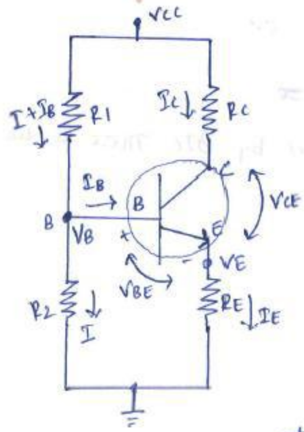
Topic 1.5 : Voltage divider bias configuration

3. Voltage Divider Bias / Self Bias / potential divider Bias



* The biasing is provided by R_1, R_2 & R_E.
* The resistors R_1 & R_2 act as a potential divider giving a fixed voltage to point B ie base.
* If I_C increases due to change in temperature (or β, The I_E also Increases & the voltage drop across R_E increases, decreasing the V_{BE}.
* Due to reduction in V_{BE}, I_B & I_C also reduced.
* ∴ We can say that negative feedback exist in the Emitter bias circuit.

* The voltage across R_2 is the base voltage V_B.
* Apply voltage divider Theorem to find V_B we get

$$V_B = \frac{R_2(I)}{R_1(I+I_B)+R_2(I)} \times V_{CC}$$

∵ $I >> I_B$ so we can omit I & I_B

So

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

* The voltage across R_E is V_E

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

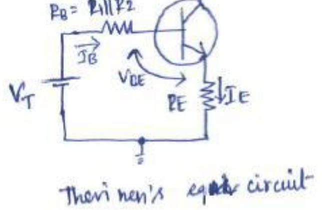
$$\therefore I_E = \frac{V_B - V_{BE}}{R_E}$$

* Apply KVL to the collector - Emitter circuit we get

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

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

Modified circuit



Thevinen's equiv circuit

* Here, R_1 & R_2 are replaced by R_B & V_T, where R_B is the parallel combination of R_1 & R_2 & V_T is the Thevenin's voltage.

* R_B is calculated as $R_B = \frac{R_1 R_2}{R_1+R_2}$

* Apply KVL to the Base – Emitter junction

$$V_T = I_B R_B + V_{BE} + I_E R_E \qquad \because I_E = I_C + I_B$$

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

$$= I_B R_B + V_{BE} + I_C R_E + I_B R_E$$

$$V_T = I_B (R_B + R_E) + V_{BE} + I_C R_E$$

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

Stability Factors

S

* Here the Thevinen's voltage V_T is given by

$$V_T = \frac{R_2 V_{CC}}{R_1 + R_2}$$ 4 R_1 4 R_2 replaced by R_B.

* Apply KVL to the base – Emitter junction

$$V_T = I_B R_B + V_{BE} + (I_B + I_C) R_E \quad —①$$

* differentiate eqn ① w.r.to I_C 4 V_{BE} to be independent of I_C we get

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

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

$$\frac{\partial I_B}{\partial I_C} = \frac{-R_E}{R_B + R_E} \quad —②$$

* W.K.T

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

* Take LCM

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

* Dividing each term by R_E we get

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

* The ratio R_B/R_E controls value of stability factor S.
* If $R_B/R_E << 1$ then $S = \frac{1+\beta}{1+\beta} = 1$

S'

$$S' = \frac{\partial I_C}{\partial V_{BE}} \Big| I_{CO} \text{ \& } \beta \text{ constant}$$

* W.K.T

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

$$V_T = I_B R_B + V_{BE} + (I_B + I_C) R_E \quad \text{—} ②$$

$$V_{BE} = V_T - (R_E + R_B) I_B - R_E I_C \quad \text{—} ③$$

* By rewriting the eqn ① interms of I_B

$$I_B = \frac{I_C - (1+\beta) I_{CO}}{\beta} \quad \text{—} ④$$

* Substitute I_B in eqn ③ we get

③ $V_{BE} = V_T - (R_E + R_B) I_B - R_E I_C$

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

$$= V_T - \frac{(R_E + R_B) I_C}{\beta} + \frac{(R_E + R_B)(1+\beta) I_{CO}}{\beta} - R_E I_C$$

* Take the common term's Outside

$$V_{BE} = V_T - \frac{\left[(1+\beta) R_E + R_B\right] I_C}{\beta} + \frac{(R_E + R_B)(1+\beta) I_{CO}}{\beta} \quad \text{—} ⑤$$

* differentiate eqn ⑤ w.r.to V_{BE}

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

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

$$S' = \frac{-\beta}{R_B + (1+\beta) R_E}$$

S'':

$$S'' = \frac{\partial I_C}{\partial \beta} \Big| I_{CO} \text{ \& } V_{BE} \text{ as constants}$$

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

$$= V_T - \frac{[R_B + (1+\beta)R_E]I_C}{\beta} + V' \quad -⑥$$

* We can rewrite the eqn ⑥ interms of I_C

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

$$I_C = \frac{(V_T - V' - V_{BE})\beta}{R_B + (1+\beta)R_E} \quad -⑦ \Rightarrow \frac{u}{v} \text{ format}$$

$$\hookrightarrow \frac{v\,du - u\,dv}{v^2}$$

* differentiating eqn ⑦ w.r.to β

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

* Multiply numerator & denominator by $(1+\beta)$ & β

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

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

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

Advantages

* The stability factor S for voltage divider bias is less as compared to another biasing circuit

* So This circuit is more stable & hence it's most commonly used.

Load line Analysis for voltage divider bias

* Apply KVL to the collector - Emitter circuit

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

* Assume $I_E \simeq I_C$

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

$$I_C = -\frac{1}{R_C + R_E} V_{CE} + \frac{V_{CC}}{R_C + R_E}$$

* This equation represents the dc load line with slope of $-\frac{1}{R_C + R_E}$ & y-intercept of $\frac{V_{CC}}{R_C + R_E}$

* When $I_C = 0$ ie the transistor is in cut-off region
$V_{CE} = V_{CC}$

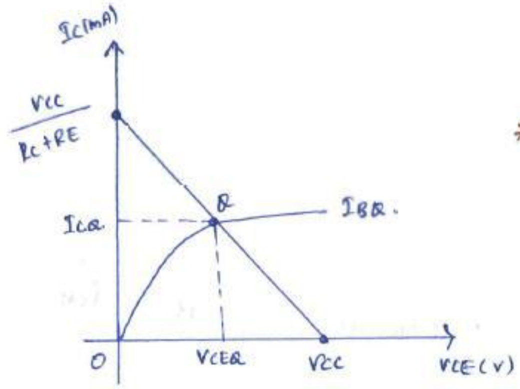
* When $V_{CE} = 0$ ie the transistor is in saturation region

$$I_C = \frac{V_{CC}}{R_C + R_E}$$

* Thus the 2 end points are $(V_{CC}, 0)$ & $\left(0, \frac{V_{CC}}{R_C + R_E}\right)$ By joining these 2 end points, a DC load line is drawn.

* From the base - emitter circuit

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



* The saturation current for the circuit is $I_{C\,sat} = \frac{V_{CC}}{R_C + R_E}$