Ch-2 Biasing of BJT

Introduction :-

→ The basic function of transistor is to do amplification

→ One important requirement during amplification is that only the magnitude of signal should increase and there should no change in signal shape.

→ The process of raising the strength of a weak signal without any change in its general shape is known as faithful amplification.

→ In order to obtain this, J_E of transistor remain forward biased & J_C of transistor remains reverse biased during all parts of the signal. Thus maintaing J_E forward biased & J_C reverse biased is called biasing.

→ Biasing is nothing but application of d.c voltages to establish a fixed level of current & voltage.

→ The levels of I_C & V_{CE} defines the transistor d.c operation point or quiscent point

→ In practical ckts these quantities are affected by the transistor current gain (β) or (h_{fe}) and by temperature change.

→ So different biasing methods are used for stabilization of operating point.

→ To make J_E forward biased & J_C reverse biased, the following condn must be satisfied.

(i) Proper Zero signal Collector Current
(ii) Minm proper base emitter voltage at any instant.
(iii) Minm proper Collector-emitter (V_{CE}) at any instant.

(i) Proper Zero signal Collector current:-

Consider an npn transistor shown in fig(i). During +ve half cycle of the signal, base is +ve w.r.to emitter & hence base-emitter junction is forward biased. This will cause a base current & much larger collector current to flow in the ckt.

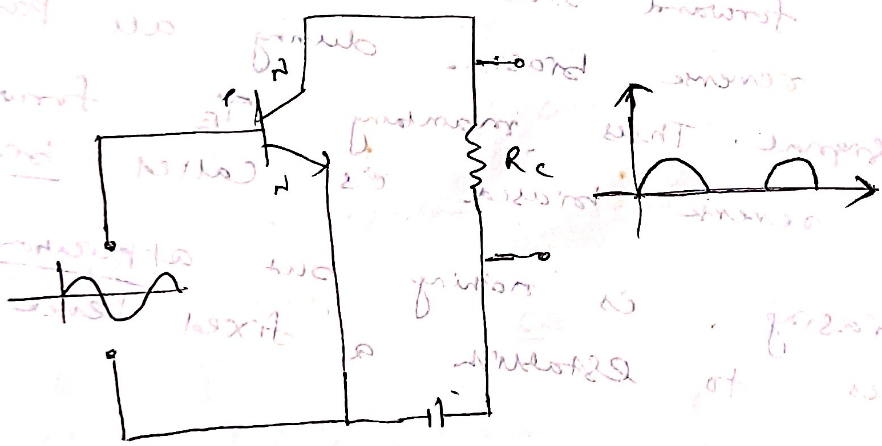
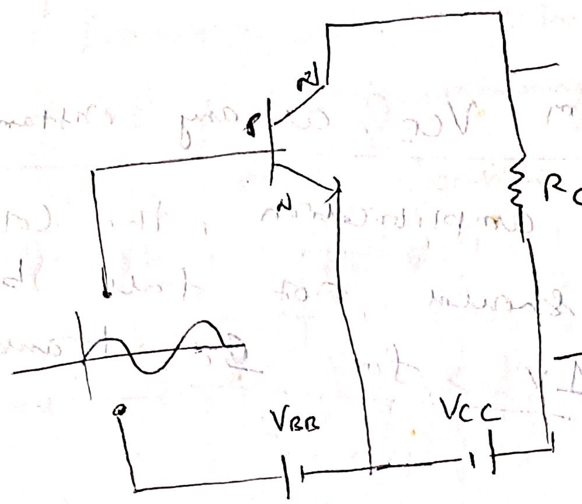


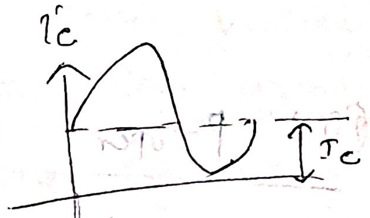
fig (i)

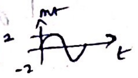
The result is that +ve half-cycle of the signal is amplified in the collector. But during the -ve half cycle of the signal, base-emitter junction is reverse biased and hence no current flows in the ckt. This results in that there is no output due to -ve half cycle of the signal. This is an unfaithful amplification.

Now, we will introduce a battery V_{BB} in the base ckt. The magnitude of this voltage should be such that it keeps the i/p ckt.

forward biased even during the peak of -ve half cycle of the signal.





Ex :  Before biasing.

Due to biasing $I_C = 3$ mA

$\underline{\text{max}^m}$ Current becomes $= 2+3 = 5$ mA

$\underline{\text{min}^m}$ " " $-2+3 = 1$ mA

→ When no signal is applied, a d.c current I_C will flow in the collector ckt due to V_{BB}. This is known as <u>zero signal collector current</u>. So during both the cycle of the signal, the base emitter junction is forward biased, <u>faithful amplification</u> results.

✓ Zero signal collector current $\geq$ Max^m collector current due to signal alone.

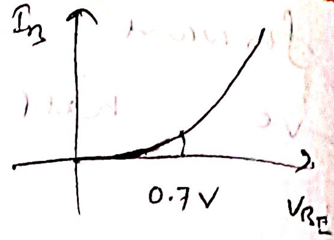
i.e zero signal collector should be at least equal to max^m collector current during signal alone so that during -ve peak of the signal there is no cutoff.

(ii) <u>Proper min^m base-emitter voltage:-</u>

In order to achieve faithful amplification, the base-emitter voltage (V_{BE}) should not fall below 0.5V for 'Ge' transistor & 0.7V for 'Si' transistor at any instant. Because this much potential barrier to be overcome to make the base-emitter j^n forward biased.

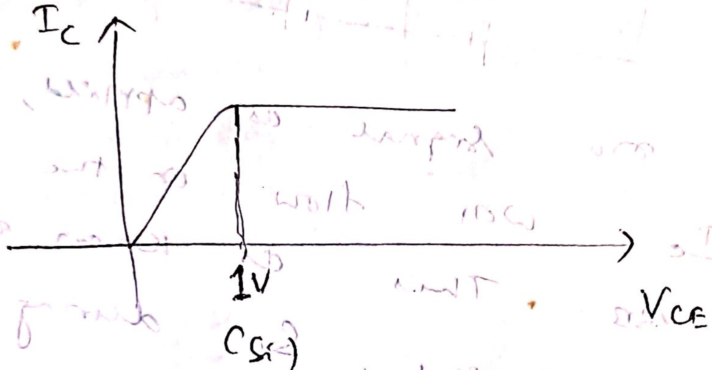
So $V_{BE} > 0.7V$ for Si

$V_{BE} > 0.5V$ for Ge



(iii) Proper minm V_{CE} at any instant :-

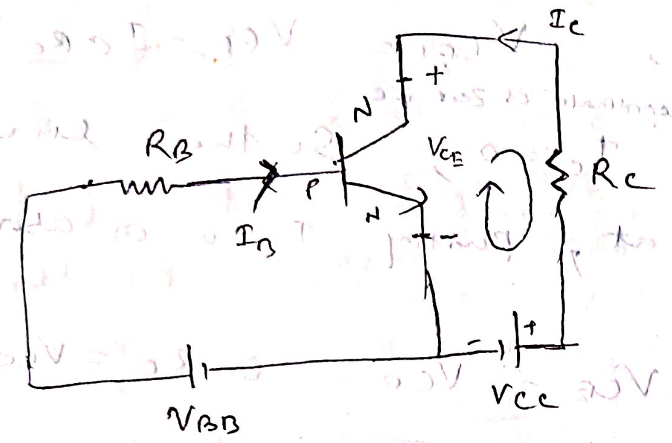
For faithful amplification, the collector-emitter voltage V_{CE} should not fall below 0.5V for Ge & 1V for Si transistors.



When V_{CE} is too low, the collector-base junction is not properly reverse-biased. Therefore, the collector can't attract the charge carriers emitted by emitter, and hence a greater portion of them goes to base. So I_B will increase, I_C will decrease. $\beta = \frac{I_C}{I_B}$ will decrease. So amplification will decrease, this results unfaithful amplification. So V_{CE} should be properly maintained. (0.5V for Ge, 1V for Si)

D.C Load Line:-

It is the line on the o/p characteristics of a transistor ckt which gives value of I_C & V_{CE} corresponding to zero signal or d.c conditions. Consider the CE ckt.



Applying KVL on the o/p ckt.

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

$$\Rightarrow V_{CE} = V_{CC} - I_C R_C \quad \text{---} (1)$$

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

$$\Rightarrow I_C = \frac{V_{CC}}{R_C} - \frac{1}{R_C} \cdot V_{CE}$$

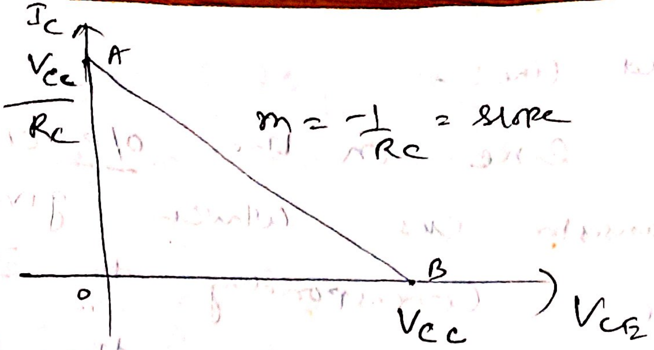
$$\Rightarrow I_C = \left(-\frac{1}{R_C}\right) \cdot V_{CE} + \frac{V_{CC}}{R_C}$$

$$[\, y = m \cdot x + c \,]$$

(Equation of a straight line having slope m & y-intercept c)

$m = -\frac{1}{R_C}$ = slope

c = y-intercept = $\frac{V_{CC}}{R_C}$



From eq^n ①, $V_{CE} = V_{CC} - I_C R_C$

For X-axis, Y-coordinate is zero i.e $I_C = 0$, So the line cut X-axis at, putting $I_C = 0$ in above eq^n,

$$V_{CE} = V_{CC} - 0 \cdot R_C = V_{CC}$$

$$\Rightarrow \boxed{V_{CE} = V_{CC}} \quad \text{——— ②}$$

So load line touches V_{CE} at V_{CC}.

Similarly :- For Y-axis or I_C axis i.e, X-coordinate $V_{CE} = 0$, putting $V_{CE} = 0$, in eq^n ①

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

$$\Rightarrow \boxed{I_C = \frac{V_{CC}}{R_C}} \quad \text{——— ③}$$

∴ Load line touches I_C at $\left(\frac{V_{CC}}{R_C}\right)$.

So when $I_C = 0$, [from eq^n ②]

$$\boxed{V_{CE_{sat}} = V_{CE_{max}} = V_{CC}}$$

i.e V_{CE}'s max^m or saturation value is V_{CC}.

From eqn (3),

when $V_{CE}=0$, I_C is max^m

$$\boxed{I_C = I_{C\,sat} = I_{C\,max} = \frac{V_{CC}}{R_C}}$$

Why it is called load line?

Because the load (R_C) of the network defined the slope of the straight line connecting the points defined by the n/w parameters.

$$\boxed{\text{Slope} = -\frac{1}{R_C}}$$

Why DC load line?

Because transistor is operated by DC supply (No ~~A/C~~ AC signal is applied).

The end points of load lines (AB) are

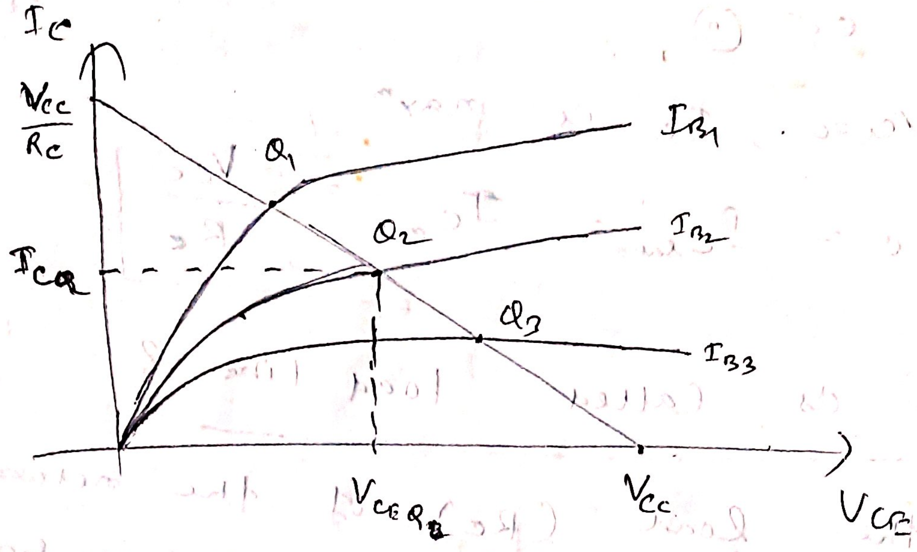
$$A\left(0, \frac{V_{CC}}{R_C}\right), \quad B(V_{CC}, 0)$$

Operating Point (Q-Point):

→ The zero signal (means no signal → no AC signal) value of collector current (I_C) and output collector emitter voltage (V_{CE}) is known as operating point.

→ It is also known as quiescent point (Q-point), silent point.

→ Consider fig (1) shown below, The load line intersects the o/p characteristics at Q_1, Q_2 & Q_3 points.

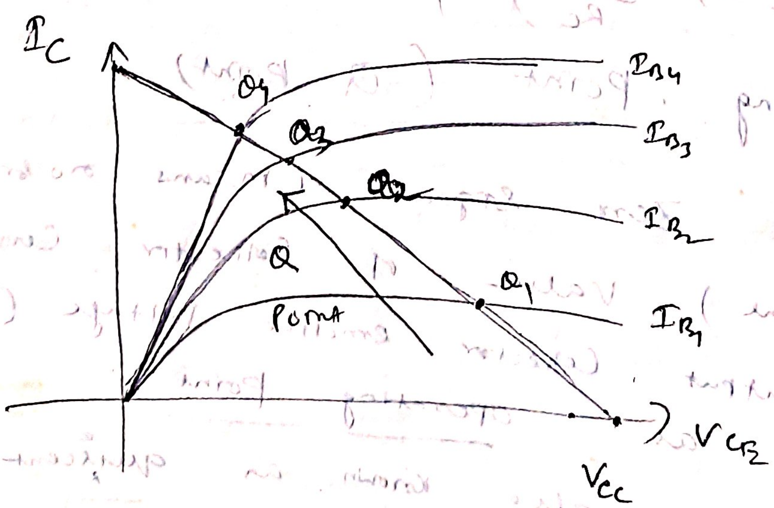


The Q_1, Q_2, Q_3, are operating points for different values of I_B i.e I_{B_1}, I_{B_2} and I_{B_3}.

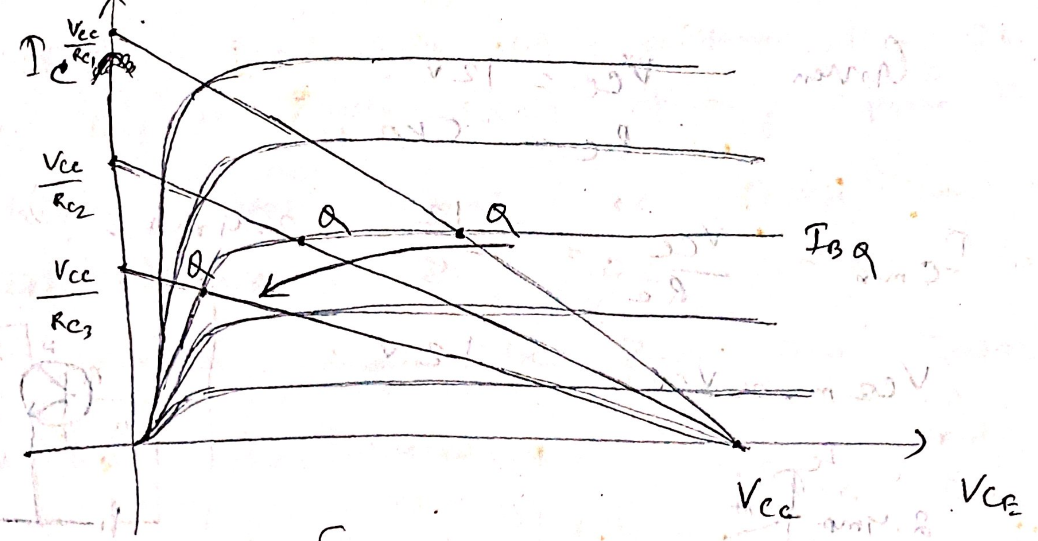
But actual standard operating point is Q_2, which is chosen middle of the (active region) of the load line.

→ $Q_2(V_{CE}, I_C)$, is noted as (V_{CEQ}, I_{CQ})

Case-I :- Movement of Q point with increasing level of I_B.



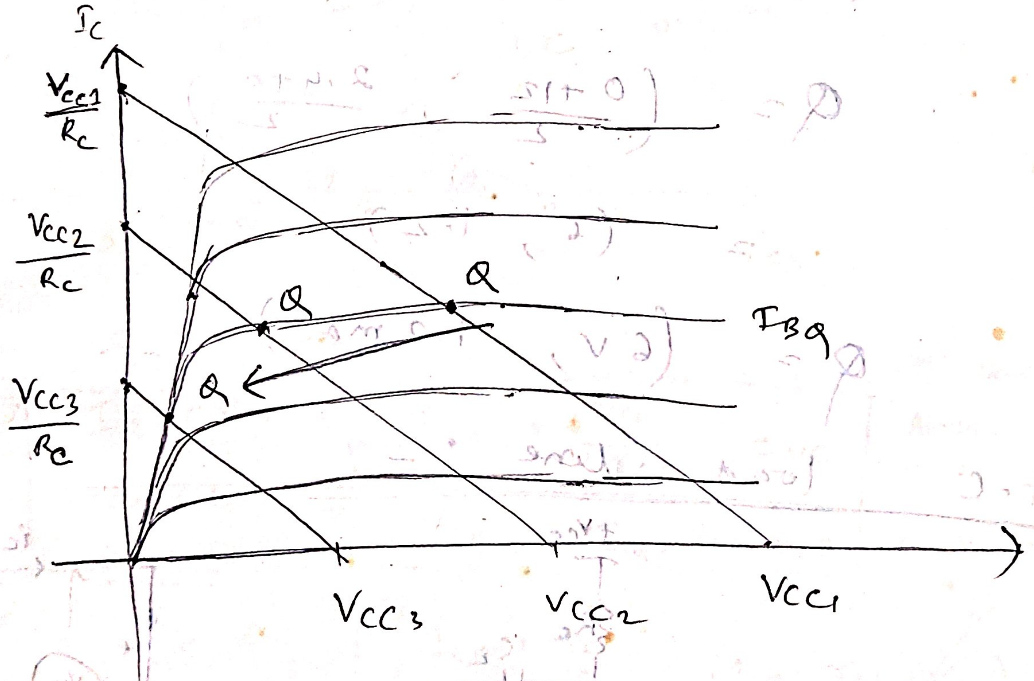
Case-II :- Keeping V_{CC} const, R_C is increased



$$\left[R_{C3} > R_{C2} > R_{C1} \right]$$

fig:- Effect of increasing level of R_C on the loadline and Q point

Case-III :- If R_C is fixed, V_{CE} is decreased



(fig:- Effect of lower values of V_{cc} on the load line and Q point)

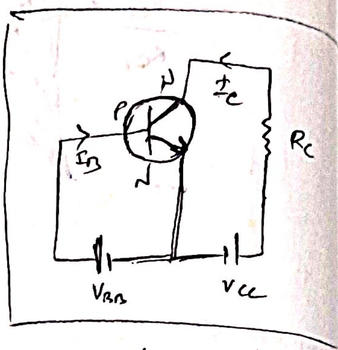
Ex:-1 :- For an N-P-N transistor $V_{cc} = 12V$, $R_C = 5k\Omega$, $\beta = 50$. Draw a load line and determine Q point (graphically):

Ans :-

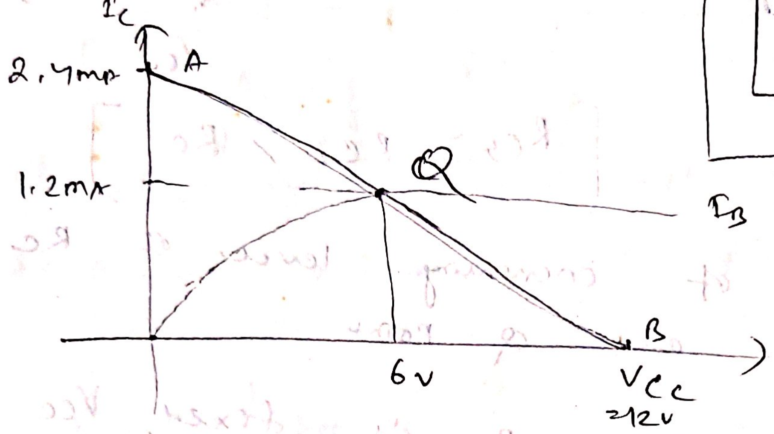
Given $V_{CC} = 12V$.

$R_C = 5k\Omega$.

$$I_{C_{max}} = \frac{V_{CC}}{R_C} = \frac{12}{5} = 2.4mA.$$



$V_{CE\,max} = V_{CC} = 12V$.



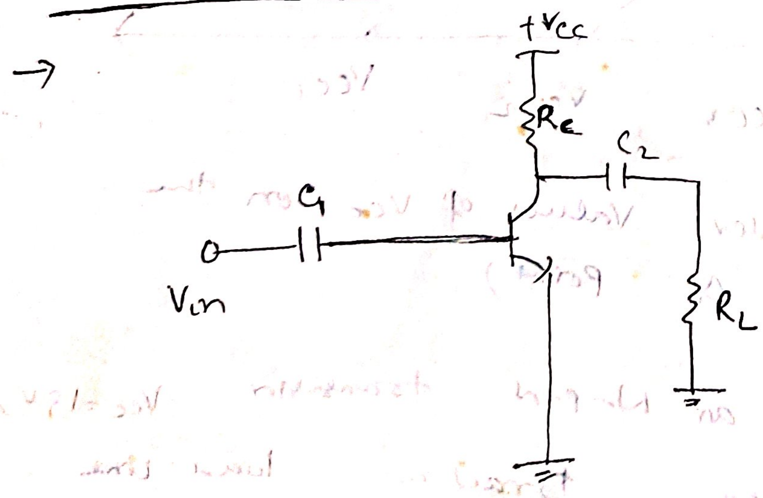
$A\,(0, 2.4)$, $B = (12, 0)$

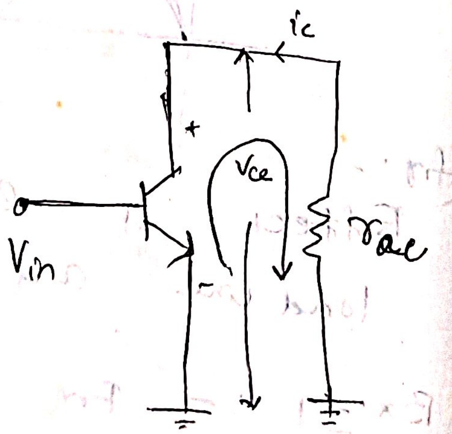
$$Q = \left(\frac{0+12}{2}, \frac{2.4+0}{2}\right)$$

$$= (6, 1.2)$$

$$Q = (6V, 1.2mA)$$

A.C load line :-





Capacitors short ckted.

A/C equivalent ckt

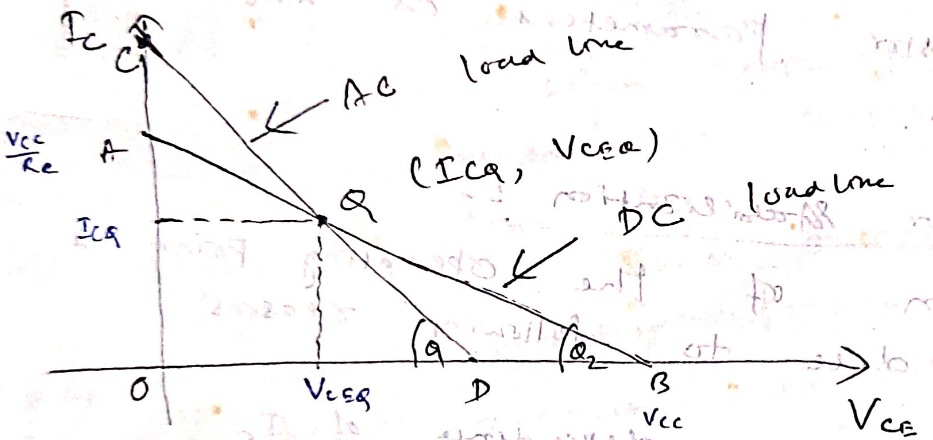
$$r_{ac} = R_C \,||\, R_L$$

→ AC load line is different than DC load line but in both Cases operating point is same.

→ When AC ~~signal~~ signal is applied, then this concept arises. For ac operation all dc sources should be zero and capacitor should be short ckted. ($X_C = \frac{1}{2\pi f C}$ for AC, f is high $X_C \simeq 0$.].

→ Since C_1 & C_2 are short ckted, R_C and R_L (Load Resistance) are parallel.

$$r_{ac} = R_C // R_L$$



→ For AC load line

$$\boxed{\begin{aligned} I_C(sat) &= I_{CQ} + \frac{V_{CQ}}{r_{ac}} = OC \rightarrow \text{in } I_C \text{ axis.} \\ V_{CE}(off) &= V_{CQ} + I_{CQ} \cdot r_{ac} = OD \rightarrow \text{in } V_{CE} \text{ axis.} \end{aligned}}$$

* Derivation After 5 pages

$$\text{Slope } (m_{ac}) = \frac{OC}{OD} = \frac{I_{CQ} + \frac{V_{CQ}}{r_{ac}}}{V_{CQ} + I_{CQ} \cdot r_{ac}} = \frac{(I_{CQ} \cdot r_{ac} + \cancel{V_{CQ}})}{r_{ac}(V_{CQ} + I_{CQ} \cancel{r_{ac}})} = \frac{1}{r_{ac}}$$

$$\text{Slope } (m_{dc}) = \frac{OA}{OB} = \frac{\frac{V_{CC}}{R_C}}{V_{CC}} = \frac{1}{R_C}.$$

$r_{ac} < R_C$ ($\because r_{ac} = R_C // R_L$)

$\Rightarrow \frac{1}{r_{ac}} > \frac{1}{R_C} \Rightarrow$ AC load line slope > D.C load line slope.

→ AC load line gives information about the max^m possible peak-to-peak o/p voltage (V_{P-P}) from a given amplifier.

* Derivation of A-C load line.

Applying KVL, in the collector loop

$$v_{ce} + i_c \cdot r_{ac} = 0 \qquad \text{--- (1)}$$

$\underset{(Net)}{I_c} = \underset{(d.c)}{I_{CQ}} + \underset{(a.c)}{i_c}$

~~$I_c = I_c$ (Sat)~~

~~$V_{CE} = V_{CE}$ (Cut off)~~

But
$$i_c = I_c - I_{CQ} \qquad \text{--- (2)}$$

$$v_{ce} = V_{CE} - V_{CQ} \qquad \text{--- (3)}$$

Putting eqn (2) & (3), in eqn (1), we have

$$V_{CE} - V_{CQ} + (I_c - I_{CQ}) \cdot r_{ac} = 0.$$

$$\Rightarrow (I_c - I_{CQ}) \cdot r_{ac} = V_{CQ} - V_{CE}$$

$$\Rightarrow I_c - I_{CQ} = \frac{V_{CQ}}{r_{ac}} - \frac{V_{CE}}{r_{ac}}$$

$$\Rightarrow \boxed{I_c = I_{CQ} + \frac{V_{CQ}}{r_{ac}} - \frac{V_{CE}}{r_{ac}}} \qquad \text{--- (4)}$$

For A-C loadline

For, $I_{C(sat)}$, $V_{CE} = 0$. Putting $V_{CE} = 0$ in eqn (4)

$$\Rightarrow \boxed{I_{C(sat)} = I_{CQ} + \frac{V_{CQ}}{r_{ac}}}$$

For $V_{CE}(\text{off})$, $I_C = 0$, Putting I_{CEO} in eqn (4)

$$0 = I_{CQ} + \frac{V_{CEQ}}{r_{ac}} - \frac{V_{CE}(\text{off})}{r_{ac}}$$

$$\Rightarrow \frac{V_{CE}(\text{off})}{r_{ac}} = I_{CQ} + \frac{V_{CEQ}}{r_{ac}}$$

$$\Rightarrow \boxed{\begin{aligned} V_{CE}(\text{off}) &= I_{CQ} \cdot r_{ac} + V_{CQ} \\ V_{CE}(\text{off}) &= V_{CQ} + I_{CQ} \cdot r_{ac} \end{aligned}}$$

Necessity of Biasing

→ Maintaining Q-point in the middle of active region

→ Biasing ckt. must stabilize I_C against temperature.

→ It must ensure Q-point should be independent of 'β' value.

Stabilization :-

The process of making operating point independent of temperature changes or variation in transistor parameters is known as Stabilization.

Need for Stabilization :-

Stabilization of the operating point is necessary due to following reasons

(a) Temperature dependence of I_C

(b) Individual variations

(c) Thermal runaway

(a) Temperature dependence of I_C

The Collector Current (I_C) is given by

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

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

→ The Collector leakage current I_{CBO} is greatly influenced (especially 'Ge' transistor) by temperature changes. A rise of 10°C doubles the collector leakage current which may be as high as 0.2mA for low powered 'Ge' transistor.

→ Transistor current gain 'β', which increases with temperature

→ Base emitter voltage V_{BE}, which decreases 2.5 mV/°C.

So any or all the factor can cause the bias point to shift, from the values originally fixed by the ckt because of change in temperature.

(b) Individual Variation :-

The value of β and V_{BE} are not exactly the same for any transistors even if of same type. Further V_{BE} itself decreases when temperature increases. When a transistor is replaced by another of the same type, these variations change the operating point. This necessitates to stabilize the operating point. i.e to hold I_C constant, irrespective of individual variations in transistor parameters.

(c) Thermal Runaway :-

The collector current for a CE configuration is given by

$$\Uparrow \uparrow I_C = \beta I_B + (\beta+1) I_{CBO} \uparrow \Uparrow$$

The collector leakage current I_{CBO} is strongly dependent on temperature. The flow of collector current produces heat within the transistor. This raises the transistor temperature, which in turn will cause I_{CBO} to increase. This effect is cummulative and in matter of seconds, the collector current may become very large, causing transistor to burn out.

The self-destruction of an unbiased transistor is known as thermal runaway.

In order to avoid thermal runaway and consequent destruction of transistor, it is very essential that operating point is stabilized i.e. I_c is kept constant.

So we need to bias a transistor

(a) To fix the Q-point

(b) To stabilize I_c against temperature variation i.e. to eliminate thermal runaway.

(c) To make operation independent of variations in β.

Stability factor:-

It is desirable and necessary to keep I_c constant in the face of variation of I_{CBO} or I_{co}. The extent to which a biasing CKt is succeeful in achieving this goal is measured by stability factor 'S'.

In any amplifier using a transistor the collector current I_c sensitive to the following parameters.

(i) β increase with increase in temperature

(ii) $|V_{BE}|$ decreases about 2.5 mV per degree celsius (°C) increase in temperature

(iii) I_{co} (reverse saturation current):- doubles in value per every 10°C increase in temperature.

→ The rate of change of collector current I_c w.r.to collector leakage current I_{co} at const. β and V_{BE} is called stability factor (S).

(i) $S(I_{co}) = \left.\dfrac{\Delta I_c}{\Delta I_{co}}\right|_{\text{at const } \beta \text{ and } V_{BE}}$ $\Rightarrow \Delta I_c = S(I_{co})\,\Delta I_{co}$

Similarly

(ii) $S(V_{BE}) = \left.\dfrac{\Delta I_c}{\Delta V_{BE}}\right|_{\text{at const } I_{co}\ \&\ \beta}$ $\Rightarrow \Delta I_c = S(V_{BE}) \cdot \Delta V_{BE}$

(iii) $S(\beta) = \left.\dfrac{\Delta I_c}{\Delta \beta}\right|_{\text{at const. } I_{co}\ \&\ V_{BE}}$ $\Rightarrow \Delta I_c = S(\beta) \cdot \Delta\beta$

So combining all 3 cases.

$$\boxed{\Delta I_c = S(I_{co}) \cdot \Delta I_{co} + S(V_{BE}) \cdot \Delta V_{BE} + S(\beta) \cdot \Delta\beta}$$

Consider $S = \dfrac{\Delta I_c}{\Delta I_{co}}$,

If with denominator large (i.e change in leakage current more) numerator is small (change in collector current is small), stability is more.

i.e smaller the value of S, more is the stability.

→ Ideal value of $S = 1$.

General expression for $S(I_{CO}) \rightarrow \frac{dI_C}{dI_{CO}}$

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

Differentiating w.r.t. I_C, considering β as const.

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

$$\Rightarrow \quad 1 = \beta \cdot \frac{dI_B}{dI_C} + (\beta+1) \cdot \frac{1}{S}$$

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

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

General expression for $S(\beta) \rightarrow \frac{dI_C}{d\beta}$

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

Differentiating with respect to I_C keeping I_{CO} as const.

$$\frac{dI_C}{dI_C} = \frac{d}{dI_C}(\beta I_B) + I_{CO} \cdot \frac{d}{dI_C}(\beta+1)$$

$$= \left[\beta \cdot \frac{dI_B}{dI_C} + I_B \cdot \frac{d\beta}{dI_C}\right] + I_{CO} \cdot \frac{d\beta}{dI_C}$$

$$\left(\because \frac{d}{dx}(u \cdot v) = u \cdot \frac{dv}{dx} + v \cdot \frac{du}{dx} \right)$$

$$\cancel{= \beta \cdot \frac{dI_B}{dI_C} + I_B = \frac{d\beta}{dI_C}(I_B + I_C) + I_B \frac{d\beta}{dI_C}}$$

$$= \frac{d\beta}{dI_C}\left[I_B + I_{CO}\right] + \beta \cdot \frac{dI_B}{dI_C}$$

$$\Rightarrow \cancel{1 = \frac{d\beta}{dI_C}\left(I_B + I_{Co}\right) + \beta \cdot \frac{1}{S}}$$

$$\Rightarrow \cancel{1 - \frac{d\beta}{dI_C}\left(I_B + I_{Co}\right) = \frac{\beta}{S}}$$

$$\Rightarrow \cancel{S = \frac{\beta}{1 - \frac{d\beta}{dI_C}\left(I_B + I_{Co}\right)}}$$

$$\Rightarrow 1 = \frac{1}{S} \cdot \left[I_B + I_{Co}\right] + \beta \cdot \frac{dI_B}{dI_C} \qquad \left(\because S = \frac{dI_C}{d\beta}\right)$$

$$\Rightarrow \left(1 - \beta \frac{dI_B}{dI_C}\right) = \frac{I_B + I_{Co}}{S}$$

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

Methods of transistor Biasing :-

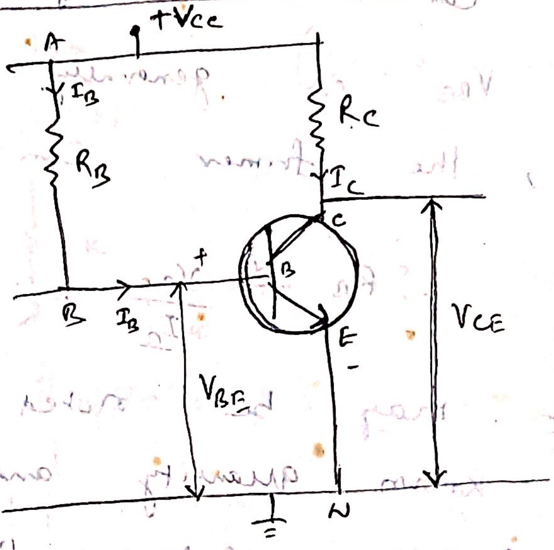
(a) Fixed Bias (Base - Resistor Method)

(b) Self bias (Emitter bias)

(c) Biasing with feedback Resistor

(d) Voltage - divider bias.

(a) Fixed Biasing (Base Resistor Biasing)



In this method, a high resistance R_B (Several hundred kΩ) is connected between the base & +ve end of supply for n-p-n transistor as shown in the figure.

Here, the required zero signal base current is provided by V_{cc} & it flows through R_B. It is because now base is +ve w.r.to emitter i.e base emitter junction is forward biased.

Ckt Analysis :-

It is required to find the value of R_B so that required collector current flows in the zero signal condition. Let I_C be the required zero signal collector current.

$$I_B = \frac{I_C}{\beta}$$

Considering the closed ckt ABENA, & apply KVL, we get

$$V_{CC} - I_B R_B - V_{BE} = 0$$

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

$$\Rightarrow \quad \boxed{R_B = \frac{V_{CC} - V_{BE}}{I_B}} \quad \text{——} ①$$

As V_{CC} & I_B are known & V_{BE} can be seen from transistor manual, therefore value of R_B can be readily found.

Since V_{BE} is generally quite small as compared to V_{CC}, the former can be neglected with little error.

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

→ It may be noted that V_{CC} is a fixed known quantity and I_B is chosen at some suitable value. Hence R_B can always be found directly and for this reason, this method is sometimes called fixed bias method.

→ In the output loop applying KVL,

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

$$\Rightarrow \quad \boxed{V_{CE} = V_{CC} - I_C R_C} \quad \text{——} ②$$

from eqⁿ ①,
$$\boxed{I_B = \frac{V_{CC} - V_{BE}}{R_B}} \quad \text{——} ③$$

→ If V_{CC}, V_{BE}, R_B are given, first we find $\boxed{I_B}$

→ Then I_C can be found by $\boxed{I_C = \beta I_B}$.

V_{CE} Can be found out by eq^n (2),

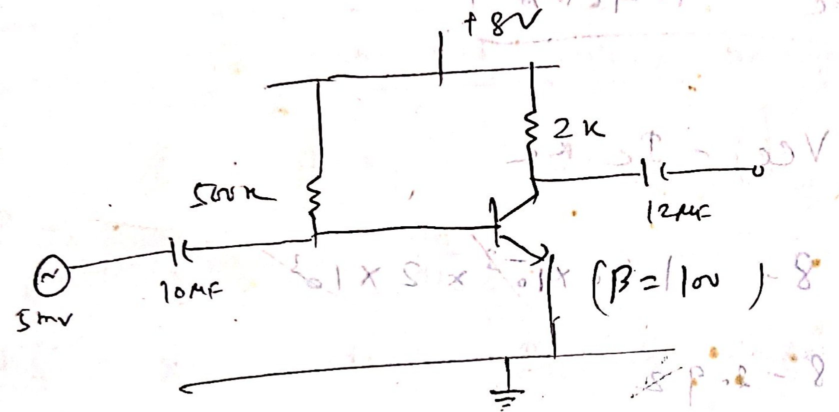
i.e $V_{CE} = V_{CC} - I_C R_C$.

There these I_C & V_{CE} are the operating point Q (V_{CEQ}, I_{CQ}).

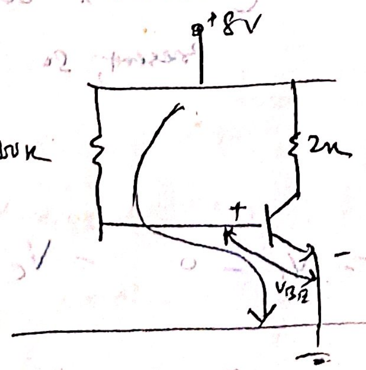
→ Since $R_E = 0$, $V_E = I_E R_E = 0$, so $V_{CE} = V_C - V_E = V_C - 0 = V_C$ and $V_{BE} = V_B - V_E = V_B$.

$I_C(sat) = V_{CC}/R_C$, $V_{CE}(sat) = V_{CC}$.

Ex :- 1 Determine the operating point, V_B, V_C & draw the load line. ($\beta = 100$ given)



Ans :- For d.c biasing, a.c sources should be zero, since no a.c signal frequency 'f' = 0, $X_C = \frac{1}{2\pi f C} = \infty$. So capacitor act as open ckt. So figure can be redrawn as



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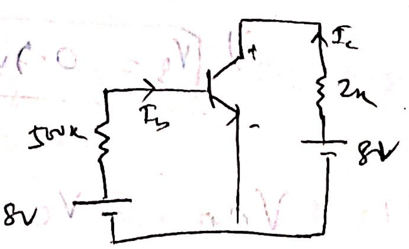


Applying KVL in the i/p loop.

$$8 - I_B \times 500 \times 10^3 - V_{BE} = 0$$

$\Rightarrow 8 - I_B \times 5\times10^5 - 0.7V = 0$ $\quad | \because V_{BE} = 0.7V$

$\Rightarrow 7.3 = I_B \times 5\times10^5$

$\Rightarrow I_B = \frac{7.3}{5\times10^5} = \frac{7.3\times10}{5\times10^6} = 14.6\ \mu A$

$I_C = \beta I_B = 100 \times 14.6 \times 10^{-6}$

$= 1000 \times 1.46 \times 10^{-6}$

$\boxed{I_C = 1.46\,mA}$

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

$= 8 - 1.46\times\cancel{10^{-3}} \times 2\times\cancel{10^3}$

$= 8 - 2.92$

$\boxed{V_{CE} = 5.08}$

(i) $Q(5.08V, 1.46\,mA)$

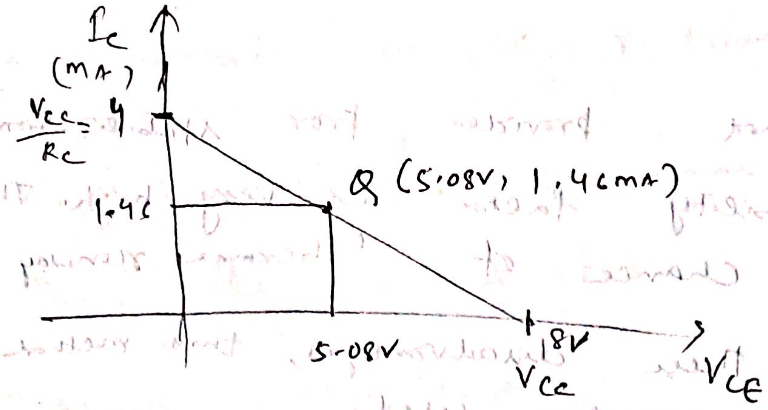
(ii) $V_{BE} = V_B - V_E$

$\Rightarrow 0.7 = V_B - 0$ $\quad$ ($R_E = 0$, due to R_E not present, so $V_E = I_E R_E = 0$)

$\Rightarrow \boxed{V_B = 0.7V}$

(iii) $V_{CE} = V_C - V_E = V_C - 0 = V_C$

$V_C = V_{CC} - I_C R_C = 5.08\,V.$



$$\frac{V_{CC}}{R_C} = \frac{8}{2\,K\Omega} = 4\,mA$$

Stability factor of fixed biasing:-

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

In fixed bias, I_B is independent of I_C.

So $\frac{dI_B}{dI_C} = 0$

$\Rightarrow S = \beta + 1$

If $\beta = 100$, $S = 101$

Due to large value of S, in fixed bias, it has poor thermal stability.

Advantage:-

(i) This biasing ckt is very simple as only one Resistance R_B is required.

(ii) Biasing Condn can easily be set & Calculations are simple.

(iii) There is no loading of the source by the biasing ckt since no resistor is employed across base-emitter junction.

Disadvantages :-

1) This method provides poor stabilization.

2) The stability factor is very high. There is strong chance of 'thermal runway'

3) Due to these disadvantages, this method of biasing is rarely used.

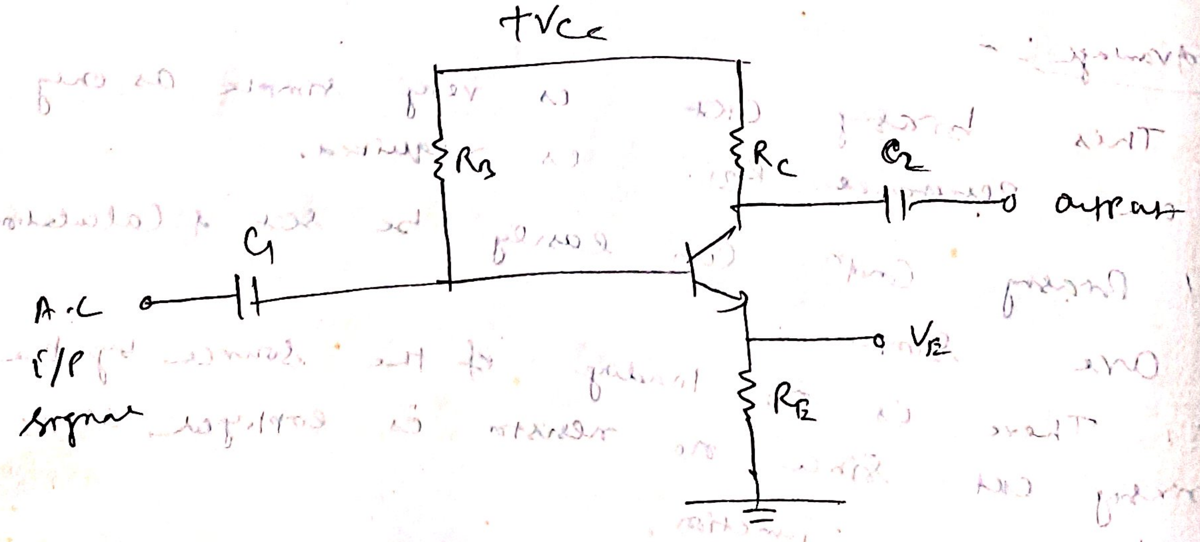
(b) Emitter Bias or Self bias

→ It is a improved stabilized ckt than fixed biasing ckt

→ In this additional R_E (Emitter Resistor) is connected to emitter terminal compare to fixed biasing where R_E stabilize the self biasing ckt.

→ Here, emitter bias is applied by a resistor R_E between the emitter and ground.

→ When the Collector current increases the Voltage drop across R_E increases and reduces the forward bias there by reducing the base current I_B and keeping the operating point stable. So the resistor R_E provides stabilization.

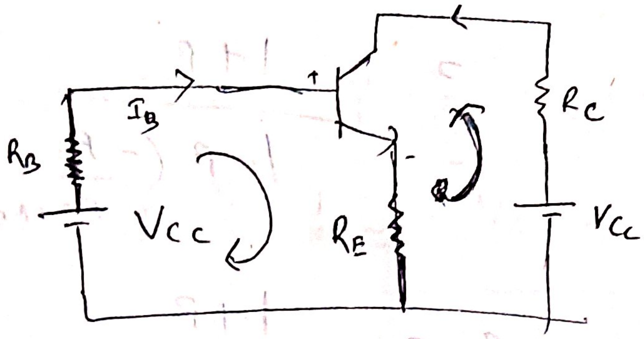


The figure can be redrawn,

Since d.c biasing, a.c signal = 0,

$$X_C = \frac{1}{2\pi f \cdot C} = \frac{1}{2\pi \cdot 0 \cdot C} = \infty$$

Capacitor open circuited.



Applying KVL in i/p loop:-

$$V_{CC} - I_B R_B - V_{BE} - I_E R_E = 0 \quad \text{——— (1)}$$

$$\Rightarrow V_{CC} - I_B R_B - V_{BE} - (\beta+1) I_B R_E = 0$$

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

$$\Rightarrow \boxed{I_B = \frac{V_{CC} - V_{BE}}{R_B + (1+\beta) R_E}} \quad \text{——— (A)}$$

From eqn (1),

$$V_{CC} - I_B R_B - V_{BE} - (I_C + I_B) R_E = 0$$

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

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

$$\Rightarrow I_B = \left(\frac{V_{CC} - V_{BE}}{R_B + R_E} \right) - \frac{I_C R_E}{R_B + R_E} \quad \text{——— (2)}$$

$$\Rightarrow \frac{dI_B}{dI_C} = 0 - \frac{R_E}{R_B+R_E}$$

Stability factor

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

$$= \frac{1+\beta}{1-\beta\left(-\frac{R_E}{R_B+R_E}\right)}$$

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

From this eqn, we conclude that R_E should be much greater than R_B, to improve stability.

Note:- If $R_E >> R_B$, $R_E + R_B \simeq R_E$

$S \simeq \frac{1+\beta}{1+\beta \cdot \frac{R_E}{R_E}} = 1$, more stable

How it works:-

Suppose there is increase in temperature, leakage current will increase & collector current (I_C) increases. Then drop across R_E i.e $I_C R_E$ or $I_E R_E$ will increase, Refering to eqn ②, I_B will decrease and control the further increase in I_C. So Q-point becomes more stable. So there is self understanding between I_B & I_E. So it is called Self biasing.

O/P loop

$$V_{CC} - I_C R_C - V_{CE} - I_E R_E = 0.$$

If $I_C \simeq I_E$

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

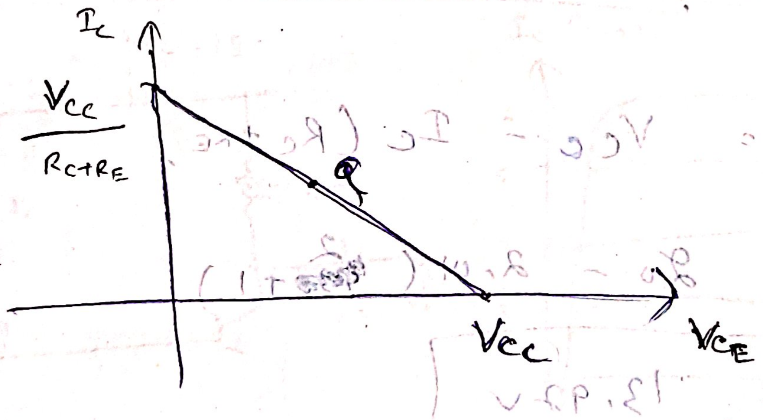
$$\Rightarrow V_{CC} - V_{CE} = I_C (R_C + R_E)$$

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

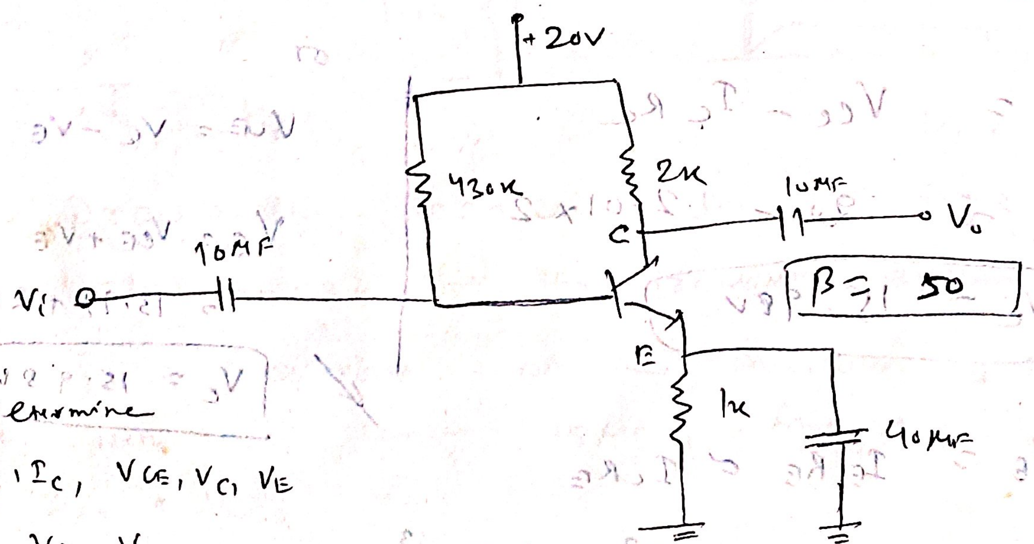
For

I_C (Sat), or $V_{CE} = 0$ $\Rightarrow$ $\boxed{I_C = \frac{V_{CC}}{R_C + R_E}}$

V_{CE} (off), $I_C = 0$, $\boxed{V_{CE} = V_{CC}}$



Ex:- 2



Determine

$I_B, I_C, V_{CE}, V_C, V_E$

V_B, V_{BC}.

Ans :- Using KVL in the i/p loop

$20 - R_B I_B - V_{BE} - I_E \cdot R_E = 0$

$20 - 430 \times 10^3 I_B - 0.7 - (50+1) I_B \times 10^3 = 0$

$\Rightarrow 19.3 = (430 + 51) \times 10^3 \cdot I_B$

$\Rightarrow \frac{19.3}{481} \times 10^{-3} = I_B$

$\Rightarrow I_B = 0.0401 \times 10^{-3} = 40.1 \mu A$

(a) $\boxed{I_B = 40.1 \mu A}$

(b) $I_C = \beta I_B = 50 \times 40.1 \times 10^{-6}$

$\boxed{I_C = 2.01 mA}$

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

$= 20 - 2.01 (2 + 1)$

$\boxed{V_{CE} = 13.97 V}$

(d) $V_C = V_{CC} - I_C R_C$

$= 20 - 2.01 \times 2$

$\boxed{V_C = 15.98 V}$

or

$V_{CE} = V_C - V_E$

$V_C = V_{CE} + V_E$

$= 13.97 + 2.01$

$\boxed{V_C = 15.98 V}$

(e) $V_E = I_E R_E \simeq I_C R_E$

$= 2.01 \times 10^{-3} \times 1 \times 10^3$

$\boxed{V_E = 2.01 V}$

(f) $V_B = V_{BE} + V_E$

$= 0.7 + 2.01$

$\boxed{V_B = 2.71 V}$

(g) $V_{BC} = V_B - V_C$

$= 2.71 - 15.98$

$\boxed{V_{BC} = -13.27 V}$

∴ −ve sign shows, base collector jn is reversed biased as required.

→ Ex- 4.7 Homework

Ex:- 3

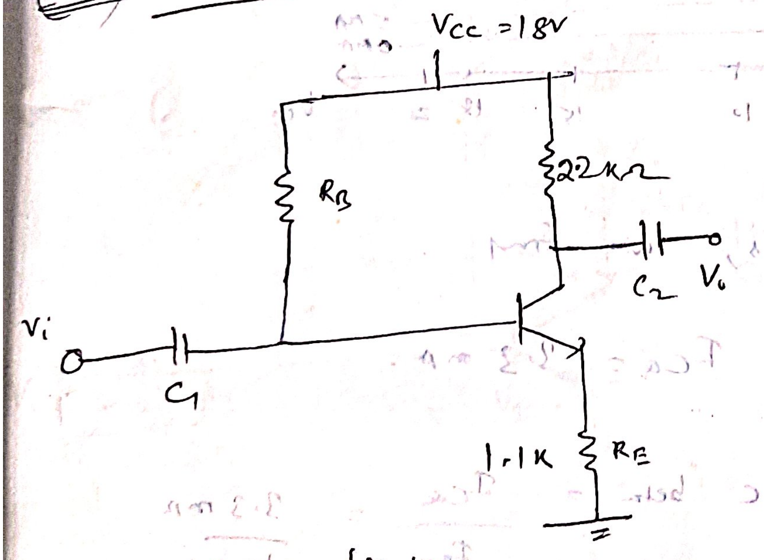


fig 1

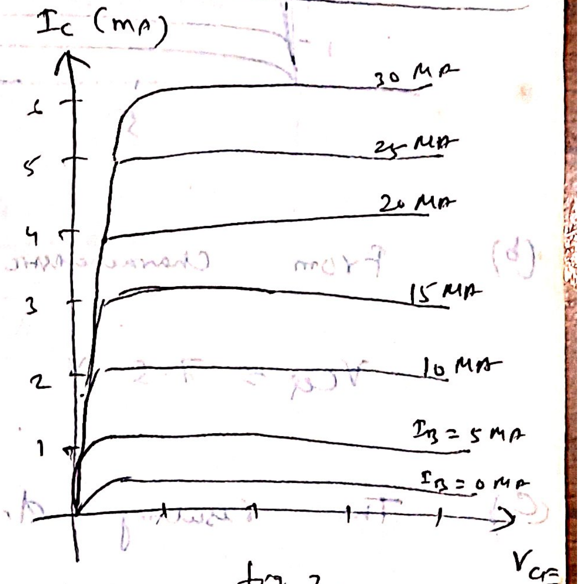


fig 2

(a) Draw the load line for the fig 1 on the characteristics for the transistor appearing in fig 2.

(b) For a Q-point at the intersection of the load line with base current 15 μA find the value of I_{CQ} & V_{CEQ}

(c) Find the dc beta at the Q-point.

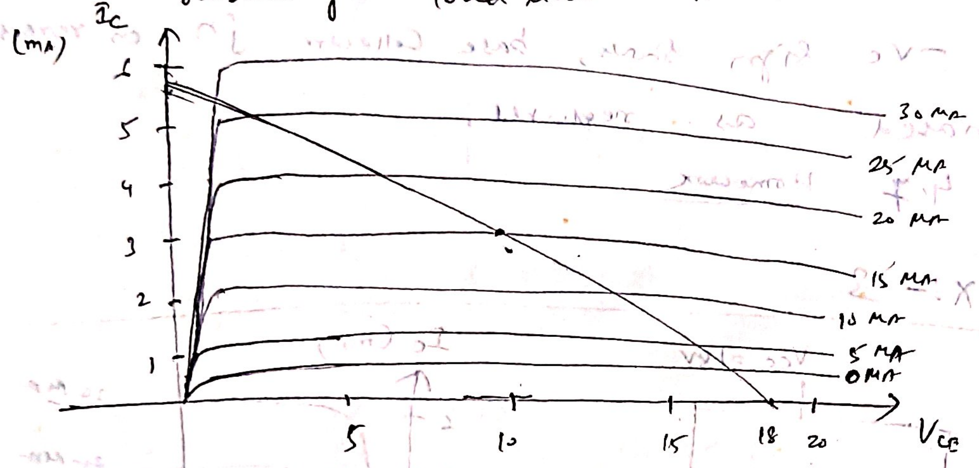
(d) Using the beta for the n/w determined in part c, Calculate the required value of R_B and suggest a possible standard value.

Ans :- Two points on the characteristics are required to draw the load line.

At $V_{CE} = 0V$, $I_C = \frac{V_{CC}}{R_C + R_E} = \frac{18}{2.2 + 1.1} = \frac{18\,V}{3.3\,k\Omega} = 5.45\,mA$.

At $I_C = 0\,mA$, $V_{CE} = V_{CC} = 18V$.

The resulting load line appears as shown below



(b) From characteristics, we find

$V_{CQ} \simeq 7.5\,V$, $I_{CQ} = 3.3\,mA$.

(c) The resulting d.c beta $= \frac{I_{CQ}}{I_{BQ}} = \frac{3.3\,mA}{15\,\mu A}$

$= 220$.

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

$\Rightarrow 15 \times 10^{-6} = \frac{18 - 0.7}{R_B + (221).1.1 \times 10^3} = \frac{17.3}{R_B + 243.1 \times 10^3}$

$\Rightarrow 15\times10^{-6}(R_B + 243.1\times10^{3}) = 17.3$

$\Rightarrow 15\times10^{-6} R_B + 3646.5\times10^{-3} = 17.3$

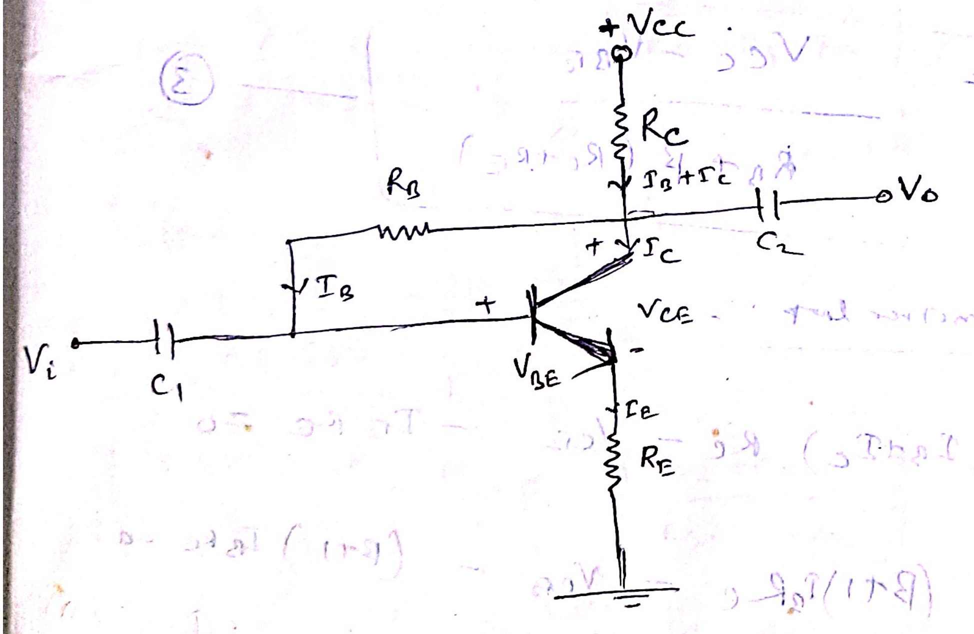
$\Rightarrow 15\times10^{-6} R_B = 17.3 - 3.65$

$\Rightarrow R_B = \dfrac{13.65}{15\times10^{-6}}$

$$\boxed{R_B = 910\ k\Omega}$$

(C) Collector feedback Configuration:

An improved level of stability can be obtained by introducing a feedback path from collector to base as shown in figure below.



Although the Q-point is not totally independent of 'β', the sensitivity to changes in β or temperature variations is normally less than encountered for fixed bias or emitter-biased configurations. The analysis will be performed by first analyzing the base-emitter loop, with the results then applied to collector-emitter loop.

Base-emitter loop:-

$$V_{CC} - (I_B + I_C) R_C - I_B R_B - V_{BE} - I_E R_E = 0 \quad \text{—①}$$

$$\Rightarrow V_{CC} - (I_B + \beta I_B) R_C - I_B R_B - V_{BE} - (\beta+1) I_B R_E = 0$$

$$\Rightarrow V_{CC} - (\beta+1) I_B R_C - I_B R_B - V_{BE} - (\beta+1) I_B R_E = 0$$

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

$$\Rightarrow \boxed{I_B = \frac{V_{CC} - V_{BE}}{R_B + (\beta+1)(R_C + R_E)}} \quad \text{—②}$$

If $\beta + 1 \simeq \beta$

$$\boxed{I_B = \frac{V_{CC} - V_{BE}}{R_B + \beta (R_C + R_E)}} \quad \text{—③}$$

Collector-emitter loop:-

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

$$\Rightarrow V_{CC} - (\beta+1) I_B R_C - V_{CE} - (\beta+1) I_B R_E = 0.$$

$$\Rightarrow \boxed{V_{CE} = V_{CC} - (\beta+1) I_B (R_C + R_E)} \quad \text{—④}$$

If $\beta + 1 \simeq \beta$

$$\boxed{V_{CE} = V_{CC} - I_C (R_C + R_E)} \quad \text{—⑤}$$

To find 'S' (Stability factor) :-

From eqn (1)

$$V_{CC} - I_B R_C - I_C R_C - I_B R_B - V_{BE} - I_B R_E - I_C R_E = 0.$$

$$(\because I_E = I_B + I_C)$$

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

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

$$\frac{dI_B}{dI_C} = \frac{1}{R_B + R_C + R_E}\left[0 - 0 - (R_C + R_E)\right]$$

$$\frac{dI_B}{dI_C} = -\left[\frac{R_C + R_E}{R_B + R_C + R_E}\right]$$

$$S(I_{CO}) = \frac{1+\beta}{1 - \beta \cdot \frac{dI_B}{dI_C}}$$

$$= \frac{1+\beta}{1+\beta \cdot \left[\frac{R_C + R_E}{R_B + R_C + R_E}\right]}$$

Since $R_B + R_C + R_E > R_C + R_E$.

$$S = \frac{1+\beta}{1+\beta \cdot \text{fraction}} = \frac{1+\beta}{1+x}$$

$$S < 1+\beta$$

$\therefore$ This method provides better thermal stability than fixed bias.

How I_{CQ} will be made independent of β :-

$$I_B = \frac{V_{CC} - V_{BE}}{R_B + \beta (R_C + R_E)} \quad \text{[from eq}^n \text{(3)]}$$

If $\beta (R_C + R_E) >> R_B$

$$I_B \simeq \frac{V_{CC} - V_{BE}}{\beta . (R_C + R_E)}$$

$$I_{CQ} = \beta . I_B$$

$$= \cancel{\beta} \left(\frac{V_{CC} - V_{BE}}{\cancel{\beta} (R_C + R_E)} \right)$$

$$I_{CQ} = \frac{V_{CC} - V_{BE}}{R_C + R_E} = \frac{V'}{R'}$$

$V' = V_{CC} - V_{BE}$
$R' = R_C + R_E$

$\therefore I_{CQ}$ is independent of value of β.

Because R' is typically larger for voltage feedback configuration than for emitter-bias configuration, the sensitivity to variation in β is less.

($\because$ I_B for emitter bias $\simeq \dfrac{V_{CC} - V_{BE}}{R_B + \beta R_E}$

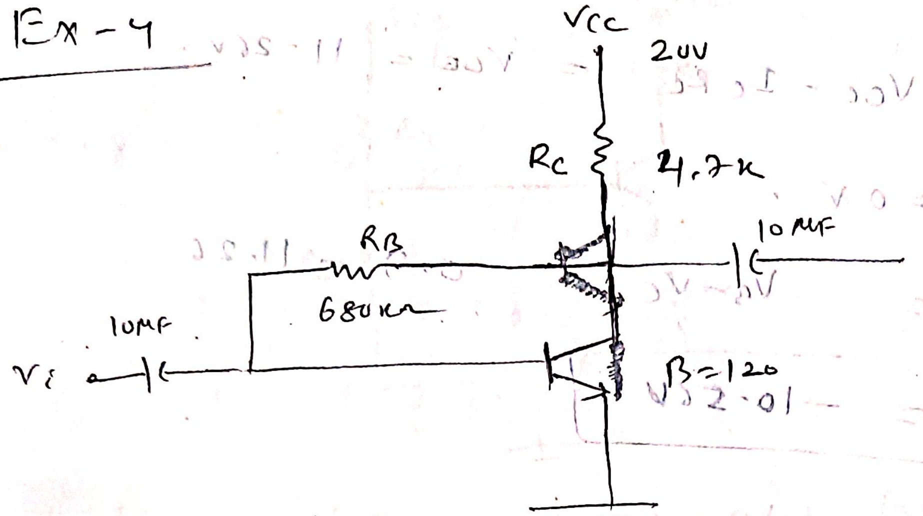
I_B for fixed bias $= \dfrac{V_{CC} - V_{BE}}{R_B}$)

So I_C for emitter bias $= \beta . \left(\dfrac{V_{CC} - V_{BE}}{R_B + \beta R_E} \right)$

I_C for fixed bias $= \beta \cdot \left(\dfrac{V_{CC} - V_{BE}}{R_B} \right)$.

So I_C is n't independent of variation of β for fixed bias or emitter bias.

Ex-4



(a) Determine I_{CQ}, V_{CEQ}

(b) Find V_B, V_C, V_E, V_{BC}

Ans :- $I_B = \dfrac{V_{CC} - V_{BE}}{R_B + \beta(R_C + R_E)}$ → from eq^n (3), $R_E = 0$

$\Rightarrow I_B = \dfrac{20 - 0.7}{680 \times 10^3 + 120(4.7 \times 10^3)}$

$\Rightarrow I_B = \dfrac{19.3}{1.244 \times 10^6}$

$\Rightarrow \boxed{I_B = 15.51 \mu A}$

$I_{CQ} \Rightarrow \beta I_B = 120 \times 15.51 \mu A = 1.86$ mA

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

$= 20 - 1.86 \times 10^{-3} \cdot (4.7 \times 10^3 + 0)$

$\boxed{V_{CEQ} = 11.26 \text{ V}}$

65

$V_{BE} = V_B - V_E$

$\Rightarrow 0.7 = V_B - 0$

$\Rightarrow \boxed{V_B = 0.7V}$

$V_C = V_{CC} - I_C R_C = V_{CE} = 11.26V.$

$V_E = 0V.$

$V_{BC} = V_B - V_C = 0.7 - 11.26$

$\boxed{V_{BC} = -10.56V}$

(d) Voltage divider Biasing

→ The circuit required for voltage divider biasing is shown below. In this R_1 & R_2 are connected across Vcc is divided into R_1 & R_2 section, that's why it is called voltage divider biasing.

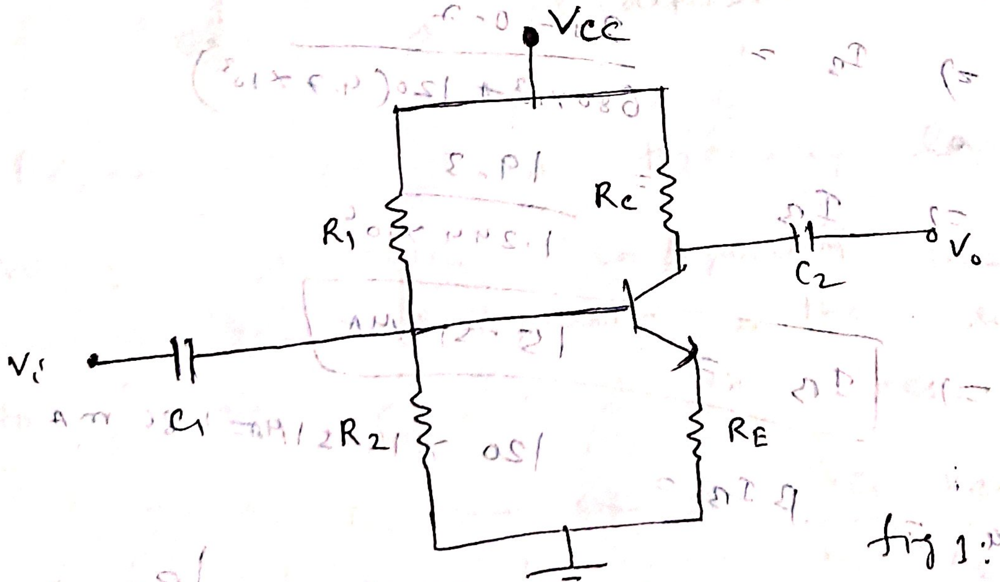
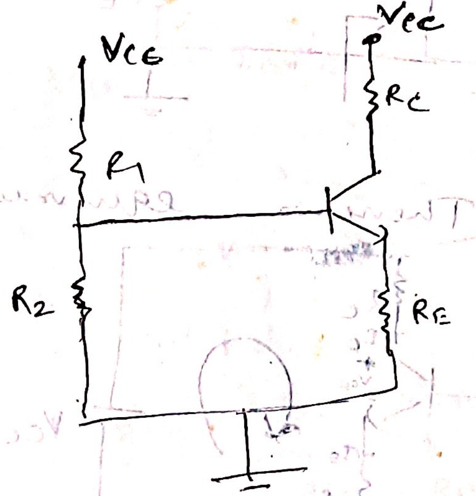


fig 1:

→ This biasing method is more stable due to stability factor is very less, and more importantly the Q point (V_{CEQ}, I_{CQ})

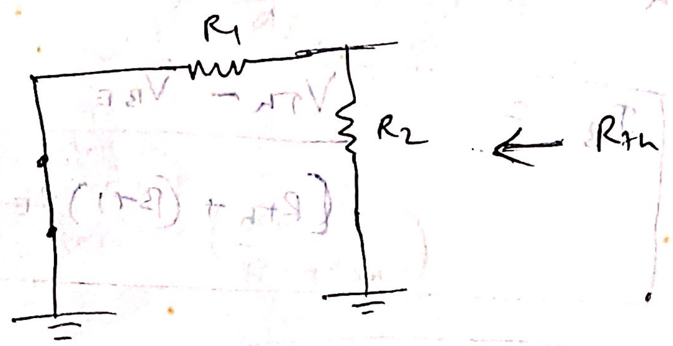
is fixed i.e V_{CQ} & I_{CQ} are independent of 'β'.

For d.c analysis, fig 1, can be redrawn as shown below.



The Thevenin equivalent n/w for the n/w to the left of the base terminal can be found in the following manner:

R_{th} :- The voltage source is replaced by a short-ckt equivalent

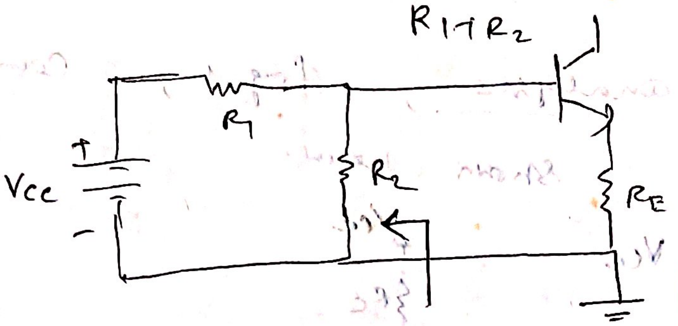


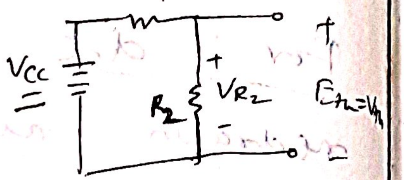
$$R_{th} = R_1 // R_2 = \frac{R_1 . R_2}{R_1 + R_2} \quad (1)$$

E_{th} :- The voltage source Vcc is returned to the n/w and the open-ckt Thevenin voltage determined as follows,

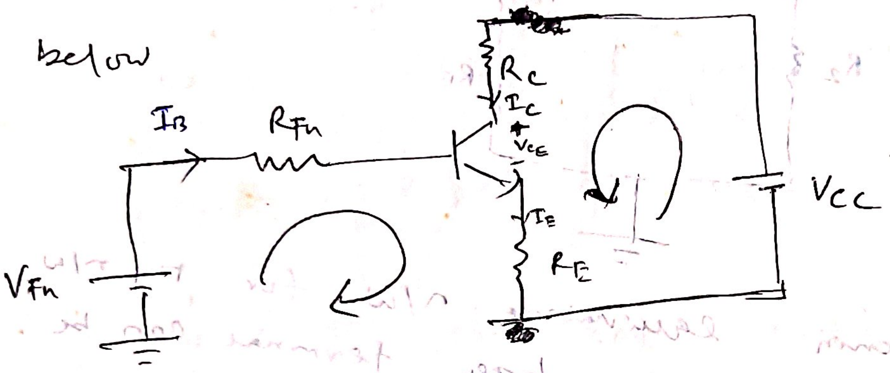
(Applying voltage-divider rules

$$V_{Th} = E_{th} = V_{R_2} = \frac{V_{CC}}{R_1 + R_2} \times R_2 \quad \text{--- (2)}$$





The Complete Thevenin equivalent is shown below



i/p loop.

$$V_{Th} - I_B R_{Th} - V_{BE} - I_E R_E = 0 \quad \text{--- (3)}$$

$$\Rightarrow V_{Th} - I_B R_{Th} - V_{BE} - (\beta+1) I_B R_E = 0 \qquad \because I_E = (\beta+1) I_B$$

$$\Rightarrow \boxed{I_B = \frac{V_{Th} - V_{BE}}{[R_{Th} + (\beta+1) R_E]}} \quad \text{--- (4)}$$

$$\boxed{I_C = \beta I_B}$$

o/p loop

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

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

$$(\because I_C \simeq I_E)$$

To Calculate Stability factor $S(I_{co})$

From eqⁿ ③,

$$V_{Th} - I_B R_{Th} - V_{BE} - (I_B + I_C) R_E = 0$$

$$\Rightarrow V_{Th} - V_{BE} - I_C R_E = I_B (R_{Th} + R_E)$$

$$\Rightarrow I_B = \frac{V_{Th} - V_{BE} - I_C R_E}{R_{Th} + R_E}$$

$$I_B = \frac{V_{Th} - V_{BE}}{R_{Th} + R_E} - \frac{I_C R_E}{R_{Th} + R_E}$$

$$\Rightarrow \frac{dI_B}{dI_C} = 0 - \frac{R_E}{R_{Th} + R_E} = \frac{-R_E}{R_E + R_{Th}}.$$

$$S(I_{co}) = \frac{1+\beta}{1 - \beta \cdot \frac{dI_B}{dI_C}} = \frac{1+\beta}{1 - \beta \cdot \left(\frac{-R_E}{R_E + R_{Th}}\right)}$$

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

Since $R_{TH} = R_1 // R_2$, which is very small.

$$R_E + R_{Th} \simeq R_E$$

$$S = \frac{1+\beta}{1 + \beta \cdot \frac{R_E}{R_E}} \simeq 1$$

Practical value 'S' for voltage-divider biasing is found to be $\underline{10}$.

Since 'S' value is very small, it gives more thermal stability.

From eqn (4)

$$I_B = \frac{V_{Th} - V_{BE}}{R_{Th} + (1+\beta) R_E}$$

$$\simeq \frac{V_{Th} - V_{BE}}{R_{Th} + \beta R_E}$$

Since $R_{Th} = R_1 // R_2$ is very small,

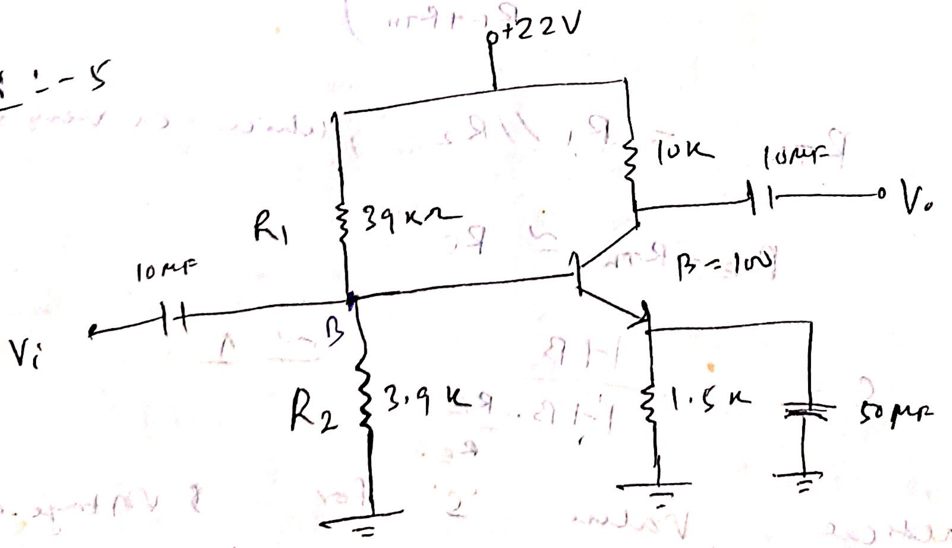
$$I_B \simeq \frac{V_{Th} - V_{BE}}{\beta \cdot R_E}$$

$$I_C = \beta \cdot I_B = \frac{V_{Th} - V_{BE}}{R_E}$$

$\therefore$ I_{CQ} ~~and~~ can be approximated, so that it is almost independent of β.

→ Hence this method is popularly used in all BJT amplifier ckt.

Ex:-5



Determine d.c bias voltage V_{CE} & I_C for voltage divider configuration.

Approximate Analysis:-

The reflected resistance between base and Emitter is defined by

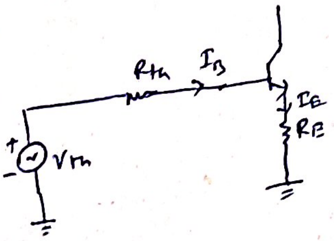
$$\boxed{R_i = (\beta+1)R_E}.$$

$\because$ ~~$V_B = I_B$~~. From, Eq^n (4)

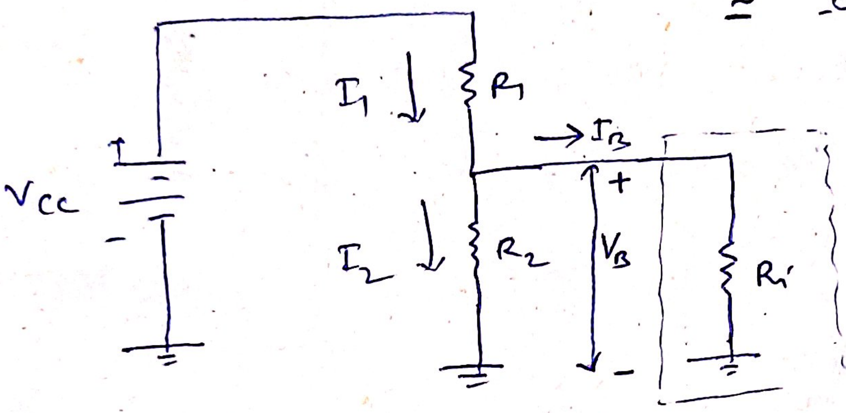
$\Rightarrow I_B = \dfrac{V_{th} - V_{BE}}{R_{th} + (\beta+1)R_E}$

If $R_i >> R_2$, $I_B \simeq 0$

($\because$ current always follow the path of low resistance)



$\simeq$



$R_i' >> R_2$

$I_1 \simeq I_2$

$\Rightarrow I_B \simeq 0$ Amp,

$R_i' = (\beta+1)R_E$

$\simeq \beta R_E$

$\therefore$ when $\boxed{\beta R_E \geq 10 R_2}$

$I_B \simeq 0$

$I_1 = I_2$, means R_1 & R_2 are in series with Vcc.

$$\boxed{I_1 = I_2 = \frac{V_{CC}}{R_1+R_2}}$$

$$\boxed{V_B = I_2 \times R_2 = \frac{V_{CC} \cdot R_2}{R_1+R_2}}$$

$\boxed{V_E = V_B - V_{BE}}$, $\boxed{I_E = \dfrac{V_E}{R_E}}$

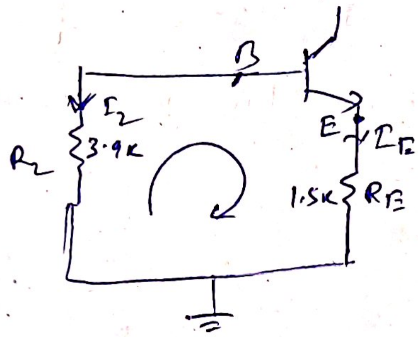
$\boxed{V_{CEQ} = V_{CC} - I_C(R_C+R_E)}$

Ex:-5 By Approximation method :-

Testing :- $\beta R_E \geq 10 R_2$

$100 \times 1.5\,k\Omega \geq 10 \times 3.9\,k\Omega$

$\Rightarrow 150\,k\Omega \geq 39\,k\Omega$ (Satisfied)



$$V_B = \frac{V_{CC}}{R_1 + R_2} \times R_2$$

$$= \frac{22}{39 + 3.9} \times 3.9$$

$$= \frac{22}{42.9} \times 3.9$$

$$\boxed{V_B = 2V.}$$

$I_2 R_2 - V_{BE} - I_E R_E = 0$

$\Rightarrow V_B - V_{BE} - V_E = 0$

$\Rightarrow \boxed{V_E = V_B - V_{BE}}$

$\Rightarrow V_E = 2 - 0.7$

$\boxed{V_E = 1.3V}$

$I_E R_E = 1.3V \Rightarrow I_C R_E \simeq 1.3V$

$\Rightarrow I_C \simeq \frac{1.3}{1.5K} = 0.867\,mA$

$\Rightarrow \boxed{I_C \simeq 0.867\,mA}$

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

$= 22 - 0.867 \times \cancel{10^{-3}} (10 + 1.5) \times \cancel{10^{3}}$

$\boxed{V_{CE} \simeq 12.03V}$

Ans:- **Exact method:-**

$$R_{Th} = R_1 // R_2$$

$$= \left(\frac{39 \times 3.9}{39 + 3.9}\right) k\Omega$$

$$\boxed{R_{Th} = 3.55\ k\Omega}$$

$$V_{Th} = \frac{V_{CC}}{R_1 + R_2} \times R_2$$

$$= \frac{22}{(39 + 3.9)} \times 3.9$$

$$= \frac{22 \times \cancel{3.9}}{\cancel{(42.9)}_{11}}$$

$$\boxed{V_{Th} = 2V}$$

using eqn (4),

$$I_B = \frac{V_{th} - V_{BE}}{R_{th} + (1+\beta) R_E}$$

$$= \frac{2 - 0.7}{10^3 \times 3.55 + (1 + 100) \cdot 1.5 \times 10^3}$$

$$= \frac{1.3}{(3.55 + 151.5) \times 10^3}$$

$$\boxed{I_B = 8.38\ \mu A}$$

$$\boxed{I_C = \beta I_B = 100 \times 8.38 \times 10^{-6} = 0.84\ mA}$$

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

$\Rightarrow V_{CE} = 22 - 0.84 \times 10^{-3} (10+1.5) \times 10^{3}$

$= 22 - 9.66$

$$\boxed{V_{CE} = 12.34\,V}$$

Stability factor Summary :-

Case-I $S(I_{co}) = \frac{dI_c}{dI_{co}}$

(a) Fixed Biasing

$$\boxed{S} = \frac{\beta+1}{1-\beta \cdot \frac{dI_B}{dI_c}} = \frac{\beta+1}{1-\beta \cdot 0} = \boxed{1+\beta}$$

(b) Self biasing

$$\boxed{S = \frac{1+\beta}{1+\beta\left(\frac{R_E}{R_B+R_E}\right)}}$$

If $R_E >> R_B$

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

$$\boxed{S \simeq 1}$$

(c) voltage divider biasing

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

If $R_E >> R_{Th}$

$= \frac{1+\beta}{1+\beta \cdot \frac{R_E}{R_E}}$

$$\boxed{S \simeq 1}$$

~~Best~~ Among voltage divider & self biasing voltage divider is best because stability factor is lowest & change of β is very less effective in this method.

~~Case-II : $S(V_{BE}) = \frac{dI_c}{dV_{BE}}$~~.

(d) Collector - feedback biasing

$$S = \frac{1+\beta}{1+\beta.\left[\frac{R_C+R_E}{R_B+R_C+R_E}\right]}$$

Case - II $\quad S(V_{BE}) = \frac{\Delta I_C}{\Delta V_{BE}}$

(a) Fixed biasing :-

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

$$I_C = \frac{\beta(V_{CC}-V_{BE})}{R_B}.$$

$$\frac{\Delta I_C}{\Delta V_{BE}} = \frac{\beta.(0-1)}{R_B} = \frac{-\beta}{R_B}.$$

$$\boxed{S(V_{BE}) = \frac{-\beta}{R_B}}$$

(b) Self biasing :-

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

$$\frac{\Delta I_C}{\Delta V_{BE}} = \frac{\beta.(0-1)}{R_B+(1+\beta)R_E}$$

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

(c)

<u>Voltage divider biasing</u>

$$I_C = \beta I_B = \beta \cdot \left(\frac{V_{th} - V_{BE}}{R_{th} + (\beta+1) R_E} \right)$$

$$\boxed{\frac{\Delta I_C}{\Delta V_{BE}} = \frac{-\beta}{R_{Th} + (1+\beta) R_E}} \quad \left(\because \frac{dV_{th}}{dV_{BE}} = 0\right)$$

(d) <u>Collector-feedback biasing :-</u>

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

$$\boxed{\frac{\Delta I_C}{\Delta V_{BE}} = \frac{-\beta}{R_B + (1+\beta)(R_C + R_E)}} \quad \left(\because \frac{dV_{CC}}{dV_{BE}} = 0\right)$$

<u>Case III</u> $\quad S(\beta) = \frac{\Delta I_C}{\Delta \beta}$

The mathematical development is more complex for $S(\beta)$. The eq^n for <u>emitter-bias</u> configuration

$$\boxed{S(\beta) = \frac{\Delta I_C}{\Delta \beta} = \frac{I_{C_1}\left(1 + \frac{R_B}{R_E}\right)}{\beta_1\left(1 + \beta_2 + \frac{R_B}{R_E}\right)}}$$

The notation I_{C1} of β_1 is used to define their values under one set of n/w conditions, whereas the notation β_2 is used to define the new value of β as established by such cases as temperature changes variation in β for same transistor or change in transistor.

→ For fixed-bias configuration, $\boxed{S(\beta) = \dfrac{I_{C1}}{\beta_1}}$

→ For voltage divider,

$$\boxed{S(\beta) = \frac{I_{C1}\left(1+\frac{R_{Th}}{R_E}\right)}{\beta_1\left(1+\beta_2+\frac{R_{Th}}{R_E}\right)}}$$

→ For collector feedback with $R_E = 0\,\Omega$,

$$\boxed{S(\beta) = \frac{I_{C1}\,(R_B+R_C)}{\beta_1\,(R_B+R_C(1+\beta_2))}}$$

→ ~~$\Delta I_C = S(I_{CO})$~~

Since

$$S(I_{CO}) = \frac{\Delta I_C}{\Delta I_{CO}} \Rightarrow \Delta I_C = S(I_{CO})\cdot\Delta I_{CO}.$$

$$S(V_{BE}) = \frac{\Delta I_C}{\Delta V_{BE}} \Rightarrow \Delta I_C = S(V_{BE})\cdot\Delta V_{BE}$$

$$S(\beta) = \frac{\Delta I_C}{\Delta\beta} \Rightarrow \Delta I_C = S(\beta)\cdot\Delta\beta.$$

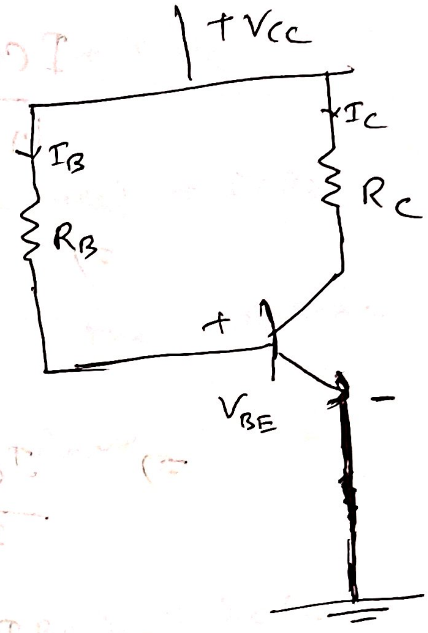
$$\therefore\ \Delta I_C = S(I_{CO})\cdot\Delta I_{CO} + S(V_{BE})\cdot\Delta V_{BE} + S(\beta)\cdot\Delta\beta.$$

ex:- For fixed bias configuration

$$\Delta I_C = (\beta+1)\,\Delta I_{CO} - \frac{\beta}{R_B}\,\Delta V_{BE} + \frac{I_{C1}}{\beta_1}\cdot\Delta\beta$$

gmp Derivation of Stability factor S(β)

1) Fixed Bias



$$V_{CC} - I_B R_B - V_{BE} = 0$$

$$V_{CC} - V_{BE} = I_B R_B \quad \text{— ①}$$

But

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

$$\Rightarrow I_B = \frac{I_C - (\beta+1) I_{CO}}{\beta} \quad \text{— ②}$$

Putting eqn ② in eqn ①, we have

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

$$\frac{V_{CC} - V_{BE}}{R_B} \simeq \frac{I_C}{\beta} - I_{CO}$$

$$\Rightarrow \frac{I_C}{\beta} = \frac{V_{CC} - V_{BE}}{R_B} + I_{CO} \quad \text{— ③}$$

Let the initial value of β is β_1.

Due to temperature change $\beta \to \beta_2$

$$\therefore \frac{I_{C_1}}{\beta_1} = \frac{V_{CC} - V_{BE}}{R_B} + I_{CO} \quad \text{— ④}$$

$$\frac{I_{C_2}}{\beta_2} = \frac{V_{CC} - V_{BE}}{R_B} + I_{CO} \quad \text{— ⑤}$$

(∵ I_{CO} is const)

$$\therefore S(\beta) = \frac{\Delta I_C}{\Delta \beta} \Bigg|_{\text{At Const. } I_{CO},\, V_{BE}}$$

Equating (4) & (5), we have

$$\frac{I_{C_1}}{\beta_1} = \frac{I_{C_2}}{\beta_2}$$

$$\Rightarrow \frac{I_{C_2}}{I_{C_1}} = \frac{\beta_2}{\beta_1}$$

$$\Rightarrow \frac{I_{C_2}}{I_{C_1}} - 1 = \frac{\beta_2}{\beta_1} - 1$$

$$\Rightarrow \frac{I_{C_2} - I_{C_1}}{I_{C_1}} = \frac{\beta_2 - \beta_1}{\beta_1}$$

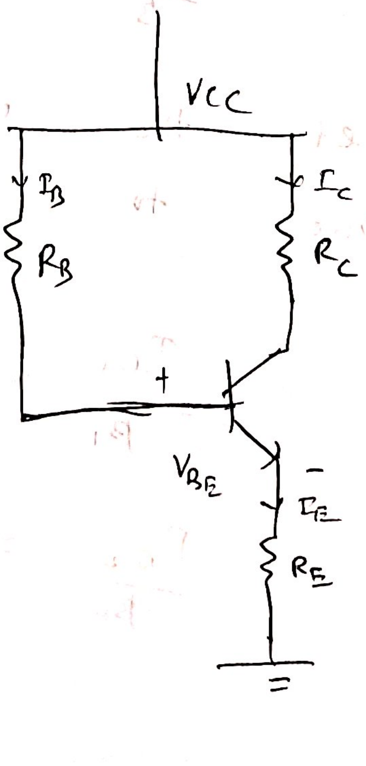
$$\Rightarrow \frac{\Delta I_C}{I_{C_1}} = \frac{\Delta\beta}{\beta_1}$$

$$\Rightarrow \frac{\Delta I_C}{\Delta\beta} = \frac{I_{C_1}}{\beta_1}$$

$$\Rightarrow \boxed{S(\beta) = \frac{I_{C_1}}{\beta_1}}$$

(Proved)

2) Emitter Bias



We know

$$I_C = \beta I_B + (\beta+1) I_{C0}$$

$$\Rightarrow I_B = \frac{I_C - (\beta+1) I_{C0}}{\beta} \quad -(1)$$

Putting KVL in the i/p loop

$$V_{CC} - I_B R_B - V_{BE} - I_E R_E = 0$$

$$V_{CC} - I_B R_B - V_{BE} - (I_B + I_C) R_E = 0$$

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

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

Assuming $(\beta+1) \simeq \beta$, and the initial value of $\beta = \beta_1$, we have:

$$\Rightarrow V_{CC} - V_{BE} = \left(\frac{I_{C_1}}{\beta_1} - I_{CO} \right) (R_B + R_E) + I_C R_E$$

$$\Rightarrow V_{CC} - V_{BE} + I_{CO} (R_B + R_E) = \frac{I_{C_1}}{\beta_1} (R_B + R_E) + I_{C_1} R_E$$

$$\Rightarrow \frac{I_{C_1}}{\beta_1} \left[R_B + R_E + \beta_1 R_E \right] = V_{CC} - V_{BE} + I_{CO} (R_B + R_E) \quad \text{--- (1)}$$

When temp changes $\beta_1 \rightarrow \beta_2$, $I_{C_1} \rightarrow I_{C_2}$

$$\Rightarrow \frac{I_{C_2}}{\beta_2} (R_B + R_E + \beta_2 R_E) = V_{CC} - V_{BE} + I_{CO} (R_B + R_E) \quad (2)$$

[$\because I_{CO}$ is const while calculating $S(\beta)$]

Equating (1) & (2), we have

$$\frac{I_{C_1}}{\beta_1} (R_B + R_E + \beta_1 R_E) = \frac{I_{C_2}}{\beta_2} (R_B + R_E + \beta_2 R_E)$$

$$\Rightarrow \frac{I_{C_2}}{I_{C_1}} = \frac{\beta_2}{\beta_1} \left(\frac{R_B + R_E + \beta_1 R_E}{R_B + R_E + \beta_2 R_E} \right)$$

$$\Rightarrow \frac{I_{C_2}}{I_{C_1}} - 1 = \frac{\beta_2}{\beta_1} \left(\frac{R_B + R_E + \beta_1 R_E}{R_B + R_E + \beta_2 R_E} \right) - 1$$

$$\Rightarrow \frac{I_{C_2} - I_{C_1}}{I_{C_1}} = \frac{\beta_2 (R_B + R_E) + \cancel{\beta_2 \beta_1 R_E} - \beta_1 (R_B + R_E) - \cancel{\beta_1 \beta_2 R_E}}{\beta_1 (R_B + R_E + \beta_2 R_E)}$$

$$\Rightarrow \frac{\Delta I_C}{I_{C_1}} = \frac{(R_B + R_E) \cdot (\Delta\beta)}{\beta_1 (R_B + R_E + \beta_2 R_E)} \quad \left(\because (\beta_2 - \beta_1) = \Delta\beta \right)$$

$$\Rightarrow \frac{\Delta I_C}{\Delta\beta} = \frac{I_{C_1}}{\beta_1} \frac{(R_B + R_E)}{(R_B + R_E + \beta_2 R_E)}$$

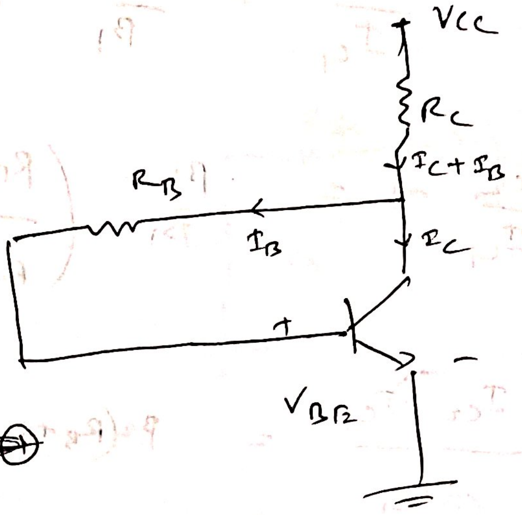
$$= \frac{\frac{I_{C_1}}{\beta_1} \cdot \cancel{R_E} \left(1 + \frac{R_B}{R_E}\right)}{\cancel{R_E} \left(1 + \beta_2 + \frac{R_B}{R_E}\right)}$$

$$\Rightarrow \boxed{S(\beta) = \frac{I_{C_1} \left(1 + \frac{R_B}{R_E}\right)}{\beta_1 \left(1 + \beta_2 + \frac{R_B}{R_E}\right)}}$$

(Proved)

3) Collector feedback

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



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

$\Rightarrow I_B \simeq \dfrac{I_C}{\beta} - I_{CO}$

$\Rightarrow I_B = \dfrac{I_{C1}}{\beta_1} - I_{CO}$ — (1)

KVL in the i/p loop

$V_{CC} - (I_B + I_C) R_C - I_B R_B - V_{BE} = 0$

$\Rightarrow V_{CC} - V_{BE} = I_B (R_B + R_C) + I_C R_C$ — (2)

Putting eqn (1) in eqn (2)

$\Rightarrow V_{CC} - V_{BE} = \left(\dfrac{I_{C1}}{\beta_1} - I_{CO}\right)(R_B + R_C) + I_{C1} R_C$

$\Rightarrow V_{CC} - V_{BE} + I_{CO} (R_B + R_C) = \dfrac{I_{C1}}{\beta_1} (R_B + R_C + \beta_1 R_C)$ — (3)

When $\beta_1 \rightarrow \beta_2$ due to temp. change

$\Rightarrow V_{CC} - V_{BE} + I_{CO} (R_B + R_C) = \dfrac{I_{C2}}{\beta_2} (R_B + R_C + \beta_2 R_C)$ — (4)

Equating (3) & (4), we have

$\dfrac{I_{C1}}{\beta_1} (R_B + R_C + \beta_1 R_C) = \dfrac{I_{C2}}{\beta_2} (R_B + R_C + \beta_2 R_C)$

$$\Rightarrow \frac{I_{C_2}}{I_{C_1}} = \frac{\beta_2}{\beta_1}\left(\frac{R_B+R_C+\beta_1 R_C}{R_B+R_C+\beta_2 R_C}\right)$$

$$\Rightarrow \frac{I_{C_2}}{I_{C_1}} - 1 = \frac{\beta_2}{\beta_1}\left(\frac{R_B+R_C+\beta_1 R_C}{R_B+R_C+\beta_2 R_C}\right) - 1$$

$$\Rightarrow \frac{I_{C_2}-I_{C_1}}{I_{C_1}} = \frac{\beta_2(R_B+R_C) + \cancel{\beta_2\beta_1 R_C} - \beta_1(R_B+R_C) - \cancel{\beta_1\beta_2 R_C}}{\beta_1(R_B+R_C+\beta_2 R_C)}$$

$$\Rightarrow \frac{\Delta I_C}{I_{C_1}} = \frac{(R_B+R_C)(\beta_2-\beta_1)}{\beta_1(R_B+R_C+\beta_2 R_C)}$$

$$\Rightarrow \frac{\Delta I_C}{\beta_2-\beta_1} = \frac{I_{C_1}(R_B+R_C)}{\beta_1\left[R_B+R_C(1+\beta_2)\right]}$$

$$\Rightarrow \frac{\Delta I_C}{\Delta\beta} = \frac{I_{C_1}(R_B+R_C)}{\beta_1(R_B+R_C(1+\beta_2))}$$

$$\Rightarrow S(\beta) = \frac{I_{C_1}(R_B+R_C)}{\beta_1(R_B+R_C(1+\beta_2))}$$

(Proved)

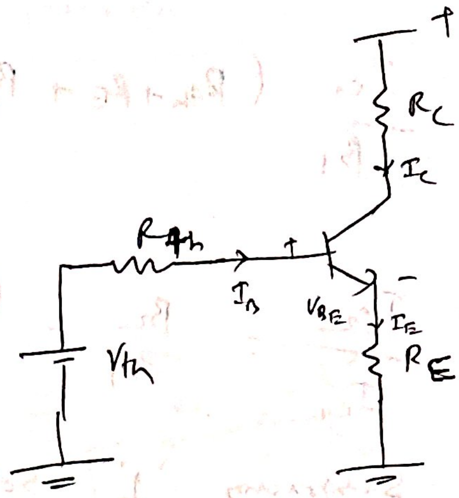
4) Voltage divider bias

Similar to Emitter bias

Replace

$V_{CC} \rightarrow V_{th}$

$R_B \rightarrow R_{th}$.



I/p eqn

$$V_{th} - I_B R_{th} - V_{BE} - I_E R_E = 0. \quad \text{— (1)}$$

$$I_B = \frac{I_C - (\beta+1) I_{CO}}{\beta} \quad \text{— (2)} \quad \left(\because I_C = \beta I_B + (\beta+1) I_{CO} \right)$$

$$V_{th} - V_{BE} = I_B R_{th} + I_E R_E = I_B R_{th} + (I_C + I_B) R_E$$

$$\Rightarrow V_{th} - V_{BE} = I_B (R_{th} + R_E) + I_C R_E$$

$$\Rightarrow V_{th} - V_{BE} = \left(\frac{I_C - (\beta+1) I_{CO}}{\beta} \right) (R_{th} + R_E) + I_C R_E \quad \left(\text{Putting eq}^n \text{ (2) in place of } I_B \right)$$

$$\Rightarrow V_{th} - V_{BE} \simeq \left(\frac{I_C}{\beta} - I_{CO} \right) (R_{th} + R_E) + I_C R_E$$

$$\Rightarrow V_{th} - V_{BE} + I_{CO} (R_{th} + R_E) = \frac{I_C}{\beta} (R_{th} + R_E + \beta R_E)$$

Similar to Emitter bias, Initial value of $\beta \rightarrow \beta_1$, then $\beta \rightarrow \beta_2$

$$\therefore \frac{I_{C_1}}{\beta_1} (R_{th} + R_E + \beta_1 R_E) = V_{th} - V_{BE} + I_{CO} (R_{th} + R_E) \quad \text{— (3)}$$

$$\therefore \frac{I_{C_2}}{\beta_2} (R_{th} + R_E + \beta_2 R_E) = V_{th} - V_{BE} + I_{CO} (R_{th} + R_E) \quad \text{— (4)}$$

Equating eqn (3) & (4)

$$\frac{I_{C_1}}{\beta_1}(R_{th}+R_E+\beta_1 R_E) = \frac{I_{C_2}}{\beta_2}(R_{th}+R_E+\beta_2 R_E)$$

$$\Rightarrow \frac{I_{C_2}}{I_{C_1}} = \frac{\beta_2}{\beta_1}\cdot\frac{(R_{th}+R_E+\beta_1 R_E)}{(R_{th}+R_E+\beta_2 R_E)}$$

Substracting '1' both the sides

$$\Rightarrow \frac{I_{C_2}-I_{C_1}}{I_{C_1}} = \frac{\beta_2(R_{th}+R_E)+\cancel{\beta_2\beta_1 R_E} - \beta_1(R_{th}+R_E) - \cancel{\beta_1\beta_2 R_E}}{\beta_1(R_{th}+R_E+\beta_2 R_E)}$$

$$\Rightarrow \frac{\Delta I_C}{I_{C_1}} = \frac{(R_{th}+R_E)(\Delta\beta)}{\beta_1(R_{th}+R_E+\beta_2 R_E)}$$

$$\Rightarrow \frac{\Delta I_C}{\Delta\beta} = \frac{I_{C_1}}{\beta_1}\cdot\frac{(R_{th}+R_E)}{(R_{th}+R_E(1+\beta_2))}$$

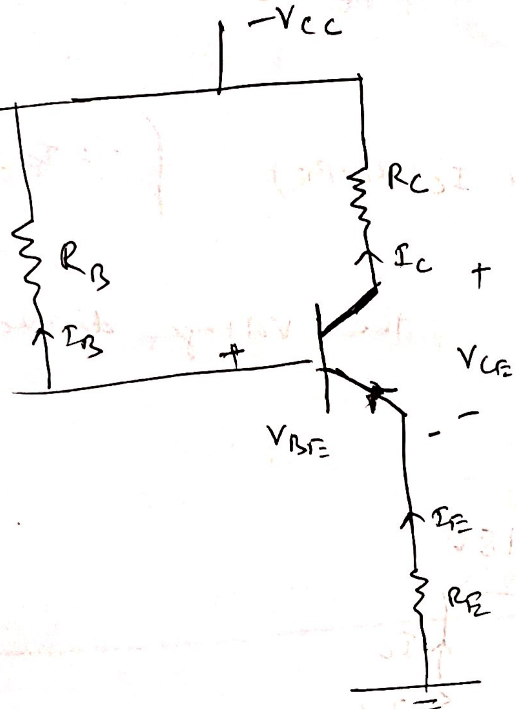
$$\Rightarrow \frac{\Delta I_C}{\Delta\beta} = \frac{I_{C_1}}{\beta_1}\cdot\frac{\cancel{R_E}\left(1+\frac{R_{Th}}{R_E}\right)}{\cancel{R_E}\left[1+\beta_2+\frac{R_{Th}}{R_E}\right]}$$

$$\Rightarrow \boxed{S(\beta) = \frac{I_{C_1}}{\beta_1}\cdot\frac{\left(1+\frac{R_{Th}}{R_E}\right)}{\left((1+\beta_2)+\frac{R_{Th}}{R_E}\right)}}$$

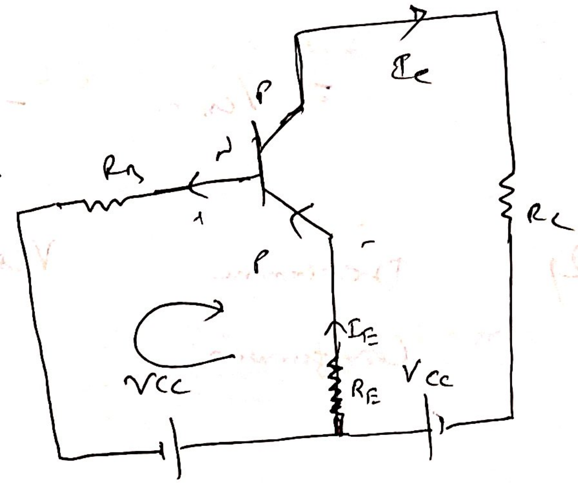
(proved)

Biasing Problem with PNP transistor

1)



$\simeq$



I/p loop

$$\boxed{-V_{CC} + I_B R_B - V_{BE} + I_E R_E = 0}$$

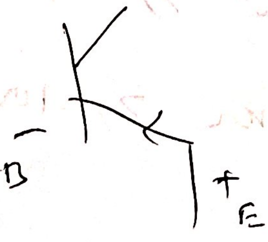
$$\Rightarrow I_B R_B = V_{CC} + V_{BE} - I_E R_E = V_{CC} + V_{BE} - (\beta+1) I_B R_E$$

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

$$\Rightarrow I_B = \frac{V_{CC} + V_{BE}}{R_B + (\beta+1) R_E}$$

But here $V_{BE} = -0.7V$

Because actual direction is



Current direction is into the transistor. $V_E > V_B$

$V_B < V_E$

$V_B - V_E < 0$

$\Rightarrow V_{BE} < 0$.

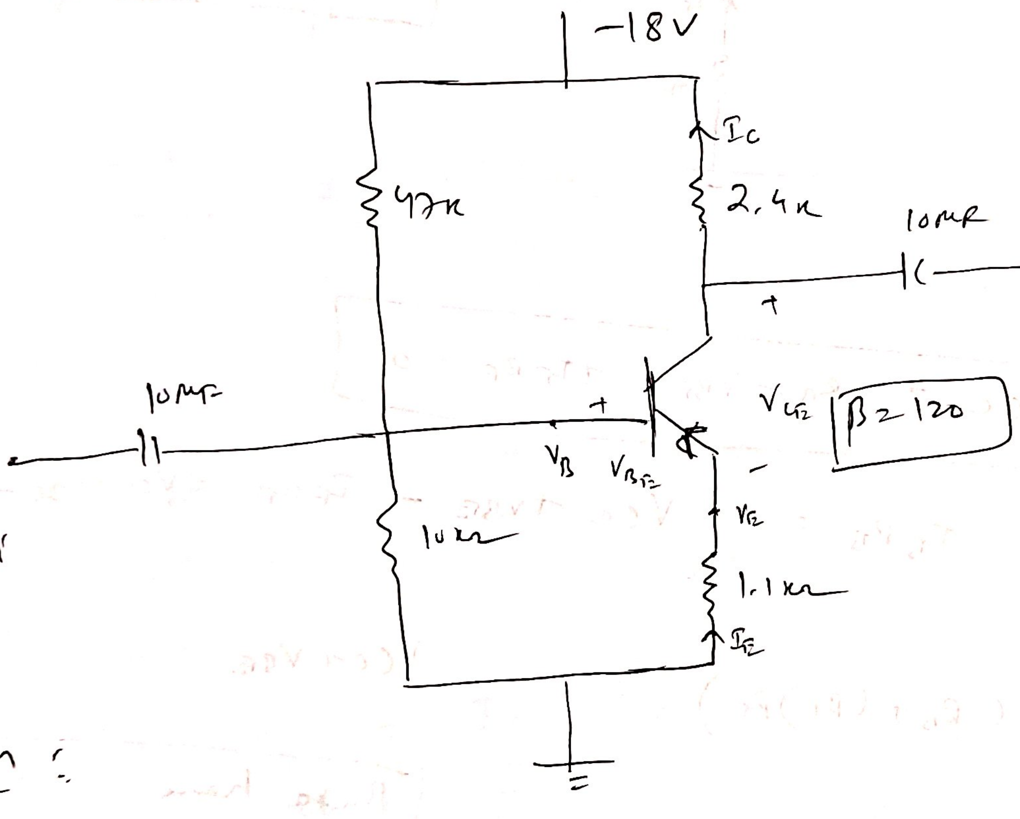
Since we want to take same convention as for NPN, we have $\longrightarrow$ B + − E, $V_{BE} = -0.7V$

O/p loop

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

$$\Rightarrow V_{CE} = -V_{CC} + I_C(R_C + R_E) \quad (\because I_E \simeq I_C)$$

2) Determine V_{CE} for the voltage divider bias configuration.



Soln :

Testing condition

$$\beta R_E \geq 10 R_2$$

$$120 \times 1.1 \times 10^3 \geq 10 \times 10k\Omega$$

$$\Rightarrow 132\ k\Omega \geq 100\ k\Omega \text{ (Satisfied)}$$

Approximate Analysis.

$$V_B = \frac{V_{CC}}{R_1 + R_2} \times R_2 = \frac{-18}{47+10} \times 10 = -3.16\,V$$

$$V_{BE} = V_B - V_E$$

$$\Rightarrow -0.7 = \cancel{V_B} -3.16 - V_E$$

$$\Rightarrow V_E = -3.16 + 0.7 = -2.46\ V$$

$$V_E + I_E R_E = 0$$

$$\Rightarrow I_E = \frac{-V_E}{R_E} = \frac{-(-2.46)}{1.1\,k\Omega} = 2.24\,mA.$$

KVL in the o/p loop.

$$-18 + I_C R_C - V_{CE} + I_E R_E = 0$$

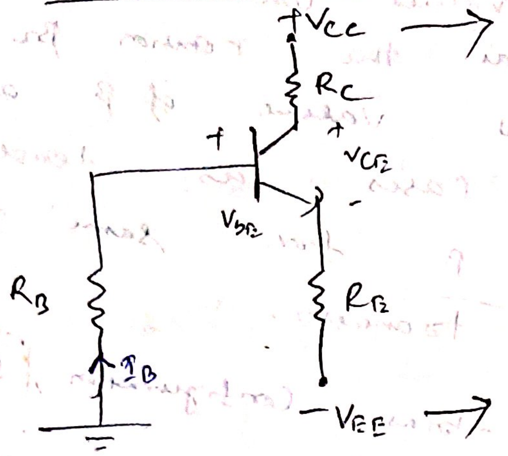
$$-18 - V_{CE} + I_C (R_C + R_E) = 0 \qquad (\because I_C \approx I_E)$$

$$\Rightarrow V_{CE} = -18 + I_C (R_C + R_E)$$

$$= -18 + 2.24 (2.4 + 1.1)$$

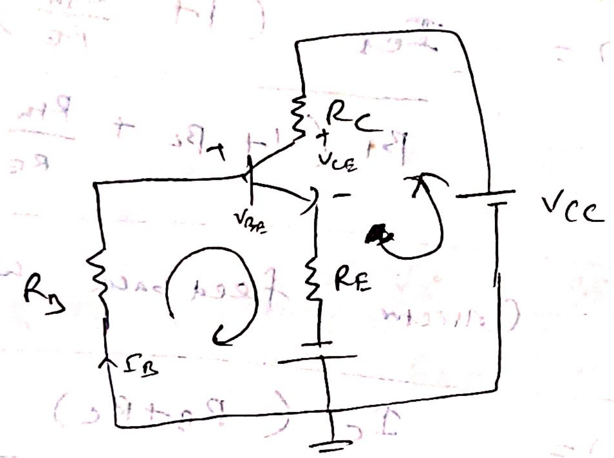
$$\boxed{V_{CE} = -10.16\,V}$$

Ex-6 :- Emitter bias with 2 d-c supply



~~I/P loop~~

The Cut can be redrawn,



I/P Loop

$$-I_B R_B - V_{BE} - I_E R_E + V_{EE} = 0$$

O/P loop

$$V_{CC} - I_C R_C - V_{CE} - I_E R_E + V_{EE} = 0$$

Ex: 7 :- Emitter follower

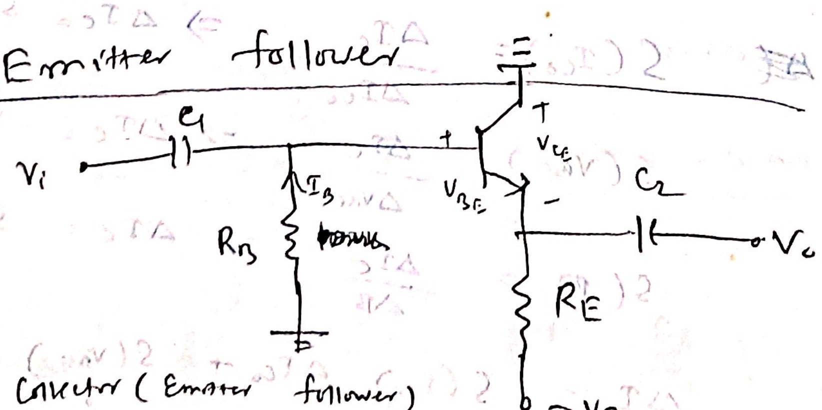


fig:- Common-Collector (Emitter follower)

In emitter follower, the O/P is taken at emitter terminal, This is also known as common-collector or emitter follower configuration.

I/P loop :-

$$-I_B R_B - V_{BE} - I_E R_E + V_{EE} = 0$$

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

$$-I_B R_B - V_{BE} - (1+\beta) I_B R_E + V_{EE} = 0$$

$$\Rightarrow \boxed{I_B = \frac{V_{EE} - V_{BE}}{(R_B + (1+\beta) R_E)}}$$

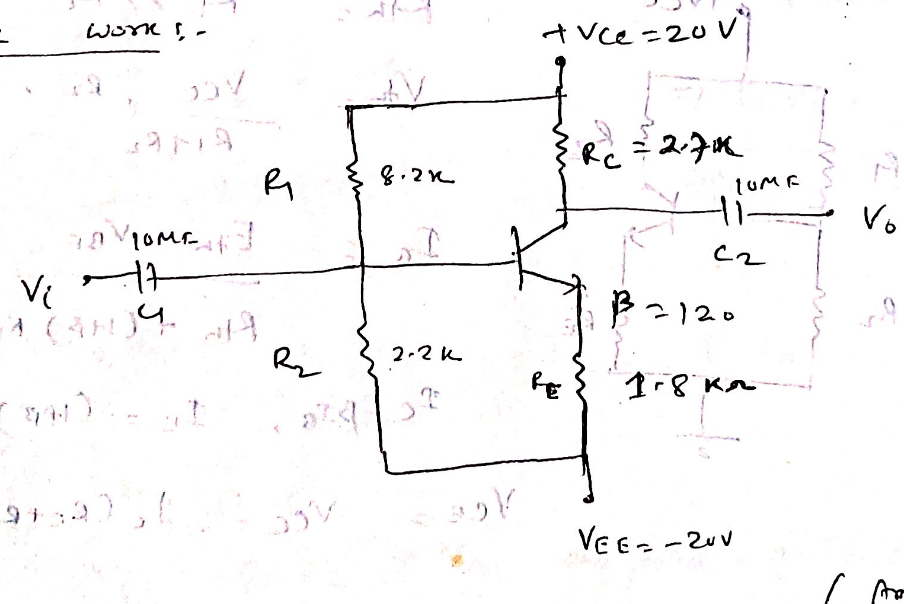
For o/p

$$-V_{CE} - I_E R_E + V_{EE} = 0$$

$$\Rightarrow \cancel{V_{CE} = V_{EE} - I_E R_E}$$

$$\Rightarrow \boxed{V_{CE} = V_{EE} - I_E R_E}$$

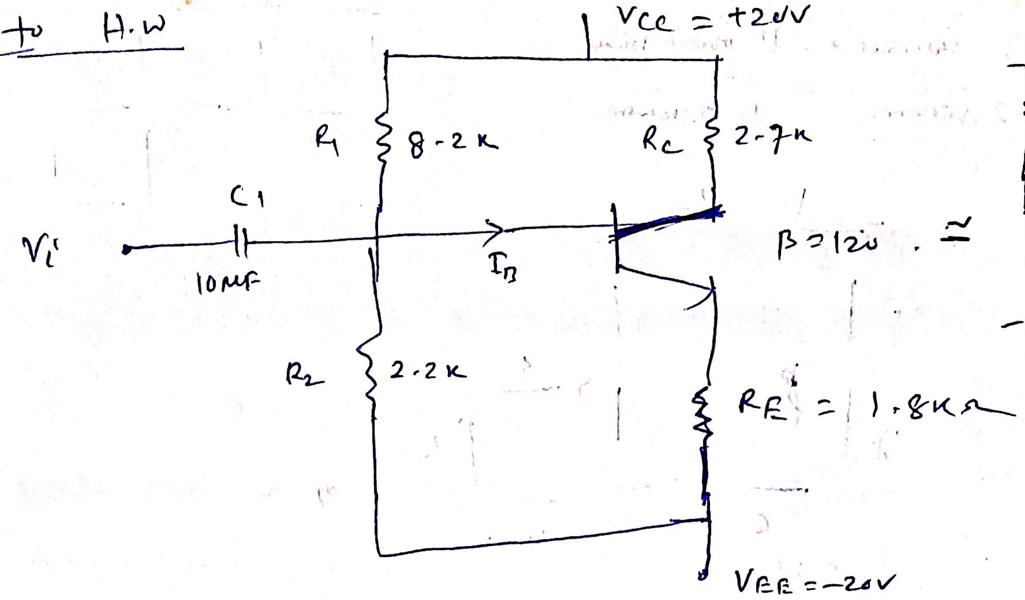
Home work :-



Determine V_C & V_B

(Ans :- $V_C = 8.53$ V
$V_B = -11.59$ V)

Soln to H.W



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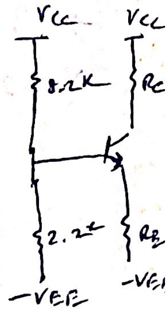
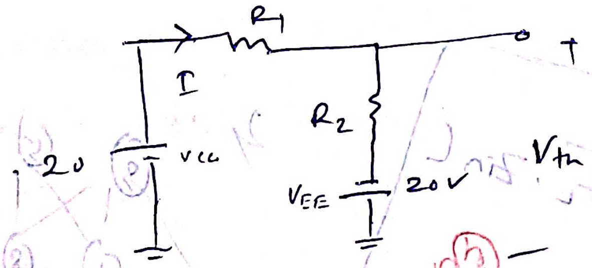


Ans: $R_{th} = 8.2\,K \parallel 2.2\,K = \frac{8.2 \times 2.2}{8.2 + 2.2}$

$$\boxed{R_{th} = 1.73\,k\Omega}$$

V_{th} =



$20 - I(R_1 + R_2) + 20 = 0$

$\Rightarrow I = \frac{40}{R_1 + R_2} = \frac{40}{10.4k} = 3.85\,mA.$

$V_{cc} - I(R_1) - V_{th} = 0$

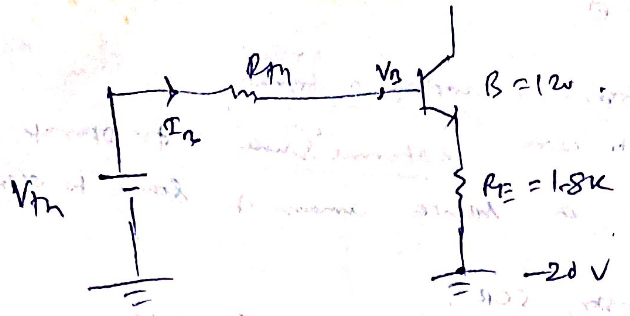
$\Rightarrow V_{th} = V_{CC} - IR_1 = 20 - 3.85 \times 8.2$

$\boxed{V_{th} = -11.57\,V}$ → Same ≈ −11.53 if instead 3.85 ≃ 3.846153[illegible]

$V_{th} - IR_2 + 20 = 0$

$\Rightarrow V_{th} = -20 + IR_2 = -20 + 3.85 \times 2.2$

$\boxed{V_{th} = -11.53\,V}$



$V_{th} - I_B R_{th} - V_{BE} - I_E R_E + 20 = 0$

$\Rightarrow V_{th} - I_B R_{th} - V_{BE} - (\beta+1) I_B R_E + 20 = 0$

$\Rightarrow I_B = \dfrac{V_{th} - V_{BE} + 20}{R_{th} + (\beta+1) R_E}$

$= \dfrac{-11.53 - 0.7 + 20}{(1.73 + 121 \times 1.8) \times 10^3}$

$= \dfrac{7.77}{219.53\,k\Omega}$

$\boxed{I_B = 35.39\,\mu A}$

$I_C = \beta I_B = 120 \times 35.39\,\mu A$

$\boxed{I_C = 4.25\,mA}$

$V_C = V_{CC} - I_C R_C$

$= 20 - 4.25 \times 2.7$

$\boxed{V_C = 8.53\,V}$

$V_{th} - I_B R_{th} - V_B = 0$

$\Rightarrow V_B = V_{th} - I_B R_{th}$

$= -11.53 - (35.39) \times 10^{-6} \times 1.73 \times 10^3$

$\boxed{V_B = -11.59\,V}$

w

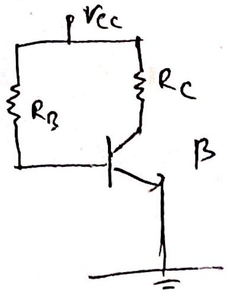
$V_B - V_{BE} - I_E R_E + 20 = 0$

$\Rightarrow V_B = V_{BE} + I_C R_E + 20 \quad 2\,0.7 + 4.25 \times 1.8 + 20$

$\boxed{V_B = -11.65\,V}$

Summary 2 - (Design operations)

1) **Fixed Bias :-**

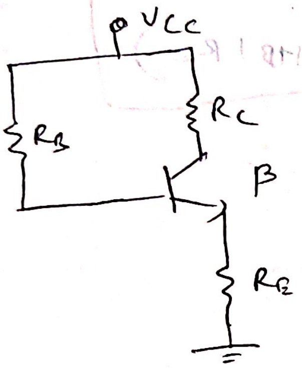


$$I_B = \frac{V_{CC} - V_{BE}}{R_B}$$

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

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

2) **Emitter bias :-**



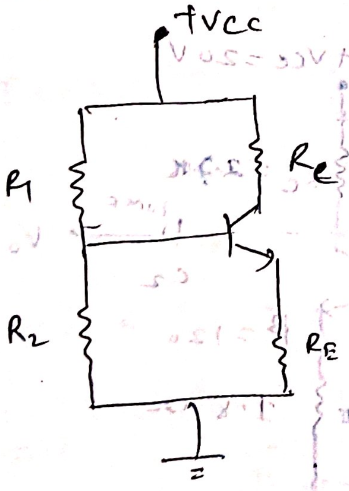
$$I_B = \frac{V_{CC} - V_{BE}}{R_B + (1+\beta) R_E}$$

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

$$R_i = (\beta+1) R_E$$

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

3) **Voltage-divider bias :-**



$$R_{th} = R_1 \,//\, R_2$$

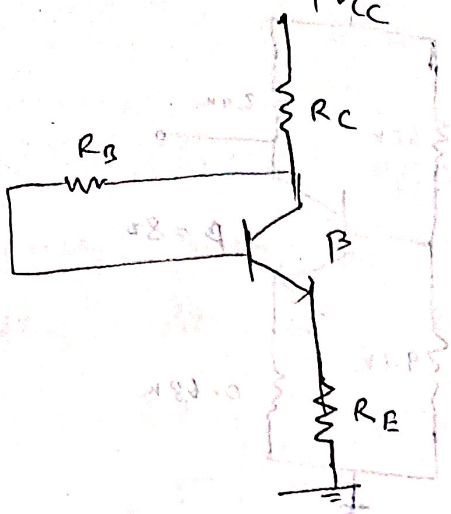
$$V_{th} = \frac{V_{CC}}{R_1 + R_2} \cdot R_2 ,$$

$$I_B = \frac{E_{th} - V_{BE}}{R_{th} + (1+\beta) R_E}$$

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

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

4) **Collector - Feedback**

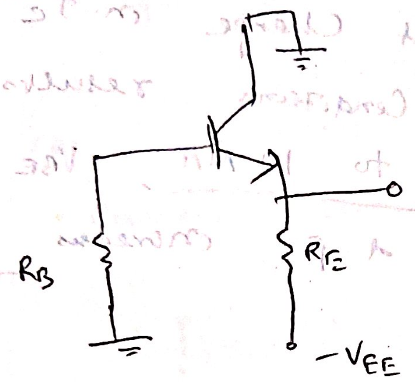


$$I_B = \frac{V_{CC} - V_{BE}}{R_B + \beta(R_C + R_E)}$$

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

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

5) Emitter follower

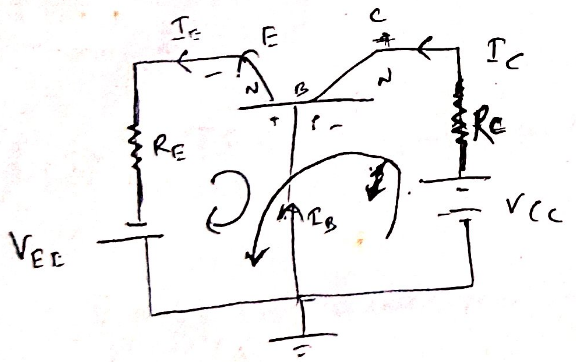


$$I_B = \frac{V_{EE} - V_{BE}}{R_B + (1+\beta) R_E}$$

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

$$V_{CE} = V_{EE} - I_E R_E$$

6) Common-base



~~$I_E R_E + V_{EE}$~~ i/p loop

$$-V_{EE} + I_E R_E + V_{BE} = 0$$

$$\Rightarrow I_E R_E = V_{EE} - V_{BE}$$

$$\Rightarrow \boxed{I_E = \frac{V_{EE} - V_{BE}}{R_E}}$$

$I_B = \frac{I_E}{\beta+1}$, $I_C = \beta I_B$

Entire loop

$$V_{CC} - I_C R_C - V_{CE} - I_E R_E + V_{EE} = 0.$$

$$\Rightarrow \boxed{V_{CE} = V_{CC} + V_{EE} - I_E (R_C + R_E)} \quad (\because I_E \simeq I_C)$$

$$\boxed{V_{CB} = V_{CC} - I_C R_C}$$

H.W 2009 BPUT

1) For the n/w determine :-

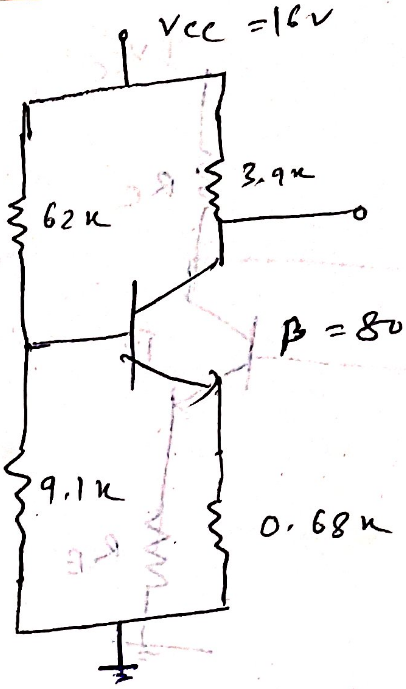
(i) $S(I_{co})$

(ii) $S(V_{BE})$

(iii) $S(\beta)$ using $\beta(T_1)$

as specified in the diagram

and $\beta(T_2)$ as 25% more.



(iv) Determine the net change in I_C if a change in operating conditions results in I_{co} increasing from 0.2 to 10 μA, V_{BE} drops from 0.7 to 0.5V & β increases 25%.

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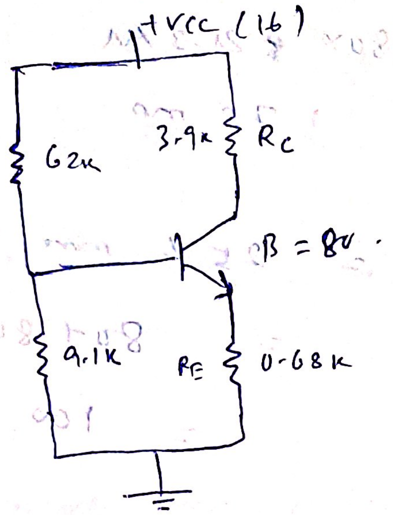
2) Soln to RPVT 2019



$$R_{th} = \frac{62 \times 9.1}{62+9.1} \, k\Omega = 7.94 \, k\Omega$$

$$S(I_{co}) = \frac{1+\beta}{1+\beta\left(\frac{R_E}{R_E+R_{th}}\right)} = \frac{1+80}{1+80\left(\frac{0.68}{0.68+7.94}\right)}$$

$$\left.\frac{\Delta I_C}{\Delta I_{co}}\right]_{\beta \,\&\, V_{BE}} \qquad = \frac{81}{1+\frac{54.4}{8.62}} = 11.08$$

(i) $\boxed{S(I_{co}) = 11.08}$

(ii) $$S(V_{BE}) = \frac{-\beta}{R_{th}+(1+\beta)R_E} = \frac{-80}{[7.94+81.(0.68)] \times 10^3}$$

$$\boxed{S_{V_{BE}} = -1.27 \times 10^{-3} \, S}$$

(iii) $$S(\beta) = \frac{I_{C1}\left(1+\frac{R_{th}}{R_E}\right)}{\beta_1\left(1+\beta_2+\frac{R_{th}}{R_E}\right)}$$

To find I_{c}

$$V_{th} = \frac{16}{62+9.1} \times 9.1 = 2.04$$

$$V_{th} - I_B R_{th} - V_{BE} - (\beta+1) I_B R_E = 0$$

$$\Rightarrow I_B = \frac{V_{th}-V_{BE}}{R_{th}+(\beta+1)R_E} = \frac{2.04-0.7}{(7.94+81 \times 0.68) \times 10^3} = .0213 \text{ mA} = 21.3 \text{ μA}$$

$$I_C = \beta I_B$$

$$= 80 \times \cancel{8}\ 21.3\ \mu A$$

$$I_c = 1.72\ mA$$

~~S(β)~~ β_2 = 25% more than β

$$= 80 + 80 \times \frac{25}{100}$$

$$= 100$$

$$S(\beta) = \frac{I_{C1}\left(1 + \frac{R_{th}}{R_E}\right)}{\beta_1\left(1 + \beta_2 + \frac{R_{th}}{R_E}\right)}$$

$$= \frac{1.72 \times 10^{-3}\left(1 + \frac{7.94}{0.68}\right)}{80\left(1 + 100 + \frac{7.94}{0.68}\right)}$$

$$S(\beta) = \left.\frac{\Delta I_C}{\Delta \beta}\right|_{V_{BE}\ \&\ I_{CO}} = \frac{12.67 \times 1.72 \times 10^{-3}}{80 \times 112.67}$$

$$\boxed{S(\beta) = 2.41 \times 10^{-6}\ Amp}$$

(d) Net Change in I_C

$$\Delta I_C = S(I_{CO})\,\Delta I_{CO} + S(\beta).\,\Delta\beta + S(V_{BE}).\,\Delta V_{BE}$$

$$= (11.08) \times 9.8\ \mu A + 2.41 \times 10^{-6} \times \frac{80 \times 25}{100} + (-1.27 \times 10^{-3}) \times (-0.2)$$

$$= \cancel{0.108}\ .108 + .0482 + 0.254$$

$$\boxed{\Delta I_C = 0.4102\ mA}$$