Biasing a BJT

Text Book

Electronic Devices and Circuit Theory

by R Boylestad and L Nashelsky

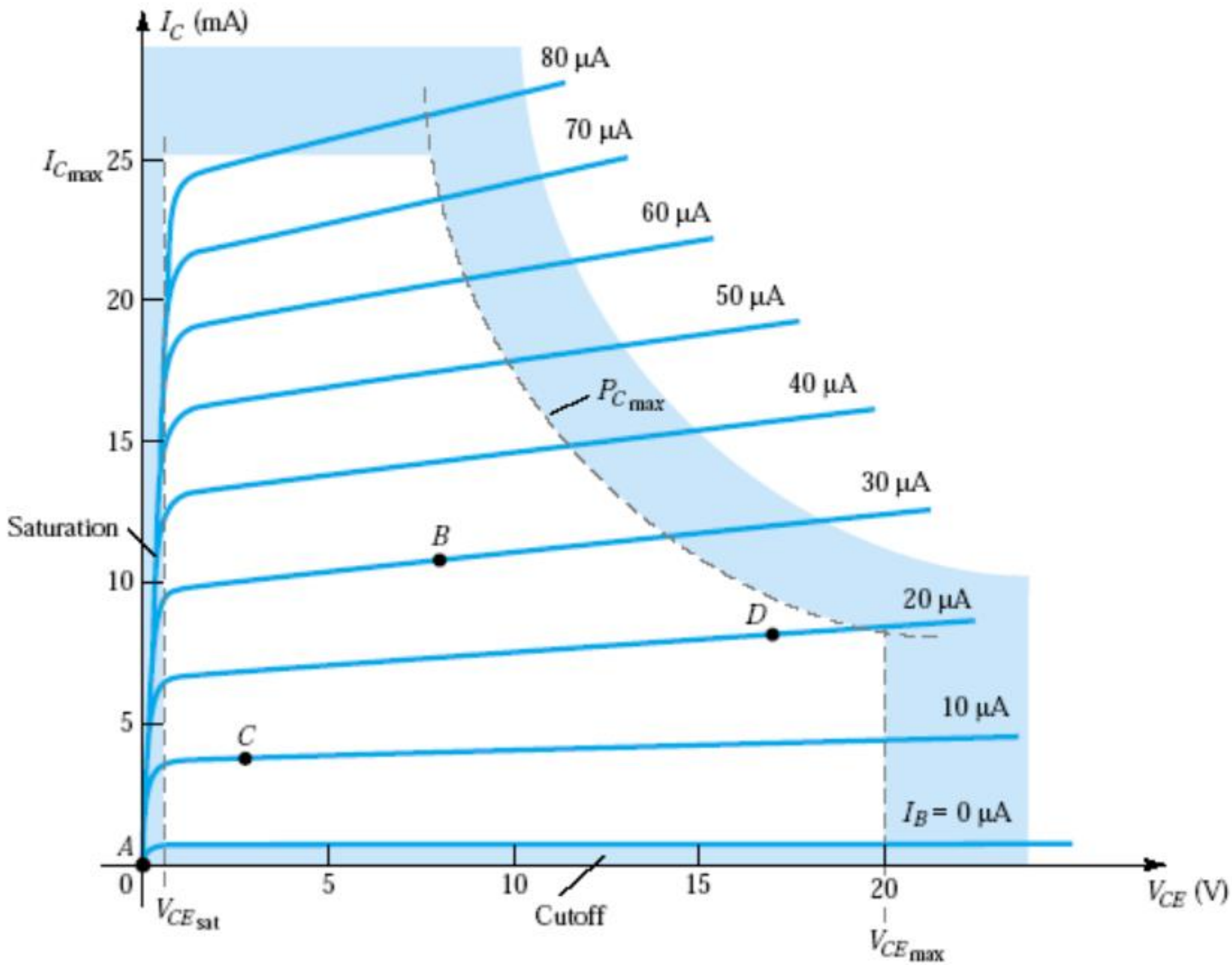
Basic relationships

$$\boxed{V_{BE} = 0.7\ \text{V}}$$

$$\boxed{I_E = (\beta + 1)I_B \cong I_C}$$

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

Operating point (Q-point)



Biasing requirement

For amplification:

1. *Linear-region operation:*
   Base–emitter junction forward biased
   Base–collector junction reverse biased

For switching:

2. *Cutoff-region operation:*
   Base–emitter junction reverse biased

3. *Saturation-region operation:*
   Base–emitter junction forward biased
   Base–collector junction forward biased

Fixed-bias circuit

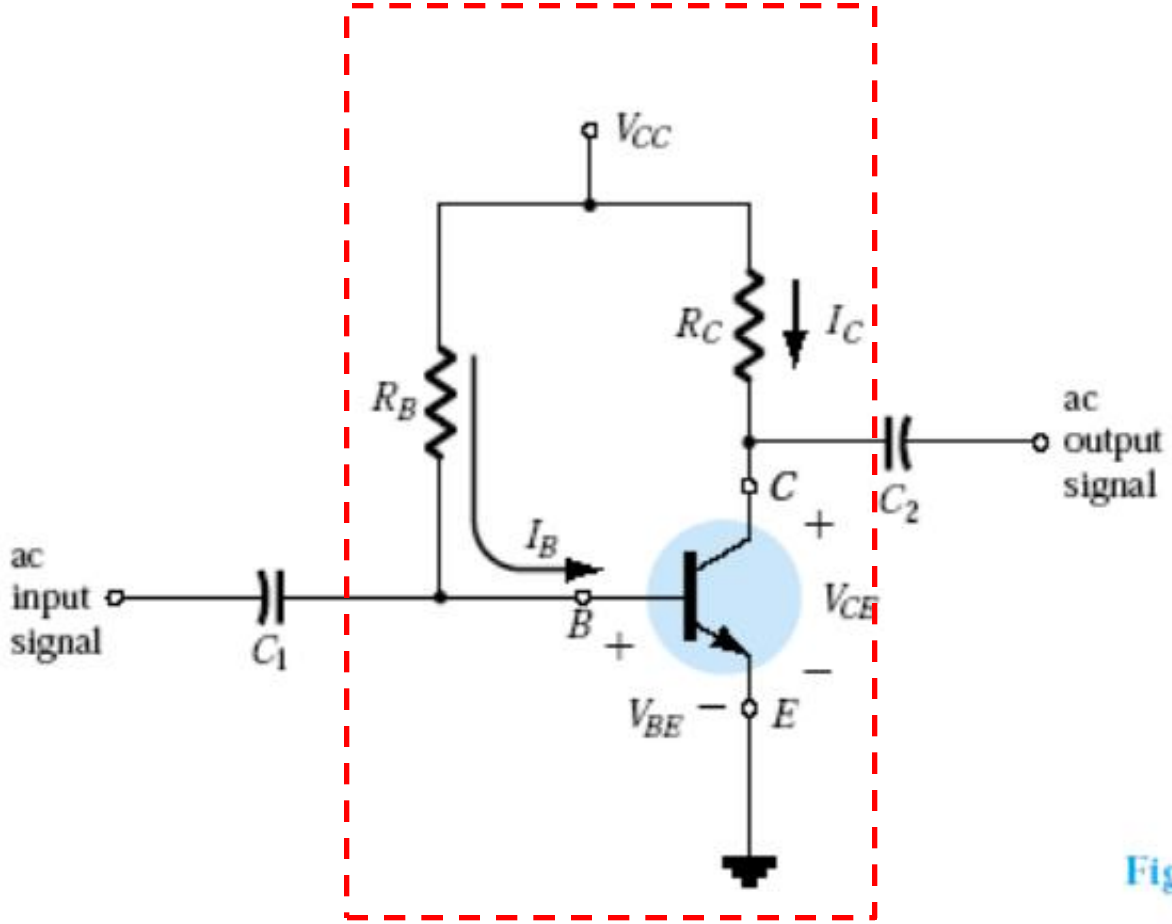
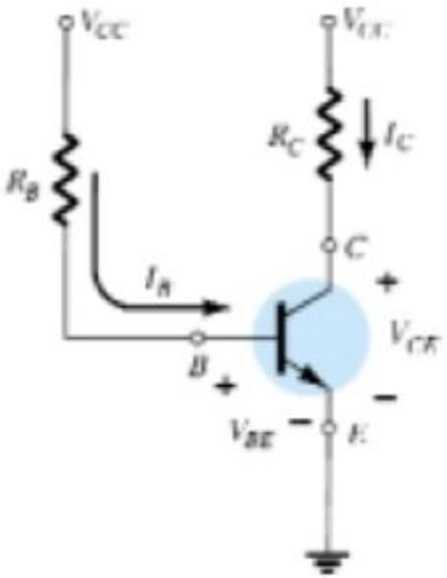


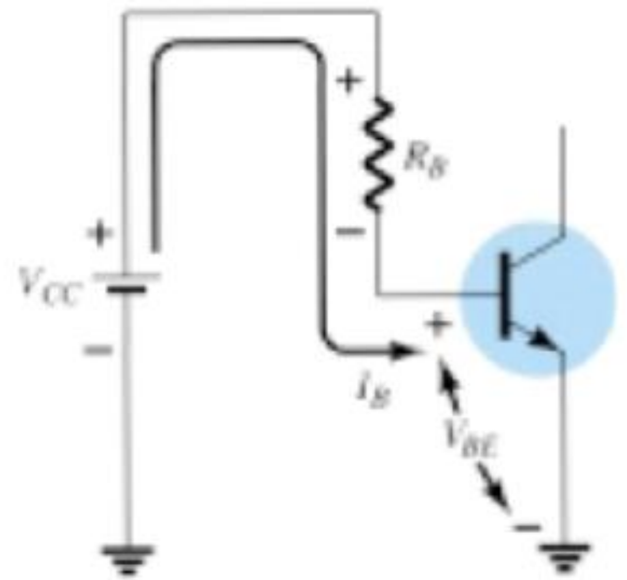
Figure 4.2

Dc analysis steps

- Open all capacitors first
- Redraw the input circuit or loop
- Apply KVL around the input loop and find I_B.
- Find I_C by using $I_C=\beta I_B$
- Apply KVL to the output loop and find V_{CE}.

Dc analysis





Applying KVL @ input loop:

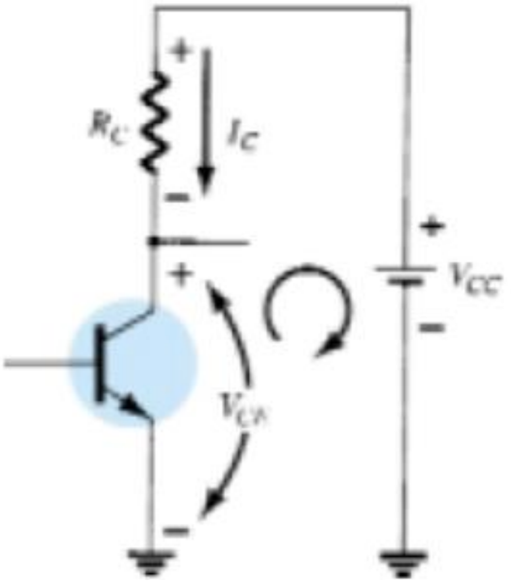
$$+V_{CC} - I_B R_B - V_{BE} = 0$$

Hence,

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

Dc analysis (continue..)

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



Applying KVL @ output loop:

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

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

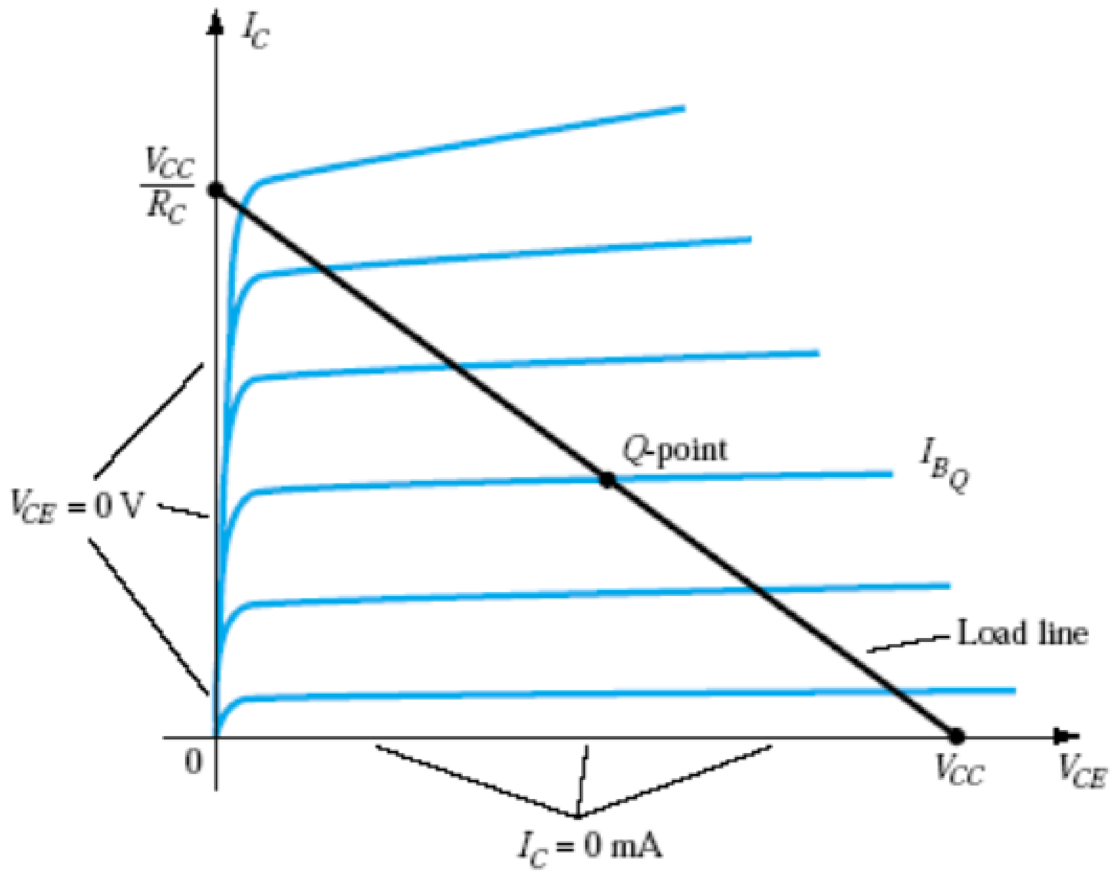
Since, $\boxed{V_{CE} = V_C - V_E}$

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

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

$$\boxed{V_{BE} = V_B}$$

Dc load line of fixed bias circuit



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

On the *y*-axis:

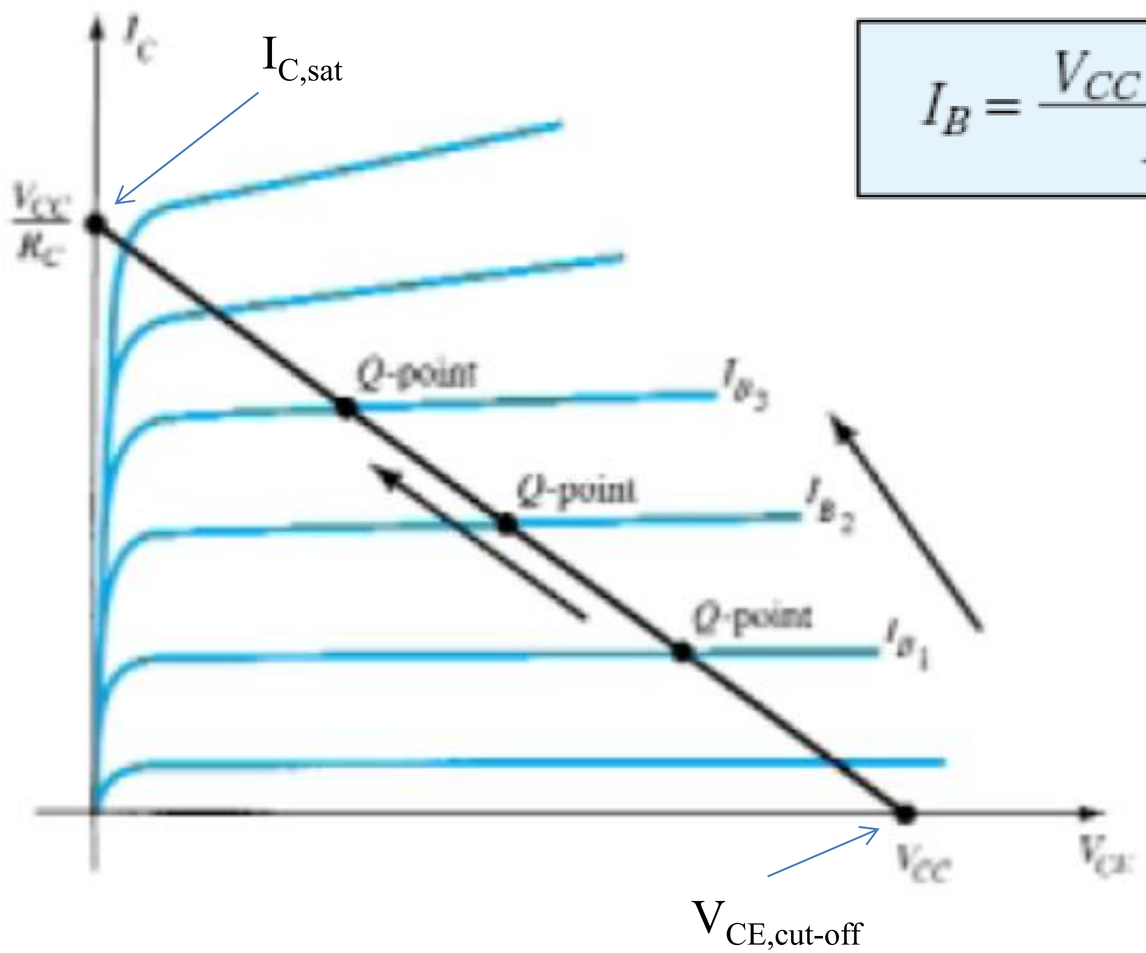
$$0 = V_{CC} - I_C R_C$$
$$I_C = V_{CC} / R_C$$

On the *x*-axis:

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

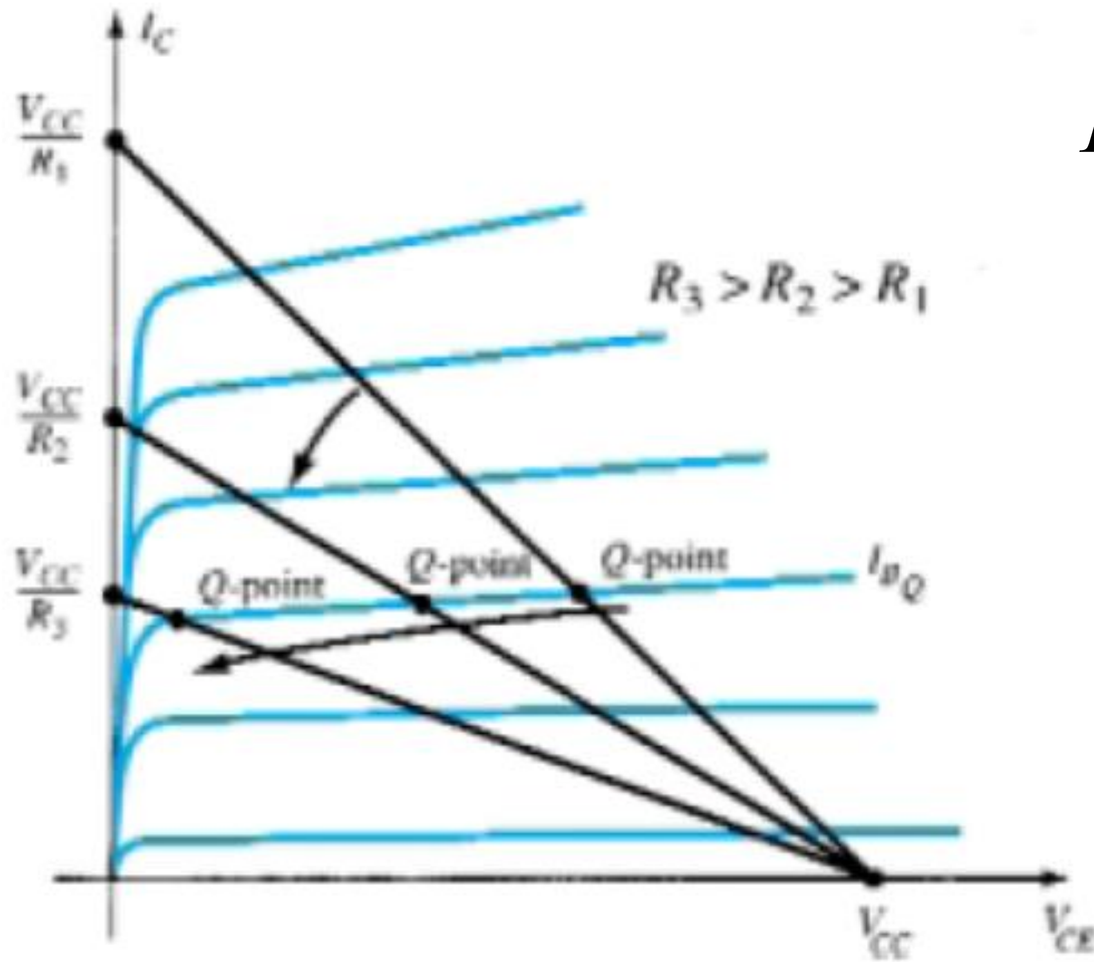
$$V_{CE}=V_{CC}$$

Effect of R_B variation



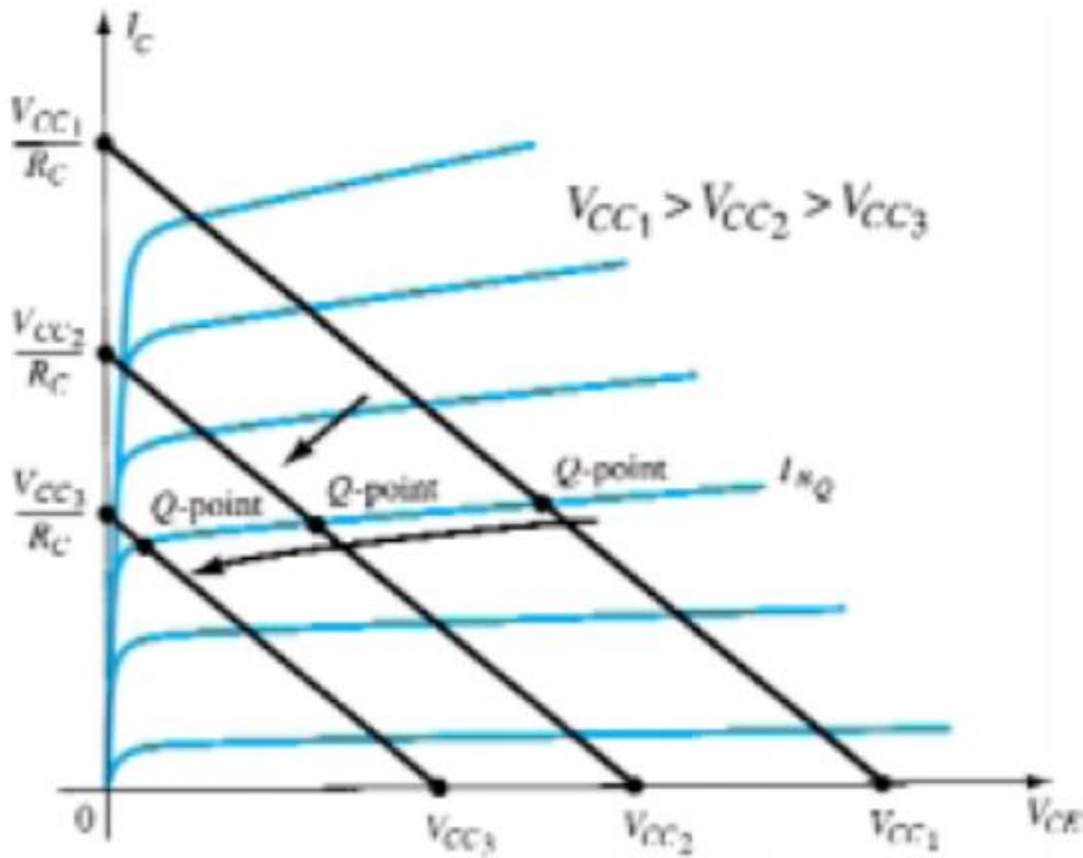
$$\boxed{I_B = \frac{V_{CC} - V_{BE}}{R_B}}$$

Effect of R_C variation

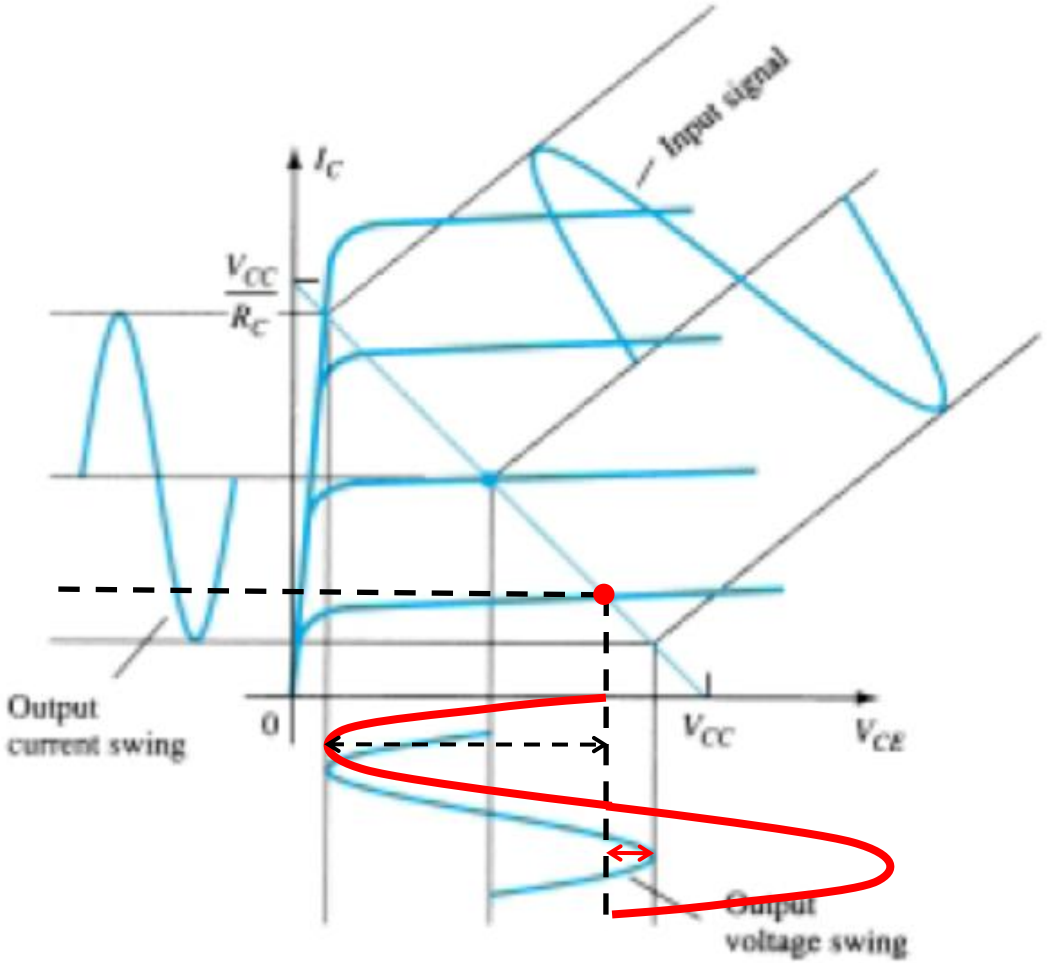


$$I_{C,sat} = \frac{V_{CC}}{R_C}$$

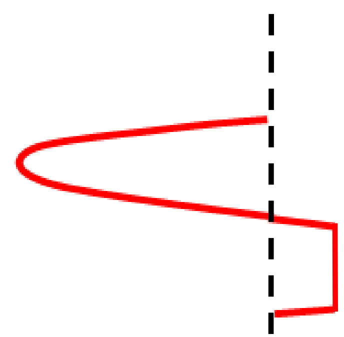
Effect of V_{CC} variation



Distortion less maximum amplification



$$V_{CE} = \frac{1}{2} V_{CC}$$



Example-1

Find: I_{BQ}, I_{CQ}, V_{CEQ}, V_B, V_C, V_{BC}

(a) Eq. (4.4): $I_{B_Q} = \dfrac{V_{CC} - V_{BE}}{R_B} = \dfrac{12\text{ V} - 0.7\text{ V}}{240\text{ k}\Omega} = \mathbf{47.08\ \mu A}$

Eq. (4.5): $I_{C_Q} = \beta I_{B_Q} = (50)(47.08\ \mu\text{A}) = \mathbf{2.35\ mA}$

(b) Eq. (4.6): $V_{CE_Q} = V_{CC} - I_C R_C$

$$= 12\text{ V} - (2.35\text{ mA})(2.2\text{ k}\Omega)$$

$$= \mathbf{6.83\ V}$$

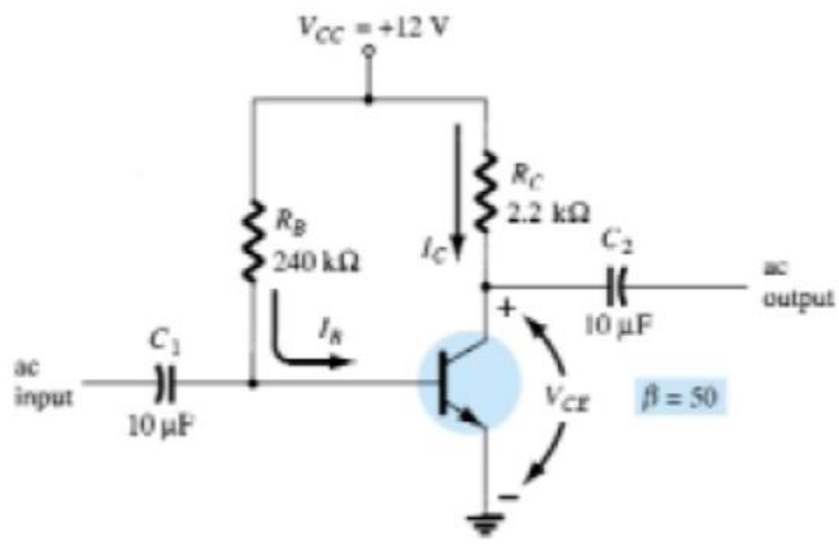
(c) $V_B = V_{BE} = \mathbf{0.7\ V}$

$V_C = V_{CE} = \mathbf{6.83\ V}$

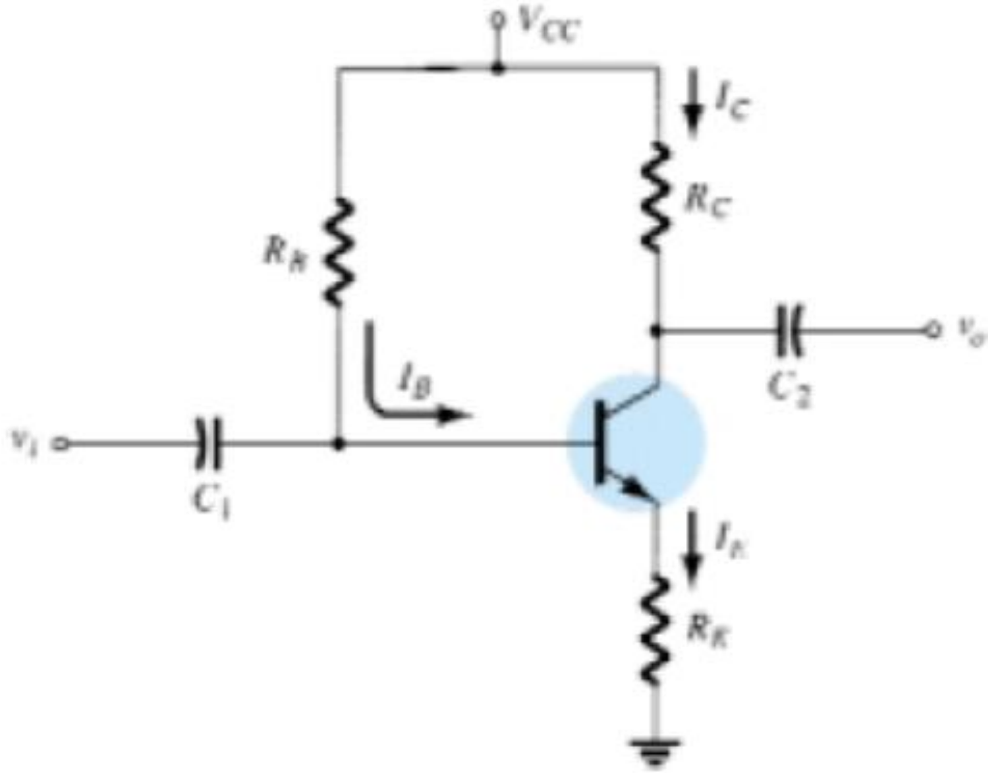
(d) Using double-subscript notation yields

$$V_{BC} = V_B - V_C = 0.7\text{ V} - 6.83\text{ V}$$

$$= \mathbf{-6.13\ V}$$



Emitter stabilized bias circuit



Analysis (input-loop)

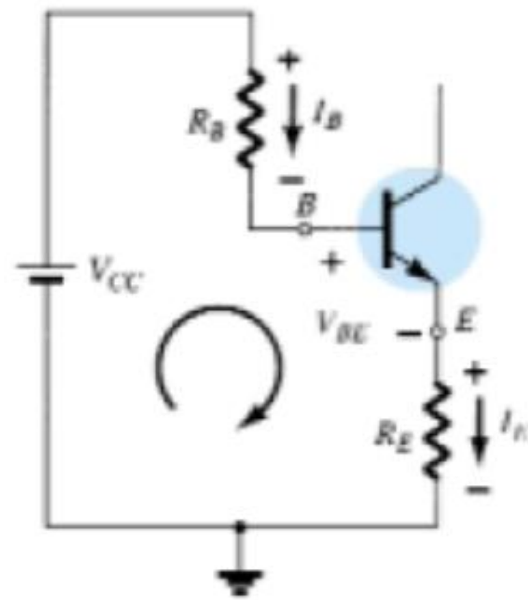
Applying KVL @ input loop:

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

We know, $I_E = (\beta + 1) I_B$

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

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



We want to reduce the effect of beta in the base current which will lead to the less effect on collector current. This can be done by choosing $R_E >>> R_B$ and $\beta+1 = \beta$. Because as $I_C = \beta\ I_B$, so β term will be cancelled in the output parameter like in Ic Equation. That's how R_E is stabilizing the previous bias configuration.

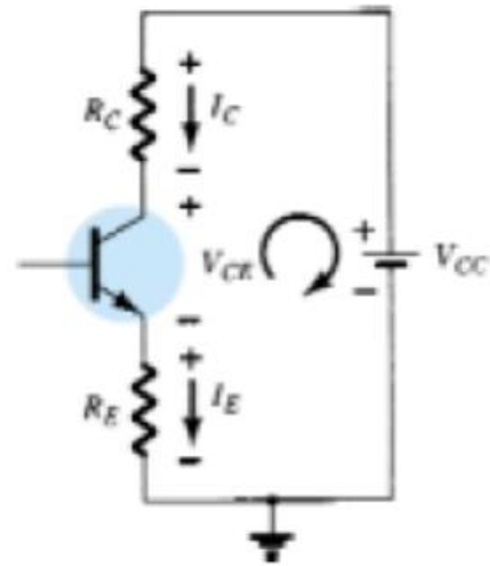
Analysis (output-loop)

Applying KVL @ output loop:

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

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

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



Now, $\boxed{V_E = I_E R_E}$

Since. $V_{CE} = V_C - V_E$

$$\boxed{V_C = V_{CE} + V_E}$$

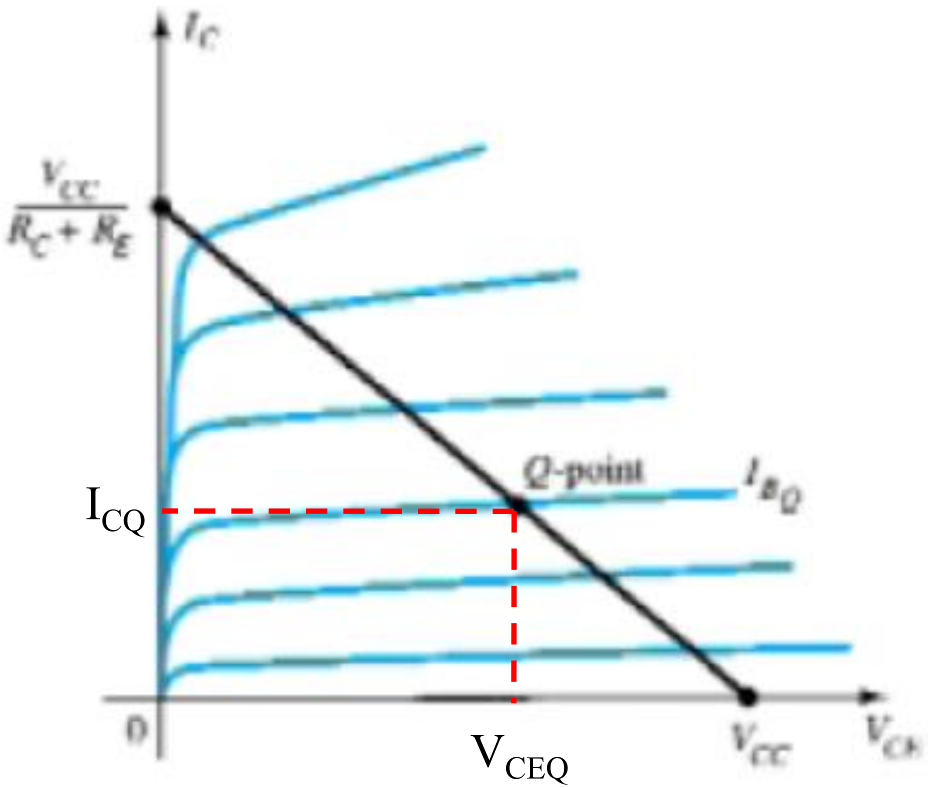
Or, $\boxed{V_C = V_{CC} - I_C R_C}$

Again,

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

Or, $\boxed{V_B = V_{BE} + V_E}$

Dc load line



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

On the *y*-axis:

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

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

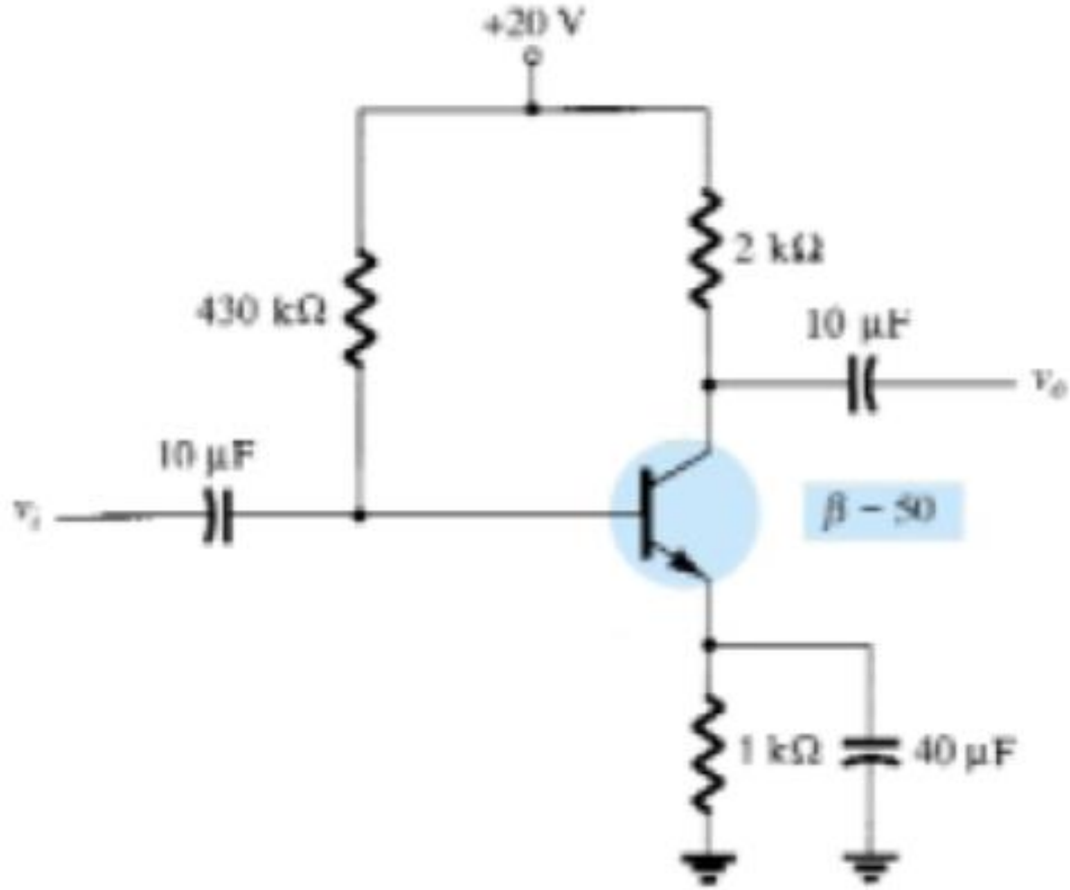
On the *x*-axis:

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

$V_{CE} = V_{CC}$

Example-2

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



Solution

(a) Eq. (4.17): $I_B = \dfrac{V_{CC} - V_{BE}}{R_B + (\beta + 1)R_E} = \dfrac{20\text{ V} - 0.7\text{ V}}{430\text{ k}\Omega + (51)(1\text{ k}\Omega)}$

$= \dfrac{19.3\text{ V}}{481\text{ k}\Omega} = \mathbf{40.1\ \mu A}$

(b) $I_C = \beta I_B$

$= (50)(40.1\ \mu\text{A})$

$\cong \mathbf{2.01\ mA}$

(c) Eq. (4.19): $V_{CE} = V_{CC} - I_C(R_C + R_E)$

$= 20\text{ V} - (2.01\text{ mA})(2\text{ k}\Omega + 1\text{ k}\Omega) = 20\text{ V} - 6.03\text{ V}$

$= \mathbf{13.97\ V}$

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

$= 20\text{ V} - (2.01\text{ mA})(2\text{ k}\Omega) = 20\text{ V} - 4.02\text{ V}$

$= \mathbf{15.98\ V}$

(e) $V_E = V_C - V_{CE}$

$= 15.98\text{ V} - 13.97\text{ V}$

$= \mathbf{2.01\ V}$

or $V_E = I_E R_E \cong I_C R_E$

$= (2.01\text{ mA})(1\text{ k}\Omega)$

$= \mathbf{2.01\ V}$

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

$= 0.7\text{ V} + 2.01\text{ V}$

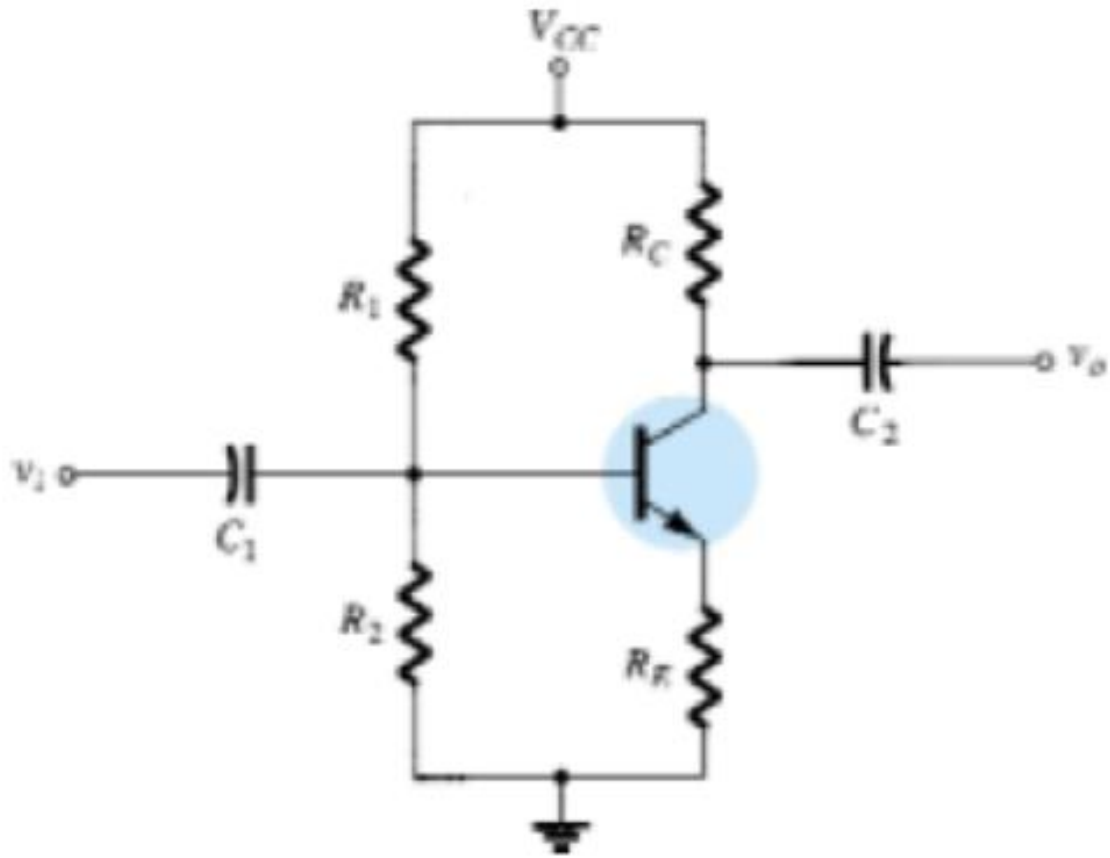
$= \mathbf{2.71\ V}$

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

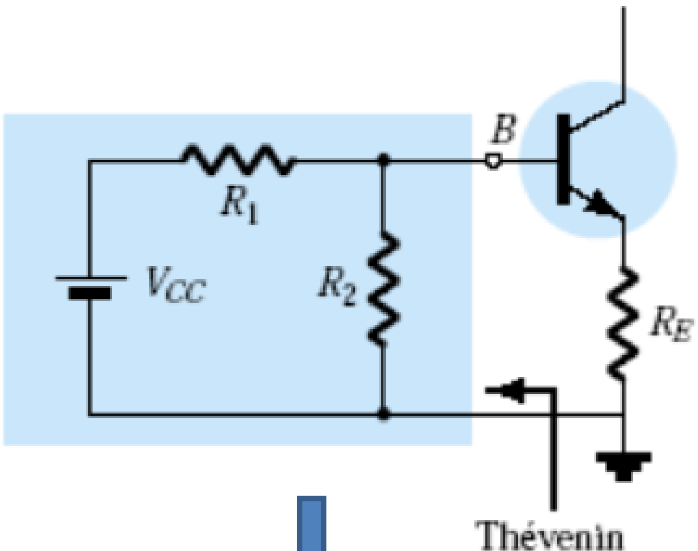
$= 2.71\text{ V} - 15.98\text{ V}$

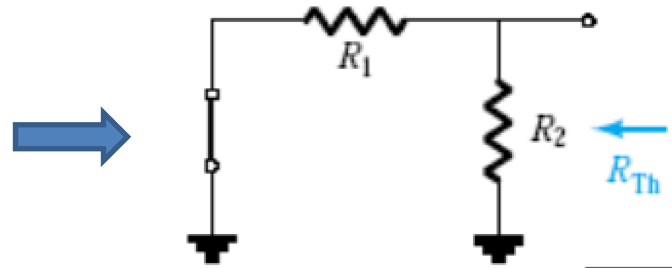
$= \mathbf{-13.27\ V}$ (reverse-biased as required)

Voltage divider bias

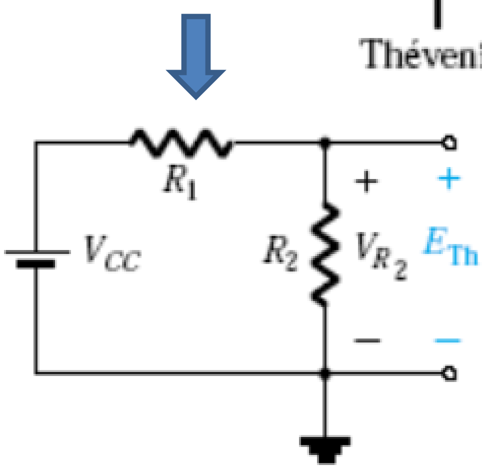


Input loop



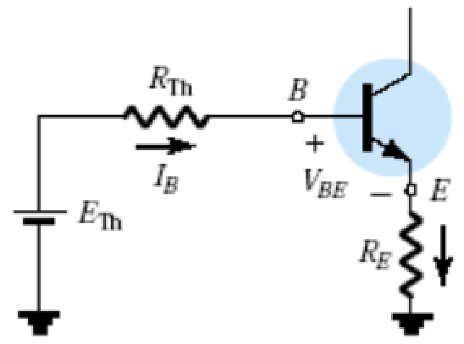


$$R_{Th} = R_1 \| R_2$$



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

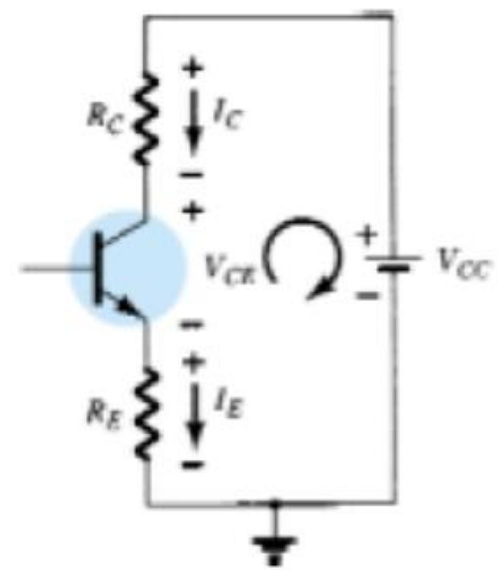
Analysis (input loop)



Applying KVL @ input loop:

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

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

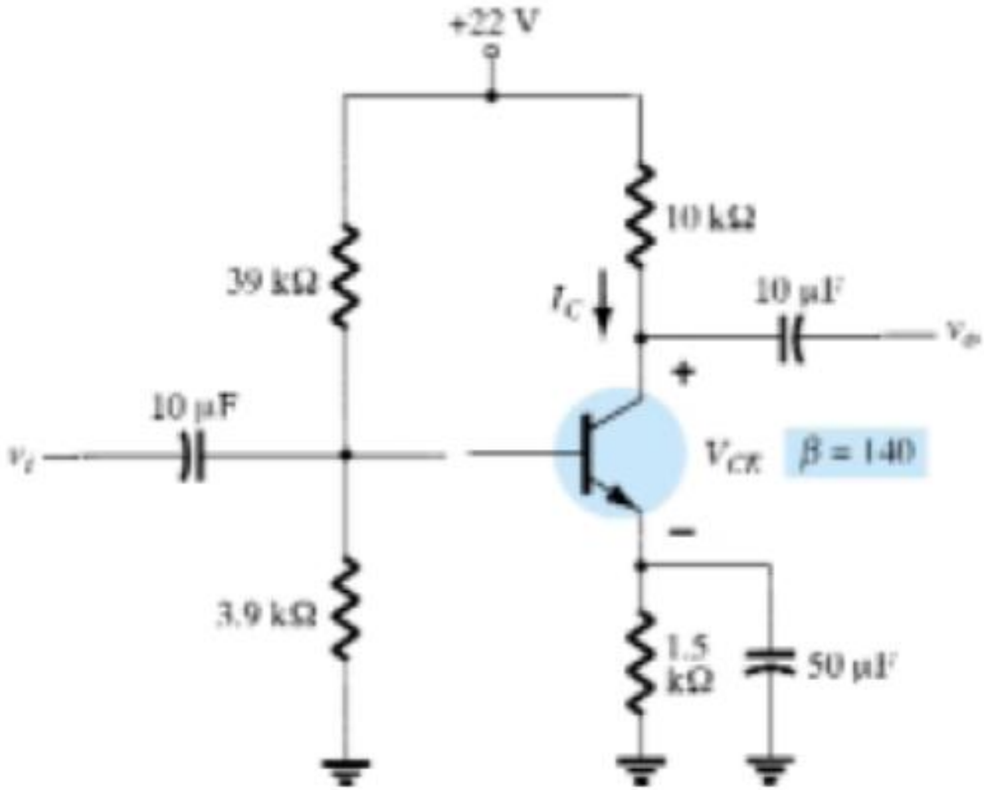


Applying KVL @ output loop:

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

Example-3

Determine the dc bias voltage V_{CE} and current I_C.



Solution

$$\text{Eq. (4.28):} \quad R_{\text{Th}} = R_1 \| R_2$$

$$= \frac{(39\ \text{k}\Omega)(3.9\ \text{k}\Omega)}{39\ \text{k}\Omega + 3.9\ \text{k}\Omega} = 3.55\ \text{k}\Omega$$

$$\text{Eq. (4.29):} \quad E_{\text{Th}} = \frac{R_2 V_{CC}}{R_1 + R_2}$$

$$= \frac{(3.9\ \text{k}\Omega)(22\ \text{V})}{39\ \text{k}\Omega + 3.9\ \text{k}\Omega} = 2\ V$$

$$\text{Eq. (4.30):} \quad I_B = \frac{E_{\text{Th}} - V_{BE}}{R_{\text{Th}} + (\beta + 1)R_E}$$

$$= \frac{2\ \text{V} - 0.7\ \text{V}}{3.55\ \text{k}\Omega + (141)(1.5\ \text{k}\Omega)} = \frac{1.3\ \text{V}}{3.55\ \text{k}\Omega + 211.5\ \text{k}\Omega}$$

$$= 6.05\ \mu A$$

$$I_C = \beta I_B$$

$$= (140)(6.05\ \mu\text{A})$$

$$= \mathbf{0.85\ mA}$$

$$\text{Eq. (4.31):} \quad V_{CE} = V_{CC} - I_C(R_C + R_E)$$

$$= 22\ \text{V} - (0.85\ \text{mA})(10\ \text{k}\Omega + 1.5\ \text{k}\Omega)$$

$$= 22\ \text{V} - 9.78\ \text{V}$$

$$= \mathbf{12.22\ V}$$

Collector-Feedback conf.

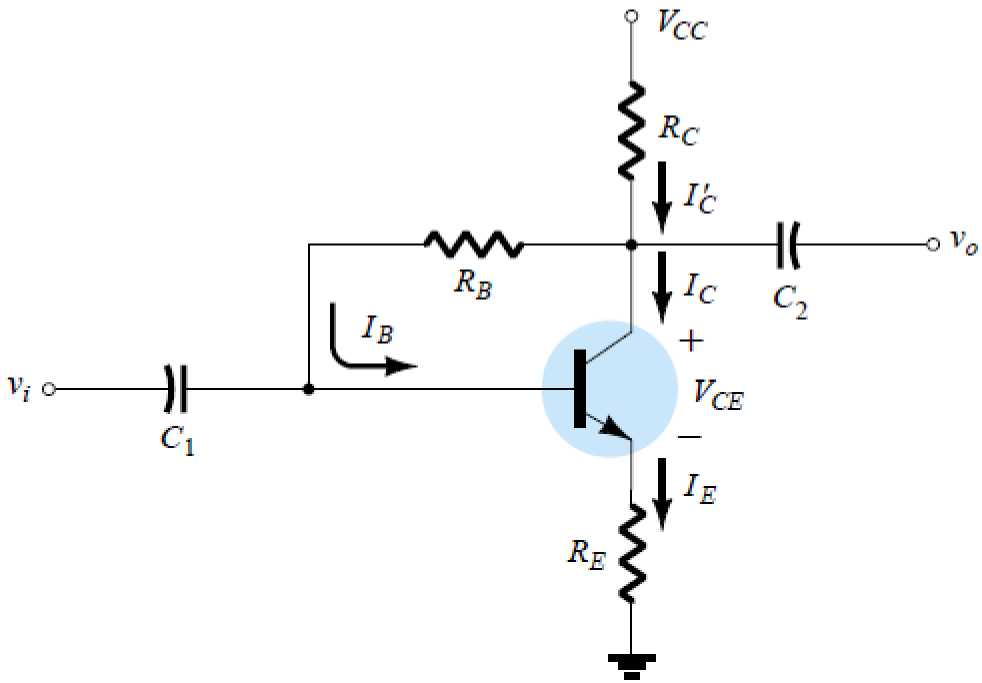


Figure 4.34 dc bias circuit with voltage feedback.

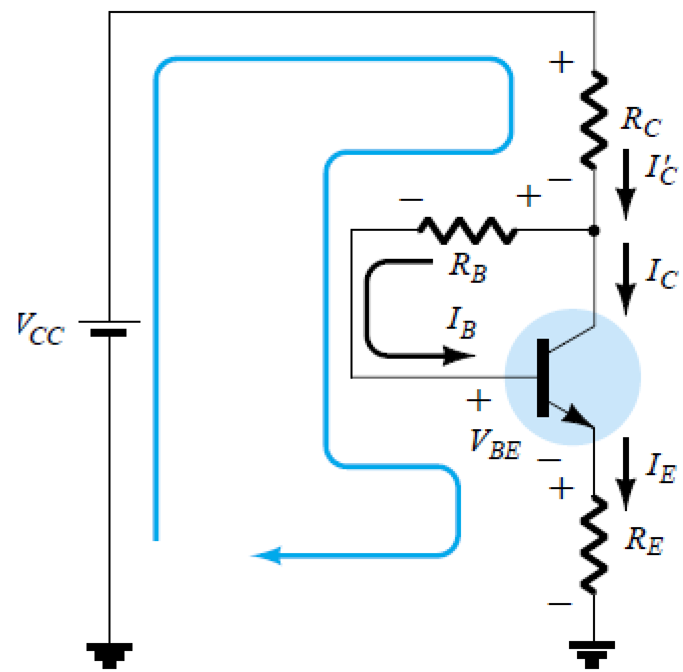


Figure 4.35 Base–emitter loop for the network of Fig. 4.34.

Collector-Emitter conf.

$$V_{CC} - I'_C R_C - I_B R_B - V_{BE} - I_E R_E = 0$$

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

Gathering terms, we have

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

and solving for I_B yields

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

Collector–Emitter Loop

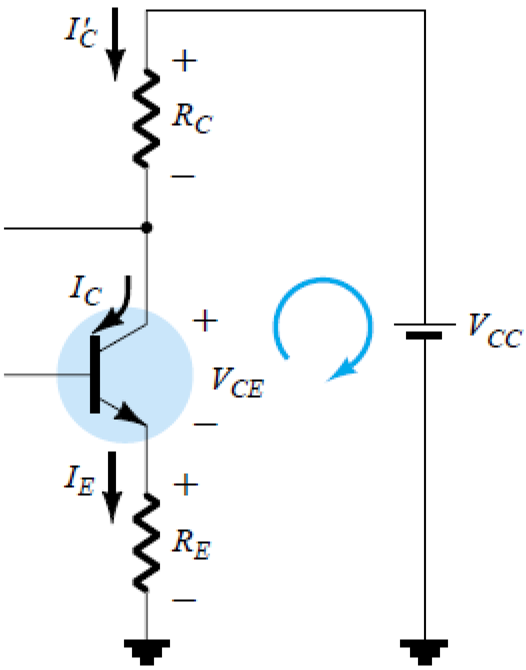


Figure 4.36 Collector–emitter loop for the network of Fig. 4.34.

$$I_E R_E + V_{CE} + I'_C R_C - V_{CC} = 0$$

Since $I'_C \cong I_C$ and $I_E \cong I_C$, we have

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

and

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

EXAMPLE 4.11 Determine the quiescent levels of I_{C_Q} and V_{CE_Q} for the network of Fig. 4.37.

Solution

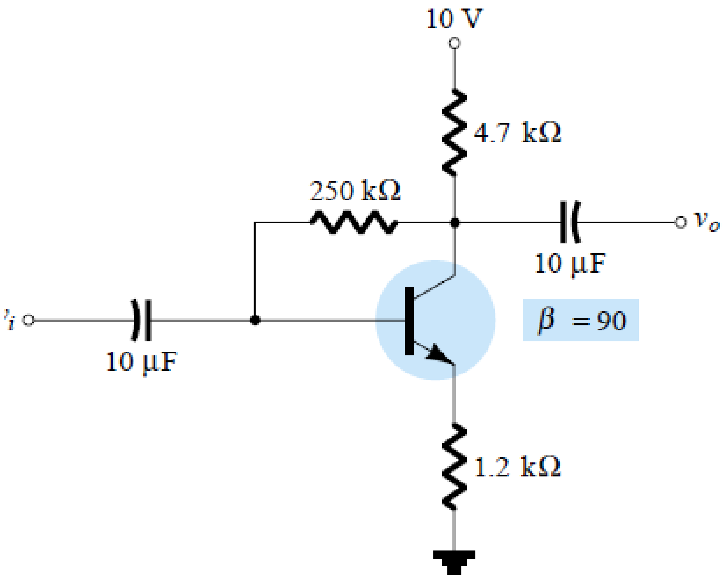


Figure 4.37 Network for Example 4.11.

Eq. (4.41):
$$I_B = \frac{V_{CC} - V_{BE}}{R_B + \beta(R_C + R_E)}$$
$$= \frac{10\text{ V} - 0.7\text{ V}}{250\text{ k}\Omega + (90)(4.7\text{ k}\Omega + 1.2\text{ k}\Omega)}$$
$$= \frac{9.3\text{ V}}{250\text{ k}\Omega + 531\text{ k}\Omega} = \frac{9.3\text{ V}}{781\text{ k}\Omega}$$
$$= 11.91\ \mu\text{A}$$
$$I_{C_Q} = \beta I_B = (90)(11.91\ \mu\text{A})$$
$$= \mathbf{1.07\ mA}$$
$$V_{CE_Q} = V_{CC} - I_C(R_C + R_E)$$
$$= 10\text{ V} - (1.07\text{ mA})(4.7\text{ k}\Omega + 1.2\text{ k}\Omega)$$
$$= 10\text{ V} - 6.31\text{ V}$$
$$= \mathbf{3.69\ V}$$

Common-collector (emitter-follower) configuration

Determine V_{CE_Q} and I_E for the network of Fig. 4.41.

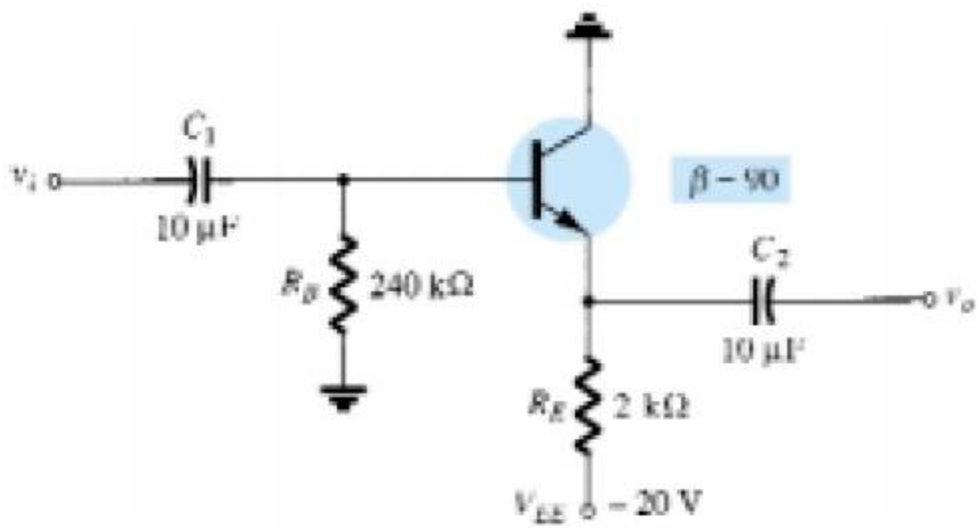


Figure 4.41 Common-collector (emitter-follower) configuration.

Common-base configuration.

EXAMPLE 4.17 Determine the voltage V_{CB} and the current I_B for the common-base configuration of Fig. 4.42.

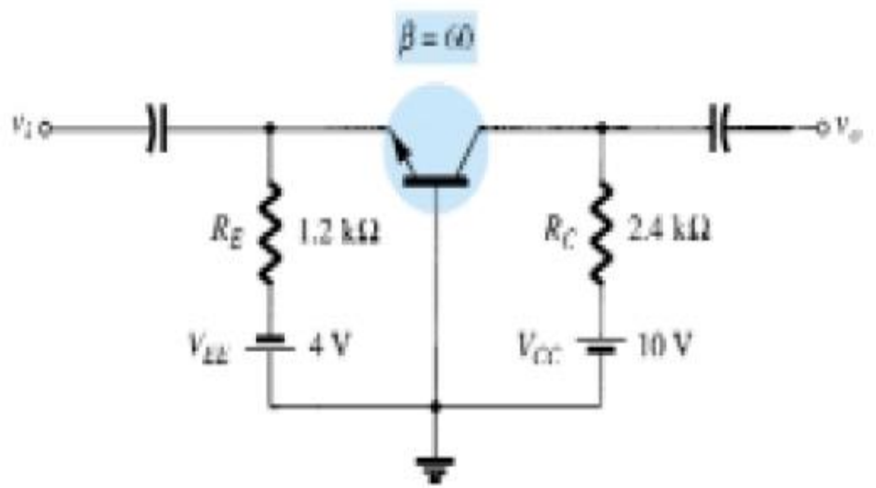


Figure 4.42 Common-base configuration.

Tricky question: Why the term Saturation comes?

In saturation

$V_{CE} \approx 0\ V$

$$I_{C\,(Sat)} = \frac{V_{CC}}{R_C}$$

This (Ic(sat)) is the maximum current passing through the collector.
If Ic > Ic(sat) then the BJT will operate in saturation region.
That mean, Ic which is depending on the input side parameters, can not be greater than Ic(sat).

Practice yourself and send me your feedback, if any.