Thapar University, Patiala

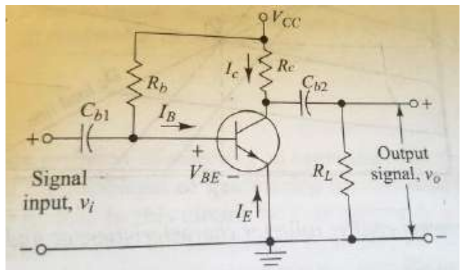
DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

Course Code: UEC 301; Course Name: Analog Electronics

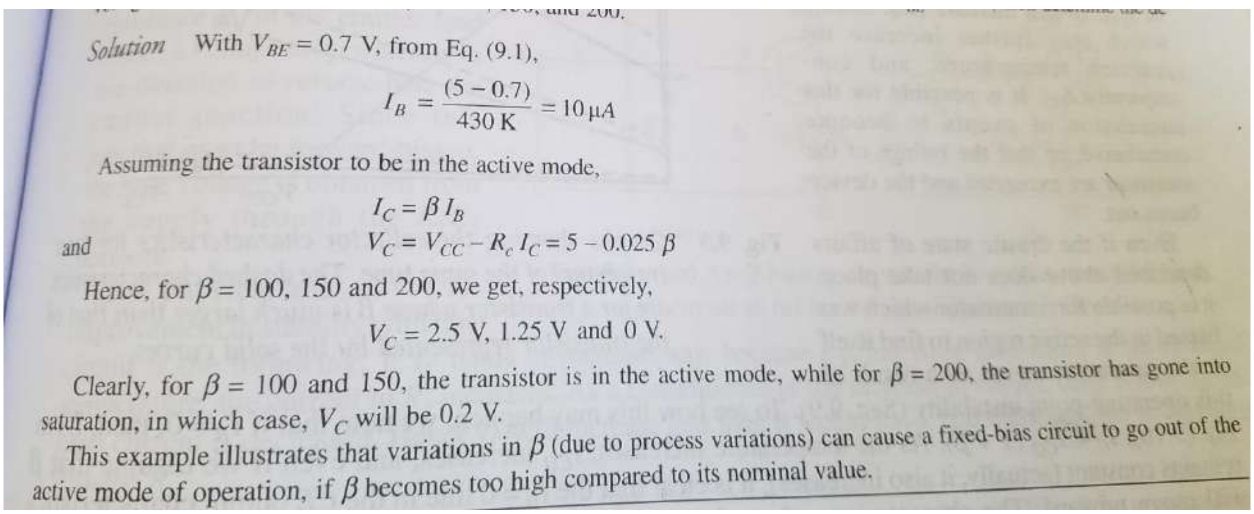
B. Tech, ECE (III-Sem), "Tutorial Sheet No. - 3"

Solution

Q.1 In the circuit of Fig.1, let $V_{CC} = 5\ V, R_b = 430k\Omega, and\ R_c = 2.5\ k\Omega$. If $V_{BE} = 0.7$, then determine the dc voltage at the collector for $\beta = 100, 150, and\ 200$.



$$I_B = \frac{V_{CC} - V_{BE}}{R_b} = I_{B2} \approx \frac{V_{CC}}{R_b}$$



Solution With $V_{BE} = 0.7$ V, from Eq. (9.1),

$$I_B = \frac{(5 - 0.7)}{430\ \text{K}} = 10\ \mu A$$

Assuming the transistor to be in the active mode,

$$I_C = \beta I_B$$

and $$V_C = V_{CC} - R_c I_C = 5 - 0.025\ \beta$$

Hence, for $\beta = 100$, 150 and 200, we get, respectively,

$$V_C = 2.5\ \text{V},\ 1.25\ \text{V and } 0\ \text{V}.$$

Clearly, for $\beta = 100$ and 150, the transistor is in the active mode, while for $\beta = 200$, the transistor has gone into saturation, in which case, V_C will be 0.2 V.

This example illustrates that variations in β (due to process variations) can cause a fixed-bias circuit to go out of the active mode of operation, if β becomes too high compared to its nominal value.

Q.2 Assume that a silicon transistor with $\beta = 50, V_{BE} = 0.6\ V, V_{cc} = 22.5\ V, and\ R_C = 5.6\ K$ is used in Fig. given below. It is desired to establish a Q-point at $V_{CE} = 12\ V, I_C = 1.5\ mA$,. and a stability factor $S \leq 3$. then determine $R_E, R_1\ and\ R_2$

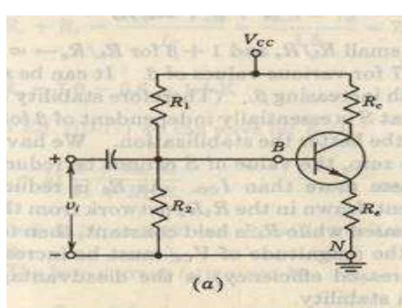


Fig. 10-6 (a) A self-biasing circuit.

Solution The current in R_e is $I_C + I_B \approx I_C$. Hence, from the collector circuit of Fig. 10-6*b*, we have

$$R_e + R_c = \frac{V_{CC} - V_{CE}}{I_C} = \frac{22.5 - 12}{1.5} = 7.0 \text{ K}$$

or

$$R_e = 7.0 - 5.6 = 1.4 \text{ K}$$

From Eq. (10-17) we can solve for R_b/R_e:

$$3 = 51 \frac{1 + R_b/R_e}{51 + R_b/R_e}$$

We find $R_b/R_e = 2.12$ and $R_b = 2.12 \times 1.4 = 2.96$ K. If $R_b < 2.96$ K, then $S < 3$.

The base current I_B is given by

$$I_B \approx \frac{I_C}{\beta} = \frac{1.5}{50} \text{ mA} = 30\ \mu\text{A}$$

We can solve for R_1 and R_2 from Eqs. (10-14). We find

$$R_1 = R_b \frac{V_{CC}}{V} \qquad R_2 = \frac{R_1 V}{V_{CC} - V} \tag{10-18}$$

From Eqs. (10-15) and (10-18) we obtain

$$V = (0.030)(2.96) + 0.6 + (0.030 + 1.5)(1.4) = 2.83 \text{ V}$$

$$R_1 = \frac{2.96 \times 22.5}{2.83} = 23.6 \text{ K}$$

$$R_2 = \frac{23.6 \times 2.83}{22.5 - 2.83} = 3.38 \text{ K}$$

Q3. For a voltage divider biasing circuit with $V_{BE} = 0.65\ V, V_{cc} = 22.5\ V, and\ R_C = 5.6\ K, R_E = 1\ K, R_1 = 90K, R_2 = 10K.$

(i) Determine Q-point if $\beta = 55.$
(ii) Determine Q-point if $\beta = 200$
(iii) Compare the results of both (i) and (ii) and give the comment on insensitivity of self-bias circuit to the variation in β

$$V_{th} = V_{cc} \times \frac{R_2}{R_1 + R_2} = 22.5 * \frac{10}{100} = 2.25\ V, \quad R_{th} = 10 * \frac{90}{100} = 9\ K$$

Applying KVL in Base Emitter loop

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

$$2.25 - 0.65 = I_B * (1 + 9)\ + I_C * 1,$$

Applying KVL in Collector Emitter loop

$$V_{CC} - V_{CE} = I_B * 1 + (I_C) * 6.6,$$

We know that $I_B = \frac{I_C}{\beta},$

After substituting all values, we got $\boldsymbol{I_B = 24.8\ \mu A, I_C = 1.36\ mA, and\ V_{CE} = 13.5\ V}$

(ii) For second part we have to find all values with $\beta = 200$

$$\boldsymbol{I_B = 7.6\ \mu A, I_C = 1.52\ mA, and\ V_{CE} = 12.5\ V}$$

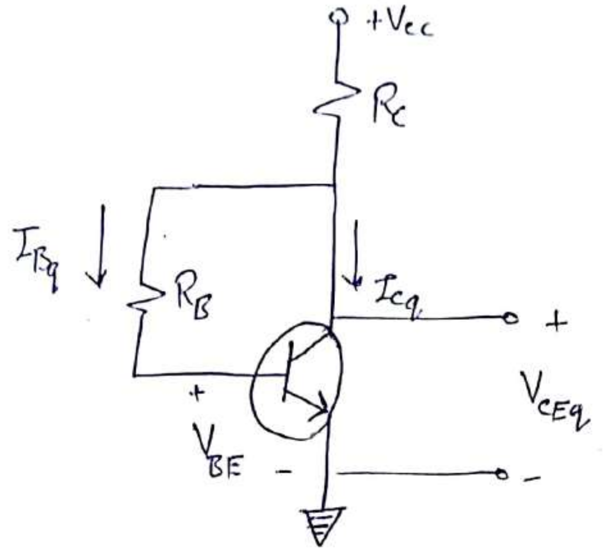
(ii) Comparing these values with that of previous values shows that V_{CE} changes by only 1 volt as beta changes from 55 to 200. This demonstrate the relative in-sensitivity of the self-bias circuit to variation in beta

Q4. Determine the stability factor (S and S”) for collector to base biasing circuit.

Q5. Derive an expression of stabilization factor ($S'' = \frac{\Delta I_C}{\Delta \beta}$) in terms of stabilization factor (S).

Q4 →

Collector to Base Biasing



Applying KVL in Base-emitter loop through Vcc

$$V_{cc} - V_{BE} = (I_B + I_c) R_c + I_B R_B \quad \text{——— (1)}$$

$$\Rightarrow \quad I_{Bq} = \frac{V_{cc} - V_{BE}}{R_B + (1+B) R_c} \qquad \because I_c \approx B I_B$$

$$I_{cq} = B I_{Bq}$$

$$V_{CEq} = V_{cc} - (I_B + I_c) R_c$$

Differentiate equ. (1) w.r.t I_c

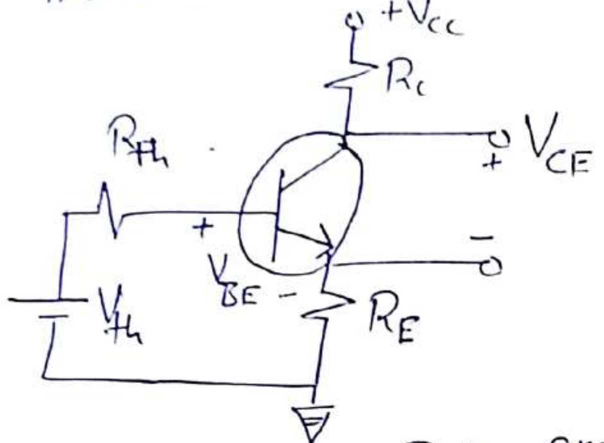
$$R_B \frac{\partial I_B}{\partial I_c} + R_c \frac{\partial I_B}{\partial I_c} + R_c = 0$$

$$\boxed{\frac{\partial I_B}{\partial I_c} = \frac{-R_c}{R_B + R_c}}$$

Stability factor $S = \dfrac{1+B}{1 - \dfrac{\partial I_B}{\partial I_c} \cdot B} = \dfrac{1+B}{1 + B \dfrac{R_c}{R_B + R_c}}$

Q5 Solution of $S'' = \frac{\partial I_c}{\partial \beta}$

For a voltage divider circuit; after applying Thevenin theorem the resultant ckt is



$$V_{th} = \frac{V_{cc} R_2}{R_1 + R_2}$$

$$R_{th} = \frac{R_1 R_2}{R_1 + R_2}$$

Applying KVL in Base-emitter loop

$$V_{th} - V_{BE} = I_B R_{th} + (I_B + I_c) R_E \quad \text{— (1)}$$

We know that $I_c = \beta I_B + (1+\beta) I_{co}$ — (2)

Substitute the value of I_B from eqn.(2) into (1)

$$I_B = \frac{I_c}{\beta} - \frac{I_{co}(1+\beta)}{\beta}$$

$$V_{th} - V_{BE} = I_B (R_{th} + R_E) + I_c R_E \quad \text{— (3)}$$

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

Differentiate w.r.t β (I_{co} & V_{BE} = constant)

$$\frac{\partial (V_{th} - V_{BE})}{\partial \beta} = 0 = \frac{\partial I_c}{\partial \beta} \frac{(R_{th} + R_E)}{\beta} - \frac{I_c (R_{th} + R_E)}{\beta^2} + \frac{I_{co}(R_{th} + R_E)}{\beta^2} + \frac{\partial I_c}{\partial \beta} \cdot R_E \quad \text{— (3)}$$

$$\Rightarrow \frac{(R_{th}+R_E)}{\beta^2}\left[I_C - I_{C0}\right] = \frac{\partial I_C}{\partial \beta}\left[\frac{R_{th}+R_E}{\beta} + R_E\right] \quad \text{—— (4)}$$

$\Rightarrow$ Since $I_C >> I_{C0}$; I_{C0} can be neglected.

$$\Rightarrow \left(\frac{R_{th}+R_E}{\beta^2}\right) I_C = S''\left[\frac{R_{th}+R_E(1+\beta)}{\beta}\right] \quad \text{—— (5)}$$

$$\Rightarrow \quad S'' = \frac{I_C\,(R_{th}+R_E)}{(\beta)\,(R_{th}+R_E(1+\beta))} \quad \text{—— (6)}$$

$$\Rightarrow \quad S'' = \frac{I_C}{\beta}\,\frac{(1+R_{th}/R_E)}{(1+\beta+R_{th}/R_E)} \quad \text{—— (7)}$$

$$\because \quad S = \frac{(1+\beta)\,(1+R_{th}/R_E)}{1+\beta+R_{th}/R_E}$$

$$\Rightarrow \quad S'' = \frac{I_C\,S}{(\beta)\,(1+\beta)} \quad \text{—— (8)}$$

Change in collector current due to change in β is

$$\Delta I_C = S''\Delta I_\beta = \frac{I_C\,S}{\beta(1+\beta)}\cdot(\Delta\beta) \quad \text{—— (9)}$$

where $\Delta\beta = \beta_2 - \beta_1$

From eqv. (9), it is not clear whether to use β_1, β_2 or some average value of β.

This problem may be avoided if S'' is obtained by taking finite differences rather than by evaluating a derivative. $S'' = \frac{\Delta I_C}{\Delta\beta} = \frac{I_{C_2} - I_{C_1}}{\beta_2 - \beta_1}$

Now consider eqn. (3) again

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

$\because I_B \approx \frac{I_C}{\beta}$ neglecting I_{CO}

$$\Rightarrow \quad I_C = \frac{\beta (V_{th} - V_{BE})}{R_{th} + (1+\beta) R_E} \quad \text{——— (4)}$$

$\Rightarrow$ at $\underline{\underline{\beta = \beta_1}}$

$$I_C = I_{C1} = \frac{\beta_1 (V_{th} - V_{BE})}{R_{th} + (1+\beta_1) R_E} \quad \text{——— (5)}$$

at $\beta = \beta_2$

$$I_C = I_{C2} = \frac{\beta_2 (V_{th} - V_{BE})}{R_{th} + (1+\beta_2) R_E} \quad \text{——— (6)}$$

$$\Rightarrow \quad \frac{I_{C2}}{I_{C1}} = \frac{\beta_2}{\beta_1} \left[\frac{R_{th} + R_E (1+\beta_1)}{R_{th} + R_E (1+\beta_2)} \right] \quad \text{——— (7)}$$

$$\Rightarrow \quad \frac{I_{C2}}{I_{C1}} - 1 = \left(\frac{\beta_2}{\beta_1} - 1 \right) \left[\frac{R_{th} + R_E}{R_{th} + R_E (1+\beta_2)} \right] \quad \text{——— (8)}$$

$$\Rightarrow \quad S'' = \frac{I_{C2} - I_{C1}}{\beta_2 - \beta_1} = \frac{(I_{C1})(R_{th} + R_E)}{\beta_1 \left[R_{th} + R_E (1+\beta_2) \right]} \quad \text{——— (9)}$$

$$\Rightarrow \quad \boxed{S'' = \frac{I_{C1} S_2}{\beta_1 (1+\beta_2)}} \quad \text{——— (10)}$$

<u>This is the final expression</u>