IV TRANSISTOR BIASING AND STABILIZATION

4.1 NEED FOR TRANSISTOR BIASING:

If the o/p signal must be a faithful reproduction of the i/p signal, the transistor must be operated in active region. That means an operating point has to be established in this region . To establish an operating point (proper values of collector current I_c and collector to emitter voltage V_{CE}) appropriate supply voltages and resistances must be suitably chosen in the ckt. This process of selecting proper supply voltages and resistance for obtaining desired operating point or Q point is called as biasing and the ckt used for transistor biasing is called as biasing ckt.

There are four conditions to be met by a transistor so that it acts as a faithful ampr:

1) Emitter base junction must be forward biased (V_{BE}=0.7Vfor Si, 0.2V for Ge) and collector base junction must be reverse biased for all levels of i/p signal.

2) V_{ce} voltage should not fall below $V_{CE\,(sat)}$ (0.3V for Si, 0.1V for Ge) for any part of the i/p signal. For V_{CE} less than $V_{CE\,(sat)}$ the collector base junction is not probably reverse biased.

3) The value of the signal I_c when no signal is applied should be at least equal to the max. collector current t due to signal alone.

4) Max. rating of the transistor $I_{c(max)}$, $V_{CE\,(max)}$ and $P_{D(max)}$ should not be exceeded at any value of i/p signal.

Consider the fig shown in fig1. If operating point is selected at A, A represents a condition when no bias is applied to the transistor i.e, I_c=0, V_{CE} =0. It does not satisfy the above said conditions necessary for faithful amplification.

Point C is too close to $P_{D(max)}$ curve of the transistor. Therefore the o/p voltage swing in the positive direction is limited.

Point B is located in the middle of active region .It will allow both positive and negative half cycles in the o/p signal. It also provides linear gain and larger possible o/p voltages and currents

Hence operating point for a transistor amplifier is selected to be in the middle of active region.
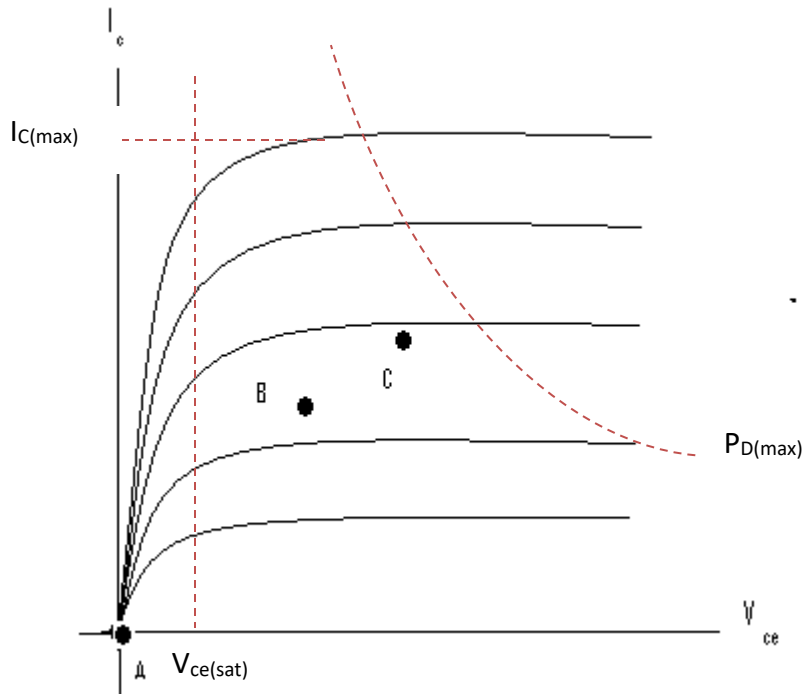
fig1

4.2 DC LOAD LINE:

Referring to the biasing circuit of fig 4.2a, the values of V_{CC} and R_C are fixed and Ic and V_{CE} are dependent on R_B.

Applying Kirchhoff's voltage law to the collector circuit in fig. 4.2a, we get
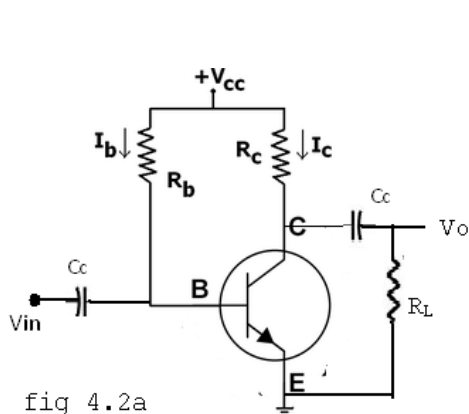
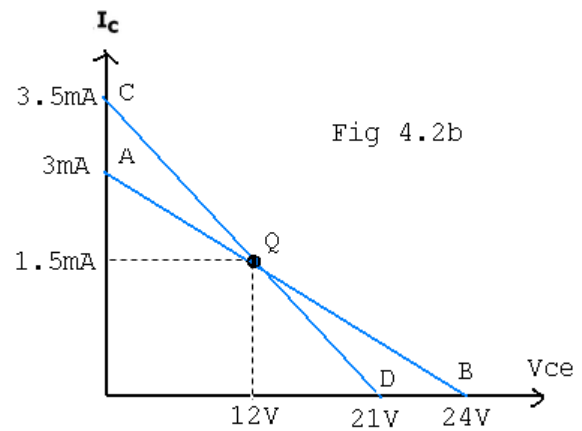$$Vcc = IcRc + Vce$$

fig 4.2a

Fig 4.2b

The straight line represented by AB in fig4.2b is called the dc load line. The coordinates of the end point A are obtained by substituting V_{CE} =0 in the above equation. Then $Ic = \frac{Vcc}{Rc}$.

Therefore The coordinates of A are V_{CE} =0 and $Ic = \frac{Vcc}{Rc}$.

The coordinates of B are obtained by substituting Ic=0 in the above equation. Then Vce = Vcc. Therefore the coordinates of B are V_{CE} =Vcc and Ic=0. Thus the dc load line AB can be drawn if the values of Rc and Vcc are known.

As shown in the fig4.2b, the optimum POINT IS LOCATED AT THE MID POINT OF THE MIDWAY BETWEEN a AND b. In order to get faithful amplification, the Q point must be well within the active region of the transistor.

Even though the Q point is fixed properly, it is very important to ensure that the operating point remains stable where it is originally fixed. If the Q point shifts nearer to either A or B, the output voltage and current get clipped, thereby o/p signal is distorted.

In practice, the Q-point tends to shift its position due to any or all of the following three main factors.

1) Reverse saturation current, Ico, which doubles for every $10°C$ raise in temperature

2) Base emitter Voltage ,VBE, which decreases by 2.5 mV per $°C$

3) Transistor current gain, h_{FE} or β which increases with temperature.

If base current I_B is kept constant since I_B is approximately equal to Vcc/RB. If the transistor is replaced by another one of the same type, one cannot ensure that the new transistor will have identical parameters as that of the first one. Parameters such as β vary over a range. This results in the variation of collector current Ic for a given I_B. Hence , in the o/p characteristics, the spacing between the curves might increase or decrease which leads to the shifting of the Q-point to a location which might be completely unsatisfactory.

4.3 AC LOAD LINE:

After drawing the dc load line, the operating point Q is properly located at the center of the dc load line. This operating point is chosen under zero input signal condition of the circuit. Hence the ac load line should also pas through the operating point Q. The effective ac load

resistance R$_{ac}$, is a combination of R$_C$ parallel to R$_L$ i.e. $R_{ac} = R_L || R_C$. So the slope of the ac load line CQD will be $\left(\frac{-1}{R_{ac}}\right)$. To draw the ac load line, two end points, I.e. V$_{CE(max)}$ and I$_{C(max)}$ when the signal is applied are required.

$V_{CE(max)} = V_{CEQ} + I_{CQ}R_{ac}$, which locates point D on the Vce axis.

$I_{c(max)} = I_{CQ} + \frac{V_{CEQ}}{R_{ac}}$, which locates the point C on the I$_C$ axis.

By joining points c and D, ac load line CD is constructed. As R$_C$ > R$_{ac}$, The dc load line is less steep than ac load line.

4.4 STABILITY FACTOR (S):

The rise of temperature results in increase in the value of transistor gain β and the leakage current Ico. So, I$_C$ also increases which results in a shift in operating point. Therefore, The biasing network should be provided with thermal stability. Maintenance of the operating point is specified by S, which indicates the degree of change in operating point due to change in temperature.

The extent to which I$_C$ is stabilized with varying I$_C$ is measured by a stability factor S

$$S = \frac{\partial I_c}{\partial I_{co}} \approx \frac{dI_c}{dI_{co}} \approx \frac{\Delta I_c}{\Delta I_{co}} \text{ '}\beta \text{ and } I_B \text{ constant}$$

For CE configuration $I_C = \beta I_B + (1+\beta)I_{co}$

Differentiate the above equation w.r.t I$_C$, We get

$$1 = \beta \frac{dI_B}{dI_c} + (1+\beta)\frac{dI_{co}}{dI_c}$$

$$\therefore \left(1 - \beta \frac{dI_B}{dI_C}\right) = \frac{(\beta + 1)}{S}$$

$$\therefore \quad S = \frac{1 + \beta}{1 - \beta \frac{dI_B}{dI_C}}$$

S should be small to have better thermal stability.

Stability factor S' and S'':

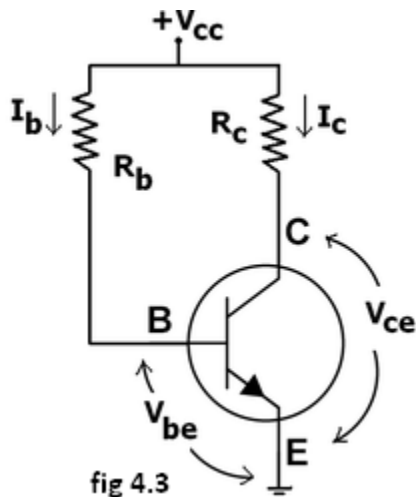S' is defined as the rate of change of I_C with V_{BE}, keeping I_C and V_{BE} constant.

$$S' = \frac{\partial I_c}{\partial V_{BE}}$$

S'' is defined as the rate of change of I_C with β, keeping I_{CO} and V_{BE} constant.

$$S'' = \frac{\partial I_c}{\partial \beta}$$

4.5 METHODS OF TRANSISTOR BIASING:

1) Fixed bias (base bias)

fig 4.3

This form of biasing is also called *base bias*. In the fig 4.3 shown, the single power source (for example, a battery) is used for both collector and base of a transistor, although separate batteries can also be used.

In the given circuit,

$V_{cc} = I_B R_B + V_{be}$

Therefore, $I_B = (V_{cc} - V_{be})/R_B$

Since the equation is independent of current $I_C R$, $dI_B/dI_C R = 0$ and the stability factor is given by the equation..... reduces to

$$S = 1 + \beta$$

Since β is a large quantity, this is very poor biasing circuit. Therefore in practice the circuit is not used for biasing.

For a given transistor, V_{be} does not vary significantly during use. As V_{cc} is of fixed value, on selection of R_B, the base current I_B is fixed. Therefore this type is called *fixed bias* type of circuit.

Also for given circuit, $V_{cc} = I_C R_C + V_{ce}$

Therefore, $V_{ce} = V_{cc} - I_C R_C$

Merits:

• It is simple to shift the operating point anywhere in the active region by merely changing the base resistor (R_B).

• A very small number of components are required.

Demerits:

• The collector current does not remain constant with variation in temperature or power supply voltage. Therefore the operating point is unstable.

• Changes in V_{be} will change I_B and thus cause R_E to change. This in turn will alter the gain of the stage.

• When the transistor is replaced with another one, considerable change in the value of β can be expected. Due to this change the operating point will shift.

2) EMITTER-FEEDBACK BIAS:

The emitter feedback bias circuit is shown in the fig 4.4. The fixed bias circuit is modified by attaching an external resistor to the emitter. This resistor introduces negative feedback that stabilizes the Q-point. From Kirchhoff's voltage law, the voltage across the base resistor is

$V_{Rb} = V_{CC} - I_e R_e - V_{be}$.

fig 4.4
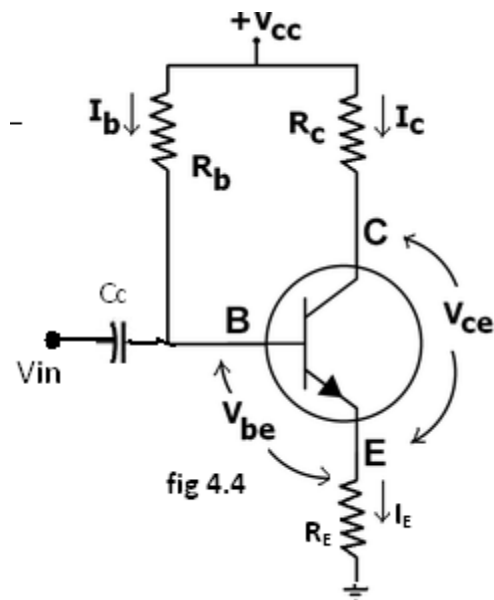
From Ohm's law, the base current is

$I_b = V_{Rb} / R_b$.

The way feedback controls the bias point is as follows. If V_{be} is held constant and temperature increases, emitter current increases. However, a larger I_e increases the emitter voltage $V_e = I_e R_e$, which in turn reduces the voltage V_{Rb} across the base resistor. A lower base-resistor voltage drop reduces the base current, which results in less collector current because $I_c = \beta\, I_B$. Collector current and emitter current are related by $I_c = \alpha\, I_e$ with $\alpha \approx 1$, so increase in emitter current with temperature is opposed, and operating point is kept stable.

Similarly, if the transistor is replaced by another, there may be a change in I_C (corresponding to change in β-value, for example). By similar process as above, the change is negated and operating point kept stable.

For the given circuit,

$I_B = (V_{CC} - V_{be})/(R_B + (\beta+1)R_E)$.

Merits:

The circuit has the tendency to stabilize operating point against changes in temperature and β-value.

Demerits:

•   In this circuit, to keep I_C independent of β the following condition must be met:

$$I_C = \beta I_B = \frac{\beta(V_{CC} - V_{be})}{R_B + (\beta + 1)R_E} \approx \frac{(V_{CC} - V_{be})}{R_E}$$

which is approximately the case if $(\beta + 1)R_E \gg R_B$.

- As β-value is fixed for a given transistor, this relation can be satisfied either by keeping R_E very large, or making R_B very low.

- If R_E is of large value, high V_{CC} is necessary. This increases cost as well as precautions necessary while handling.

- If R_B is low, a separate low voltage supply should be used in the base circuit. Using two supplies of different voltages is impractical.

- In addition to the above, R_E causes ac feedback which reduces the voltage gain of the amplifier.

3)   COLLECTOR TO BASE BIAS OR COLLECTOR FEED-BACK BIAS:
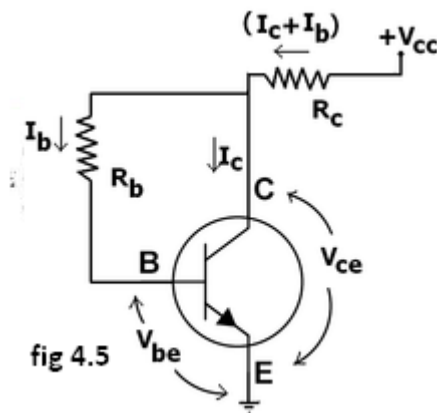
fig 4.5

This configuration shown in fig 4.5 employs negative feedback to prevent thermal runaway and stabilize the operating point. In this form of biasing, the base resistor R_B is connected to the collector instead of connecting it to the DC source V_{cc}. So any thermal runaway will induce a voltage drop across the R_C resistor that will throttle the transistor's base current.

From Kirchhoff's voltage law, the voltage V_{R_b} across the base resistor R_b is

$$V_{R_b} = V_{cc} - \overbrace{(I_c + I_b)R_c}^{\text{Voltage drop across } R_c} - \overbrace{V_{be}}^{\text{Voltage at base}}.$$

By the Ebers–Moll model, $I_c = \beta I_b$, and so

$$V_{R_b} = V_{cc} - (\overbrace{\beta I_b}^{I_c} + I_b)R_c - V_{be} = V_{cc} - I_b(\beta + 1)R_c - V_{be}.$$

From Ohm's law, the base current $I_b = V_{R_b}/R_b$, and so

$$\overbrace{I_\mathrm{b}R_\mathrm{b}}^{V_{R_\mathrm{b}}} = V_\mathrm{cc} - I_\mathrm{b}(\beta+1)R_\mathrm{c} - V_\mathrm{be}.$$

Hence, the base current I_b is

$$I_\mathrm{b} = \frac{V_\mathrm{cc} - V_\mathrm{be}}{R_\mathrm{b} + (\beta+1)R_\mathrm{c}}$$

If V_be is held constant and temperature increases, then the collector current I_c increases. However, a larger I_c causes the voltage drop across resistor R_c to increase, which in turn reduces the voltage V_{R_b} across the base resistor R_b. A lower base-resistor voltage drop reduces the base current I_b, which results in less collector current I_c. Because an increase in collector current with temperature is opposed, the operating point is kept stable.

Merits:

- Circuit stabilizes the operating point against variations in temperature and β (i.e. replacement of transistor)

Demerits:

- In this circuit, to keep I_c independent of β, the following condition must be met:

$$I_\mathrm{c} = \beta I_\mathrm{b} = \frac{\beta(V_\mathrm{cc} - V_\mathrm{be})}{R_\mathrm{b} + R_\mathrm{c} + \beta R_\mathrm{c}} \approx \frac{(V_\mathrm{cc} - V_\mathrm{be})}{R_\mathrm{c}}$$

which is the case when

$$\beta R_\mathrm{c} \gg R_\mathrm{b}.$$

- As β-value is fixed (and generally unknown) for a given transistor, this relation can be satisfied either by keeping R_c fairly large or making R_b very low.

- If R_c is large, a high V_cc is necessary, which increases cost as well as precautions necessary while handling.

- If R_b is low, the reverse bias of the collector–base region is small, which limits the range of collector voltage swing that leaves the transistor in active mode.

- The resistor R_b causes an AC feedback, reducing the voltage gain of the amplifier. This undesirable effect is a trade-off for greater Q-point stability.

Usage: The feedback also decreases the input impedance of the amplifier as seen from the base, which can be advantageous. Due to the gain reduction from feedback, this biasing form is used only when the trade-off for stability is warranted.

4) COLLECTOR –EMITTER FEEDBACK BIAS:
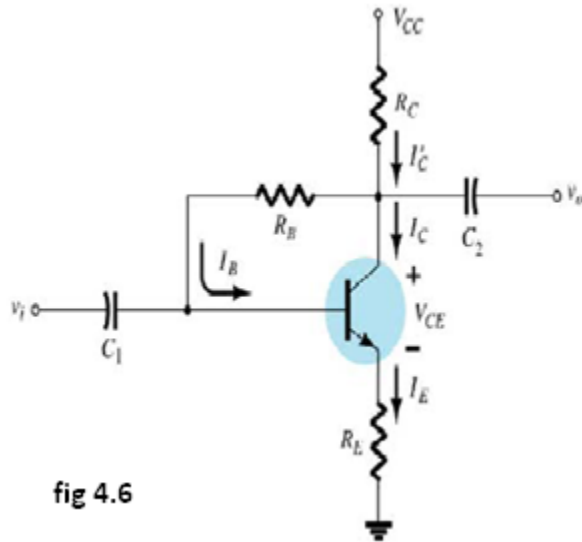
fig 4.6

The above fig4.6 shows the collector –emitter feedback bias circuit that can be obtained by applying both the collector feedback and emitter feedback. Here the collector feedback is provided by connecting a resistance RB from the collector to the base and emitter feedback is provided by connecting an emitter Re from emitter to ground. Both feed backs are used to control collector current and base current IB in the opposite direction to increase the stability as compared to the previous biasing circuits.

5) VOLTAGE DIVIDER BIAS OR SELF BIAS OR EMITTER BIAS:

The voltage divider as shown in the fig 4.7 is formed using external resistors R_1 and R_2. The voltage across R_2 forward biases the emitter junction. By proper selection of resistors R_1 and R_2, the operating point of the transistor can be made independent of β. In this circuit, the voltage divider holds the base voltage fixed independent of base current provided the divider current is large compared to the base current. However, even with a fixed base voltage, collector current varies with temperature (for example) so an emitter resistor is added to stabilize the Q-point, similar to the above circuits with emitter resistor.

fig 4.7
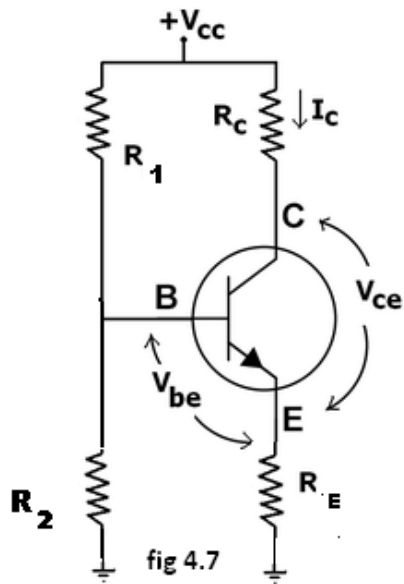
In this circuit the base voltage is given by:

$$V_B = \text{voltage across } R_2 = V_{cc}\frac{R_2}{(R_1 + R_2)} - I_B\frac{R_1 R_2}{(R_1 + R_2)}$$

$$\approx V_{cc}\frac{R_2}{(R_1 + R_2)} \text{ provided } I_B << I_2 = V_B/R_2.$$

Also $V_B = V_{be} + I_E R_E$

For the given circuit,

$$I_B = \frac{\frac{V_{CC}}{1+R_1/R_2} - V_{be}}{(\beta + 1)R_E + R_1 \| R_2}.$$

Let the current in resistor R1 is I1 and this is divided into two parts – current through base and resistor R2. Since the base current is very small so for all practical purpose it is assumed that I1 also flows through R2, so we have

$$I_1 = \frac{V_{CC}}{R_1 + R_2}$$

$$V_2 = \frac{V_{CC}}{R_1 + R_2} \cdot R_2$$

Applying KVL in the circuit, we have

$$V_2 = V_{BE} + V_E$$

$$V_2 = V_{BE} + I_E R_E$$

$$I_E = \frac{V_2 - V_{BE}}{R_E}$$

$$I_C = \frac{V_2 - V_{BE}}{R_E} \qquad \because I_C \cong I_E$$

$$I_C = \frac{\dfrac{V_{CC}}{R_1 + R_2} \cdot R_2 - V_{BE}}{R_E}$$

It is apparent from above expression that the collector current is independent of ? thus the stability is excellent. In all practical cases the value of VBE is quite small in comparison to the V2, so it can be ignored in the above expression so the collector current is almost independent of the transistor parameters thus this arrangement provides excellent stability.

Again applying KVL in collector circuit, we have

$$V_{CC} = I_C R_C + V_{CE} + I_E R_E$$

$$\because I_C \cong I_E$$

$$\therefore V_{CC} = I_C R_C + V_{CE} + I_C R_E$$

$$V_{CE} = V_{CC} - I_C(R_C + R_E)$$

The resistor RE provides stability to the circuit. If the current through the collector rises, the voltage across the resistor RE also rises. This will cause VCE to increase as the voltage V2 is independent of collector current. This decreases the base current, thus collector current increases to its former value.

Stability factor for such circuit arrangement is given by

$$S = \frac{(1+\beta)\left(R_{eq} + R_E\right)}{R_{eq} + R_E(1+\beta)}$$

$$R_{eq} = R_1 \| R_2$$

$$S = \frac{(1+\beta)\left(1 + \dfrac{R_{eq}}{R_E}\right)}{\dfrac{R_{eq}}{R_E} + 1 + \beta}$$

If Req/RE is very small compared to 1, it can be ignored in the above expression thus we have

$$S = \frac{1+\beta}{1+\beta} = 1$$

Which is excellent since it is the smallest possible value for the stability. In actual practice the value of stability factor is around 8-10, since Req/RE cannot be ignored as compared to 1.

Merits:

- Unlike above circuits, only one dc supply is necessary.

- Operating point is almost independent of β variation.

- Operating point stabilized against shift in temperature.

Demerits:

- In this circuit, to keep I$_C$ independent of β the following condition must be met:

$$I_C = \beta I_B = \beta \frac{\frac{V_{CC}}{1+R_1/R_2} - V_{be}}{(\beta+1)R_E + R_1 \parallel R_2} \approx \frac{\frac{V_{CC}}{1+R_1/R_2} - V_{be}}{R_E},$$

which is approximately the case if $(\beta+1)R_E >> R_1 \parallel R_2$

where R$_1$ || R$_2$ denotes the equivalent resistance of R$_1$ and R$_2$ connected in parallel.

- As β-value is fixed for a given transistor, this relation can be satisfied either by keeping R$_E$ fairly large, or making R$_1$||R$_2$ very low.

- If R$_E$ is of large value, high V$_{CC}$ is necessary. This increases cost as well as precautions necessary while handling.

- If R$_1$ || R$_2$ is low, either R$_1$ is low, or R$_2$ is low, or both are low. A low R$_1$ raises V$_B$ closer to V$_C$, reducing the available swing in collector voltage, and limiting how large R$_C$ can be made without driving the transistor out of active mode. A low R$_2$ lowers V$_{be}$, reducing the allowed collector current. Lowering both resistor values draws more current from the power supply and lowers the input resistance of the amplifier as seen from the base.

- AC as well as DC feedback is caused by R$_E$, which reduces the AC voltage gain of the amplifier. A method to avoid AC feedback while retaining DC feedback is discussed below.

Usage: The circuit's stability and merits as above make it widely used for linear circuits.

4.6 BIAS COMPENSATION USING DIODE AND TRANSISTOR:

The various biasing circuits considered use some type of negative feedback to stabilize the operation point. Also, diodes, thermistors and sensistors can be used to compensate for variations in current.

DIODE COMPENSATION:
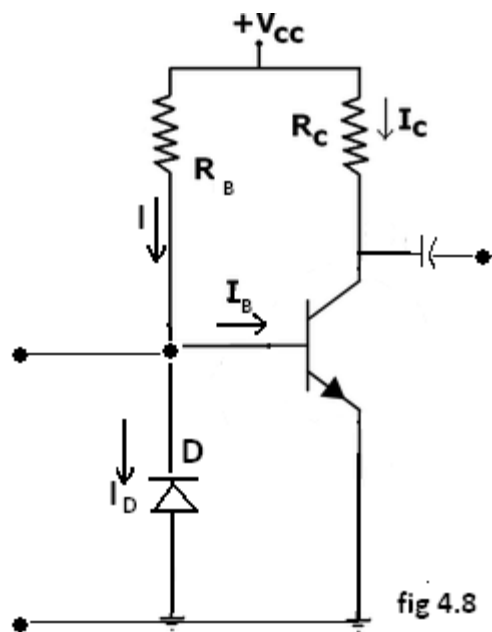
fig 4.8

The following fig4.8 shows a transistor amplifier with a diode D connected across the base-emitter junction for compensation of change in collector saturation current I_{CO}. The diode is of the same material as the transistor and it is reverse biased by e the emitter-base junction voltage V_{BE}, allowing the diode reverse saturation current I_O to flow through diode D. The base current $I_B = I - I_O$.

As long as temperature is constant, diode D operates as a resistor. As the temperature increases, I_{CO} of the transistor increases. Hence, to compensate for this, the base current I_B should be decreased.

The increase in temperature will also cause the leakage current I_O through D to increase and thereby decrease the base current I_B. This is the required action to keep I_C constant.

This type of bias compensation does not need a change in Ic to effect the change in I_C, as both I_O and I_{CO} can track almost equally according to the change in temperature.

THERMISTOR COMPENSATION:

The following fig4.9 a thermistor R_T, having a negative temperature coefficient is connected in parallel with R_2. The resistance of thermistor decreases exponentially with increase of temperature. An increase of temperature will decrease the base voltage V_{BE}, reducing I_B and I_C.
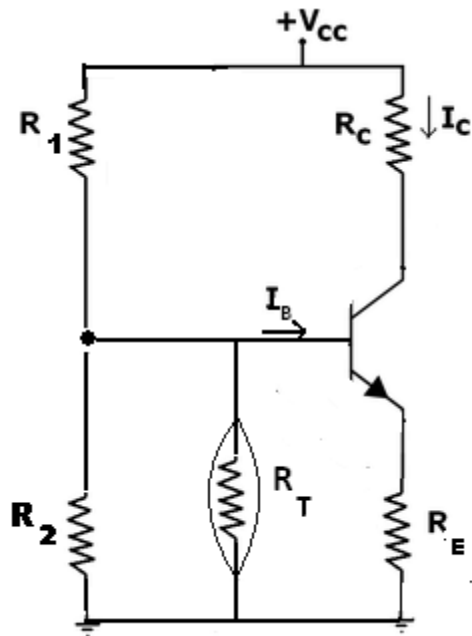
fig 4.9

SENSISTOR COMPENSATION:

In the following fig4.10 shown a sensistor Rs having a positive temperature coefficient is connected across R_1 or R_E. Rs increases with temperature. As the temperature increases, the equivalent resistance of the parallel combination of R1 and Rs also increases and hence V_{BE} decreases, reducing I_B and Ic. This reduced Ic compensates for increased Ic caused by the increase in V_{BE}, I_{CO} and β due to temperature.

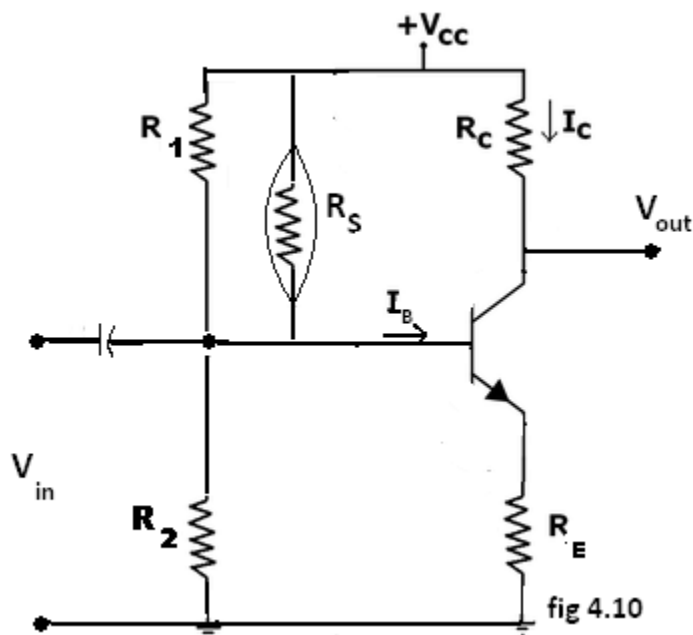fig 4.10

4.7 THERMAL RUNAWAY AND THERMAL STABILITY:

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°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.

THERMAL RESISTANCE

Consider transistor used in a circuit where the ambient temperature of the air around the transistor is T_A°C and the temperature of the collector-base junction of the transistor is T_J°C.

Due to heating within the transistor T_J is higher than T_A. As the temperature difference T_J- T_A is greater, the power dissipated in the transistor, P_D will be greater, i.e, T_J- $T_A \propto P_D$

The equation can be written as T_J- $T_A = \theta P_D$. , where θ is the constant of proportionality and is called the Thermal resistance. Rearranging the above equation $\theta = T_J$- T_A /P_D. Hence θ is measured in °C/W which may be as small as 0.2 °C/W for a high power transistor that has an efficient heat sink or up to 1000°C/W for small signal, low power transistor which have no cooling provision.

As Θ represents total thermal resistance from a transistor junction to the ambient temperature, it is referred to as Θ_{J-A}. However, for power transistors, thermal resistance is given form junction to case, Θ_{J-C}.

The amount resistance from junction to ambience is considered to consist of 2 parts.

$$\Theta_{J-A} = \Theta_{J-C} - \Theta_{C-A}.$$

Which indicates the heat dissipated in the junction must make its way to the surrounding air through two series paths from junction to case and from case to air. Hence the power dissipated.

$$P_D = (T_J - T_A) / \Theta_{J-A}$$

$$= (T_J - T_A) / (\Theta_{J-C} + \Theta_{C-A})$$

Θ_{J-C} is determined by the type of manufacture of the transistor and how it is located I the case, but Θ_{C-A} is determined by the surface area of the case or flange and its contact with air. If the effective surface area of the transistor case could be increased, the resistance to heat flows, or could be increased Θ_{C-A}, could be decreased. This can be achieved by the use of a heat sink.

The heat sink is a relatively large, finned, usually black metallic heat conducting device in close contact with transistor case or flange. Many versions of heat sink exist depending upon the shape and size of the transistor. Larger the heat sink smaller is the thermal resistance Θ_{HS-A}.

This thermal resistance is not added to Θ_{C-A} in series, but is instead in parallel with it and if

Θ_{HS-A} is much less than Θ_{C-A}, then Θ_{C-A} will be reduced significantly, thereby improving the dissipation capability of the transistor. Thus

$\Theta_{J-A} = \Theta_{J-C} + \Theta_{C-A} || \Theta_{HS-A}.$

4.8 CONDITION FOR THERMAL STABILITY:

For preventing thermal runaway, the required condition I the rate at which the heat is released at the collector junction should not exceed the rate at which the heat can be dissipated under steady state condition. Hence the condition to be satisfied to avoid thermal runaway is given by

$$\frac{\partial P_C}{\partial T_j} < \frac{1}{\Theta}$$

If the circuit is properly designed, then the transistor cannot runaway below a specified ambient temperature or even under any conditions.

In the self biased circuit the transistor is biased in the active region. The power generated at the junction without any signal is

$$P_C = I_C V_{CB} \approx I_C V_{CE}$$

Let us assume that the quiescent collector and the emitter currents are equal. Then

$$P_C = I_C V_{CC} - I_C^2 (R_E + R_C) \quad\text{.....................(1)}$$

The condition to prevent thermal runaway can be written as

$$\frac{\partial P_C}{\partial I_C}\frac{\partial I_C}{\partial T_j} < \frac{1}{\Theta} \quad\text{................................(2)}$$

As Θ and $\dfrac{\partial I_C}{\partial T_j}$ are positive, $\dfrac{\partial P_C}{\partial I_C}$ should be negative in order to satisfy the above condition.

Differentiating equation (1) w.r.t I_C we get

$$\frac{\partial P_C}{\partial I_C} = V_{CC} - 2I_C (R_E + R_C) \quad\text{........................(3)}$$

Hence to avoid thermal runaway it is necessary that

$$I_C > \frac{V_{CC}}{2(R_E + R_C)} \quad\text{........................(4)}$$

SinceVCE=VCC-IC(RE+RC) then eq(4) implies that VCE<VCC/2. IF the inequality of eq(4) is not satisfied and VCE<VCC/2, then from eq(3), $\dfrac{\partial P_C}{\partial I_C}$ is positive., and the corresponding eq(2) should

be satisfied. Other wise thermal runaway will occur.