1. Transistor Biasing & Stabilization

DC Load Line Analysis :-

Definition:-

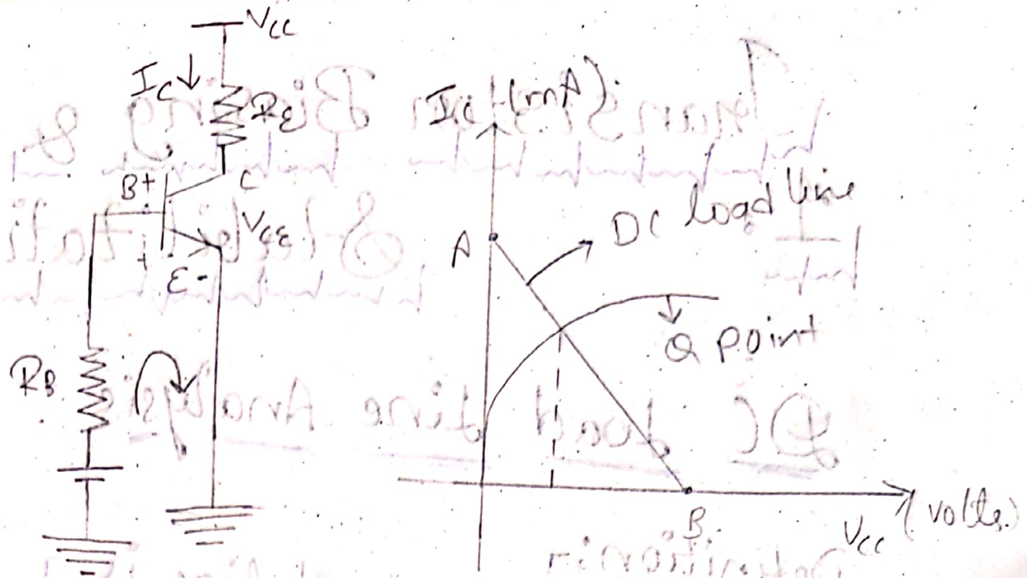
The D.C load line is a graph that has all possible volumes of output current (I_c) & output voltage (V_c) for a given region of operation.

The load line of a d.c equivalent circuit, defined by reducing the reactive components to zero. This load line calculates the D.C operating point. And it is drawn between V_{CE} & I_c characteristics of a transistor in CE mode or in amplifier

↳ If we analyse the circuit that has a DC output then it is called as D.C analysis.

↳ To get D.C load line, we need to apply "kirchoff's voltage law" to the circuit or output

↳ The main intension of this load line is to find "overload" ship using the load line markers on the ship



By applying KVL to output

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

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

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

To obtain load line the two end points of the straight line can be determined. Let the two points are A & B

To obtain 'A'

When $V_{CE} = 0$, I_C is maximum & equal to V_{CC}/R_C. This gives the maximum value of V_{CE}.

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

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

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

$$\Rightarrow I_C = \frac{V_{CC}}{R_C}$$

$\therefore$ A $\left(OA = \frac{V_{CC}}{R_C}\right)$ on I_C as shown in the figure.

To obtain B :-

when $I_C = 0$, V_{CE} is maximum & equal to V_{CC}. This is shown as

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

$$\Rightarrow V_{CE} = V_{CC} - R_C(0)$$

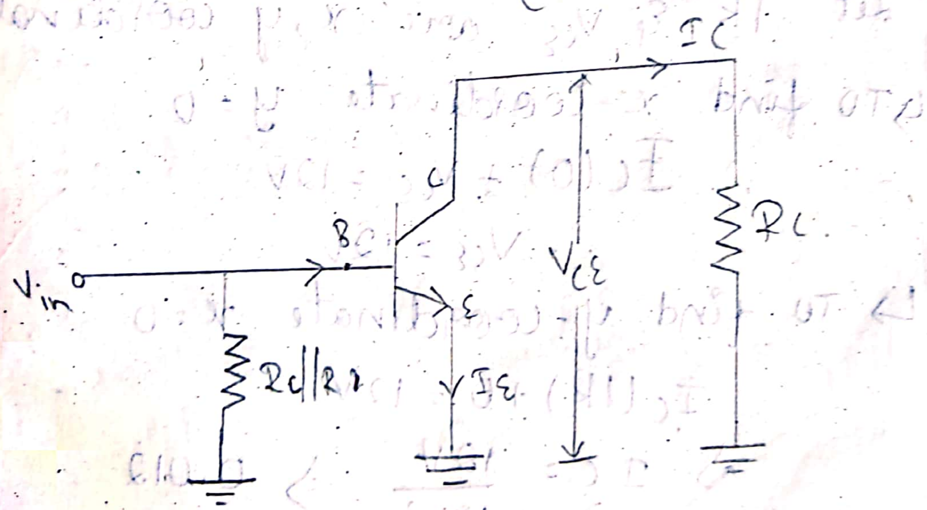
$$\therefore V_{CE} = V_{CC}$$

Hence we get point A & B that is Saturation & cut off point & it is a straight line. So, a DC Line can be drawn.

AC Load Line Analysis :

If the load line is plot between Transistor current & voltage across A.C Signals then it is called A.C Load line. It gives the peak to peak voltage of CE mode :

A.C equivalent circuit (Amplifier)

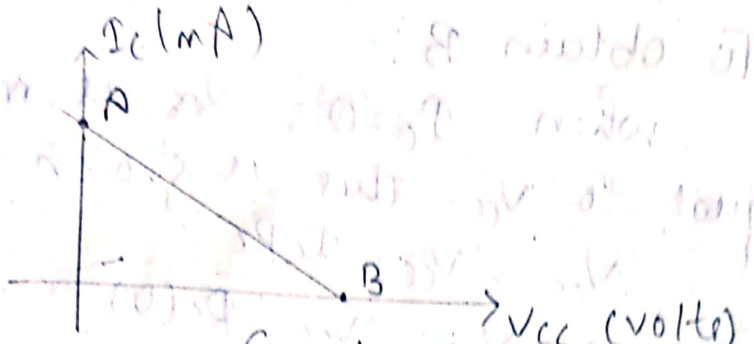


From the circuit,

$$V_{CE} = (R_C || R_1) I_C \qquad \{\because R_C||R_1 = r_c\}$$

$$\Rightarrow I_{C(sat)} = I_{eq} + V_{ceq} / (R_C || R_1)$$

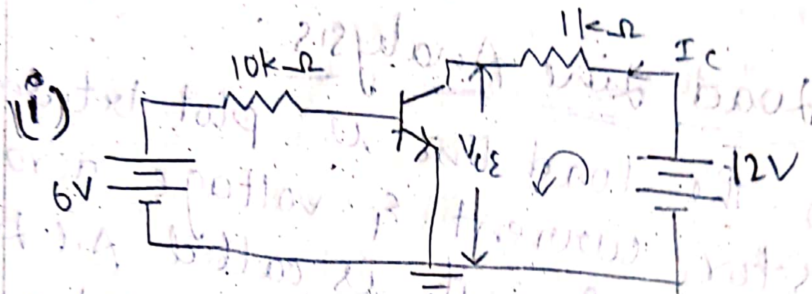
$$\therefore V_{CE(off)} = V_{ceq} + I_{eq} r_c$$



Graph

* From the above graph, it was conclude that $x = V_{CO}$ & $y = I_C$
* The line $\overline{AB}$ is called load line for AC circuit (AC load line)

(ii)



Applying KVL at output loop

$$12V = I_C(1 \times 10^3) + V_{CE}$$

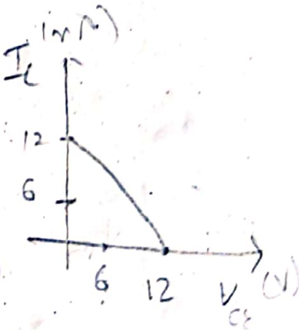
$$\Rightarrow \underset{y}{I_C (1k)} + \underset{x}{(V_{CE})} = 12V$$

Let 1k & V_{CE} are x, y coordinates.

↳ To find x-coordinate y = 0

$$\therefore I_C(0) + V_{CE} = 12V$$

$$\therefore V_{CE} = 12V.$$



↳ To find y-coordinate x = 0

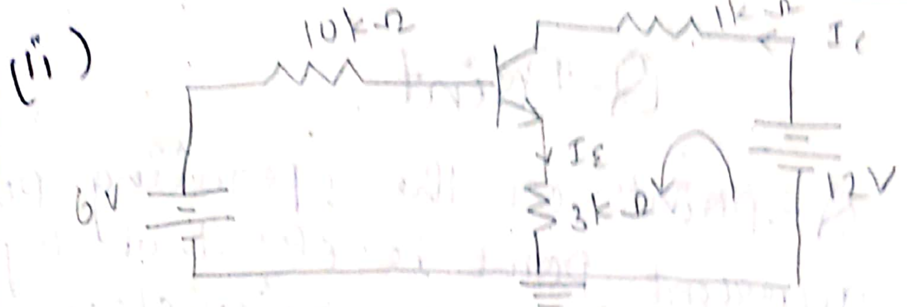
$$I_C(1k) + 0 = 12V$$

$$\Rightarrow I_C = \frac{12V}{1 \times 10^3} \Rightarrow 0.012$$

$$\therefore I_C = 12\,mA$$

Thus we obtain a straight line from KVL

(ii)



Applying KVL at output loop

$$12V = I_C(1k) + V_{CE} + 3k(I_E)$$

$$\Rightarrow -12V + I_C(1k) + V_{CE} + 3k(I_E) = 0$$

$$I_E = I_B + I_C$$

$$\left[I_C = \beta I_B \Rightarrow I_B = \frac{I_C}{\beta}\right]$$

$$\therefore I_E = \frac{I_C}{\beta} + I_C = \frac{I_C}{100} + I_C$$

$$\therefore I_E = I_C\left(\frac{1}{100} + 1\right) \Rightarrow I_E = I_C(0.01+1)$$

$$\therefore I_E = 1.01 I_C \qquad 4k(1.01) = 4.01k$$

$$\therefore \Rightarrow -12V + I_C(1k) + V_{CE} + 3k(1.01)I_C = 0$$

$$\Rightarrow \underset{x}{V_{CE}} + \underset{y}{I_C}(4.01k) = 12$$

Let V_{CE} & I_C are x,y coordinates

→ To know x coordinate : $y = 0$

$$\therefore V_{CE} + 0(4.01k) = 12$$

$$\therefore V_{CE} = 12V$$

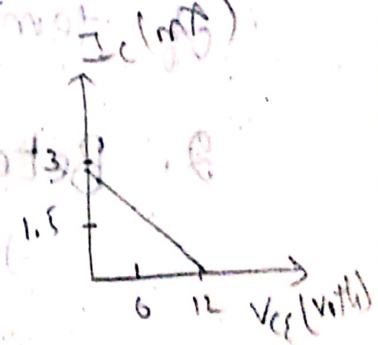
→ To know y coordinate : $x = 0$

$$0 + I_C(4.01k) = 12$$

$$\therefore I_C = \frac{12}{4.01 \times 1000}$$

$$= 0.00299$$

$$= 2.99\,mA$$



Q-Point.

Q-point or the operating point or quiescent point is obtained by the graph of output characteristics i.e, value of I_C & V_{CE} when no signal is applied in input.

Factors affecting stability of Q-point.

1. Temperature
2. Beta (β)
3. Transistor Parameters.

1. Temperature :-

* As the temperature increases the values of I_C, β, V_{BE} gets affected.
* Reverses saturation current (I_{CBO}) get doubled for every raise in 10°C.
* V_{BE} decreases by 2.5mV for every 1°C raise in temperature.
* Due to change in these values, the Saturation current (I_C) also varies.

Hence Q-point should be made independent of temperature as to achieve stability.

2. Beta (β) :-

$$I_C \propto \beta_{DC} \quad \text{or} \quad \beta = \frac{\Delta I_C}{\Delta I_B}$$

* β is dependent on transistor replacement

* Replacing a transistor with larger β will shift Q-point upwards i.e, saturation. as β increase I_c also increases

* Replacing a transistor with smaller β will shift Q-point downwards i.e, cutoff as β decreases I_c also decreases.

* current gain β_{dc} of transistor normally has a very wide tolerance. The value of β_{dc} may typically range from 50 to 150 (or) more dependent on value of I_c

The wide tolerance can seriously affect the transistor bias conditions

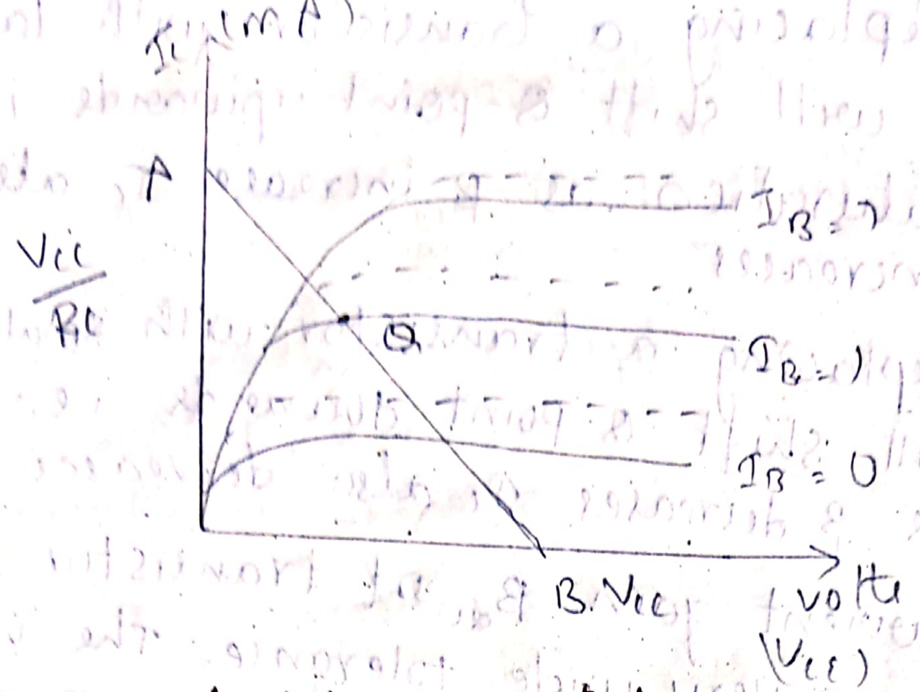
* β current gain is temperature dependent

3. Transistor Parameters :-

* Two transistors of identical numbers do not have exactly the same characteristics.

* Important factor β is not same for every transistor. when β change, Q-point also change.

* Hence if we replace one transistor by other of same number, the Q-Point is going to be shifted.



More about Q-point.

* It is the point of interaction between output characteristics & load line of given transistor.

* Q-point is used when transistor acts as amplifying device & hence operated in active region.

* There can be infinite no. of inter-secting points but Q-point is selected in such a way that irrespective of A.C signal swing the transistor.

* For a good amplifier, the Q-point should be at middle, as to acts as a switch.

Stabilization:-

The process of making operating point independent of temperature changes or variations in transistor parameters.

* What are the stability factors?

↳ It is defined as the degree of change in operating point due to variation in temperature

inf ↳ The extent to which the collector current I_C is stabilized with varying I_{CO} is measured by a stability factors.

↳ It is defined as the rate of change of collector current I_C with respect to the collector base current I_{CBO}, keeping both the current I_B & current gain β is constant $\left(\frac{I_C}{I_{CBO}}\right)$

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

1. If I_{CBO} 2 μA to 10 μA & I_C 0.5 mA to 0.55 mA. Calculate stability.

sol $\frac{I_C}{I_{CO}}$ = stability

$$\Rightarrow \frac{(0.55-0.5)\times 10^{-3}}{(10-2)\times 10^{-6}} = \frac{0.05\times 10^{-3}}{8\times 10^{-6}}$$

$\Rightarrow \frac{0.05}{8\times10^{-3}}$ $\Rightarrow \frac{0.05\times10^{3}}{8} = \frac{50}{8}$

$= 6.25$ is the stability factor

Stability factor (S)

$$\boxed{S = \frac{\Delta I_C}{\Delta I_{CO}}}$$

The collector current for a CE amplifier is given by $I_C = \beta I_B + (1+\beta) I_{CO}$ — (1)

Dividing eq (1) by I_C

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

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

$$\boxed{S = \frac{1+\beta}{1-\beta\frac{(dI_B)}{(dI_C)}}}$$ → Expression for stability → Important

From this equation it is clear that the factor S should be small as possible to have better thermal stability.

Lowest stability factor $S = 1$.

* Relation b/w stability factor & bias stability.

The small value of stability factor indicates the good bias stability whereas

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large value of stability factor indicates poor bias stability

Ideal value of stability factor is "zero"

$$\boxed{S = \frac{1+\beta}{1-\beta\left[\frac{dI_B}{dI_C}\right]}}$$

Biasing

Biasing is the process of providing DC voltage which helps in the functioning of the circuit for the desired application.

↳ The biasing in transistor circuits is done by using two dc sources V_{BB} and V_{CC}

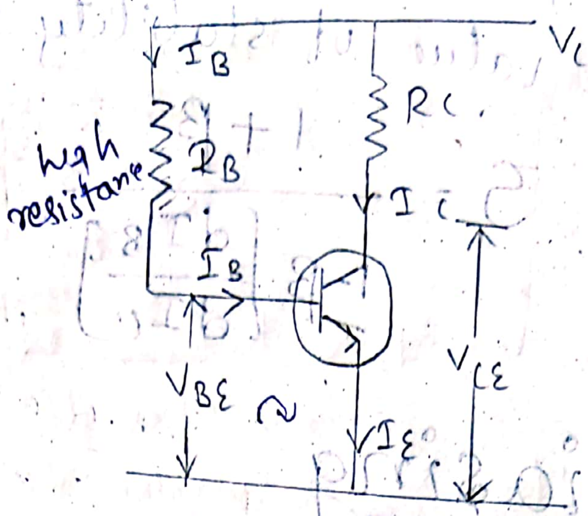
↳ It is economical to minimize the DC source to one supply instead of two which also makes the circuit simple

↳ The commonly used methods of transistor biasing are

* Base-resistor method
* collector to base bias
* Biasing with collector feedback resistor
* voltage-divider bias

* All these methods have same basic principle of obtaining the required value of I_B & I_C from V_{CC} in zero signal conditions

1. * Base Resistor Method :-



* There is no emitter resistor in fixed bias
* In this method, a Resistor R_B of high resistance is connected to base, as the name implies. The required zero signal base current is provided by V_{CC} which flows through R_B. The base emitter junction is forward biased as base is +ve with respect to emitter
* The required value of zero signal base current & hence the collector current as ($I_C = \beta I_B$) can be made to flow by selecting the proper value of base resistor R_B. Hence the value of R_B is known.

By applying KVL at output loop.

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

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

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

Loading effect: The effect on the source by the ... impedance

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

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

In this method V_{CC} is a fixed known quantity & I_B is choset at some suitable value. And R_B is directly known so it is also called as fixed base bias method

$$\text{Stability factor } (S) = \frac{1+\beta}{1-\beta\left[\frac{dI_B}{dI_C}\right]}$$

In fixed bias. I_B is independent of I_C. So that $\frac{dI_B}{dI_C} = 0$

substituting the above value.

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

Thus the stability factor in a fixed bias is $\beta+1$ which means that I_C changes $(\beta+1)$ times as much as any change in I_{CO} Hence this method is rarely employed

Advantages	Disadvantages
* Simple circuit	* The stabilization is poor as heat development can't be stoped
* only one resistor R_B is required	* stability factor is very high. so there are strong chances to thermal runaway
* Biasing conditions are set easily	

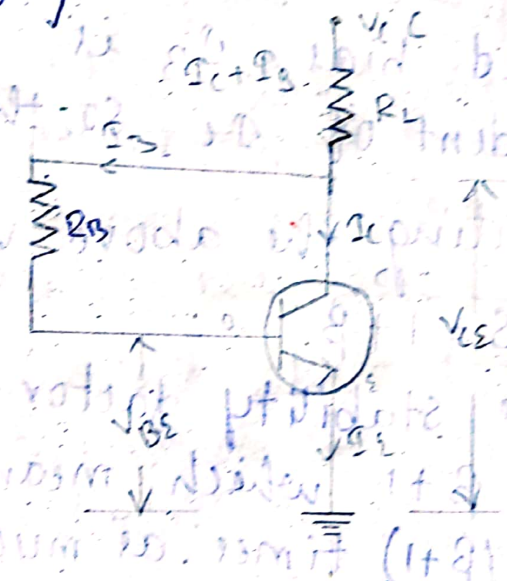
* No loading effect as there is no resistor at emitter junction

Q.* Collector to Base Bias

* The collector to bias circuit is same as fixed bias circuit except that the base resistor R_B is returned to collector, rather than to V_{cc} voltage or supply.

* The circuit helps in improving the stability considerably. If the value of I_c increases, the voltage across R_L increases & hence the V_{CE} also increases.

* This in turn reduces the base current I_B. This action somewhat compensates the original increase.



The required value of R_B needed to give the zero signal collector current I_c can be calculated as :-

Voltage drop across R_L will be

$$R_B = (I_C + I_B) R_L \cong I_C R_L$$

From figure

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

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

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

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

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

$$\Rightarrow \frac{1}{I_B} = \frac{\beta}{I_C}$$

Apply KVL we have

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

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

$$\Rightarrow I_B = \frac{V_{CC} - V_{BE} - I_C R_L}{R_L + R_B}$$

since V_{BE} is alsmost independent of I_C

we ged $\frac{dI_B}{dI_C} = \frac{R_L}{R_L + R_B}$

we know that

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

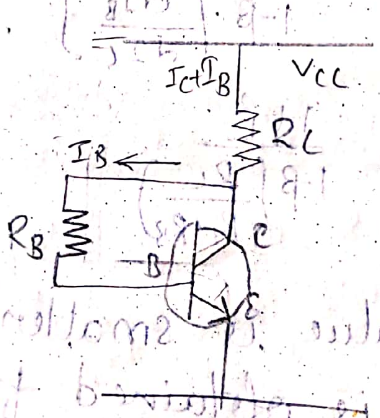
$$\Rightarrow \boxed{S = \frac{1+\beta}{1-\beta\left(\frac{R_L}{R_L+R_B}\right)}}$$

* This value is smaller than $(1+\beta)$ which is obtained for fixed base bias circuit. Thus there is an improvement in the stability.

* This circuit provides a negative feedback which reduces the gain of the amplifier so the increased stability of the collector to base circuit is obtained at the cost of AC voltage gain.

3* Biasing with Collector feedback Resistor

* In this method, the base resistor R_B has its one end connected to base and the other to the collector as its name implies. In this current the zero signal base current is determined by V_{CB} but not by V_{CC}.
* It is clear that V_{CB} forward biases the base emitter junction & hence base current I_B flows through R_B. This causes the zero signal collector current to flow in the circuit.



The required value of R_B needed to give the zero signal current I_C can be determined as :-

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

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

$$= \frac{V_{CC} - V_{BE} - \beta I_B R_C}{I_B} \quad [\because I_C = \beta I_B]$$

Alternatively

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

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

$\therefore$ Since $R_B = \frac{V_{CB}}{I_B} = \frac{V_{CE} - V_{BE}}{I_B}$

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

Mathematically, stability factor $S < (\beta + 1)$

* therefore, this method provides better thermal stability than fixed bias.
* the Q-point values for the circuit are

$$I_C = \frac{V_{CC} - V_{BE}}{R_B / \beta + R_C} \quad \& \quad V_{CE} = V_{CC} - I_C R_C$$

Advantages	Disadvantages
1. The circuit is simple as it needs only one resistor	1. The circuit doesn't provide good stabilitation
2. This circuit provides some stabilization, for lesser changes.	2. The circuit provides negative feedback

4* Voltage Divider Bias Method (or) Self Bias

Imp

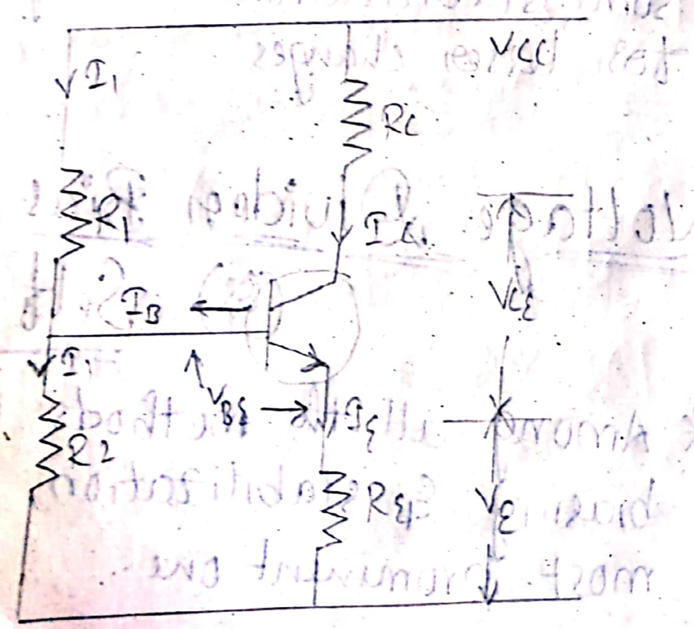
* Among all the methods of providing biasing & stabilization, it is the most prominent one.

* Here, two resistors R_1 & R_2 are employed, which are connected to V_{CC} and provide biasing. The Resistor R_E employed in the emitter provide stabilization

* The name voltage divider comes from the voltage divider formed by R_1 & R_2. The voltage drop across R_2 forward biases the base-emitter junction. This causes the base current & hence collector current flow in the zero signal conditions

* As per diagram;
  Suppose that the current flowing through resistance R_1 is I_1. As base current I_B is very small, it can be assumed with reasonable accuracy that current flowing through R_2 is also I_1.

* Now let us try to derive the experiment expressions for collector current & collector voltage



From the circuit, it is evident that

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

Voltage across Resistance R_2 is

$$V_2 = \left(\frac{V_{CC}}{R_1+R_2}\right) R_2$$

Applying KVL to the base circuit

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

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

$$\therefore I_E = \frac{V_2 - V_{BE}}{R_E} \qquad [\because I_E \approx I_C]$$

$$\Rightarrow I_C = \frac{V_2 - V_{BE}}{R_E}$$

From above expression, it is evident that I_C doesn't depend upon β

* V_{BE} is very small that I_C doesn't get affected by V_{BE} at all.
* Thus I_C in this circuit is almost independent of transistor parameters & hence good stabilization is achieved.

Applying KVL to collector circuit.

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

Since $I_E \cong I_C$

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

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

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

R_E provides excellent stabilization in this circuit

$V_2 = V_{BE} + I_C R_E$

Suppose there is a rise in temperature, then the I_C decreases, which cause voltage drop across R_E to increase. As the voltage drop across R_2 is V_2 which is independent of I_C, the value of V_{BE} decreases. The reduced value of I_B tends to restore I_C to the original value

Stability

The equation for stability factor of this circuit is

Stability factor $S = \dfrac{(\beta+1)(R_0+R_E)}{R_0+R_E+\beta R_E}$

$$\therefore S = (\beta+1) \times \left(\frac{1 + \frac{R_0}{R_E}}{\beta + 1 + \frac{R_0}{R_E}} \right)$$

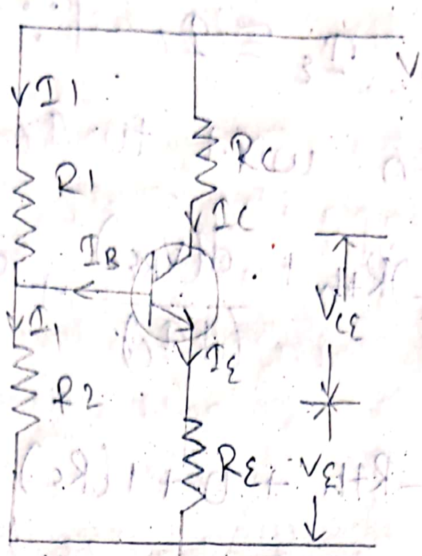
where $R_0 = \dfrac{R_1 R_2}{R_1 + R_2}$

If the ratio of R_0/R_E is very small, then R_0/R_E is neglected as compared to 1 & stability factor becomes

$$S = \cancel{(\beta+1)} \times \frac{1}{\cancel{(\beta+1)}} = 1$$

This is the smallest possible value of S and leads to the maximum possible thermal stability

* To prove voltage-divider bias has smaller stability factor

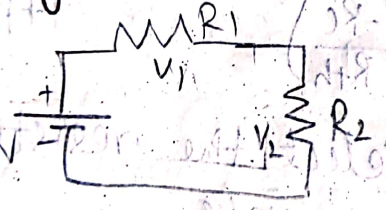


voltage divider Bias circuit

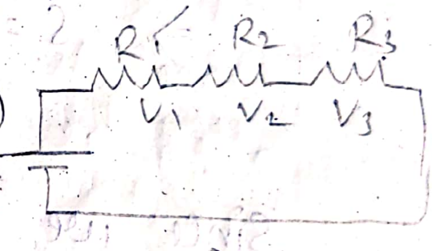
* To get I_B & I_C relation, we have to modify the above circuit as per the thevenin rule & voltage division rule

Voltage division rule :-

(i)



(ii)



$$V_1 = \frac{V \times R_1}{R_1 + R_2}$$

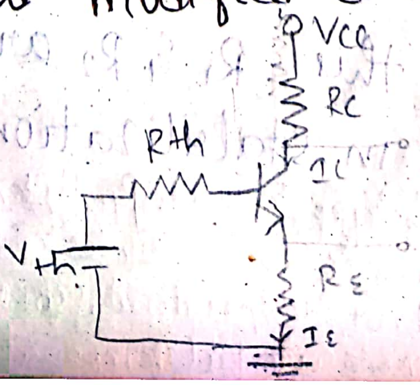
$$V_2 = \frac{V \times R_2}{R_1 + R_2}$$

$$V_1 = \frac{V \times R_1}{R_1 + R_2 + R_3}$$

$$V_2 = \frac{V \times R_2}{R_1 + R_2 + R_3}$$

$$V_3 = \frac{V \times R_3}{R_1 + R_2 + R_3}$$

Now the modified circuit is:-



Apply KVL to this circuit

$\Rightarrow V_{th} = I_B R_{Th} + V_{BE} + I_E R_E$

since $I_E \cong I_C$ [$\because$ Active region only]

Derivation w.r.t to I_C

$$\Rightarrow \left(\frac{dI_B}{dI_C}\right)R_{th} + \frac{d(V_{BE})}{(dI_C)} + \frac{d(I_C R_E)}{dI_C} = 0$$

$$\Rightarrow \frac{dI_B}{dI_C} R_{th} + 0 + 1(R_E) = 0$$

$$\Rightarrow \frac{dI_B}{dI_C} R_{th} + R_E = 0$$

$$\Rightarrow \frac{dI_B}{dI_C} = \frac{-R_E}{R_{th}}$$

substitute this in stability factor

$$\Rightarrow S = \frac{1+\beta}{1-\beta\left(\frac{-R_C}{R_{th}}\right)} \Rightarrow S = \frac{1+\beta}{1+\beta\left(\frac{R_E}{R_{th}}\right)}$$

Since we can select the resistor values as per th convinience

$$\Rightarrow S = \frac{1}{1(1)} = 1$$

$\therefore S = 1$

In voltage divider bias, $S = 1$ & this is the smallest possible value of S.

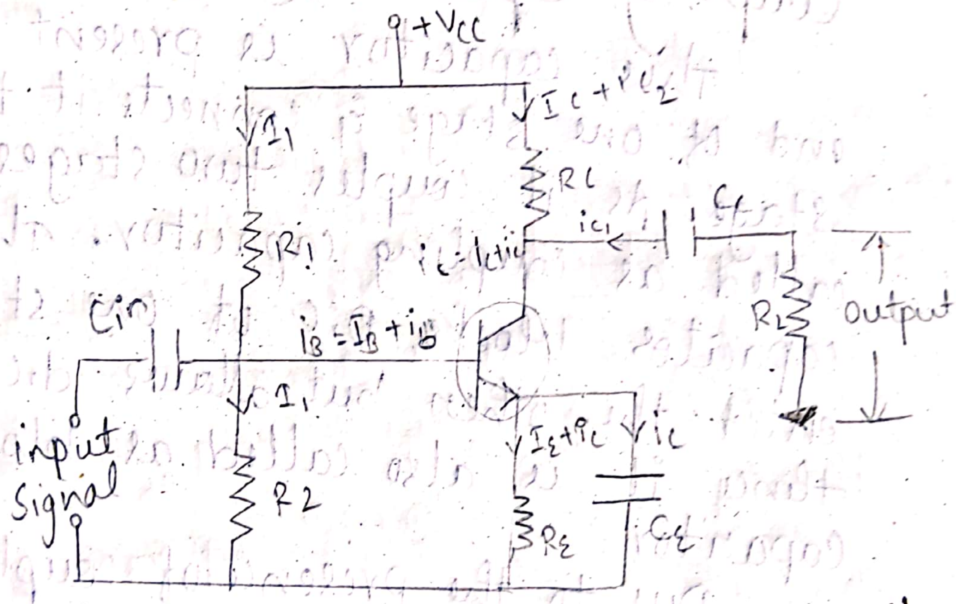
Note :- In this R_1 & R_2 are help in biasing R_E helps in stabilization, R_E acts as Load. It is independent of β. If temperature $T\uparrow = I_C\uparrow = I_E\uparrow$ then R_E decreases I_C. So I_C is constant. So it is also independent of Temperature, so Q point is constant so it is more useful.

* what are the stability factors?

sol
$$S_\beta = \frac{dI_C}{d\beta} \quad (\text{w.r.t } \beta)$$
$$S_T = \frac{dI_C}{dT} \quad (\text{w.r.t temperature})$$
$$S_{ICO} = \frac{dI_C}{dI_{CO}} \quad (\text{w.r.t leakage current})$$

there are 3 equations of stability factors regarding to their dependency. But in this exercise we just consider leakage current dependent stability factor

7/9 Practical Circuit of a transistor as an Amplifier (voltage-divider bias)



Q write the importance of 3 capacitors in the above circuit

Ans In the Practical circuit of a transistor while biasing we usually keep 3 capacitors in the circuit to fulfill some needs

They are :-

* ~~capacitor~~ * Input capacitor (C_{in})
* coupling capacitor (C_c)
* Emitter by-pass capacitor (C_E)

Input capacitor (Cin) :

This capacitor couples the input signal to the base of the transistor. The input capacitor Cin allows AC signal, but isolates the signal source from R_2.

* If this capacitor is not present, the input signal gets directly applied, which changes the bias at R_2.

Coupling capacitor (C_c) :-

This capacitor is present at the end of one stage & connects it to other stage. As it couples two stages. it is called as coupling capacitor. This capacitor blocks D.C of one stage to enter the other but allows d.c to pass. Hence it is also called as blocking capacitor.

Due to the presence of coupling capacitor C_c, the output across the resistor R_L is free from the collectors D.C voltage.

* If this is not present, the bias conditions of the next stage will be drastically changed due to the shunting effect of R_C, as it would come in parallel to R_2 of next stage

Emitter - by pass capacitor (C_E)
(electrolytic capacitor).

This capacitor is employed in parallel to the emitter resistor (R_E). The amplified A.C signal is by passes through this.

* If this is not present, that signal will pass through R_E which produces a voltage drop across R_E that will feedback the input signal reducing the output voltage.

9/9/20

Bias Compensation :-

So far we have seen different stabilization techniques. The stabilization occurs due to negative feedback action. The negative feedback although improves the stability of operating point, it reduces the gain of amplifier

As the gain of the amplifier is a very important consideration, some Some compensation techniques are used to maintain excellent bias & thermal stabilization

Diode compensation for instability :-

These are the circuits that implement compensation techniques using diodes to deal with biasing instability.

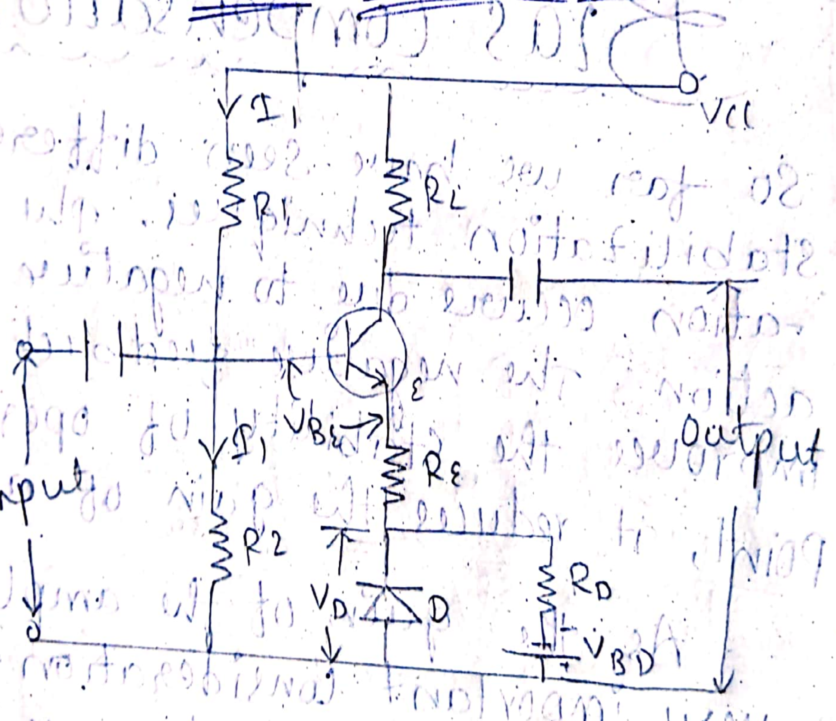
The stabilization techniques refer to the use of resistive biasing circuits which permit I_B to vary as to keep I_C relatively constant.

These are two types of diode compensation for instability methods. They are :-

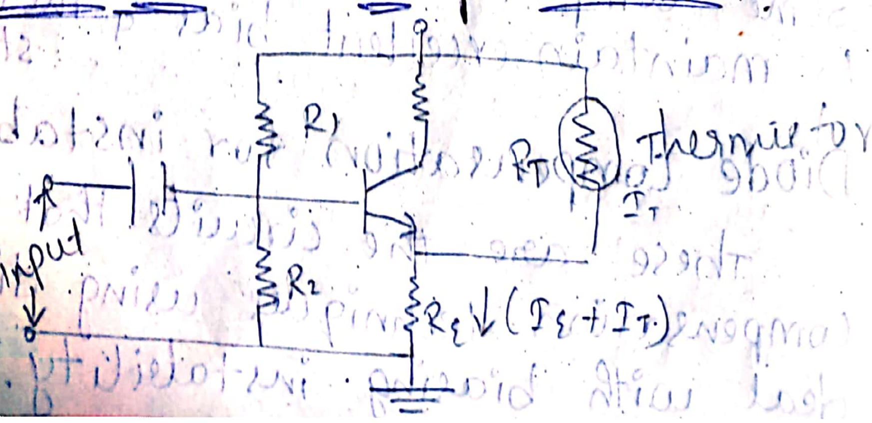
↳ Due to V_{BE} Variation

↳ Due to I_{CO} Variation

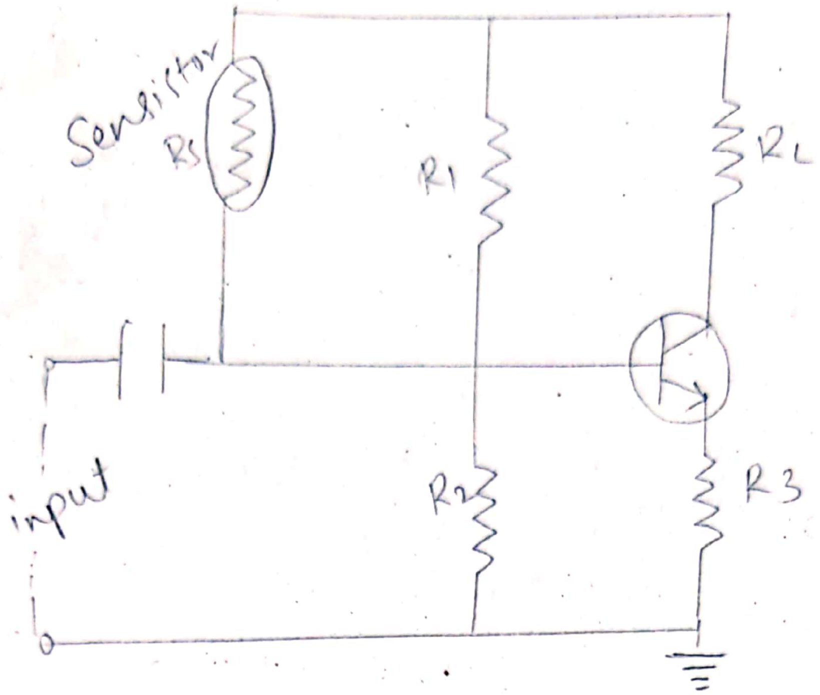
SELF BIAS WITH COMPENSATION AND STABILISATION



Thermistor Compensation:



Sensistor compensation:-



DIODE COMPENSATION FOR INSTABILITY DUE to I_{CO} VARIATION:-