Various Bias Compensation Methods

The 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 Bias Compensation techniques in order to reduce the drift of the operating point.

Sometimes both stabilization and bias compensation techniques are used for providing excellent bias and thermal stabilization. In Bias Compensation Methods temperature-sensitive devices such as diodes, transistors, thermistors, etc. are used to provide compensation for variations in currents.

Diode Compensation for Variations in Base-Emitter Voltage V_{BE}

A circuit utilizing the self-bias stabilization and diode compensation is shown in below Figure.

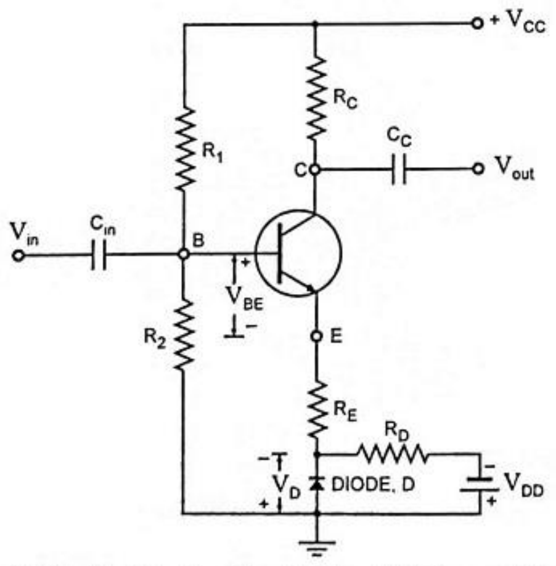

Fig. 12.54 *Stabilization Circuit Using Self Bias and Diode Compensation Techniques*

The Thevenin's equivalent circuit is given in Figure as follows;

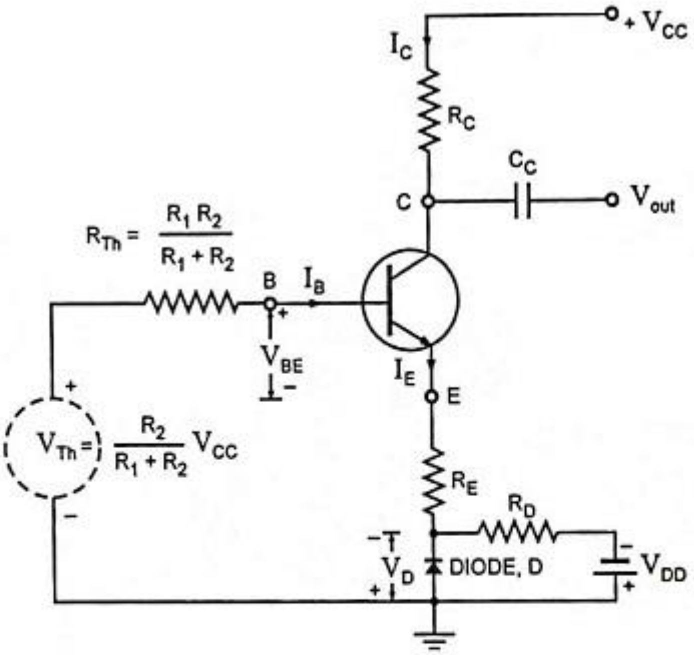

Fig. 12.55 *Simplified Equivalent Circuit of Circuit Shown in Fig. 12.54*

The diode is kept forward biased by the source VDD and resistor RD. 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 VBE of the transistor. Applying Kirchhoff's voltage law to the base portion of the circuit shown in Fig. 12.55, we have

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

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

or Collector current,

$$
I_C = \frac{\beta[V_{Th} - (V_{BE} - V_D) + (1+\beta) I_{CO} (R_{Th} + R_E)]}{R_{Th} + (1+\beta) R_E} \quad ...(12.48)
$$

Since variations in VBE and VD are the same due to temperature variation, so (VBE – VD) remains unchanged in above Eq. (12.48) and collector current IC, therefore, becomes insensitive to variations in VBE. In practice, the compensation of VBE 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 VBE.

Diode Compensation For Variations in I_{CO}

In silicon transistors the variations in base-emitter voltage VBE 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 amplifier is given in Fig. 12.56. 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, Io will increase at the same rate with the increase in temperature.

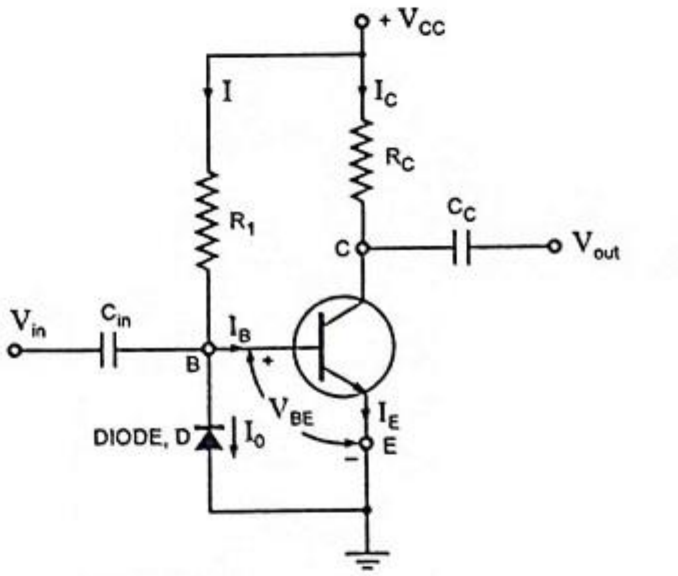

Fig. 12.56 *Circuit Using Diode Compensation For a Germanium Transistor*

From circuit diagram shown in Fig. 12.56.

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

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

Since diode is reverse biased by base-emitter voltage VBE (0.3 V in case of Ge transistor), the current through diode is the reverse saturation current I0. Now base current $I_B = I - I_0$, Substituting $I_B = (I - I_0)$ in equation of collector current,

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

$$I_C = \beta I - \beta I_0 + (1 + \beta)I_{CO} \qquad ...(12.49)$$

From Eq. (12.49) it is obvious that if $\beta \gg 1$ and if Io of diode and I_{CO} of transistor track each other over the desired temperature range, then collector current IC remains essentially constant.

Thermistor Compensation

Circuit using thermistor compensation in a self-bias CE amplifier is shown in Fig. 12.57. The thermistor R_T has a negative temperature coefficient of resistance (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 and therefore, collector current I_C remains constant.

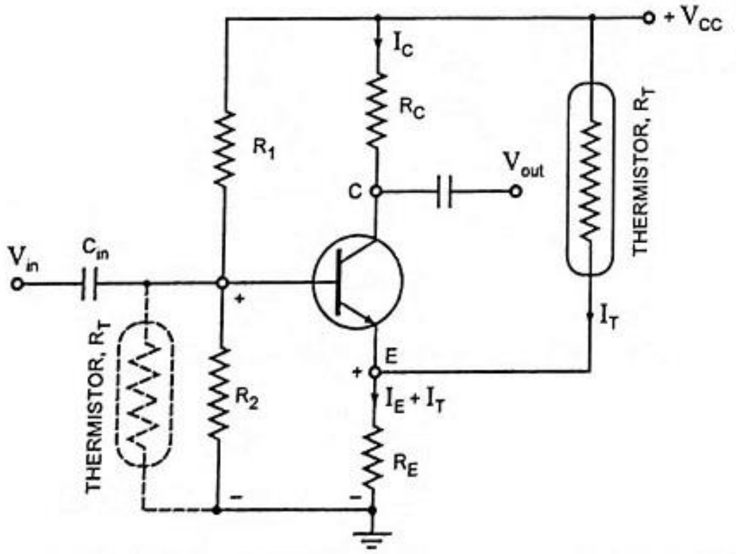

Fig. 12.57 *Circuit Using Thermistor Compensation in a Self-Biased CE Amplifier*

The thermistor can also be placed, as an alternative, in the base circuit across R2 instead of in collector circuit, as shown dotted in the Fig. 12.57. With the increase in temperature T, voltage drop across RT decreases and thus the forward-biasing base voltage decreases. As a result collector current IC decreases and thus increase in I_C due to increase in temperature is compensated for.

Thermal Runaway

The collector current for the CE circuit is given by $I_C = \beta I_B + (1+\beta)I_{CO}$. The three variables in the equation, **β , I_B and I_{CO}** increases with rise in temperature. In particular, the reverse saturation current or leakage current **I_{CO} changes greatly with temperature.** Specifically, it doubles for every 10^{o}C rise in temperature. The **collector current I_C** causes the collector base junction temperature to rise which in turn, **increase I_{CO}**, as a result **I_C** will increase still further, which will further rise the temperature at the collector base junction. This process will become cumulative leading at the collector base junction. This process will become cumulative leading to ***"thermal runaway".*** Consequently, the ratings of the transistor are exceeded which may destroy the transistor itself.

The collector is made larger in size than the emitter in order to help the heat developed at the collector junction. However if the circuit is designed such that the base current I_B is made to decrease automatically with rise in temperature, then the decrease in **βI_B** will compensate for increase in the $(1+\beta)I_{CO}$, keeping **I_C** almost constant.