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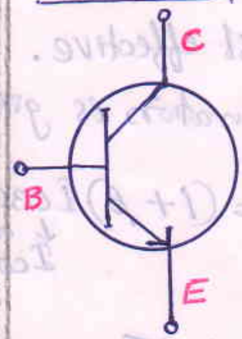
# Unit - 4

# Transistor Biasing and Stabilization

**Syllabus :** Operating point - The DC & AC load lines - Fixed bias Emitter feedback bias - Collector to Emitter feedback bias - Voltage divider bias - Bias Stability - Stabilization against variation in $V_{BE}$ and $\beta$, bias compensation using diodes and transistors, Thermal runaway Condition for thermal stability in CE configuration.




## Operating Point :

The transistor can be operated in three regions ie Cutoff, Active and Saturation by appling proper biasing. When we bias a transistor we establish a certain current and voltages conditions for the transistor. These conditions are known as operating conditions a dc operating point & Quiescent point.

The Operating point must be stable for proper operation of the transistor. However the operating point shifts with changes in transistor parameters such as '$\beta$', '$I_{CO}$' & $V_{BE}$. As transistor parameters are temperature dependent, the operating point also varies with changes in temperature.

## Biasing & Need for Biasing :

The process of giving proper supply voltages and resistances for obtaining the desired Q-point is called Biasing.

The circuits used for getting the desired and proper operating point are known as biasing circuits.

To establish the operating point in the active region biasing is required for transistors to be used as an Amplifier.

In order to produce distortion free output in amplifier ckts we need biasing to the transistor.

In transistor circuits, output signal power is always greater than input signal power. Now the Question is how this amplification of power is achieved. ie The d.c sources (d.c biasing) supplies the power to the transistor ckt to get the output signal power greater than input signal power.

The circuit must be easily implemented and cost effective.

The collector current for common-Emitter configuration is given by

$$I_C = \beta I_B + I_{CEO} \quad \text{where } I_{CEO} = (1+\beta) I_{CBO} \text{ or } I_{CO}.$$

In Practical $\therefore \boxed{I_C = \beta I_B + (1+\beta) I_{CO}.}$

Q-point tends to shift its position due to following factors.

a) Reverse saturation current '$I_{CO}$' which doubles for every 10°C increase in temperature.

b) Base-Emitter voltage '$V_{BE}$' which decreases by 2.5 mV per °C.

c) Transistor current gain '$\beta$' ie $h_{fe}$ which increases with temperature.

## Stability factor 'S':

In order to compare the stability provided by the circuits one term is called stability factor. which indicates degree of change in operating point due to variation in temperature.

Since there are three variables which are temperature dependent so, we can define three stability factors as below.

The total change in the collector current due to change in the $I_{CO}$, $V_{BE}$ and $\beta$ is given by

$$\Delta I_C = S \Delta I_{CO} + S' \Delta V_{BE} + S'' \Delta\beta .$$

a) Stability factor 'S' is defined as the rate of change of collector current due to the collector base leakage current $I_{CO}$. Keeping both current $I_B$ & current gain '$\beta$' constant.

$$\boxed{S = \frac{\Delta I_C}{\Delta I_{CO}} \Bigg|_{\beta \,\&\, I_B \text{ constant}}} \quad \& \therefore S = \frac{dI_C}{dI_{CO}} \;\&\; \frac{\partial I_C}{\partial I_{CO}}.$$

b) Stability factor $S'$ is defined as the rate of change of $I_C$ with $V_{BE}$, keeping $I_{CO}$ and $\beta$ constant.

$$\boxed{S' = \frac{\Delta I_C}{\Delta V_{BE}}\Bigg|_{I_{CO}\ \&\ \beta\ \text{Constant}}} \quad \& \quad S' = \frac{dI_C}{dV_{BE}} \quad \text{or} \quad \frac{\partial I_C}{\partial V_{BE}}.$$

c) Stability factor $S''$ is defined as the rate of change of $I_C$ with respect to $\beta$ keeping $I_{CO}$ and $V_{BE}$ constant.

$$\boxed{S'' = \frac{\Delta I_C}{\Delta \beta}\Bigg|_{I_{CO}\ \&\ V_{BE}\ \text{Constant}}} \quad \& \quad S'' = \frac{dI_C}{d\beta} \quad \text{or} \quad \frac{\partial I_C}{\partial \beta}.$$

## General Procedure to obtain Stability factors:

The collector current for Common Emitter configuration is given by

$$I_C = \beta I_B + I_{CEO}$$

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

Differentiating the above equation w.r.t. $I_C$ we get

$$\Rightarrow \quad \frac{dI_C}{dI_C} = \beta \frac{dI_B}{dI_C} + (1+\beta)\frac{dI_{CO}}{dI_C}$$

$$\Rightarrow \quad \left(1 - \beta \frac{dI_B}{dI_C}\right) = (1+\beta)\frac{1}{S} \qquad \left(\because S = \frac{dI_C}{dI_{CO}}\right).$$

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

It is clear that Stability factor $S$ should be as small as possible to have better thermal stability of a transistor.

**Procedure:**

Step 1 : Obtain the Expression for $I_B$.

Step 2 : Obtain $\frac{dI_B}{dI_C}$ and use it in equation $S$ ie $S = \frac{(1+\beta)}{1-\beta\left(\frac{dI_B}{dI_C}\right)}$ to get $S$

Step 3 : In standard equation $I_C$ replace $I_B$ in terms of $V_{BE}$ to get $S'$.

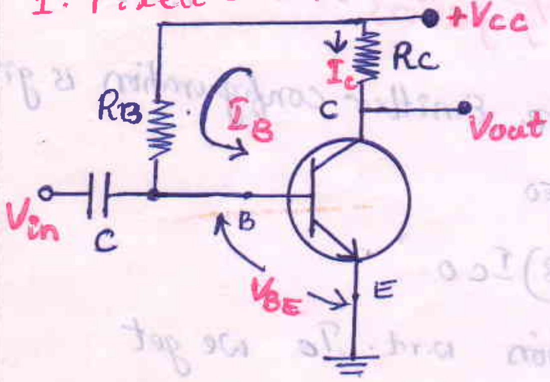
Step 4 : Differentiate the equation obtained in step 3 w.r.t $\beta$ to get $S''$.

# Methods of Transistor Biasing:

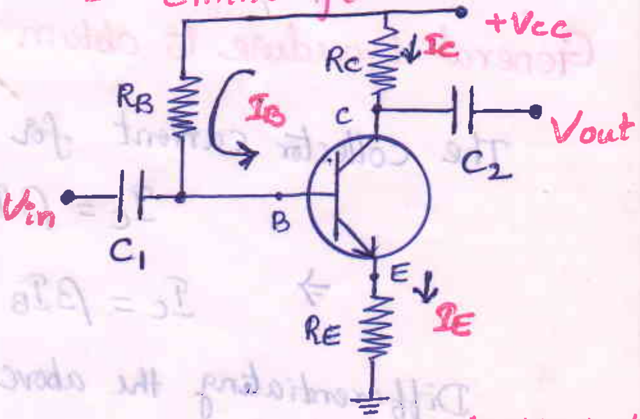
Methods of Transistor biasing of five (5) types they are.

1. Fixed Bias & Base resistor bias.
2. Emitter-feedback bias. & Fixed bias with Emitter resistor.
3. Collector to Base bias & Collector feedback bias.
4. Collector-Emitter feedback bias.
5. Self bias & Voltage divider bias & Emitter bias.

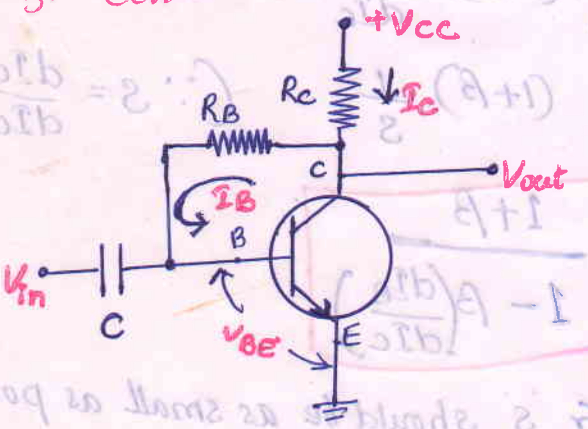
1. Fixed bias:



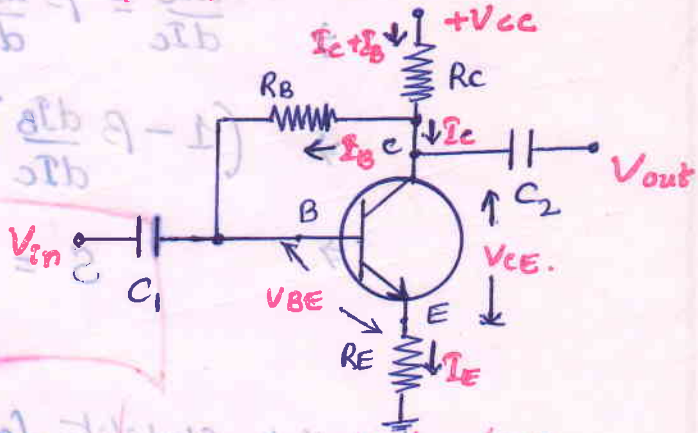

2. Emitter feedback bias:



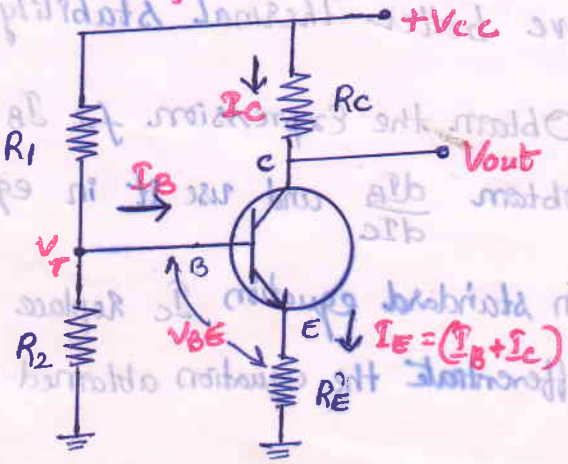

3. Collector to Base bias.




4. Collector-Emitter feedback bias

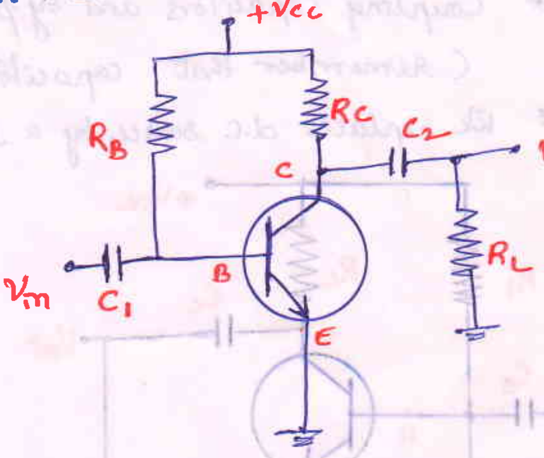



5. Self bias & Voltage divider bias



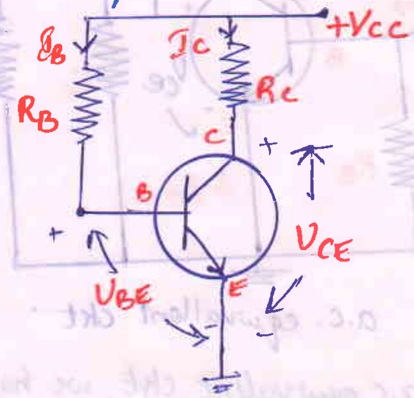
# DC Load Line :

Consider a Common Emitter ckt. It is biased with a common Supply as Fixed bias ckt.




In the absence of ac signal, the capacitors provide very high impedance, ie Open circuit.

∴ The equivalent ckt becomes.




Applying Kirchhoff's Voltage Law to the collector ckt.

$$V_{CC} - I_C R_C - V_{CE} = 0$$

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

$$\Rightarrow \boxed{V_{CE} = V_{CC} - I_C R_C}$$

&

$$\boxed{I_C = \frac{V_{CC} - V_{CE}}{R_C}}$$

By rearranging the eqn.

$$I_C = \left(-\frac{1}{R_C}\right) V_{CE} + \frac{V_{CC}}{R_C}$$

compare with $y = mx + c$. where $m$ is slope of the line.

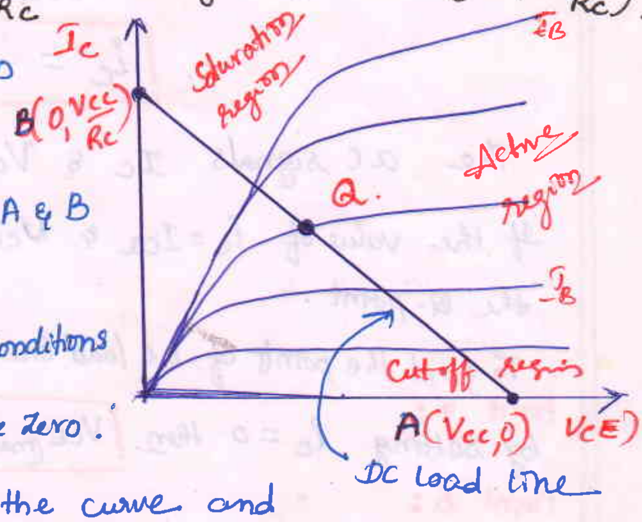
The graph $I_C$ versus $V_{CE}$ ($I_C$ Vs $V_{CE}$) with a slope of '$-\frac{1}{R_C}$'

To determine the two points on the line we assume $V_{CE} = V_{CC}$ & $V_{CE} = 0$.

(i) When $V_{CE} = V_{CC}$ then $I_C = 0$ and we get a point A ($V_{CC}$, 0).

& (ii) When $V_{CE} = 0$ then $I_C = \frac{V_{CC}}{R_C}$ and we get a point B $\left(0, \frac{V_{CC}}{R_C}\right)$.

The output characteristics of CE configuration with points A & B and line drawn between them. The line drawn between points A & B is called d.c load line.




The word 'DC' indicates that only dc conditions are considered ie input signal is assumed to be zero.

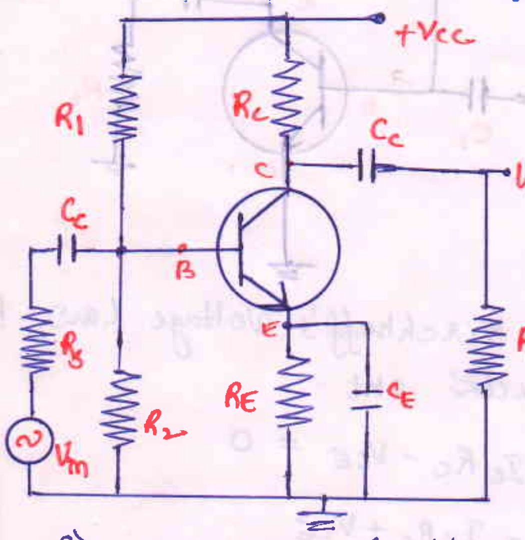
Q-point : The point of intersection of the curve and dc load line is the Operating point a Q-point.

(Quiescent means quiet, still, inactive).

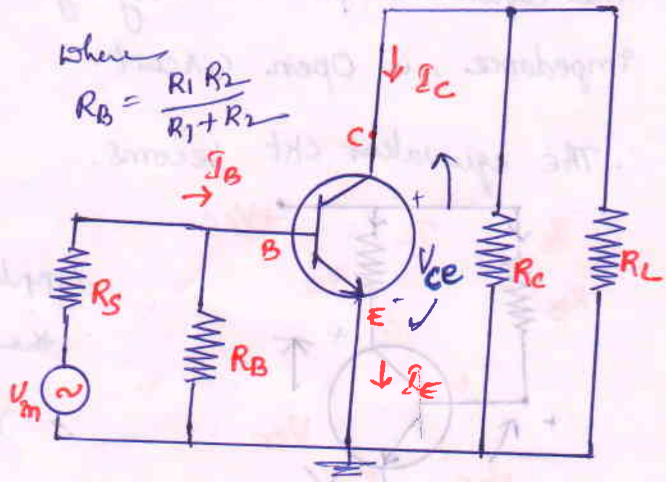
# AC load Line :

Consider the Common Emitter amplifier, for ac analysis,

* Coupling capacitors and by-pass capacitor act as a short ckt (remember that capacitor blocks d.c signals & passes a.c signals)
* We replace d.c source by a short ckt. ie shorting $V_{CC}$ & ground lines.




a) CE amplifier (self bias ckt).




b) a.c. equivallent ckt.

Applying KVL to the collector ckt of the a.c equivalent ckt, we have.

$$\boxed{V_{ce} = I_c \cdot R_{ac}} \rightarrow ① \quad \text{where } R_{ac} = R_C \| R_L = \frac{R_C R_L}{R_C + R_L}$$

where $V_{ce}$ - a.c collector to Emitter voltage
$I_c$ - a.c collector current.

Since $I_c = i_c - I_{CQ}$ and $V_{ce} = V_{CEQ} - v_{CE}$ $\longrightarrow$ ②

where $i_c$ - Total instantaneous collector current
$v_{CE}$ - Total instantaneous collector to Emitter voltage.

$\therefore$ From ① + ②

$$V_{CEQ} - v_{CE} = (i_c - I_{CQ}) \cdot R_{ac}.$$

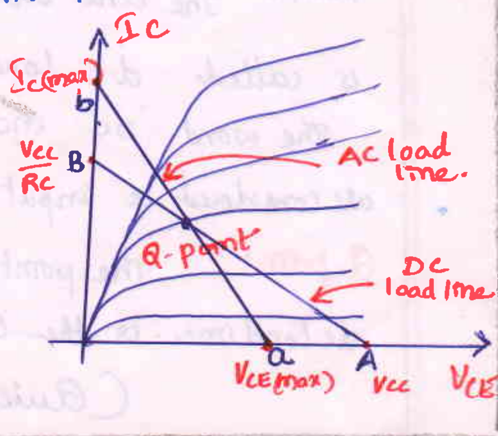
$$\therefore \boxed{i_c = \frac{V_{CEQ}}{R_{ac}} - \frac{v_{CE}}{R_{ac}} + I_{CQ}}$$

The a.c signals $I_c$ & $V_{ce}$ are represented by points on ac load line. If the value of $i_c = I_{CQ}$ & $v_{CE} = V_{CEQ}$ ie a.c load line & DC line intersects at the Q-point.

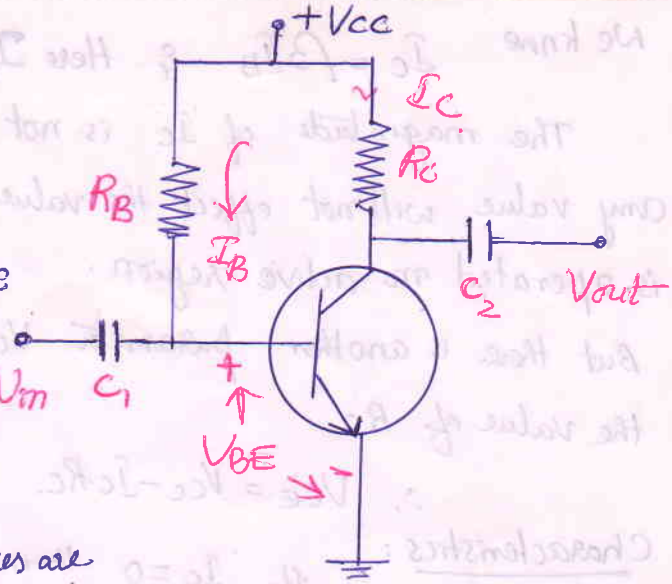
$\therefore$ To find the points of ac load line.

**Point 'a' :**
By setting $i_c = 0$ then $\boxed{V_{CE(max)} = V_{CEQ} + I_{CQ} \cdot R_{ac}}$.

**Point b :**
By setting $v_{CE} = 0$ then $\boxed{I_{C(max)} = \frac{V_{CEQ}}{R_{ac}} + I_{CQ}}$.



# (1) Fixed Bias:

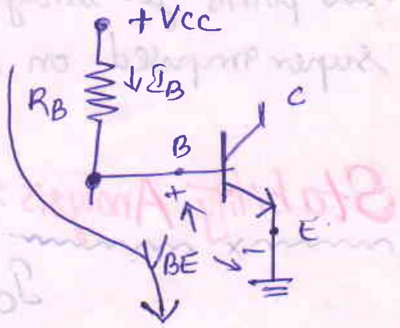



## Circuit Description:

In this method a high resistance $R_B$ (several 100's of $k\Omega$) is connected the +ve terminal of powersupply and base of the transistor. For Analysis capacitances are opened.

## Circuit Analysis:

* It is required to find the value of $R_B$ so that required zero signal collector flows in the ckt.




Apply KVL for input loop.

$$\therefore \quad V_{CC} = I_B R_B + V_{BE}$$

$$\& \quad V_{CC} - I_B R_B - V_{BE} = 0$$

$$\Rightarrow I_B R_B = V_{CC} - V_{BE}$$

$$\therefore \boxed{I_B = \frac{V_{CC} - V_{BE}}{R_B}.}$$

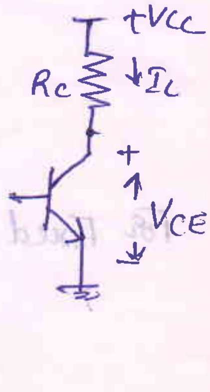
Since $V_{BE}$ is very small compared to $V_{CC}$

$$\therefore \boxed{I_B \simeq \frac{V_{CC}}{R_B}.}$$

The Current $I_B$ is constant since $V_{CC}$ & $R_B$ is fixed values. Hence the name for the network is called "Fixed Bias Circuit".

The selection of $R_B$ sets the level of base current for operating point.

* Apply KVL for output loop.




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

$$\Rightarrow V_{CE} = V_{CC} - I_C R_C.$$

$$\& \quad I_C R_C = V_{CC} - V_{CE}$$

$$\boxed{I_C = \frac{V_{CC} - V_{CE}}{R_C}.}$$

We know $I_C = \beta I_B$ & Here $I_B$ is controlled by $R_B$

The magnitude of $I_C$ is not a fun. of $R_C$. So change in $R_C$ to any value will not effect the value of $I_B$ & $I_C$ as long as the device is operated in active region.

But there is another parameter $V_{CE}$ whose magnitude is determined by the value of $R_C$.

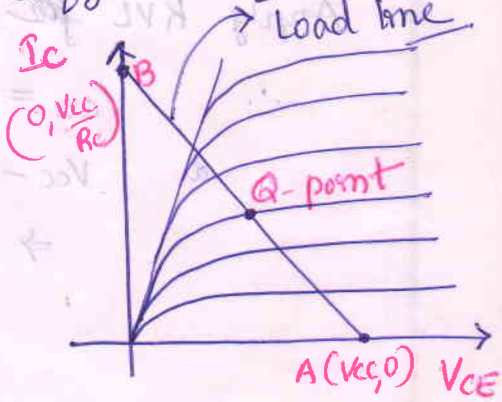
$$\therefore \; V_{CE} = V_{CC} - I_C R_C.$$

<u>Characteristics</u>:

If $I_C = 0$ then $V_{CE} = V_{CC}$

If $V_{CE} = 0$ then $I_C = \frac{V_{CC}}{R_C}$.

$\therefore$ The two points are $A(V_{CC}, 0)$ and $B\left(0, \frac{V_{CC}}{R_C}\right)$ joining these two points get straight line & it is called as Load line & it is superimposed on output characteristics of CE configuration of transistor.




## Stability Analysis:

$$I_C = f(I_{CO}, \beta, V_{BE})$$

$$\Delta I_C = \frac{\partial I_C}{\partial I_{CO}} \cdot \Delta I_{CO} + \frac{\partial I_C}{\partial V_{BE}} \Delta V_{BE} + \frac{\partial I_C}{\partial \beta} \cdot \Delta\beta.$$

$$\Rightarrow S = \left.\frac{\partial I_C}{\partial I_{CO}}\right|_{V_{BE} \;\&\; \beta \text{ constant}}.$$

We know that $I_C = \beta I_B + (1+\beta) I_{CO}$ for CE of transistor.

Differentiat above eqn w.r.t. $I_C$

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

$$\Rightarrow 1 = \beta \frac{\partial I_B}{\partial I_C} + (1+\beta)\cdot\frac{1}{S} \qquad \left(S = \frac{\partial I_C}{\partial I_{CO}}\right).$$

$$\Rightarrow \boxed{S = \frac{1+\beta}{1-\beta\left(\frac{\partial I_B}{\partial I_C}\right)}}$$

For Fixed bias ckt $I_B = \frac{V_{CC}}{R_B}$, is constant & independent of $I_C$ so.

$\frac{\partial I_B}{\partial I_C} = 0$ then

$$\boxed{\text{Stability factor } S = 1+\beta}$$

The stability factor of fixed bias ckt is very high since the value of $\beta$ is several hundreds.

Ex. If $\beta = 200$ then $S = 201$ ie $\frac{\partial I_C}{\partial I_{CO}} = 201 \Rightarrow \partial I_C = (201)\partial I_{CO}$

ie with small changes in $I_{CO}$, $I_C$ changes by 201 times. Thus this biasing is rarely or not used.

**Stability factor S':** $S' = \frac{\partial I_C}{\partial V_{BE}} \Big|$ $I_{CO}$ & $\beta$ constant.

Consider $I_B = \frac{V_{CC} - V_{BE}}{R_B}$ → ① & $I_C = \beta I_B + (1+\beta)I_{CO}$ → ②

From ① & ②

$$I_C = \beta\left(\frac{V_{CC} - V_{BE}}{R_B}\right) + (1+\beta)I_{CO}$$

Differentiate above eqn w.r.t. $V_{BE}$.

$$\frac{\partial I_C}{\partial V_{BE}} = \beta\left(\frac{-1}{R_B}\right) + 0$$

$$\Rightarrow \boxed{S' = \frac{\partial I_C}{\partial V_{BE}} = \frac{-\beta}{R_B}.}$$

**Stability factor S'':** $S'' = \frac{\partial I_C}{\partial \beta} \Big|$ $I_{CO}$ & $V_{BE}$ constant.

From eqn ① & ②

$$I_C = \beta\left(\frac{V_{CC} - V_{BE}}{R_B}\right) + (1+\beta)I_{CO}$$

differentiate above eqn w.r.t. $\beta$

$$\frac{\partial I_C}{\partial \beta} = \frac{\partial \beta}{\partial \beta}\left(\frac{V_{CC} - V_{BE}}{R_B}\right) + 0 + I_{CO}\frac{\partial \beta}{\partial \beta}$$

$$\therefore \boxed{S'' = \frac{\partial I_C}{\partial \beta} = \frac{V_{CC} - V_{BE}}{R_B} + I_{CO}}$$

Fixed Bias.

**Advantages:**

1. The circuit is simple, which uses very few components.
2. The operating point can be fixed any where in the active region.
3. There is no loading effect on the source.

**Disadvantage:**

1. Stability factor is high $S = 1+\beta$.
2. There are strong chances of Thermal runaway.

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

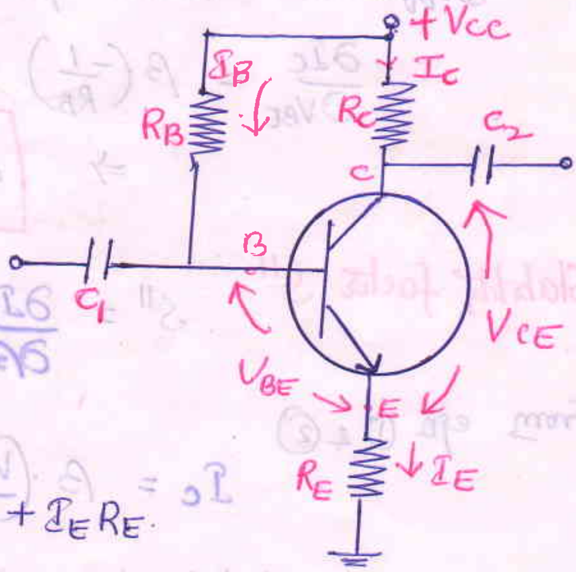
4. When the transistor is replaced with another one, considerable change in the value of '$\beta$' can be expected. Due to this change the operating point will shift.

**Usage:** Fixed bias is rarely used in linear Ckts. Instead it is often used in Ckts where transistor is used as a switch. ie One application is to achieve crude automatic gain control in the transistor by feeding the base resistor from a DC signal derived from the AC output of a later stage.

## (2) Emitter feedback bias & Fixed bias with Emitter Resistor:

The fixed bias circuit is modified by attaching an external resistor.
& It stabilizes the Q-point.

For circuit analysis all capacitors are opened.




Consider Base Emitter loop.

Apply KVL
$$V_{CC} = I_B R_B + V_{BE} + I_E R_E$$
$$V_{CC} - I_B R_B - V_{BE} - (I_B + I_C) R_E = 0 \qquad (\because I_E = I_B + I_C)$$
$$V_{CC} - I_B [R_B + R_E] - V_{BE} - I_C R_E = 0.$$

$\because I_E = I_B + I_C$
$+ I_C = \beta I_B$

$$V_{CC} - V_{BE} = I_B [R_B + R_E] + I_C \cdot R_E$$

$\boxed{I_E = (1+\beta) I_B}$

$$\therefore I_B = \frac{(V_{CC} - V_{BE})}{(R_B + R_E)} - \left(\frac{R_E}{R_B + R_E}\right) I_C \longrightarrow (1)$$

Here $V_{BE}$ is independent of $I_C$

differentiate above eqn. w.r.t. $I_C$
$$\therefore \frac{\partial I_B}{\partial I_C} = -\left[\frac{R_E}{R_E + R_B}\right] \longrightarrow (2)$$

$\boxed{\therefore I_B = \dfrac{V_{CC} - V_{BE}}{R_B + (1+\beta) R_E}}$

We know the General equation for Stability factor

If $\beta >> 1$

$\boxed{\therefore I_B = \dfrac{V_{CC} - V_{BE}}{R_B + \beta R_E}}$

$$S = \frac{1+\beta}{1 - \beta\left(\frac{\partial I_B}{\partial I_C}\right)} \longrightarrow (3)$$

(PTO)

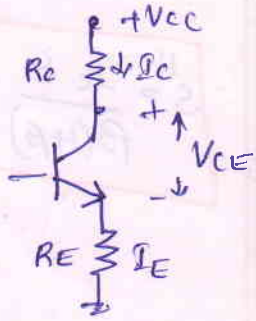
From 2 & 3  Stability factor $\boxed{S = \dfrac{1+\beta}{1+\beta\left(\dfrac{R_E}{R_E+R_B}\right)}}$

Since $1+\beta\left(\dfrac{R_E}{R_E+R_B}\right) > 1$, so $S < (1+\beta)$

Hence the value of the stability factor $S$ is always lower in Emitter feedback bias ckt than that of the fixed bias ckt.

Thus it is clear that a better thermal stability can be achieved in Emitter feedback bias ckt than fixed bias ckt.

Consider Collector - Emitter loop :




Apply KVL. $V_{CC} = I_C \cdot R_C + V_{CE} + I_E \cdot R_E$.

Substitute $I_E = I_C$ then

$$V_{CE} - V_{CC} + I_C(R_C + R_E) = 0$$

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

& $V_E$ is the voltage from Emitter to ground ie $\boxed{V_E = I_E R_E}$.

The voltage from collector to ground ie $V_{CE} = V_C - V_E$

& $V_C = V_{CE} + V_E$

& $\boxed{V_C = V_{CC} - I_C R_C}$.

The Voltage at the base w.r.t to ground

ie $V_B = V_{CC} - I_B \cdot R_E$

& $\boxed{V_B = V_{BE} + V_E}$.

Stability factor $S' = \dfrac{\partial I_C}{\partial V_{BE}}\Bigg|_{I_{CO}\ \&\ \beta\ \text{constant}}$

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

$$I_C = \beta\left[\frac{V_{CC} - V_{BE}}{R_B + R_E} - \left(\frac{R_E}{R_B+R_E}\right) I_C\right] + (1+\beta) I_{CO}$$

$$I_C\left[1 + \frac{\beta \cdot R_E}{R_B + R_E}\right] = \frac{\beta \cdot V_{CC}}{(R_B+R_E)} - \frac{\beta \cdot V_{BE}}{(R_B+R_E)} + (1+\beta) I_{CO}$$

Differentiate w.r.t $V_{BE}$

$$\left[1 + \frac{\beta \cdot R_E}{R_B+R_E}\right]\frac{\partial I_C}{\partial V_{BE}} = 0 - \frac{\beta}{R_B+R_E} + 0 \Rightarrow \boxed{S' = \frac{\partial I_C}{\partial V_{BE}} = \frac{-\beta}{(1+\beta)R_E + R_B}}$$

Stability factor $S''$ : $S'' = \frac{\partial I_C}{\partial \beta} \Big|_{I_{CO} \,\&\, V_{BE}}$ are Constant

$$I_C = \beta\left[\frac{V_{CC}-V_{BE}}{R_B+R_E} - \frac{R_E}{R_E+R_B} I_C\right] + (1+\beta)I_{CO} \longrightarrow ②$$

$$\left[1+\frac{R_E\cdot\beta}{R_E+R_B}\right]I_C = \beta\cdot\left[\frac{V_{CC}-V_{BE}}{R_B+R_E}\right] + I_{CO} + \beta I_{CO}$$

Differentiate eqn ② w.r.t $\beta$

$$\frac{\partial I_C}{\partial \beta} = \frac{V_{CC}-V_{BE}}{R_B+R_E} - \frac{R_E}{R_E+R_B} I_C + I_{CO}.$$

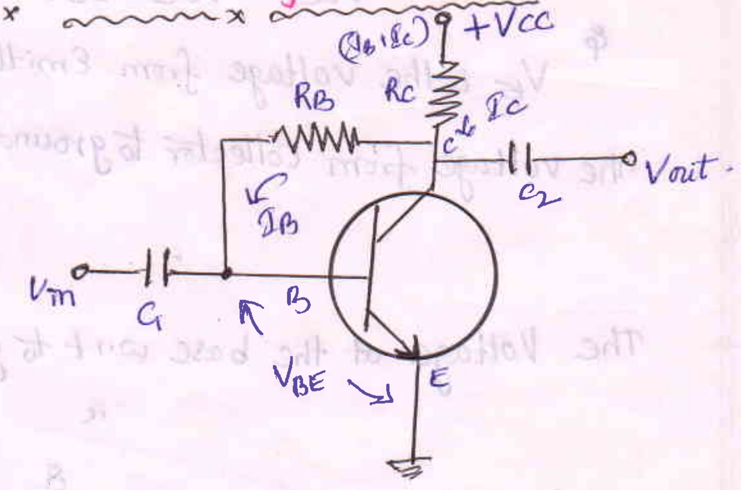
$$\boxed{S'' = \frac{I_C \cdot S}{\beta(1+\beta)}}$$

(or)

$$S'' = \frac{V_{CC}-V_{BE}-I_C R_E}{R_B+R_E} + I_{CO}.$$

$\therefore$ Stability factor $\boxed{S'' = \frac{V_{CC}-V_{BE}-I_C R_E}{R_B+R_E} + I_{CO}.}$

## ③ Collector to Base Bias or Collector feedback Bias :




* It is the simplest way to provide some degree of stabilization to the amplifier operating point.
* For circuit analysis all capacitors are opened.

Apply KVL $\Rightarrow$ $V_{CE} = I_B R_B + V_{BE}$

$$\Rightarrow I_B = \frac{V_{CE}-V_{BE}}{R_B}.$$

(or)

$$V_{CC} = (I_B+I_C)R_C + I_B R_B + V_{BE}.$$

$$V_{CC} = I_B[R_C+R_B] + I_C R_C + V_{BE}.$$ & $I_C = \beta I_B$

$$\Rightarrow I_B(R_B+R_C) = V_{CC} - V_{BE} - I_C R_C$$

$$\therefore \boxed{I_B = \frac{V_{CC}-V_{BE}-I_C R_C}{R_B+R_C}.}$$

$$\therefore \boxed{I_B = \frac{V_{CC}-V_{BE}}{R_B+\beta R_C}}$$

ie If the collector current increases due to increase in temperature (7)
& the transistor is replaced by one with higher $\beta$ the voltage drop across $R_C$ increases.

So less $V_{CE}$ and less $I_B$ to compensate increase in $I_C$ ie greater stability.

Differentiate $I_B$ w.r.t. $I_C$

$$\frac{\partial I_B}{\partial I_C} = 0 + 0 - \frac{R_C}{R_C+R_B}$$

$$\therefore \boxed{\frac{\partial I_B}{\partial I_C} = -\frac{R_C}{R_C+R_B}}$$

Substitute above eqn in general stability factor as

$$S = \frac{1+\beta}{1-\beta\left(\frac{\partial I_B}{\partial I_C}\right)} = \frac{1+\beta}{1-\beta\left(\frac{-R_C}{R_C+R_B}\right)}$$

$\therefore$ Stability factor $\boxed{S = \frac{1+\beta}{1+\beta\left(\frac{R_C}{R_C+R_B}\right)}}$

ie The value of $S$ is less than that of fixed bias (which is $S = 1+\beta$)
& $S$ can be made small and stability improved by making $R_B$ small or $R_C$ large. If $R_C$ is small $S = 1+\beta$ ie stability is poor.

Stability factor $S'$: $S' = \frac{\partial I_C}{\partial V_{BE}} \Big| I_{CO}$ & $\beta$ are constant

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

& $I_B = \frac{V_{CC} - V_{BE} - I_C R_C}{R_B + R_C} \longrightarrow (2)$

From (1) & (2)

$$I_C = \beta\left[\frac{V_{CC} - V_{BE} - I_C R_C}{R_B+R_C}\right] + (1+\beta) I_{CO}$$

$$I_C\left[1 + \frac{\beta \cdot R_C}{R_C+R_B}\right] = \beta\left(\frac{V_{CC}-V_{BE}}{R_B+R_C}\right) + (1+\beta) I_{CO}$$

$\therefore$ Differentiate above eqn w.r.t. $V_{BE}$

$$\frac{\partial I_C}{\partial V_{BE}}\left(1+\beta\frac{R_C}{R_C+R_B}\right) = \beta\left(-\frac{1}{R_B+R_C}\right) + 0$$

$$\therefore \frac{\partial I_C}{\partial V_{BE}}\left(\frac{(1+\beta)R_C+R_B}{R_C+R_B}\right) = \frac{-\beta}{R_C+R_B}$$

$$\therefore \boxed{\text{Stability factor } S' = \frac{\partial I_C}{\partial V_{BE}} = \frac{-\beta}{(1+\beta)R_C+R_B}}$$

Stability factor $S''$: $S'' = \left.\frac{\partial I_C}{\partial \beta}\right|_{I_{CO}\ \&\ V_{BE}\text{ are constant}}$

From eqn ① & ②

$$I_C = \beta\left[\frac{V_{CC}-V_{BE}-I_C R_C}{R_C+R_B}\right] + (1+\beta)I_{CO}$$

Differentiate above eqn w.r.t $\beta$

$$\frac{\partial I_C}{\partial \beta} = \frac{V_{CC}-V_{BE}-I_C R_C}{R_C+R_B} + I_{CO}.$$

$$\therefore \text{Stability factor } \boxed{S'' = \frac{V_{CC}-V_{BE}-I_C R_C}{R_C+R_B} + I_{CO}.}$$

(or)

$$\boxed{S'' = \frac{I_C \cdot S}{\beta(1+\beta)}}$$

Collector to Base Bias

Merits :

* Circuit stabilizes the operating point against variations in temperature and $\beta$ (ie replacement of transistor).

Demerits :

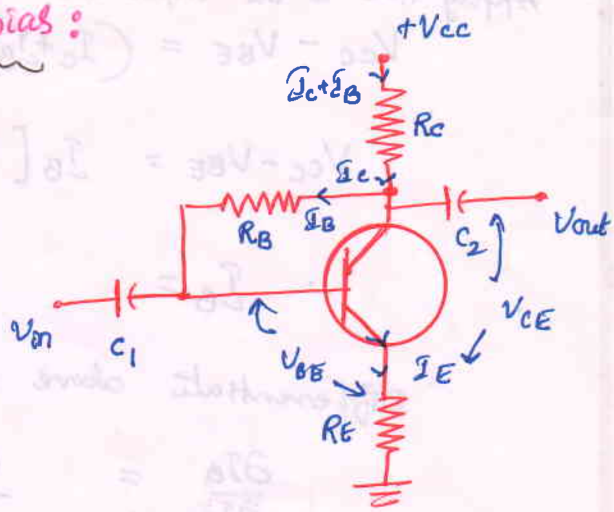
1. In this ckt to keep $I_C$ independent of $\beta$ the following condition must be met.
$$I_C = \beta I_B = \frac{\beta(V_{CC}-V_{BE})}{R_B+R_C+\beta R_C} \cong \frac{V_{CC}-V_{BE}}{R_C}.$$
which is the case when $\beta R_C >> R_B$.

2. 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 transistor 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 :




To further improve the level of stability, the Emitter resistance is connected in the collector bias ckt to provide both collector and Emitter feedback.

For D.C. Analysis all the capacitors are opened.

· Apply KVL to the ckt.

$$V_{CC} = (I_C + I_B)R_C + I_B R_B + V_{BE} + I_E \cdot R_E$$

$$V_{CC} = I_C \cdot R_C + I_B(R_C + R_B) + V_{BE} + (1+\beta) I_B \cdot R_E$$

$$V_{CC} - V_{BE} = \beta I_B \cdot R_C + I_B \cdot R_C + I_B R_B + (1+\beta) I_B \cdot R_E$$

$$\Rightarrow I_B\left[R_B + (1+\beta)R_C + (1+\beta)R_E\right] = V_{CC} - V_{BE}$$

∵ we know
$\Rightarrow I_C = \beta I_B$
$I_E = I_C + I_B$
$I_E = \beta I_B + I_B$
$\Rightarrow I_E = (1+\beta) I_B$

$$\therefore \boxed{I_B = \frac{V_{CC} - V_{BE}}{R_B + (1+\beta)(R_C + R_E)}}$$

if $\beta >> 1$

$$\therefore \boxed{I_B = \frac{V_{CC} - V_{BE}}{R_B + \beta(R_C + R_E)}}$$

ie In general we can say that

$$\boxed{I_B = \frac{V'}{R_B + \beta R'}}$$

where $V' = V_{CC} - V_{BE}$

and $R' = 0$ for Fixed bias.

$R' = R_E$ for Fixed bias with Emitter resistor.

$R' = R_C$ for Collector to Base Bias

$R' = R_C + R_E$. for Collector - Emitter feedback bias.

(a) Collector to Base bias with Emitter resistor

Apply KVL to the input ckt.

$$V_{CC} - V_{BE} = (I_C + I_B) R_C + I_B R_B + (I_C + I_B) R_E \quad (\because I_E = I_C + I_B)$$

$$V_{CC} - V_{BE} = I_B [R_C + R_B + R_E] + I_C \cdot [R_C + R_E].$$

$$\therefore I_B = \frac{V_{CC} - V_{BE} - I_C(R_C + R_E)}{R_C + R_B + R_E}$$

Differentiate above eqn w.r.t. $I_C$

$$\frac{\partial I_B}{\partial I_C} = \frac{0 - 0 - (R_C + R_E)}{R_B + R_C + R_E} = \frac{-(R_C + R_E)}{R_B + R_C + R_E}.$$

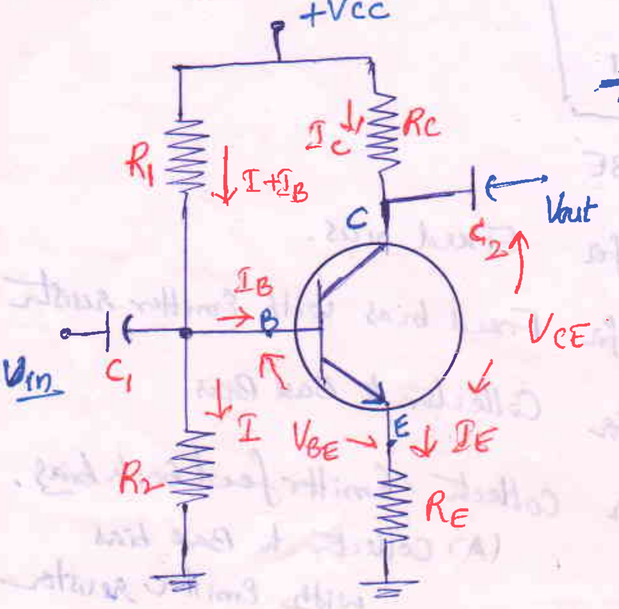
General Expression for Stability

$$S = \frac{1+\beta}{1 - \beta\left(\frac{\partial I_B}{\partial I_C}\right)} = \frac{1+\beta}{1 - \beta\left(\frac{-(R_C + R_E)}{R_B + R_C + R_E}\right)}.$$

$$\therefore \boxed{S = \frac{1+\beta}{1 + \beta \cdot \frac{(R_C + R_E)}{R_B + R_C + R_E}}}$$

ie The factor $\frac{R_C + R_E}{R_B + R_C + R_E}$ is always greater than the factors $R_C/(R_C + R_B)$ and $R_E/(R_B + R_E)$. This states that the stability of the collector-Emitter feedback bias ckt is always better than that of collector feedback and Emitter-feedback bias ckts.

## ⑤ Voltage Divider Bias & Self bias & Emitter bias :




→ In the voltage divider bias circuit the biasing is provided by three resistors. ie. $R_1$, $R_2$ & $R_E$.

→ The resistors $R_1$ & $R_2$ acts as a potential divider giving a fixed voltage to the Base.

→ If collector current increases due to change in temperature & change in $\beta$ the voltage drop across $R_E$ increases, reducing the voltage difference b/w base & Emitter $V_{BE}$.

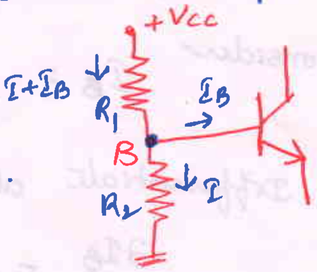
→ Due to reduction in $V_{BE}$, base current $I_B$ & hence collector current $I_C$ also reduces.

∴ The negative feedback exists in the emitter bias ckt. This reduction in collector current $I_C$ compensates for the original change in '$I_C$'.

**D.C. Analysis:** For D.C analysis all the capacitors are opened.

Voltage across '$R_2$' is the base voltage $V_B$.

Applying the voltage divider theorem to find $V_B$.




ie
$$V_B = \frac{R_2 \cdot I}{R_1(I+I_B) + R_2(I)} \cdot V_{CC}$$
If $I >> I_B$.

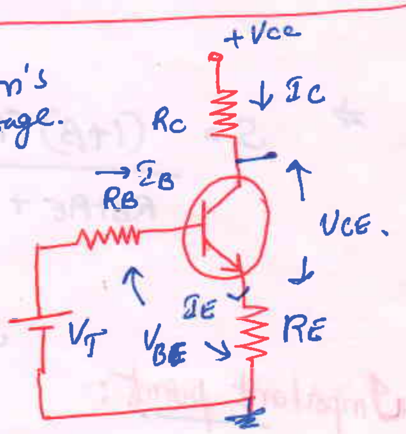
$$\therefore \boxed{V_B = \frac{R_2}{R_1+R_2} \times V_{CC}}$$
& $\boxed{R_B = R_1 // R_2 = \frac{R_1 R_2}{R_1+R_2}}$

**Simplified Ckt of Self bias:**

→ Thevinin's voltage.

Here $R_1$ & $R_2$ are replaced by $R_B$ & $V_T$.

where $R_B = R_1 // R_2 = \frac{R_1 R_2}{R_1+R_2}$




Apply KVL to the base ckt.

$$V_T = I_B \cdot R_B + V_{BE} + I_E \cdot R_E$$
$$V_T = I_B R_B + V_{BE} + I_B R_E + I_C R_E \quad (\because I_E = I_B + I_C)$$
$$V_T - V_{BE} = I_B[R_B + R_E] + I_C \cdot R_E$$

$$I_B \cdot (R_B + R_E) = V_T - V_{BE} - I_C R_E$$
$$\boxed{I_B = \frac{V_T - V_{BE} - I_C R_E}{R_B + R_E}}$$
where $V_T = \frac{R_2}{R_1+R_2} \cdot V_{CC}$.

(a) $I_C = \beta I_B$

$$V_T - V_{BE} = I_B[R_B + (1+\beta) R_E]$$
$$\therefore \boxed{I_B = \frac{V_T - V_{BE}}{R_B + (1+\beta) R_E}}$$
where $V_T$ & $V_B = \frac{R_2}{R_1+R_2} \cdot V_{CC}$.

Apply KVL to the output circuit.

$$V_{CC} = I_C \cdot R_C + V_{CE} + I_E \cdot R_E$$
$$\Rightarrow \boxed{V_{CE} = V_{CC} - I_C \cdot R_C - I_E R_E}$$

where $I_E \cdot R_E = V_E$

& $V_E = V_B - V_{BE}$

$$\therefore I_E = \frac{V_B - V_{BE}}{R_E}.$$

**Note :** We can use simplified & approximate analysis when $\boxed{\beta R_E \geq 10 R_2}$ condition is satisfied.

Under this condition results of exact & approximate analysis are nearly same.

## Stability Factor (S):

General expression for stability factor $S = \dfrac{1+\beta}{1-\beta\left(\dfrac{\partial I_B}{\partial I_C}\right)}$ ← ①

Consider $I_B = \dfrac{V_T - V_{BE} - I_C \cdot R_E}{R_B + R_E}$ where $V_T = \dfrac{R_2}{R_1+R_2} \times V_{CC}$

$R_B = R_1 || R_2 = \dfrac{R_1 R_2}{R_1 + R_2}$

Differentiate above eqn w.r.t. $I_C$

$$\frac{\partial I_B}{\partial I_C} = \frac{0 - 0 - R_E}{R_B + R_E} = \frac{-R_E}{R_B + R_E} \rightarrow ②$$

∴ From ① & ②

Stability factor $\boxed{S = \dfrac{1+\beta}{1+\beta\left(\dfrac{R_E}{R_B+R_E}\right)}}$ where $R_B = \dfrac{R_1 R_2}{R_1 + R_2}$.

$$\Rightarrow \quad S = \frac{(1+\beta)(R_B+R_E)}{R_B + R_E + \beta R_E} = \frac{(1+\beta)(R_B+R_E)}{R_B + (1+\beta)R_E}$$

Divide each term by '$R_E$'.

$$S = \frac{(1+\beta)\cdot(1 + R_B/R_E)}{(1+\beta) + (R_B/R_E)}.$$

## Important points:

①. The ratio '$R_B/R_E$' controls value of stability factor '$S$'. If $R_B/R_E \ll 1$. then above eqn reduces $S = (1+\beta) \cdot \dfrac{1}{(1+\beta)} = 1 \Rightarrow \boxed{S = 1}$

Practically '$R_B/R_E$' $\neq 0$. But to have better stability factor '$S$', we have to keep ratio '$R_B/R_E$' as small as possible.

② To keep '$R_B/R_E$' small, it is necessary to keep $R_B$ small ie $R_1 || R_2$ must be small & reducing the life of the battery.

③ & By increasing '$R_E$' we can make '$R_B/R_E$' small, But as we increase $R_E$ drop '$I_E R_E$' will aso increases & since $V_{CC}$ is constant, drop across $R_C$ will reduce. This shift the operating point 'Q' which is not desirable.

ie S - small, $R_B$ - Reasonably small & $R_E$ - not very large.

④ If ratio '$R_B/R_E$' is fixed, stability decreases with increasing '$\beta$'.

⑤ Stability factor is essentially independent of '$\beta$' for small value of '$S$'.

**Stability factor $S'$:** Stability factor $S' = \left.\dfrac{\partial I_C}{\partial V_{BE}}\right|_{I_{CO}\ \&\ \beta\ \text{constant}}$.

We know $I_C = \beta I_B + (1+\beta) I_{CO}$.

& $I_B = \left[\dfrac{V_T - V_{BE} - I_C \cdot R_E}{R_B + R_E}\right]$ where $V_T = \dfrac{R_2}{R_1+R_2} \cdot V_{CC}$

$R_B = R_1 \| R_2 = \dfrac{R_1 R_2}{R_1 + R_2}$.

$$\therefore \quad I_C = \beta\left[\frac{V_T - V_{BE} - I_C R_E}{R_B + R_E}\right] + (1+\beta) I_{CO}$$

$$I_C\left[1 + \frac{R_E}{R_B+R_E}\right] = \beta \cdot \left[\frac{V_T - V_{BE}}{R_B + R_E}\right] + I_{CO} + \beta I_{CO}$$

Differentiate above eqn w.r.t. $V_{BE}$.

$$\frac{\partial I_C}{\partial V_{BE}}\left[\frac{R_B + R_E + R_E}{R_B + R_E}\right] = \frac{-\beta}{R_B + R_E} + 0.$$

$$\Rightarrow \quad \frac{\partial I_C}{\partial V_{BE}} = \frac{-\beta}{R_B + (1+\beta) R_E}.$$

$$\therefore \quad \boxed{\text{Stability factor } S' = \frac{-\beta}{R_B + (1+\beta) R_E}.} \longrightarrow (1)$$

We know Stability factor $S = \dfrac{1+\beta}{1+\beta\left(\dfrac{R_E}{R_B+R_E}\right)} = \dfrac{1+\beta}{R_B + (1+\beta) R_E} \times (R_B + R_E)$. $\longrightarrow (2)$

**Realation b/w $S$ & $S'$:**

from (2) $\dfrac{S}{(1+\beta)(R_B+R_E)} = \dfrac{1}{R_B + (1+\beta) R_E}$

$\therefore$ from (1) $S' = \dfrac{-\beta \cdot S}{(1+\beta)(R_B+R_E)}$ $\quad \therefore \boxed{S' = \dfrac{-S}{(R_B+R_E)} \cdot \dfrac{\beta}{(1+\beta)}}$.

**Stability factor $S''$:** Stability factor $S'' = \left.\dfrac{\partial I_C}{\partial \beta}\right|_{I_{CO},\ V_{BE}\ \text{constant}}$.

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

& $I_B = \dfrac{V_T - V_{BE}}{R_B + (1+\beta) R_E} \Rightarrow I_C = \beta \cdot \left[\dfrac{V_T - V_{BE}}{R_B + (1+\beta) R_E}\right] + (1+\beta) I_{CO}$

& $I_C = \beta\left(\dfrac{V_T - V_{BE} - I_C \cdot R_E}{R_B + R_E}\right) + (1+\beta) I_{CO}$.

$$I_C = \frac{\beta(V_T - V_{BE} + V')}{R_B + (1+\beta) R_E} \longrightarrow (3)$$

where $V' = \dfrac{(R_B+R_E)(1+\beta)}{\beta} \cdot I_{CO}$

If $\beta >> 1 \Rightarrow V' = (R_B + R_E) I_{CO}$.

Differentiate eqn ③ & taking independent of '$\beta$', we get

$$\frac{\partial I_C}{\partial \beta} = \frac{[R_B+(1+\beta)R_E][V_T+V'-V_{BE}] - \beta[V_T+V'-V_{BE}]\cdot R_E}{[R_B+(1+\beta)R_E]^2}$$

$$\left[\because \frac{d}{dt}\left(\frac{u}{v}\right) = \frac{v\cdot\frac{du}{dt} - u\cdot\frac{dv}{dt}}{v^2}\right]$$

Multiplying Numerator & Denominator by $(1+\beta)$.

$$\frac{\partial I_C}{\partial \beta} = \frac{(1+\beta)[R_B+R_E](V_T+V'-V_{BE})}{(1+\beta)[R_B+(1+\beta)R_E][R_B+(1+\beta)R_E]}$$

$$\therefore \frac{\partial I_C}{\partial \beta} = \frac{V_T+V'-V_{BE}}{(1+\beta)\cdot[R_B+(1+\beta)R_E]}\cdot S. \quad \text{where } S = \frac{(1+\beta)(R_B+R_E)}{R_B+(1+\beta)R_E}.$$

Multiply NR & DR by '$\beta$'

$$S'' = \frac{(V_T+V'-V_{BE})\beta\cdot S}{\beta(1+\beta)(R_B+(1+\beta)R_E}.$$

$$\boxed{S'' = \frac{I_C\cdot S}{\beta\cdot(1+\beta)}}. \quad \text{where } I_C = \frac{\beta(V_T+V'-V_{BE})}{R_B+(1+\beta)R_E}.$$

i.e.

It is clear that minimizing 'S' also minimizes $S''$.

## Common Base Stability

In common base amplifier circuit, the equation for collector current $I_C$ is given by

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

∴ Stability factor $\boxed{S = \frac{\partial I_C}{\partial I_{CO}} = 1}$

Since this is highly stable,

The common base amplifier ckt is not in need of bias stabilization.

**Note:** According to DC & ac load line that the parallel combination $R_C$ & $R_L$ is always less than $R_C$. ∴ The slope of a.c load line is always higher than that of d.c load line.

# Stabilization of Q-point (or) Bias Compensation Using Diodes & Transistors.

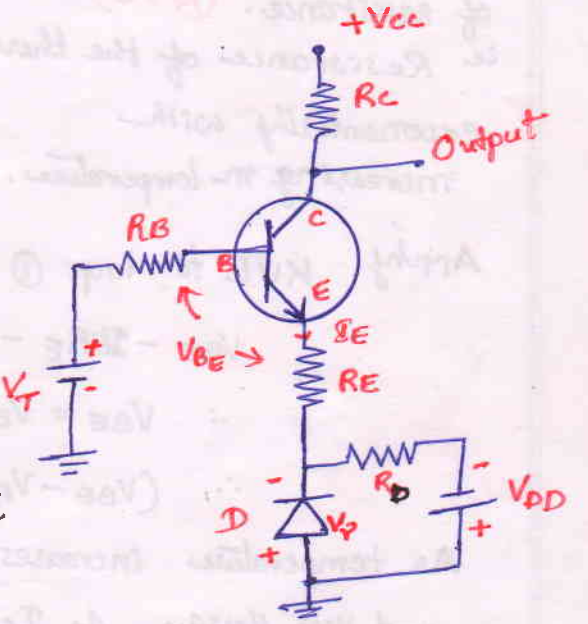
Once the Q-point is selected that Q-point can be made stable by keeping $V_{CE}$ and $I_c$ constant.

The techniques normally used to do so may be classified into two categories.

a) Stabilization technique: It refers to the use of resistive biasing circuits [ fixed - Collector-to base, Self bias circuit ].

b) Compensation technique: It refers to the use of temperature sensitive devices such as Diodes, thermistors, Sensistors.

## (i) Diode Compensation :




Consider the voltage divider bias of equivallent circuit

where $V_T = \frac{R_2}{R_1+R_2} \cdot V_{cc}$

& $R_B = R_1 \| R_2 = \frac{R_1 R_2}{R_1+R_2}$.

Here a forward bias diode is connected at the emitter as shown in fig.

The diode is always forward biased with the power supply $V_{DD}$ & $R_D$.

The diode must be connected at emitter in a direction such that $V_{BE}$ of the transistor gets cancelled with $V_\gamma$ of the diode.

Applying KVL to the input loop.

$$V_T = I_B R_B + V_{BE} + I_E \cdot R_E - V_\gamma \qquad \because I_E = I_B + I_c$$

$$V_T - V_{BE} + V_\gamma = I_B \cdot R_B + (1+\beta) I_B R_E \qquad = I_B + \beta I_B$$

$$V_T - V_{BE} + V_\gamma = [R_B + (1+\beta) R_E] I_B \qquad = (1+\beta) I_B.$$

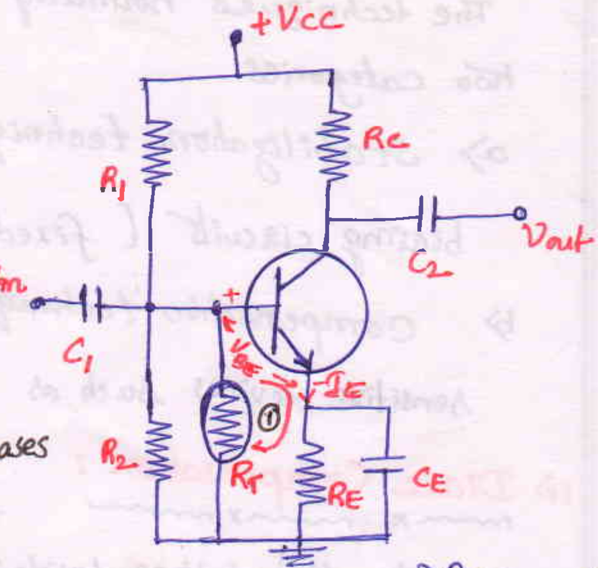
$$\therefore \boxed{I_B = \frac{V_T - (V_{BE} - V_\gamma)}{R_B + (1+\beta) R_E}} \longrightarrow (1)$$

If the diode and transistor are of same type then $V_{BE} = V_\gamma$

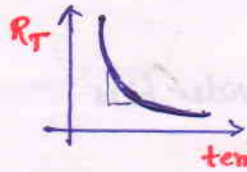
$\therefore$ Equation (1) becomes $\boxed{I_B = \frac{V_T}{R_B + (1+\beta) R_E}}$

ie Now the entire circuit will become insensitive to $V_{BE}$
Hence the variations due to temperature changes are compensated by diode 'D', which keeps $I_C$ stable at Q-point.

## (ii) Thermistor Compensation :




Here a thermistor $R_T$ is connected in parallel to $R_2$.
A Thermistor $R_T$ is a device having negative temperature coefficient of resistance. (NTC)
ie Resistance of the thermistor decreases exponentially with increasing in temperature.




Slope $= \frac{\partial R_T}{\partial T}$ is $-Ve$.

Apply KVL to loop ① we get

$$V_{BE} - I_E R_E - V_{RT} = 0$$

$I_E R_E = V_E$

$$\therefore \quad V_{BE} = V_E + V_{RT}.$$

$$\therefore \quad (V_{BE} - V_{RT}) - V_E = 0. \longrightarrow ①$$

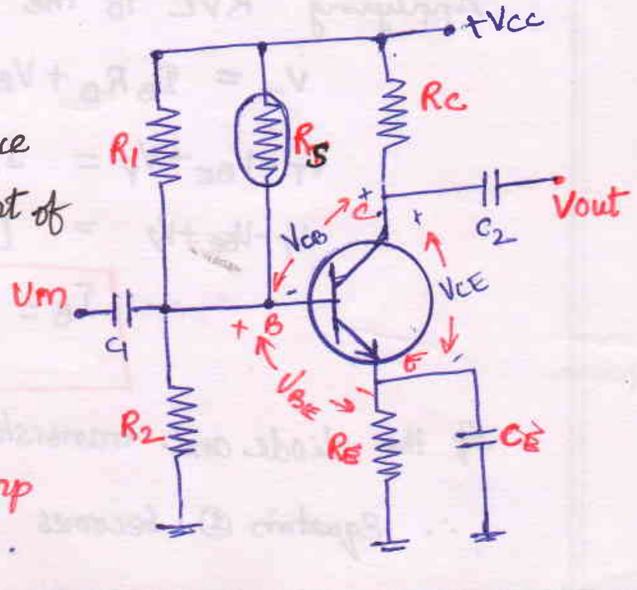
If Temp ↑, $R_T$ ↓ & $V_{RT}$ also ↓, then $V_{BE}$ ↓
If $V_{BE}$ ↓ then $I_B$ ↓

As temperature increases the $V_{BE}$ tends to decrease and also $V_{RT}$. and Vice Versa. As $I_C$ tends to ~~decrease~~ increase due to increase in temp. stabilization of Q-point is obtained due to decrease in voltage $V_{RT}$.

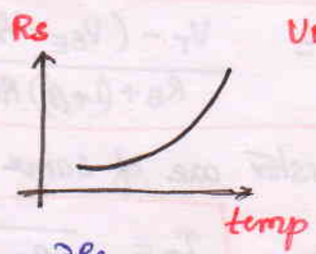
We know. $I_C = \beta I_B + (1+\beta) I_{CO}$

Here there is an increase in $I_{CO}$ and decrease in $I_B$ which keeps $I_C$ almost constant.

## (iii) Sensistor Compensation :




A sensistor $R_S$ is a ~~temperature~~ device having Positive temperature coefficient of resistance. (PTC)
ie The resistance of the sensistor increases as temperature increases.




Slope $= \frac{\partial R_S}{\partial T}$ is $+Ve$.

The sensistor '$R_S$' is connected in parallel with '$R_1$'. By adding the sensistor in the ckt the voltage drop '$V_{CB}$' can be altered as temperature varies.

As temp ↑, $R_S$ ↑ & $V_{R_S}$ ↑ & $V_{CB}$ ↑ then $V_{BE}$ will ↓ & '$I_B$' also decreases.

$$V_{CE} = V_{CB} + V_{BE}$$

$$\Rightarrow \boxed{V_{BE} = V_{CE} - V_{CB}}$$

As temperature increases ~~and~~ then current '$I_C$' increases. and to control the increase of '$I_C$' the value of '$I_B$' & $V_{BE}$ must decrease.

ie As temperature increases the voltage drop across collector & Base $V_{CB}$ increases ($\because V_{CB} = V_{RS} - I_C R_C$), which tends to decrease '$V_{BE}$'. Hence stabilization of Q-point is obtained.

Note : The sensistor '$R_S$' may also be connected parallel to $R_E$.

## Thermal Runaway:

The self destruction of a transistor is called thermal runaway.

ie "The increase in the collector current increases the power dissipated at the collector junction. This, in turn further increases the temperature of the junction and hence increase in the collector current. The process is cumulative and it is referred to as self heating. The excess heat produced at the collector base junction may even burn and destroy the transistor. This situation is called "Thermal runaway"." of the transistor.

* For Si transistor temperature is in the range 150 to 225°c.
  For Ge transistor temperature is in the range 60 to 100°c.

The collector base junction temperature may be rise because of two reasons a> Due to raise in ambient temperature.
b> Due to self heating.

ambient temperature - room temperature [PTO].

## Thermal Resistance :

The steady state temperature rise at the collector junction is proportional to the power dissipated at the junction.

It is given by $\boxed{\partial T = T_j - T_A = \theta P_D}$.

where $T_j$ - junction temperature in $^\circ C$.

$T_A$ - Ambient temperature in $^\circ C$.

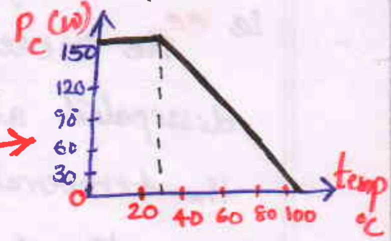
$P_D$ - Power in 'W' dissipated at the collector junction

& $\theta$ - Constant of proportionality.

The $\theta$, which is constant of proportionality is referred to as thermal resistance ie $\boxed{\theta = \dfrac{T_j - T_A}{P_D}}$.

* The unit of $\theta$, the thermal resistance is $^\circ C/\text{Watt}$.
* The typical values of '$\theta$' for various transistors vary from $0.2\ ^\circ C/W$ for a high power transistor with an efficient heat sink to $1000\ ^\circ C/W$ for a low power transistor.
* The max. collector power $P_c$ allowed for safe operation is specified at $25^\circ C$.

ie At above $25^\circ C$, collector power must be decreased, and at the extreme temperature at which the transistor may operate, $P_c$ is reduced to zero.




## Thermal Stability :

As we know the thermal runaway may even burn and destroy the transistor. It is necessary to avoid thermal runaway. The required condition to avoid thermal runaway is that the rate at which heat is released at the collector junction must not exceed the rate at which the heat can be dissipated. It is given by

$$\frac{\partial P_c}{\partial T_j} < \frac{\partial P_D}{\partial T_j},$$

Consider $T_j - T_A = \theta P_D$, differentiate w.r.t. $T_j$

$$1 = \theta \cdot \frac{\partial P_D}{\partial T_j} \Rightarrow \frac{\partial P_D}{\partial T_j} = \frac{1}{\theta}.$$

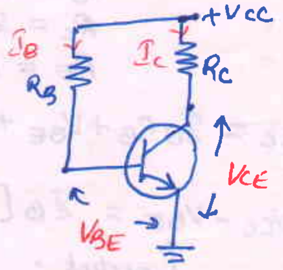
Hence $\boxed{\dfrac{\partial P_c}{\partial T_j} < \dfrac{1}{\theta}}$

This condition must be satisfied to prevent thermal runaway.

By proper design of biasing ckt it is possible to ensure that the transistor cannot runaway below a specified ambient temperature.

# Problems:

1. A Ge transistor having $\beta = 100$ and $V_{BE} = 0.2V$ is used in a fixed bias ckt where $V_{CC} = 16V$, $R_C = 5k\Omega$ & $R_B = 790k\Omega$. Determine its operating point.



Sol Given data $\beta = 100$ $\quad V_{CC} = 16V$

$V_{BE} = 0.2V$ $\quad R_C = 5k\Omega$

$R_B = 790k\Omega$

Apply KVL to the input ckt.

$$V_{CC} = I_B R_B + V_{BE}$$

$$\Rightarrow I_B = \frac{V_{CC} - V_{BE}}{R_B} = \frac{16-0.2}{790\times10^3} = 20\mu A \Rightarrow \boxed{I_B = 20\mu A}$$

$$I_C = \beta I_B = 100 \times 20\mu A = 2mA \Rightarrow \boxed{I_{C_Q} = 2mA}$$

Apply KVL to the output ckt.

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

$$V_{CE} = V_{CC} - I_C \cdot R_C = 16 - 2\times10^{-3} \times 5\times10^3 = 6V. \quad \therefore \boxed{V_{CE_Q} = 6V}$$

DC load line.

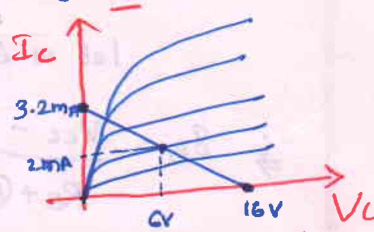
$$I_C = \frac{V_{CC} - V_{CE}}{R_C}, \quad \text{If } V_{CE} = 0, \; I_C = \frac{V_{CC}}{R_C} = \frac{16}{5\times10^3} = 3.2mA.$$

$$\text{If } I_C = 0, \; V_{CE} = V_{CC} = 16V.$$

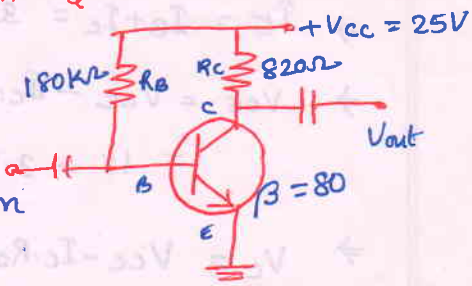
$\therefore$ The operating point is:

$I_C = 2mA$

& $V_{CE} = 6V$.




2. The ckt as shown in the fig. has fixed bias using NPN transistor. Determine the value of base current, Collector Current & Collector to Emitter voltage?




Sol From fig. $V_{CC} = 25V$

$R_B = 180k\Omega$ & $\beta = 80$.

$R_C = 820\Omega$ $\quad$ Let Si transistor

Apply KVL to the base ckt, $V_{BE} = 0.7V$.

$$V_{CC} = I_B R_B + V_{BE}$$

$$\Rightarrow I_B = \frac{V_{CC} - V_{BE}}{R_B} = \frac{25-0.7}{180\times10^3} = 135\mu A \quad \therefore \boxed{I_B = 135\mu A}$$

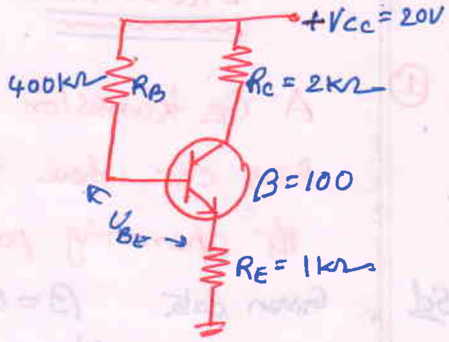
$$\Rightarrow I_C = \beta \cdot I_B = 80 \times 135\mu A = 10.8mA \Rightarrow \boxed{I_C = 10.8mA}$$

Apply KVL to the collector ckt.

$$V_{CC} = I_C \cdot R_C + V_{CE}$$

$$V_{CE} = V_{CC} - I_C R_C = 25 - 10.8\times10^{-3} \times 820 = 16.144V \Rightarrow \boxed{V_{CE} = 16.144V}$$

③ Calculate the d.c bias voltage and currents in the ckt shown in fig. below (Neglect $V_{BE}$ of transistor).




Sol From. Fig. $\beta = 100$

$R_B = 400k\Omega$

$R_C = 2k\Omega$

$R_E = 1k\Omega$

$V_{CC} = I_B R_B + V_{BE} + I_E(R_E)$  $\because I_E = I_B + I_C$

$I_C = \beta I_B$

$V_{CC} - V_{BE} = I_B[R_B + (1+\beta)R_E]$  $\therefore I_E = (1+\beta)I_B$.

↑ neglect.

$\therefore I_B = \dfrac{V_{CC}}{R_B + (1+\beta)R_E} = \dfrac{20}{400\times10^3 + (1+100)1\times10^3} = 39.92\mu A$

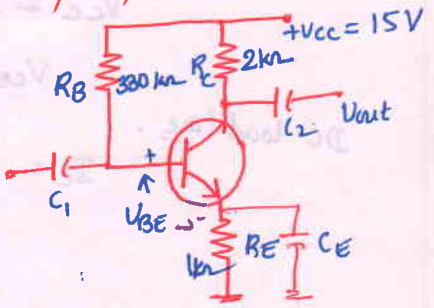
$\therefore \boxed{I_B = 39.92\mu A.}$

D.C bias voltage

$V_B = V_{CC} - I_B R_B = 20 - 39.92\times10^{-6}\times400\times10^3 = 4.032V$

$\therefore \boxed{V_B = 4\ V.}$

④ For the ckt shown in fig. Calculate $I_B, I_C, V_{CE}, V_C, V_E, V_B$ & $V_{BC}$. Assume $\beta = 100$.




Sol Given from fig. $\beta = 100$. $V_{CC} = 15V$

$R_B = 330k\Omega$

$R_C = 2k\Omega$

$R_E = 1k\Omega$

let us Assume Si transistor $V_{BE} = 0.7V$.

$\Rightarrow \therefore I_B = \dfrac{V_{CC} - V_{BE}}{R_B + (1+\beta)R_E} = \dfrac{15-0.7}{330K + (101)\times1K} = 33.18\mu A$  $\therefore \boxed{I_B = 33.18\mu A}$

$\Rightarrow I_C = \beta I_B = 100\times33.18\mu A = 3.318mA$  $\therefore \boxed{I_C = 3.318mA}$

$\Rightarrow I_E = I_B + I_C = 33.18\mu + 3.318m = 3.351mA$  $\therefore \boxed{I_E = 3.351mA}$

$\Rightarrow V_{CE} = V_{CC} - I_C\cdot R_C - I_E R_E$

$= 15 - 3.318m\times2K - 3.351m\times1K = 5V.$  $\therefore \boxed{V_{CE} = 5V.}$

$\Rightarrow V_C = V_{CC} - I_C\cdot R_C = 15 - 3.318m\times2K = 8.364V.$  $\therefore \boxed{V_C = 8.364V.}$

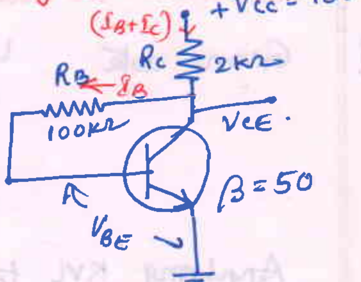
$\Rightarrow V_E = I_E\cdot R_E = 3.351m\times1K = 3.351V$  $\therefore \boxed{V_E = 3.351V.}$

$\Rightarrow V_B = V_E + V_{BE} = 3.351 + 0.7 = 4.051V$  $\therefore \boxed{V_B = 4.051V.}$

$\Rightarrow V_{BC} = V_B - V_C \Rightarrow V_{BC} = 4.051V - 8.364V$

$= -4.313V$  $\therefore \boxed{V_{BC} = -4.313V.}$

*(5) An npn transistor of $\beta = 50$ is used in common Emitter ckt with $V_{cc} = 10V$ and $R_C = 2k\Omega$ is obtained by connecting $100k\Omega$ resistance from Collector to base. Find the quiescent point & stability factors.




Sol. Given data $\beta = 50$

$V_{cc} = 10V$, let Si transistor

$R_C = 2k\Omega$ $\quad V_{BE} = 0.7V$.

$R_B = 100k\Omega$.

Applying KVL to the base ckt, we have

$$V_{cc} = (I_B + I_C)R_C + I_B \cdot R_B + V_{BE}$$

$$I_B = \frac{V_{cc} - V_{BE} - I_C R_C}{R_B + R_C} \quad \& \quad I_C = \beta I_B.$$

then $I_B = \dfrac{V_{cc} - V_{BE}}{R_B + (1+\beta) R_C}$.

$$\Rightarrow I_B = \frac{10 - 0.7}{100K + (1+50)(2K)} = 46\mu A \quad \therefore \boxed{I_B = 46\mu A}$$

$$\Rightarrow I_C = \beta I_B = 50 \times 46\mu A = 2.3mA \quad \therefore \boxed{I_C = 2.3mA}$$

Applying KVL to the Collector circuit, we have.

$$V_{CE} = V_{cc} - (I_B + I_C) R_C.$$

$$= 10 - (46\mu + 2.3m) \times 2K$$

$$= 5.308V \quad \therefore \boxed{V_{CE} = 5.308V}$$

$\therefore$ Qpoint is $I_C = 2.3mA$ & $V_{CE} = 5.308V$.

Stability factor $S = \dfrac{1+\beta}{1 + \beta\left(\dfrac{R_C}{R_C + R_B}\right)} = \dfrac{51}{1 + 50\left(\dfrac{2\times10^3}{2\times10^3 + 100\times10^3}\right)}$

$$= 25.75 \quad \therefore \boxed{S = 25.75}$$

Stability factor $S' = \dfrac{-\beta}{R_B + (1+\beta)R_C} = \dfrac{-50}{100\times10^3 + 51\times2\times10^3}$

$$= -2.475\times10^{-4} \quad \therefore \boxed{S' = -2.475\times10^{-4}}$$

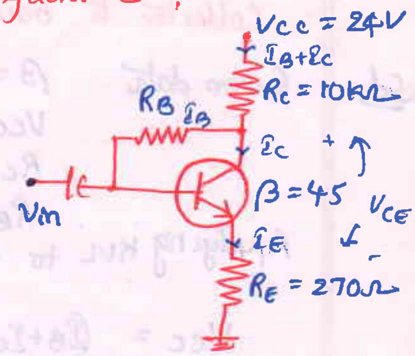
Stability factor $S'' = \dfrac{I_C}{\beta} \cdot \dfrac{S}{(1+\beta)}$

$$= \frac{2.3\times10^{-3}}{50} \times \frac{25.75}{51}$$

$$= 23.22\times10^{-6} \quad \therefore \boxed{S'' = 23.22\times10^{-6}}$$

⑥ In the ckt shown in fig. $V_{CC} = 24V$, $R_C = 10k\Omega$ & $R_E = 270\Omega$. The transistor used has $\beta = 45$. If under quiescent conditions, $V_{CE} = 5V$ & $V_{BE} = 0.6V$. Calculate the value of $R_B$ and the value of stability factor 'S'.

Sol Given data $V_{CC} = 24V$
$R_C = 10k\Omega$ $\quad V_{CE} = 5V$
$R_E = 270\Omega$ $\quad V_{BE} = 0.6V$.
$\beta = 45$. $\quad R_B = ?$




Applying KVL to the collector ckt.

$$V_{CC} = (I_B + I_C)R_C + V_{CE} + I_E \cdot R_E.$$

$\because I_E = I_B + I_C = I_B + \beta I_B = (1+\beta)I_B.$

$$\therefore V_{CC} - V_{CE} = [I_B(1+\beta)]R_C + (1+\beta)I_B \cdot R_E$$

$$= I_B[(1+\beta)R_C + (1+\beta)R_E]$$

$$\therefore I_B[(1+\beta)(R_C + R_E)] = V_{CC} - V_{CE}$$

$$\therefore I_B = \frac{V_{CC} - V_{CE}}{(1+\beta)(R_C + R_E)} = \frac{24-5}{46 \times (10k + 270)} = 40.2\,\mu A$$

$$\therefore \boxed{I_B = 40.2\mu A}$$

Applying KVL to Base circuit

$$V_{CC} = (I_B + I_C)R_C + I_B R_B + V_{BE} + I_E \cdot R_E.$$

$$\therefore I_B \cdot R_B = V_{CC} - (1+\beta)I_B \cdot R_C - V_{BE} - (1+\beta)I_B \cdot R_E.$$

$$= V_{CC} - V_{BE} - (1+\beta)(R_C + R_E) \cdot I_B.$$

$$= 24 - 0.6 - (46)(10k + 270)(40.2\mu).$$

$$= 4.4$$

$$\therefore R_B = 4.4 / 40.2 \times 10^{-6} = 109.5k\Omega \qquad \therefore \boxed{R_B = 109.5k\Omega}$$

Stability factor

$$S = \frac{1+\beta}{1+\beta\left(\frac{R_C + R_E}{R_C + R_B + R_E}\right)} = \frac{1+45}{1+45\left(\frac{10k + 270}{10k + 109.5k + 270}\right)} = 9.468$$

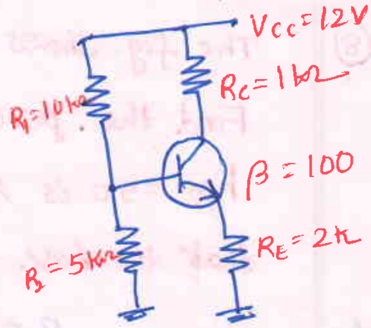
$$\therefore \boxed{S = 9.468}$$

⑦ If the various parameters of a CE amplifier which uses the self bias method are $V_{CC} = 12V$, $R_1 = 10k\Omega$, $R_2 = 5k\Omega$, $R_C = 1k\Omega$, $R_E = 2k\Omega$ and $\beta = 100$. Find,

a) The coordinates of the operating point and

b) The stability factor, assuming the transistor to be of Silicon.

Sol: Given $V_{CC} = 12V$, $R_1 = 10\,k\Omega$, $R_2 = 5\,k\Omega$, $R_C = 1\,k\Omega$, $R_E = 2\,k\Omega$, $\beta = 100$. Let us assume Given Si-transistor $V_{BE} = 0.7V$.

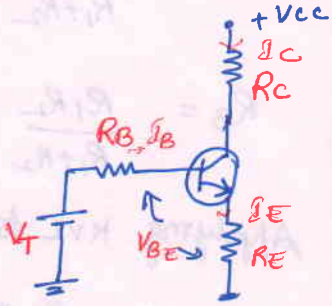



$$\beta R_E \geq 10 R_2 \Rightarrow 100 \times 2K \geq 10 \times 5K.$$
$$200K \geq 50K$$

a) We can use approximate analysis.

$$V_T = \frac{R_2}{R_1+R_2} \cdot V_{CC} = \frac{5K}{5K+10K} \times 12 = 4V \quad \therefore \boxed{V_T = 4V}$$

$$R_B = R_1 \| R_2 = \frac{R_1 R_2}{R_1+R_2} = \frac{10K \times 5K}{10K+5K} = 3.33\,k\Omega \quad \therefore \boxed{R_B = 3.33\,k\Omega}$$




Applying KVL to the Base ckt, we get

$$V_T = I_B R_B + V_{BE} + I_E \cdot R_E$$

$$V_T - V_{BE} = I_B\left[R_B + (1+\beta)R_E\right], \quad I_E = I_B + I_C = I_B + \beta I_B = (1+\beta) I_B.$$

$$\therefore I_B = \frac{V_T - V_{BE}}{R_B + (1+\beta)R_E} = \frac{4-0.7}{3.33K + (101)\times 2K} = 16\mu A$$

$$\therefore \boxed{I_B = 16\,\mu A}$$

$$I_C = \beta I_B = 16 \times 10^{-6} \times 100 = 1.6mA \quad \therefore \boxed{I_C = 1.6\,mA}$$

$$I_E = I_B + I_C = 16\mu A + 1.6mA = 1.616\,mA \quad \therefore \boxed{I_E = 1.616\,mA}$$

Applying KVL to Collector ckt, we get

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

$$\therefore V_{CE} = V_{CC} - I_C R_C - I_E R_E$$
$$= 12 - 1.6 \times 10^{-3} \times 1 \times 10^{3} - 1.616 \times 2 \times 10^{3} \times 10^{-3}$$
$$= 7.168V \quad \therefore \boxed{V_{CE} = 7.168V.}$$

The Coordinates of the operating points are

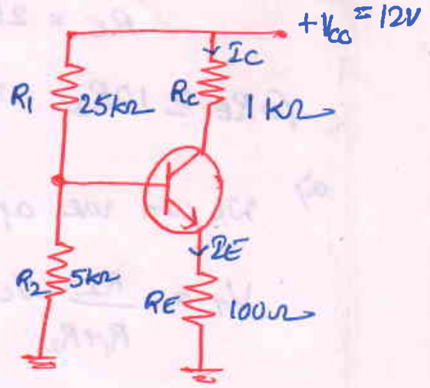
$I_C = 1.6mA$ and $V_{CE} = 7.168V$.

b) The stability factor for the self bias ckt is given by.

$$S = \frac{1+\beta}{1+\beta\left(\frac{R_E}{R_E+R_B}\right)} = \frac{1+100}{1+100\left(\frac{2K}{2K+3.33K}\right)} = 2.623$$

$$\therefore \boxed{S = 2.623}$$

⑧ The fig. Shows that dc bias ckt of a common emitter transistor amplifier. Find the percentage change in collector current of the transistor with $h_{fe} = 50$ is replaced by another transistor with $h_{fe} = 150$. It is given that the base emitter drop $V_{BE} = 0.6V$.




Sol. Given $R_1 = 25k\Omega$, $R_2 = 5k\Omega$, $R_C = 1k\Omega$, $R_E = 100\Omega$

$V_{cc} = 12V$.

$V_{BE} = 0.6V$

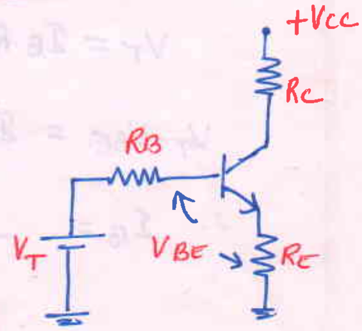
a) $h_{fe}$ & $\beta = 50$

b) $h_{fe}$ & $\beta = 150$.

$$V_T = \frac{R_2}{R_1+R_2} \cdot V_{cc} = \frac{5K}{25K+5K} \cdot 12 = 2V \quad \therefore \boxed{V_T = 2V.}$$

$$R_B = \frac{R_1 R_2}{R_1+R_2} = 25K \| 5K = 4.167k\Omega \quad \therefore \boxed{R_B = 4.167k\Omega}$$

Applying KVL to the Base circuit, we get




$$V_T = I_B R_B + V_{BE} + I_E R_E$$

$I_E = I_B + I_C$
$= I_B + \beta I_B$
$I_E = (1+\beta) I_B$

$$V_T = I_B R_B + V_{BE} + (1+\beta) I_B R_E$$

$$\therefore I_B = \frac{V_T - V_{BE}}{R_B + (1+\beta) R_E}$$

a) $\beta = 50$

$$I_{B_1} = \frac{2-0.6}{4.167K + (50+1)100} = 151\mu A \quad \therefore \boxed{I_{B_1} = 151\mu A}$$

$$I_{C_1} = \beta I_{B_1} = 50 \times 151\mu A = 7.55mA \quad \therefore \boxed{I_{C_1} = 7.55mA}.$$

b) $\beta = 150$

$$I_{B_2} = \frac{2-0.6}{4.167K + (1+150) \times 100} = 72.663\mu A \quad \therefore \boxed{I_{B_2} = 72.663\mu A}$$

$$I_{C_2} = \beta I_{B_2} = 150 \times 72.663\mu A = 10.9mA \quad \therefore \boxed{I_{C_2} = 10.9mA}$$

$$\therefore \text{Percentage Change in } I_C = \frac{I_{C_2} - I_{C_1}}{I_{C_1}} \times 100$$

$$= \frac{10.9m - 7.55m}{7.55m} \times 100$$

$$= 44.37\%$$

$$\therefore \boxed{\%\ \text{Change in } I_C = 44.37\%}$$

=*=

9. Design a Voltage divider bias network using a supply of '24V', $\beta = 110$, $I_{CQ} = 4\,mA$ & $V_{CEQ} = 8V$. Chose $V_E = V_{CC}/8$.

Sol

Given $V_{CC} = 24V$, $I_{CQ} = 4\,mA$
$\beta = 110$, $V_{CEQ} = 8V$

$$V_E = \frac{V_{CC}}{8} = \frac{24}{8} = 3V.$$

Step 1: Obtain $I_B$, $I_E$ & $V_E$:

$$I_B = \frac{I_{CQ}}{\beta} \quad (\because \beta I_B = I_C)$$

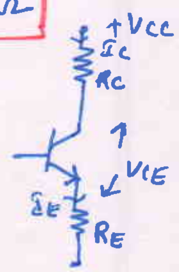
$$= \frac{4\times10^{-3}}{110} = 36.36\,\mu A \qquad \therefore \boxed{I_B = 36.36\,\mu A}$$

$$I_E = I_B + I_C = 36.36\times10^{-6} + 4\times10^{-3} = 4.03636\,mA \qquad \therefore \boxed{I_E = 4.03636\,mA}$$

$$V_E = \frac{V_{CC}}{8} = \frac{24}{8} = 3V \qquad \therefore \boxed{V_E = 3V}$$

Step 2: Obtain $R_E$ & $R_C$:

$$R_E = \frac{V_E}{I_E} = \frac{3}{4.03636\times10^{-3}} = 743.244\,\Omega \qquad \therefore \boxed{R_E = 743.244\,\Omega}$$



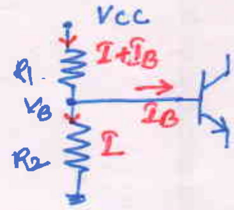

Apply KVL to the collector ckt

$$V_{CC} = I_C R_C + V_{CE} + V_E \Rightarrow R_C = \frac{V_{CC} - V_{CE} - V_E}{I_C} = \frac{24-8-3}{4\times10^{-3}} = 3.25\,k\Omega$$

$$\boxed{R_C = 3.25\,k\Omega}$$

Step 3: Obtain $R_1$ & $R_2$:

$$V_B = V_E + V_{BE} = 3 + 0.7 = 3.7V \qquad \therefore \boxed{V_B = 3.7V}$$




Consider the current '$I + I_B$' through $R_1$ & '$I$' through $R_2$.

Resistor $R_1$ & $R_2$ forms the potential divider.

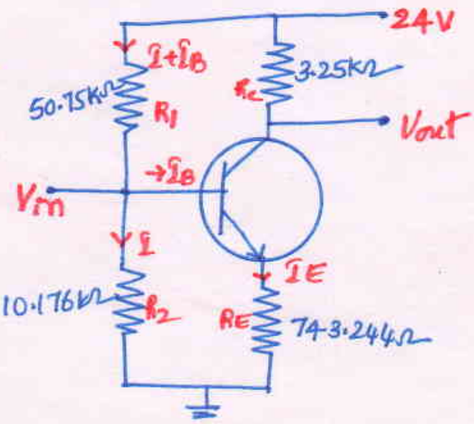
For proper operation of potential divider current '$I$' should be at least 10 times the '$I_B$' ie $I \geq 10 I_B$.

$$\therefore I = 10 I_B = 10\times 36.36\,\mu A = 363.6\,\mu A \qquad \therefore \boxed{I = 363.6\,\mu A}$$

$$R_2 = \frac{V_B}{I} = \frac{3.7}{363.6\times10^{-6}} = 10.176\,k\Omega \qquad \therefore \boxed{R_2 = 10.176\,k\Omega}$$

$$R_1 = \frac{V_{CC} - V_B}{I + I_B} = \frac{24 - 3.7}{363.6\times10^{-6} + 36.36\times10^{-6}} = 50.755\,k\Omega \qquad \therefore \boxed{R_1 = 50.755\,k\Omega}$$

Hence
∴ The voltage divider bias network have been designed.

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