partial P_D}{\partial T_j}$$

or $$\frac{\partial P_D}{\partial T_j} = \frac{1}{\theta_{jA}}$$

Substituting $\frac{\partial P_D}{\partial T_j} = \frac{1}{\theta_{jA}}$ in Eq. (11.40) we have

$$\frac{\partial P_C}{\partial T_j} < \frac{1}{\theta_{jA}} \qquad \text{...(11.41)}$$

The condition expressed by Eq. (11.41) is the condition which must be satisfied to avoid thermal runaway. By suitable design, it is possible to ensure that the transistor cannot runaway before a specified ambient temperature or even under any condition.