Bias Stabilization

:Basic Definitions

The stability of system is a measure of sensitivity of a circuit to variations in its parameters. In any amplifier employing a transistor the ***collector current I_C*** is sensitive
to each of the following parameter.

- ***I_{CO} (reverse saturation current): doubles in value for every 10°C increase in temperature***
- ***$|V_{BE}|$ (base-to-emitter voltage): decrease about 7.5 mV per 1°C increase in temperature.***
- ***β (forward current gain): increase with increase in temperature.***

Any or all of these factors can cause the bias point to drift from the design point of operation.

Stability Factors, $S(I_{CO})$, $S(V_{BE})$, and $S(\beta)$:

A stability factor, *S*, is defined for each of the parameters affecting bias stability as listed below:

$$S(I_{CO}) = \frac{\Delta I_C}{\Delta I_{CO}} = \frac{\partial I_C}{\partial I_{CO}}\bigg|_{V_{BE},\, \beta = const.} \quad [10.1a]$$

$$S(V_{BE}) = \frac{\Delta I_C}{\Delta V_{BE}} = \frac{\partial I_C}{\partial V_{BE}}\bigg|_{V_{BE},\, \beta = const.} \quad [10.1b]$$

$$S(\beta) = \frac{\Delta I_C}{\Delta \beta} = \frac{\partial I_C}{\partial \beta}\bigg|_{V_{BE},\, I_{CO} = const.} \quad [10.1c]$$

Generally, networks that are quite stable and relatively insensitive to temperature variations have low stability factors. In some ways it would seem more appropriate to consider the quantities defined by Eqs. [10.1a - 10.1c] to be sensitivity factors because:

the higher the stability factor, the more sensitive the network to variations in that parameter.
The total effect on the collector current can be determined using the following equation:

$$\Delta I_C = S(I_{CO})\Delta I_{CO} + S(V_{BE})\Delta V_{BE} + S(\beta)\Delta \beta \qquad [10.2]$$

Derivation of Stability Factors for Standard Bias Circuits:

For the ***voltage-divider bias circuit***, the exact analysis (using Thevenin theorem) for the
:input (base-emitter) loop will result in

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

$$\therefore I_E = I_c + I_B$$

$$I_c R_E + I_B (R_E + R_{Th}) + V_{BE} = E_{Th}$$

$$\therefore I_c = \beta I_B + (\beta + 1) I_{co},$$

$$\therefore I_B = \frac{I_c}{\beta} - \frac{\beta + 1}{\beta} I_{co} \Longrightarrow$$

$$I_c \left[\frac{(\beta + 1) R_E + R_{Th}}{\beta} \right] - I_{co} \left[\frac{(\beta + 1) R_E + R_{Th}}{\beta} \right] + V_{BE} = E_{Th} \qquad [10.3]$$

The partial derivation of the Eq. [10.3] with respect to I_{CO} will result:

$$\frac{\partial I_C}{\partial I_{CO}} \cdot \frac{(\beta + 1) R_E + R_{Th}}{\beta} - \frac{(\beta + 1) R_E + R_{Th}}{\beta} = 0$$

$$S(I_{CO}) = \frac{(\beta + 1)(R_E + R_{Th})}{(\beta + 1) R_E + R_{Th}} \qquad [10.4a]$$

Also, the partial derivation of the Eq. [10.3] with respect to V_{BE} will result:

$$\frac{\partial I_C}{\partial V_{BE}} \cdot \frac{(\beta + 1) R_E + R_{Th}}{\beta} + 1 = 0$$

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

[10.4b]

The mathematical development of the last stability factor $S(\beta)$ is more complex than encountered for $S(I_{CO})$ and $S(V_{BE})$. Thus, $S(\beta)$ is suggested by the following equation:

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

[10.4c]

For the ***emitter-stabilized bias circuit***, the stability factors are the same as these obtained above for the voltage-divider bias circuit except that R_{Th} will replaced by R_B. These are:

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

[10.5a]

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

[10.5b]

$$s(\beta) = \frac{I_{C1}(R_E + R_B)}{\beta_1\left((\beta_2+1)R_E + R_B\right)}$$

[10.5c]

For the ***fixed-bias circuit***, if we plug in $R_E = 0$ the following equation will result:

$$S(I_{CO}) = \beta + 1$$ [10.6a]

$$S(V_{BE}) = \frac{-\beta}{R_B}$$ [10.6b]

$$s(\beta) = \frac{I_{C1}}{\beta_1}$$ [10.6c]

Finally, for the case of the ***voltage-feedback bias circuit***, the following equation will result:

R_C 🖃 R
R_C 🖃 R
🕿 β 🖃 1) ☎ 🕒🕒 E) 🖃 R_B
🕿 β 🖃 1) ☎ 🕒🕒 E 🖃 R_B) / 🕒
S 🕿 I_{CO}) 🖬 🕒

[10.7a]

R_C 🖃 R
🕿 β 🖃 1) ☎ 🕒🕒 E) 🖃 R_B
S 🕿 V_{BE}) 🖬 $-\beta$ / 🕒

[10.7b]

R_C 🖃 R
☎ I_{C1} 🖂 β_1) ☎ 🕒🕒 E 🖃 R_B) / 🕿 β_2 🖃 1) ☎ R_C 🖃 R_E) 🖃 R_B
s 🕿 β) 🖬 🕒

[10.7c]

Example 10-1:

1. Design a voltage-divider bias circuit using a V_{CC} supply of +18 V, and an npn silicon transistor with β of 80. Choose $R_C = 5R_E$, and set I_C at 1 mA and the stability factor $S(I_{CO})$ at 3.8.

2. For the circuit designed in part (1), determine the 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 0.5 V, and β increases 25%.

3. Calculate the change in I_C from 25° to 75°C for the same circuit designed in part (1), if $I_{CO} = 0.2$ µA and $V_{BE} = 0.7$ V.

Solution:

Part 1:

$$V_{CE} = V_{CC}/2 = 18/2 = 9\,V.$$

$$V_{CE} = V_{CC} - I_C(R_C + R_E),\; R_C = 5R_E \Rightarrow$$

$$9 = 18 - (1\,m)(5R_E + R_E) \Rightarrow R_E = 1.5\,k\Omega$$

$$R_C = 5(1.5\,k) = 7.5\,k\Omega.$$

$$I_E \cong I_C = 1\,mA,\; V_E = I_E R_E = (1\,m)(1.5\,k) = 1.5\,V.$$

$$V_B = \frac{R_2 V_{CC}}{R_1 + R_2} \Rightarrow \frac{R_2}{R_1 + R_2} = \frac{V_B}{V_{CC}} = \frac{2.2}{18}$$

[10.8a]

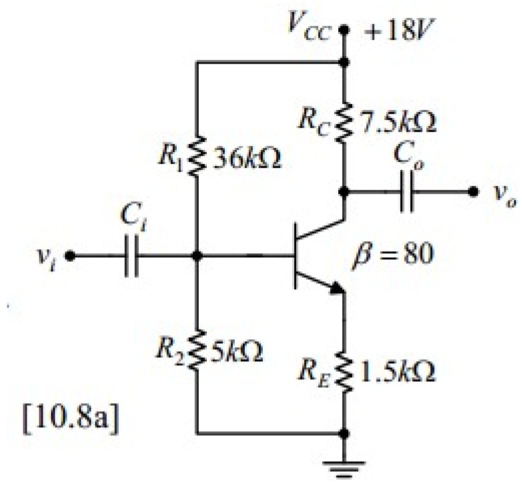


Fig. 10-1

$$S(I_{CO}) = \frac{(\beta + 1)(R_E + R_{Th})}{(\beta + 1)R_E + R_{Th}}$$

$$3.8 = \frac{(81)(1.5\,k + R_{Th})}{(81)(1.5\,k) + R_{Th}} \Rightarrow R_{Th} = 4.4\,k\Omega$$

$$R_{Th} = \frac{R_1 R_2}{R_1 + R_2} \Rightarrow \frac{R_2}{R_1 + R_2} = \frac{R_{Th}}{R_1} = \frac{4.4\,k}{R_1}$$

[10.8b]

From Eqs. [10.8a] and [10.8b]:

$$\frac{4.4k}{R_1} = \frac{2.2}{18} \Rightarrow R_1 = 36k\,\Omega.$$

From Eq. [10.8a]:

$$\frac{R_2}{36k + R_2} = \frac{2.2}{18} \Rightarrow R_2 = 5k\,\Omega.$$

Fig. 10-1 shows the final circuit.

Part 2:

$$S(I_{CO}) = 3.8,$$

$$\Delta I_{CO} = 10\mu - 0.2\mu = 9.8\mu A$$

$$S(V_{BE}) = \frac{-\beta}{(\beta+1)R_E + R_{Th}} = \frac{-80}{[81](1.5k) + 4.4K} = -0.635\,mS$$

$$\Delta V_{BE} = 0.5 - 0.7 = -0.2V.$$

$$\beta_2 = \beta_1(1 + 25/100) = 1.25\beta_1 = 1.25(80) = 100,$$

$$s(\beta) = \frac{[I_{C1}/\beta_1](R_E + R_{Th})}{(\beta_2+1)R_E + R_{Th}} = \frac{[(1m/80)](1.5k + 4.4k)}{[101](1.5k) + 4.4k} = 0.473\mu A,$$

$$\Delta\beta = 100 - 80 = 20.$$

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

$$= (3.8)(9.8\mu) + [-0.635m](-0.2) + (0.473\mu)(20) = 0.174\,mA$$

Part 3:
Since *Ico*, doubles in value for every $10^{o}C$ increase in temperature.

Thus $N = \frac{\Delta T}{10} = \frac{75-25}{10} = 5,\ I_{CO}(75^{\circ}C) = 2^N . I_{CO}(25^{\circ}C) = [2^5](0.2\mu) = 6.4\mu A$

$\Delta I_{CO} = 6.4\,\mu - 0.2\,\mu = 6.2\,\mu A.$

Since V_{BE}, decreases about 7.5 mV per 1oC increase in temperature.

Thus $\Delta T = 75-25 = 50\,°C,\; V_{BE}(25\,°C) = 0.7\,V.$

$V_{BE}(75\,°C) = 0.7 - 50(7.5\,m) = 0.325\,V.$

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

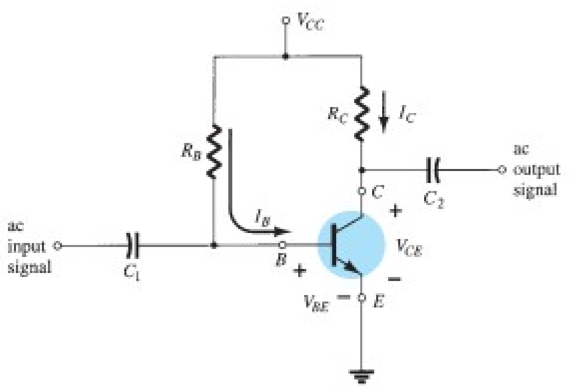
$\cong (3.8)(6.2\,\mu) + (-0.635\,m)(-0.375) = 0.262\,mA.$

Techniques of stabilizations:

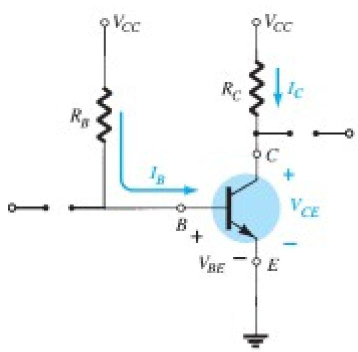
1. Stabilization technique , these use sensitive biasing circuits which allows I_B to vary so as to keep I_C relating constant with variation in $I_{CO}, \beta, V_{BE.}$
2. Compensation techniques: These use temperature sensitive devices like diodes, transistor, thermistor for providing compensating voltage and current to maintain Q-point constant.

Bias stabilization techniques:

1-Fixed-Bias circuit.



fixed-bias circuit



DC-equivalent of fixed-bias circuit

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

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

$$I_C = \beta I_B$$

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

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

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

In addition since $V_{BE} = V_B - V_E \Rightarrow V_{BE} = V_B$

Note:

$$I_E = I_C + I_B, \; I_C = \beta I_B$$

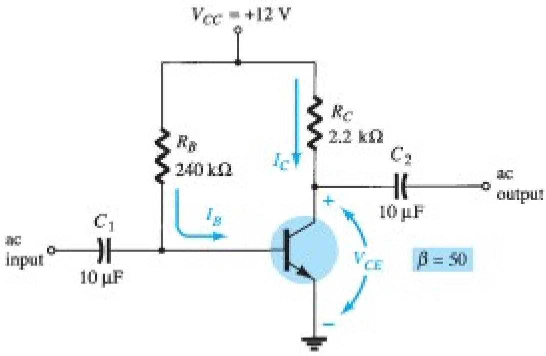
$$I_E = (1 + \beta) I_B$$

$$I_E = I_C$$

Example:

Determine the following for the fixed-bias configuration of Fig. below.

a) I_{BQ}, I_{CQ} b) V_{CEQ} c) V_B ana V_C d) V_{BC}



Solution:

a) $I_{BQ} = \frac{V_{CC}-V_{BE}}{R_B} = \frac{12-0.7}{240\,k} = 47.08\,mA.$

$I_{CQ} = \beta I_B = 50(47.08\,\mu A) = 2.35\,mA.$

b) $V_{CEQ} = V_{CC} - I_C R_C$

$= 12 - (2.35\,mA)(2.2\,k\Omega)$

$= 6.83\,V$

c) $V_{BC} = V_B - V_C = 0.7 - 6.83 = -6.13\,V$

The negative sign revealing the junction is reversed biased as it should be for linear amplification.

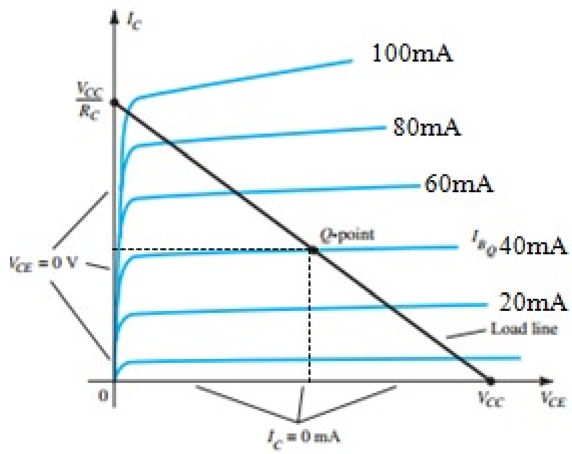
$V_{CE} = V_{CC} - I_C R_C$

$but\ V_{CE} = 0$

$I_{C(sat)} = \left.\frac{V_{CC}}{R_C}\right|,\ at\ V_{CE} = 0$

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

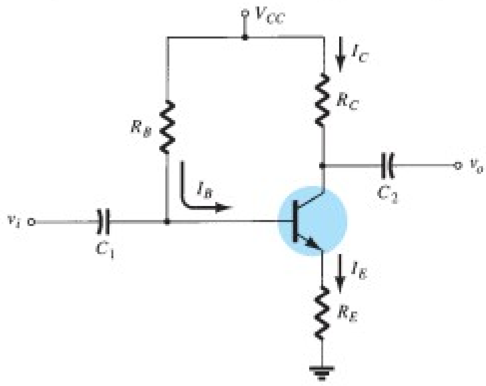
$V_{CE} = V_{CC}\big|,\ at\ I_C = 0$



2-Emitter-Stabilized Bias circuit.

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

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



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

$$I_E \cong I_C$$

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

$$V_E = I_E R_E$$

$$V_{CE} = V_C - V_E \qquad V_C = V_{CE} + V_E$$

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

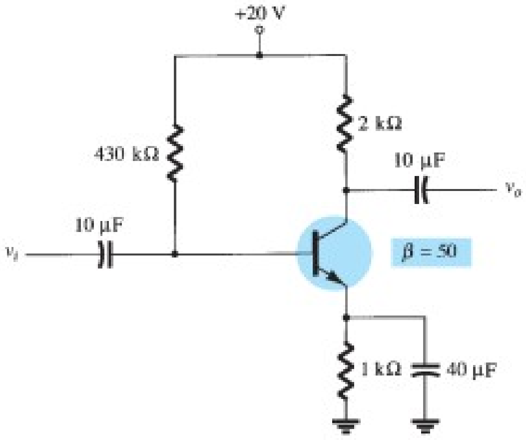
$$V_B = V_{BE} + V_E$$

$$V_B = V_{CC} - I_B R_B$$

Example:

Determine the following for the emitter-bias configuration of Fig. below.

a) I_B and I_C c) V_{CE} d) V_C e) V_E f) V_B g) V_{BC}



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

$= \dfrac{20 - 0.7}{430\,k + 51(1\,k)} = 40.1\ \mu A$

b) $I_C = \beta I_B = 50(40.1\ \mu A) = 2.01\ mA$.

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

$= 20 - (2.01\ mA)(2\,k + 1\,k)$

$= 13.97\ V$

d) $V_C = V_{CC} - I_C R_C = 20 - (2.01\,m)(2\,k) = 15.98\ V$

e) $V_E = I_E R_E \cong I_C R_C = (2.01\,m)(1\,k) = 2.01\ V$

Or $V_E = V_C - V_{cE} = 15.98 - 13.97 = 2.01\,V$

f) $V_B = V_E + V_{BE} = 2.01 + 0.7 = 2.71\,V$

g) $V_{BC} = V_B - V_C = 2.71 - 15.98 = -13.27\,V$ reverse-bias a required

Saturation Level

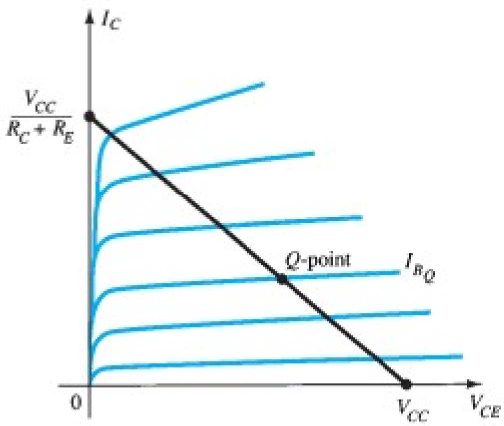
The collector saturation level or maximum collector current can be determined by :
Apply a short circuit between the collector–emitter terminals .

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

$$I_{sat} = \frac{V_{CC}}{R_C + R_E}$$

Load-line analysis

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



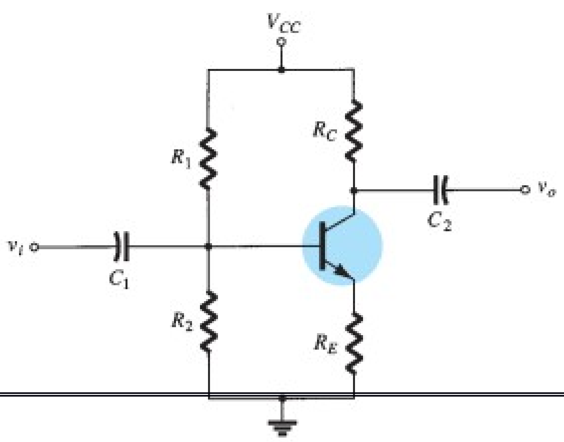
Choosing $I_C = 0\,mA$

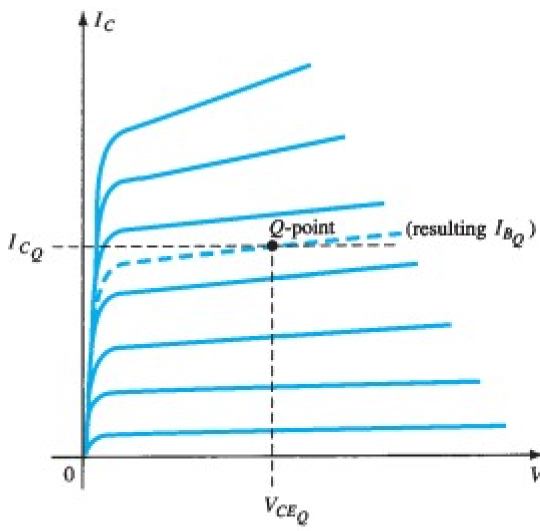
$$V_{CE} = V_{CC}\Big|_{I_C = 0}$$

Choosing $V_{CE} = 0$

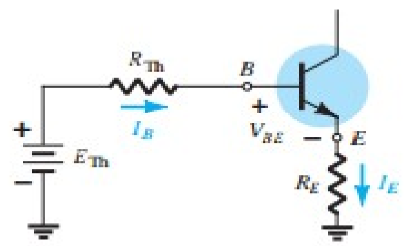
$$I_C = \frac{V_{CC}}{R_C + R_E}\Big|_{V_{CE} = 0}$$

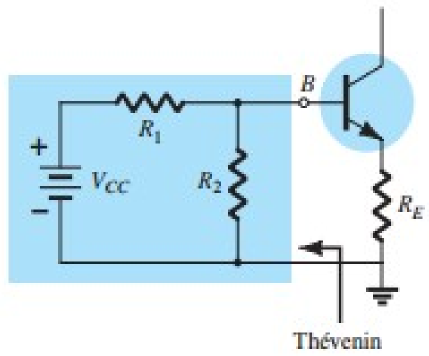
3-Voltage-Divider Bias





$$R_{Th} = R_1 \parallel R_2$$





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

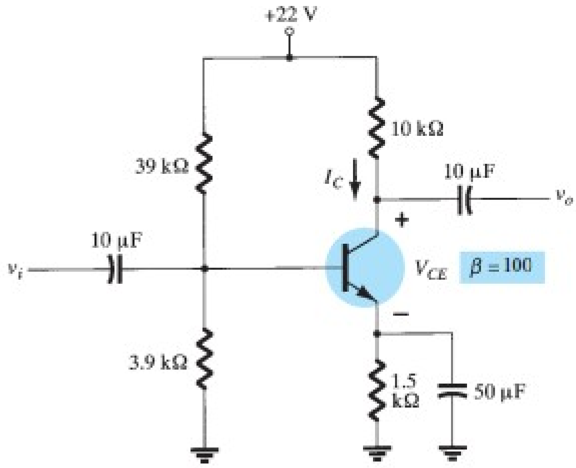
$$E_{Th} - I_B R_{Th} - V_{BE} - I_E R_E = 0$$

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

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

Example :

Determine the dc bias voltage V_{CE} and the current I_C for the voltage divider configuration



Solution:

Exact :

$$R_{Th} = R_1 \parallel R_2 = (39k) \parallel (3.9k) = 3.555\,\Omega$$

$$E_{Th} = \frac{R_2 V_{CC}}{R_1 + R_2} = \frac{(3.9k)(22)}{39k + 3.9k} = 2\,V$$

$$I_B = \frac{E_{Th} - V_{BE}}{R_{Th} + (\beta + 1) R_E} = \frac{2 - 0.7}{3.55k + (141)(1.5k)} = 6.05\,\mu A$$

$$I_{CQ} = \beta I_B = (140)(6.05\,\mu) = 0.85\,mA$$

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

Approximate Analysis:

$$V_B = \frac{R_2 V_{CC}}{R_1 + R_2} \quad if\ R_i = (\beta + 1) R_E \cong \beta R_E$$

$$then\ \beta R_E \geq 10 R_2$$

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

$$I_E = \frac{V_E}{R_E},\ I_{CQ} \cong I_E,\ V_{CEQ} = V_{CC} - I_C (R_C + R_E)$$

Load-Line Analysis:

$$I_C = \frac{V_{CC}}{R_C + R_E}\Big|,\ at\ V_{CE} = 0$$

$V_{CE} = V_{CC}, \; at \; I_C = 0$

Example:

Repeat the analysis of last example .using the approximate technique, and compare solutions I_{CQ} for and V_{CEQ} .

Solution:

Testing: $\beta R_E \geq 10 R_2$

(140)(1.5k) $\geq 10(3.9k)$

$210k\Omega \geq 39k\Omega$

$$V_B = \frac{R_2 V_{CC}}{R_1 + R_2} = \frac{(3.9k)(22)}{39k + 3.9k} = 2V$$

$$V_E = V_B - V_{BE} = 2 - 0.7 = 1.3V$$

$$I_{CQ} = I_E = \frac{V_E}{R_E} = \frac{1.3}{1.5k} = 0.867\,mA$$

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

$$= 22 - (0.85m)(10k + 1.5k)$$

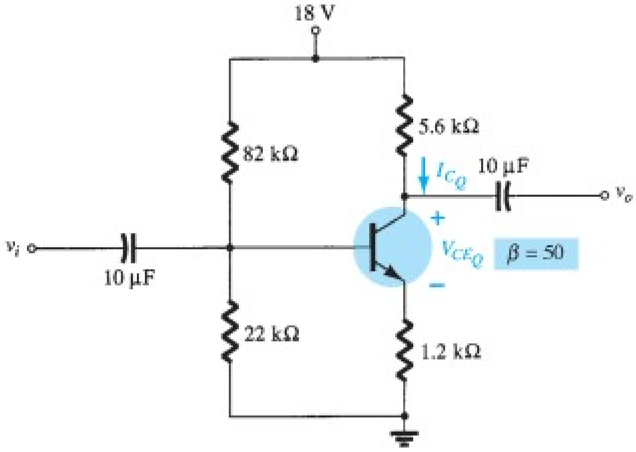
=12.23V

Home work:

Repeat the exact analysis of example if $\beta = 70$ and compare solution for I_{CQ}, V_{CEQ} .

Example:

Determine the levels of I_{CQ} and V_{CEQ} for the voltage-divider configuration using the exact and approximate techniques and compare solutions.



Solution:

Exact analysis

$\beta R_E \geq 10 R_2$

$(50)(1.2k) \geq 10(22k)$

$60\,k\Omega \ngeq 220\,k\Omega$ (not satisfied)

$R_{Th} = R_1 \| R_2 = (82k)\|(22k) = 17.35\,k\Omega$

$$E_{Th} = \frac{R_2 V_{CC}}{R_1 + R_2} = \frac{(22k)(18\,V)}{82k + 22k} = 3.81\,V$$

$$I_B = \frac{E_{Th} - V_{BE}}{R_{Th} + (\beta + 1) R_E} = \frac{3.81\,V - 0.7\,V}{17.35k + (51)(1.2k)} = 39.6\,\mu A$$

$I_{CQ} = \beta I_B = (50)(39.6\,\mu A) = 1.98\,mA$

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

Approximate Analysis:

$V_B = E_{Th} = 3.81\,V$

$$V_E = V_B - V_{BE} = 3.81 - 0.7 = 3.11\,V$$

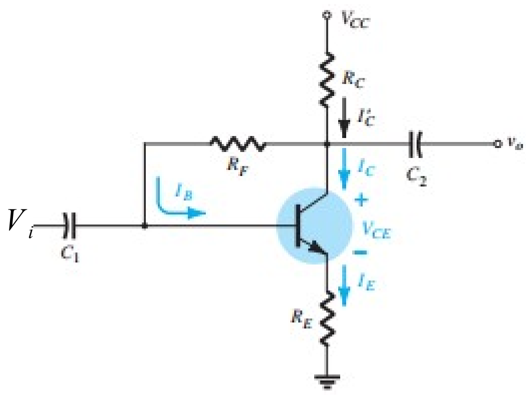
$$I_{CQ} \cong I_E = \frac{V_E}{R_E} = \frac{3.11}{1.2\,k} = 2.59\,mA$$

$$V_{CEQ} = V_{CC} - I_C(R_C + R_E) = 18 - (2.59\,m)(5.6\,k + 1.2\,k) = 3.88\,V$$

Tabulating the results, we have:

	I_{CQ}	V_{CEQ}
Exact	1.98	4.54
Approximate	2.59	3.88

DC Bias with Voltage Feedback:



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

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

$$R' = (R_C + R_E)$$

$$(R_B + \beta R') R' = $$

$$I_B = \frac{V'}{}$$

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

$$I_B = \frac{V'}{R_B + \beta R'} \quad I_{CQ} = \beta I_B$$

$$I_{CQ} = \frac{\beta V'}{R_B + \beta R'} \cong \frac{\beta V'}{\beta R'} = \frac{V'}{R'} \; if \; \beta R' \gg R_B$$

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

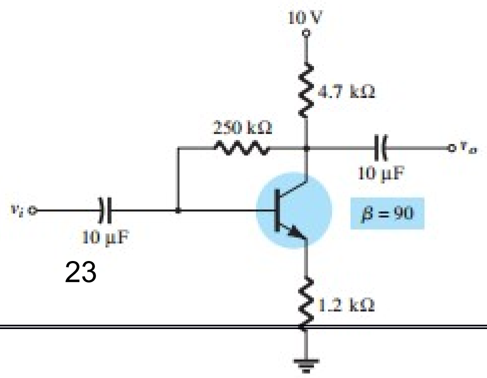
$$I_C = I_E \cong I_C$$

$$R = C + R_E$$

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

Example:

Determine the quiescent levels of I_{CQ} and V_{CEQ} .



Solution:

$$I_B = \frac{V_{CC}-V_{BE}}{R_B+(\beta+1)R_E} = \frac{10-0.7}{250\,k+90(4.7\,k+1.2\,k)} = \frac{9.3\,V}{250+531} = 11.91\,\mu A$$

$$I_{CQ} = \beta I_B = 90(11.94) = 1.07\,mA$$

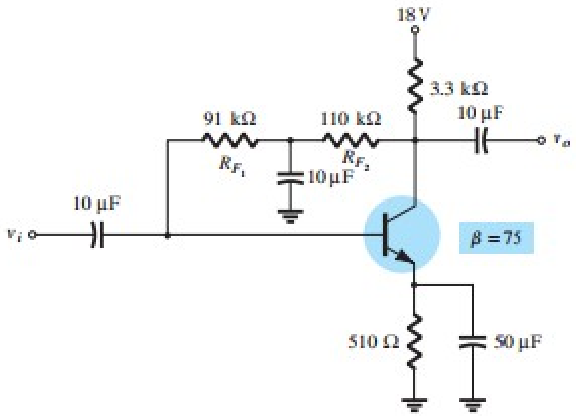
$$V_{CE} = V_{CC} - I_C(R_C + R_E)(4.7\,k+1.2\,k) = 3.69\,V$$

Home work:

Repeat last example if $\beta = 135$.

Example:

Determine the DC level of I_{CQ} and V_{CEQ}



Solution:

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

$$(91 + 110)k + 75(3.3 + 0.51)$$

$$I_{CQ} = \beta I_B = 75(35.5) = 2.66\,mA$$

$$V_C = V_{CC} - I'_C R_C \cong V_{CC} - I_C R_C$$

$$= 18 - (2.66\,m)(3.3\,k) = 18 - 8.78 = 9.22\,V$$

Saturation Conditions

$$I_{C(sat)} = I_{C(max)} = \frac{V_{CC}}{R_C + R_E}$$

Collector and base current :

1- Combination current:

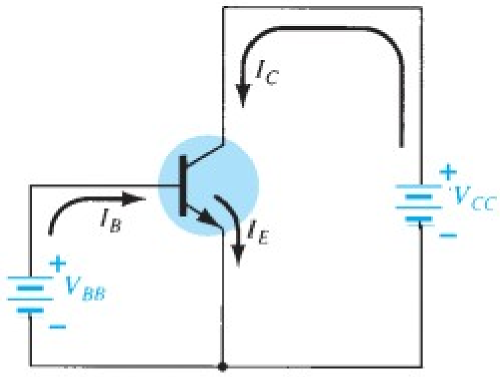
$I_B = I_E - I_C \qquad I'_B = I'_E - I'_C$

$I_C = \alpha I_E \qquad I'_C = \alpha I'_E$

$then\ I_B = (1-\alpha) I_E \qquad I'_B = (1-\alpha) I'_E$

Reverse leakage current:

$I_B = -I_{CO} + I'_B , \quad I_B = -I_{CO} + (1-\alpha) I'_E$



Then $I'_E = \dfrac{I_B + I_{CO}}{(1-\alpha)}$

$I_C = \alpha_{dc} I'_E + I_{CO}$

Then $I_B = \alpha \dfrac{I_B + I_{CO}}{(1-\alpha)} + I_{CO}$

$= \dfrac{\alpha}{1-\alpha} I_B + \dfrac{\alpha}{1-\alpha} I_{CO} + I_{CO}$

$= \dfrac{\alpha}{1-\alpha} I_B + \dfrac{\alpha}{1-\alpha} I_{CO}$

$\beta = \dfrac{\alpha}{1-\alpha} , \alpha = \dfrac{\beta}{1+\beta}$ then $1+\beta = \dfrac{\beta}{\alpha}$

$1-\alpha = \dfrac{\alpha}{\beta} , \quad \dfrac{1}{1-\alpha} = \dfrac{\beta}{\alpha} = (1+\beta)$

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

Stability factor(s)

It is ratio of rate of change of I_C with respect to the reverse saturation current, keeping β and V_{BE} constant

$$S(I_{CO}) = \frac{\partial I_C}{\partial I_{CO}} \Big| V_{BE}, \beta constant \cong \frac{\Delta I_C}{\Delta I_{CO}}$$

Other stability factors may be defined as

$$S' = S(\beta) = \frac{\partial I_C}{\partial \beta} \cong \frac{\Delta I_C}{\Delta \beta}$$

$$S(V_{BE}) = \frac{\partial I_C}{\partial V_{BE}} \Big| \beta\, I_{CO}, constant \cong \frac{\Delta I_C}{\Delta V_{BE}}$$

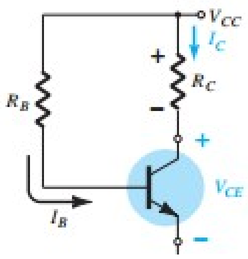
$$I_C = \beta I_B + (1+\beta) I_{CO} differentiating\ with\ I_C$$

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

$$1 = \frac{(1+\beta)}{S} + \beta \frac{d I_B}{d I_C} \Rightarrow S = \frac{1+\beta}{1 \pm \beta \frac{d I_B}{d I_C}}$$

For the fixed bias $\Rightarrow I_B = \frac{\frac{V_{CC}}{R_b} \circ d I_B}{d I_C} = 0$

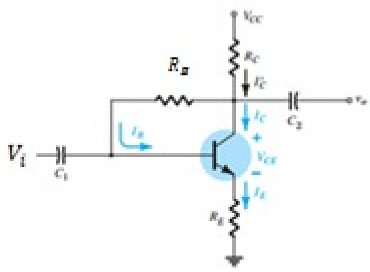
$$S = \frac{1+\beta}{1-\beta \frac{d I_B}{d I_C}} = \frac{1+\beta}{1-0} = 1+\beta$$



For $\beta = 50\ S = 1 + 50 = 51$

It means that for this circuit I_C increase 51 times as fast as I_{CO}

Networks that are quite stable and relatively insensitive to temperature variations have tow stability factor.



How to reduce (S)

In the figure. If $I_C\uparrow$ (due to $\uparrow T \uparrow \beta$), then $V_{CE}\downarrow$

And hence $I_B\downarrow$ and so also $I_C\downarrow$ and is not allowed to

Exceed as in fixed bias case.

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

$$I_B=\frac{V_{CC}-I_CR_C-V_{BE}}{R_C+R_b}$$

Then $\frac{\partial I_B}{\partial I_C}=\frac{-R_C}{R_C+R_b}$

$$S=\frac{1+\beta}{1+\beta\frac{R_C}{R_C+R_b}} \quad \therefore S<\beta+1$$

which is obtained for fixed bias

Minimum value of S>0

Stabilization with change in β

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

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

from these two equation.

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

1- To reduce I_C insensitive to β, we must $\beta R_C\gg R_b$ then

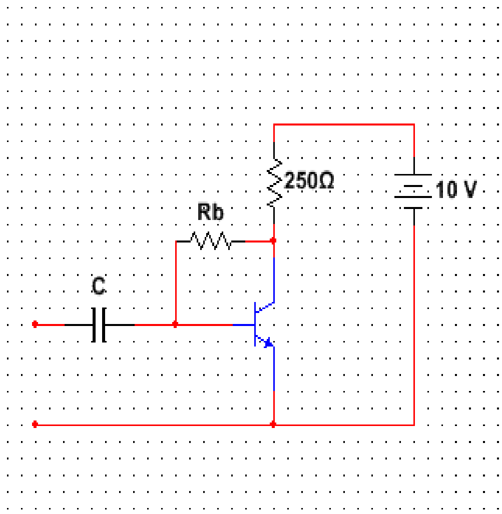
$$I_C\cong\frac{1}{R_C}[V_{CC}-V_{BE}+(R_C+R_b)I_{CO}]$$

2- If $R_b=\beta R_C$,then sensitivity to variation in β is $\frac{1}{2}$ to what it would be, if fixed bias is used ,

So feedback resistance R_b increases stability but the voltage gain of the amplifier is reduced.

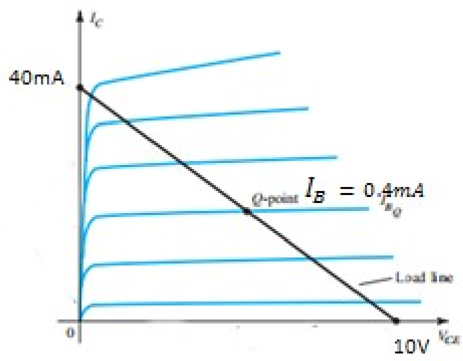
Example:

Given $\beta = 50, Q = at\ the\ middle\ of\ load\ line\ find\ R_b, S$.



Solution:

$$I_C = \frac{V_{CC}}{R_C} = \frac{10}{250} = 40\,mA$$



$I_B = 0.4\,mA$

$I_C = 20\,mA$ for Q at middle of load line

$V_C = 5\,V$

$$R_b = \frac{V_{CC} - V_{BE}}{I_B} = \frac{5 - 0.6}{0.4} = 11\,k\Omega \Longrightarrow R_B = \frac{V_C - V_B}{I_B}$$

$$S = \frac{1+\beta}{1+\beta\frac{R_C}{R_C+R_b}} = \frac{1+50}{1+50\left(\frac{0.25}{0.25+11}\right)} = 22$$

But βR_C should be $\gg R_b$ to avoid sensitivity of I_C, β

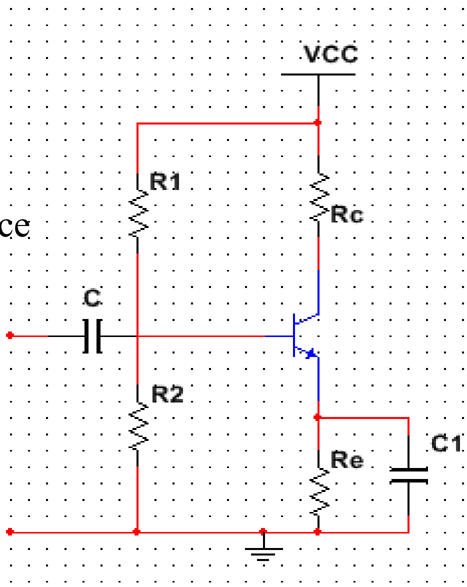
$\beta R_C = 50 \times 0.25 = 12.5\,k\Omega$

$R_b = 11\,k\Omega$

So this condition is not satisfied.

Self Bias or Emitter Bias

By thevenin's equivalent



$R_b = R_1 \parallel R_2$

If $R_b \to 0,$ then V_{BN} is independent of I_{CO} and hence

$$S = \frac{\partial I_C}{\partial I_{CO}} \to 1$$

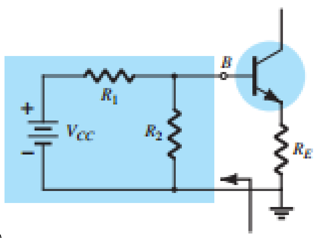
For best stability $R_1 \circ R_2$ should be as small as possible.

$$V_{Th} = \frac{R_2 V_{CC}}{R_1 + R_2} \quad \text{and} \quad R_b = \frac{R_1 R_2}{R_1 + R_2}$$

$$V_{Th} = I_B R_b + V_{BE} + (I_B + I_C) R_e$$

$$\frac{\partial I_B}{\partial I_C} = \frac{-R_e}{R_e + R_b}$$

$$S = \frac{1+\beta}{1-\beta\left(\frac{\partial I_B}{\partial I_C}\right)} = (1+\beta)\frac{1+\frac{R_b}{R_e}}{(1+\beta)+\frac{R_b}{R_e}} \qquad R_b = R_{Th}$$



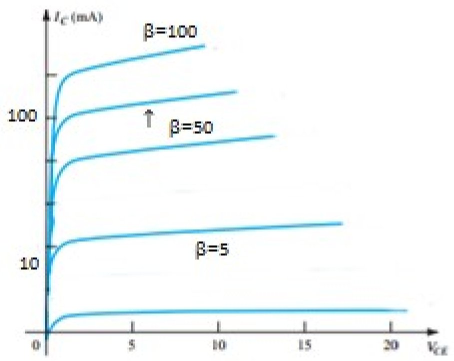
Thévenin

S varies between *1* for small $\frac{R_b}{R_e}$ and $(1+\beta)$ for $\frac{R_b}{R_e} \to \infty$

$S\uparrow, so\, \beta\uparrow$ it is independent of β stability decreases.

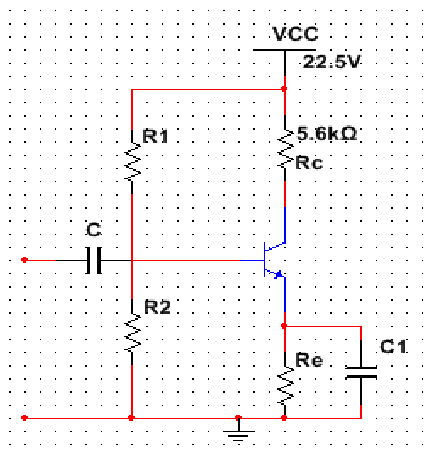
For small S , it is independent of β

Also a capacitance $C = 10\,\mu F$ is used to by pass R_e to avoid the loss of AC signal.



Example:

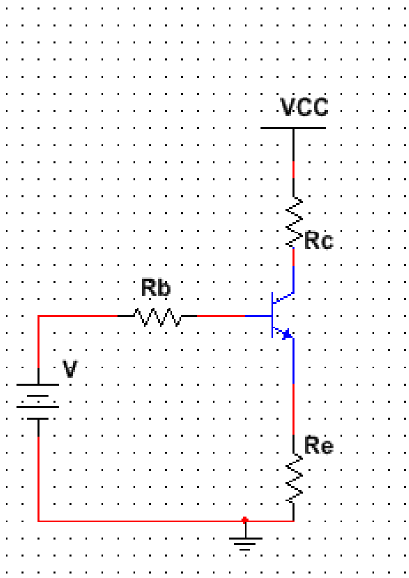
Given β =50 $V_{BE} = 0.6\,V$, $V_{CC} = 22.5\,V$ Q-point at $V_{CE} = 12\,V, I_C = 1.5\,mA\,S \le 3$,find R_e , R_1 and R_2



Solution:

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

If $I_C \gg I_B$



$$I_C (R_C + R_e) = V_{CC} - V_{BE}$$

$$R_C + R_e = \frac{22.5-12}{1.5} = 7\,k\Omega$$

$$R_e = 7 - R_C = 7 - 5.6 = 1.4\,k\Omega$$

$$S = (1+\beta)\frac{1+\frac{R_b}{R_e}}{(1+\beta)+\frac{R_b}{R_e}} \le 3 = (1+50)\frac{1+\frac{R_b}{R_e}}{1+50+\frac{R_b}{R_e}}$$

From this $\frac{R_b}{R_e} = 2.9\,k\Omega, S$ will be < 3

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

Use equivalent circuit $R_b = R_1 /\!/ R_2$

$V_{Th} = V_{CC}\frac{R_2}{R_1+R_2}$ or $R_1 = R_b\frac{V_{CC}}{V_{Th}}$ $R_2 = R_1\frac{V_{Th}}{V_{CC}-V_{Th}}$

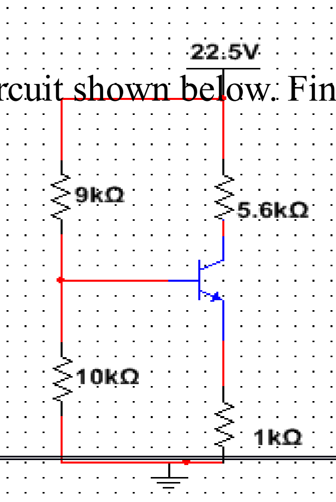
$$V = 30*10^{-3}*2-90+0.6+(3*10^{-3}+1.5)(1.4) = 2.83\,V$$

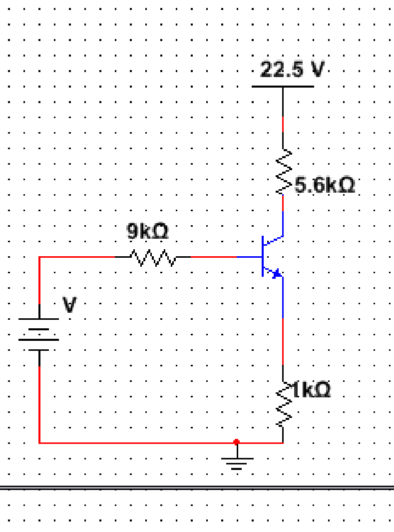
$$R_1 = 2.96\frac{22.5}{2.83} = 23.6\,k\Omega$$

$$R_2 = 23.6\frac{2.83}{22.5-2.83} = 3.38\,k\Omega$$

Example:

For the circuit shown below. Find Q-point & S





≡

Solution:

$$V = \frac{22.5 \times 10}{90 + 10} = 2.25\,V = V_2$$

$$R_b = \frac{10 \times 90}{10 + 90} = 9\,k$$

Let $V_{BE} = 0.6\,V$

$$V_{CC} = I_C R_C + R_e (I_C + I_B) + V_{CE}$$

For collector circuit

22.5=5.6 $I_C + 1(I_C + I_B) + V_{CE}$

For base circuit

2.25=0.6+1k($I_C + I_B) + 9 I_B$

Eliminate I_C from these tow equation

$$V_{CE} = 65 I_B + 11.6\ it's\ called\ biasing\ line$$

Q-point is $V_{CE} = 12\,V$

$I_C = 1.4\,mA$

$I_B = 26\,\mu A$

Alternatively , if dc in not available , one can to calculation from β. At active region $I_B \gg I_{Co}$, so $I_C = \beta I_B$

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

$I_B = \frac{I_C}{\beta} = \frac{I_C}{55}$ and from base equation

.25=0.6+1k($I_C + I_B) + 9 I_B$

.25=0.6+1k($I_C + \frac{I_C}{55}) + 9\frac{I_C}{55}$

$\therefore I_C = 1.4\,mA$

$I_B = \frac{1.4\,mA}{55} = 25.5\,\mu A$

These values are very close to these found from dc. From collector equation , can find V_{CE} .

-22.5+6.6 $)1.4 + 25.5 * 10^{-3} + V_{CE}$

$\therefore V_{CE} = 13.2\,V$

b)

$\frac{R_b}{R_e} = \frac{9k}{1k} = 9$

$S = (56)\left(\frac{1+9}{56+9}\right) = 8.61$

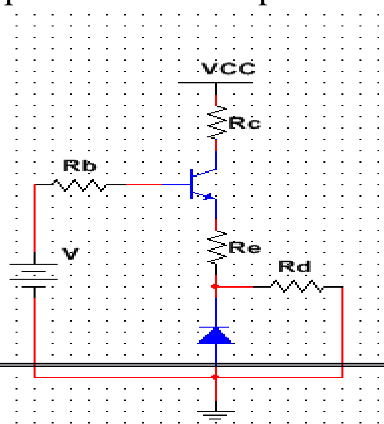
Compare with fixed bias circuit

$S = (\beta + 1) = 55 + 1 = 56$

Bias Compensation:

There is loss in gain in earlier discussed techniques. The bias compensation techniques are used to reduce drift of Q.

Diode Compensation for V_{BE} :



If diode (D) and BE junction is with same material then the junction across diode has same temperature coefficient (-2.5mV/ $^{\circ}C$) and the BE junction voltage V_{BE} .

If $T\uparrow \Rightarrow I_C\uparrow \Rightarrow I_E\uparrow$

$\downarrow I_D \,\square\, I_E \Rightarrow I_{R_d}$

$I_{R_d} \rightarrow const.$

Exercises

1. Derive a mathematical expression to determine the stability factor $S(V_{CC}) = \Delta I_C / \Delta V_{CC}$ for the emitter-stabilized bias circuit.

2. Discuss and compare (by equations) between the relative levels of stability for the following biasing circuits:

i. the fixed-bias circuit,

ii. the emitter-stabilized bias circuit,

iii. the voltage-divider bias circuit, and

iv. the voltage-feedback circuit