BJT DC-Biasing

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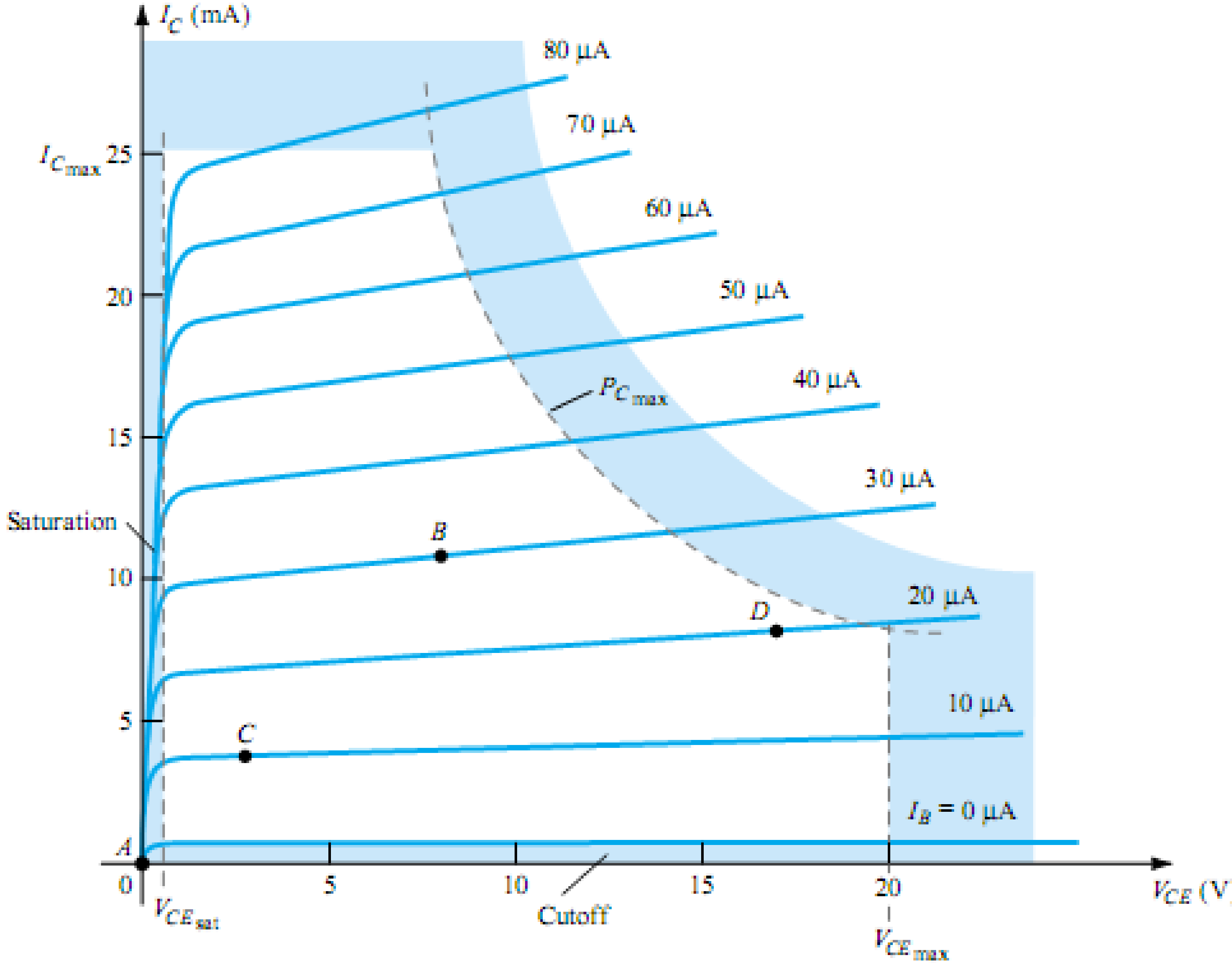
Operating Point

- Biasing – the term for the application of dc voltages to establish a fixed level of current and voltage
- For transistor amplifiers, the resulting dc current and voltage establish an operating point on the characteristics that define the region that will be employed for amplification of the applied signal.
- Since the operating point is a fixed point on the characteristics, it is also called the quiescent point (abbreviated Q-point)



I_C (mA)
80 µA
70 µA
60 µA
50 µA
40 µA
30 µA
20 µA
10 µA
I_B = 0 µA
$I_{C_{max}}$ 25
20
15
10
5
0
5
10
15
20
V_{CE} (V)
Saturation
Cutoff
$P_{C_{max}}$
$V_{CE_{sat}}$
$V_{CE_{max}}$
A
B
C
D

BJT biased in linear/active region

- The base-emitter junction must be forward-biased (p-region voltage more positive),with a resulting forward-bias voltage of about 0.6 to 0.7 V.
- The base-collector junction must be reverse-biased (n-region more positive),with the reverse-bias voltage being any value within the maximum limits of the device.

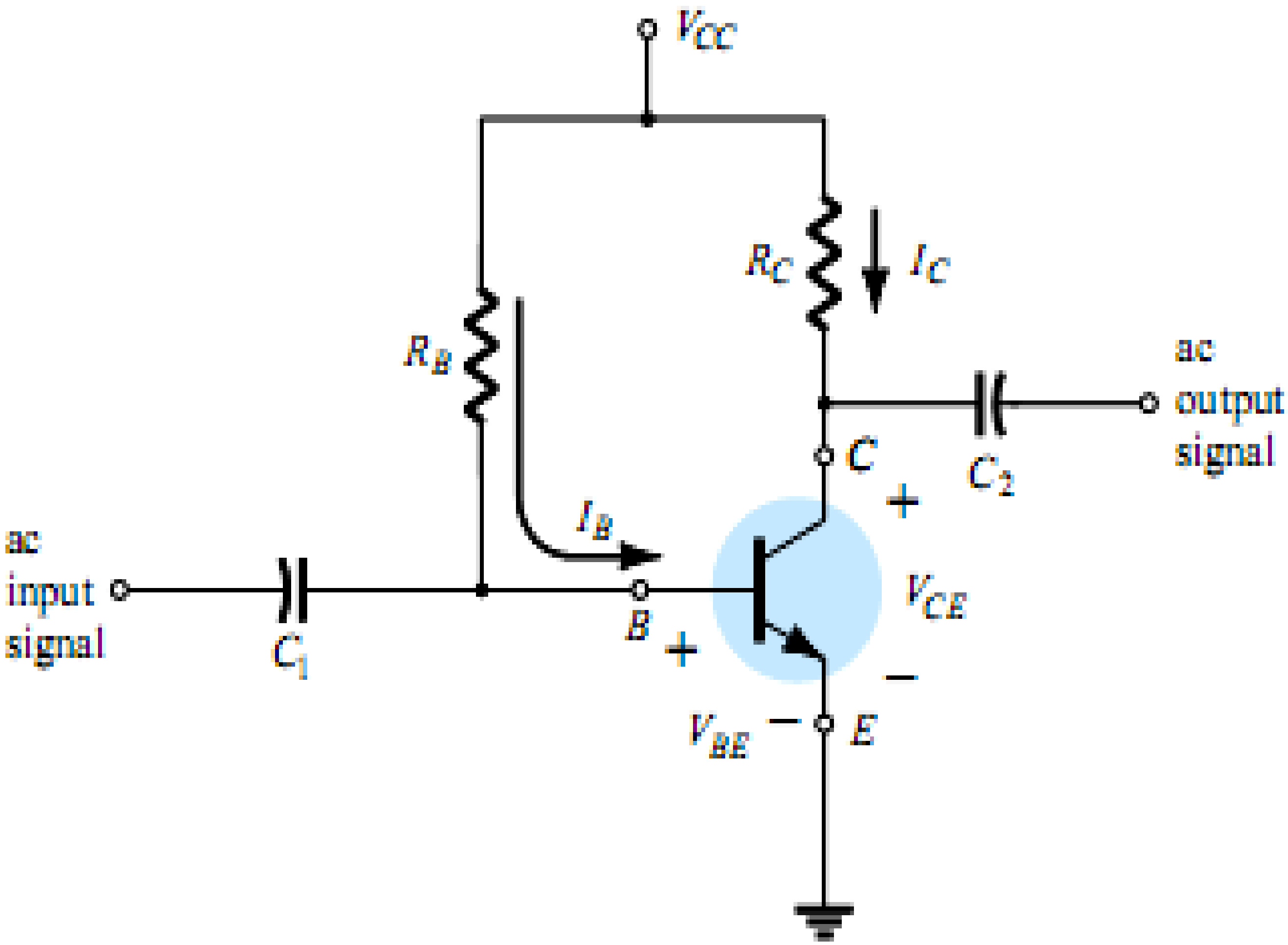
Mode of Operations

- Linear region
  - Base-Emitter junction is forward biased
  - Base=Collector junction is reverse biased

- Cut-off region
  - Base-Emitter junction is reverse biased

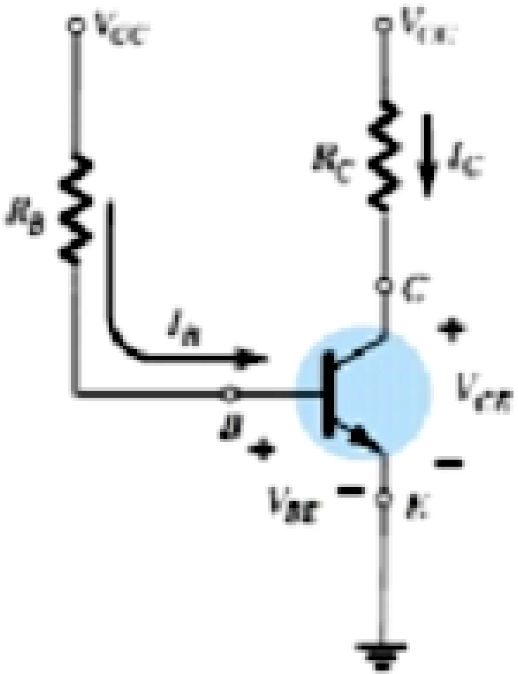
- Saturation region
  - Base-Emitter junction is forward biased
  - Base=Collector junction is forward biased

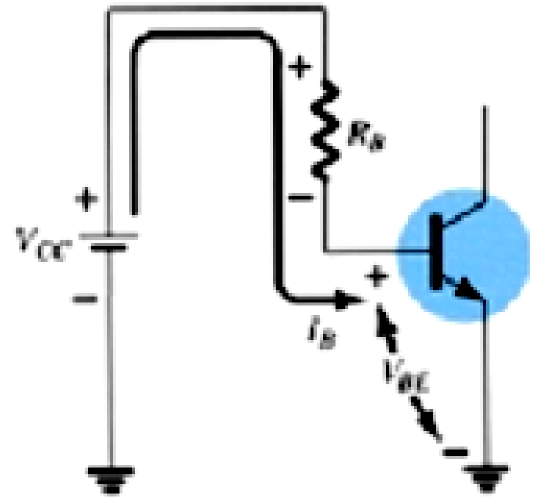
Fixed-Bias



V_{CC}
R_C
I_C
R_B
ac
output
signal
C
C_2
+
I_B
ac
input
signal
V_{CE}
B
+
C_1
−
V_{BE}
−
E

Input Side

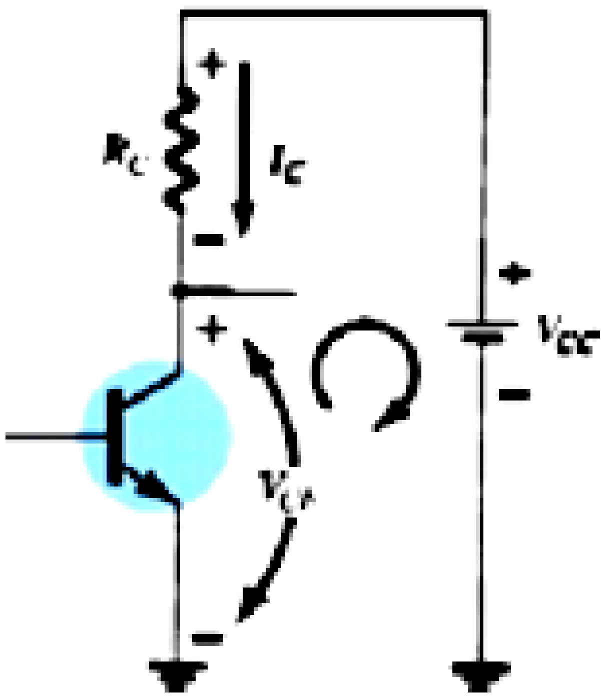




$$+V_{CC} - I_B R_B - V_{BE} = 0$$

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

Output Side



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

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

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

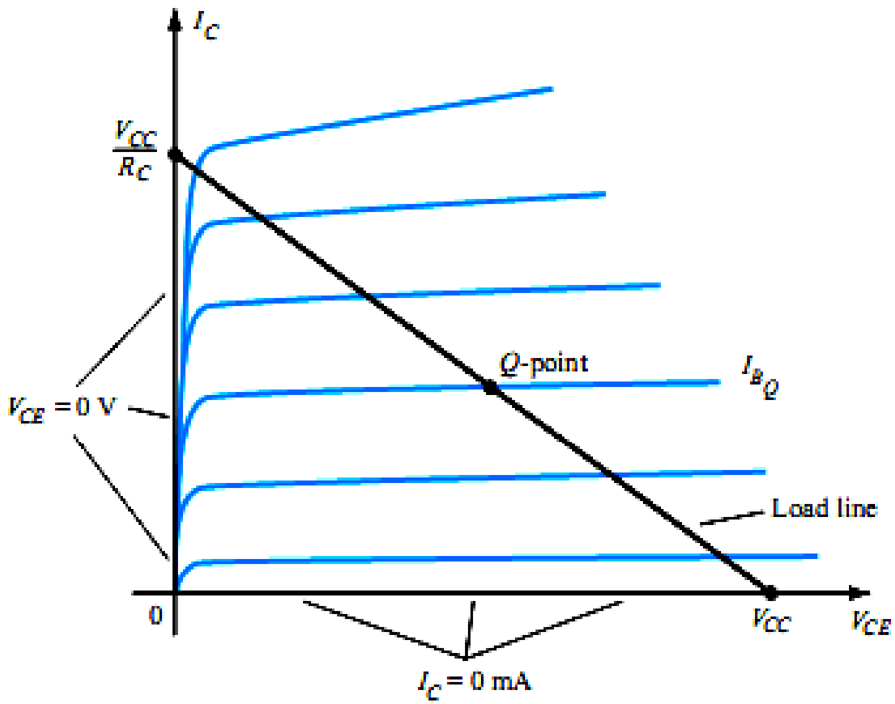
$$\boxed{V_{CE} = V_C - V_E}$$

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

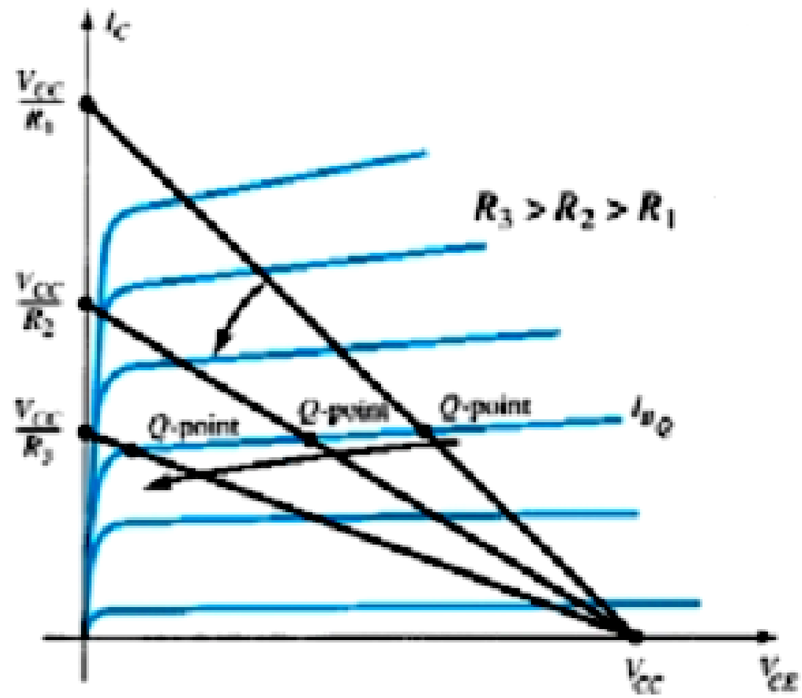
$$\boxed{V_{BE} = V_B - V_E}$$

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

Loadline



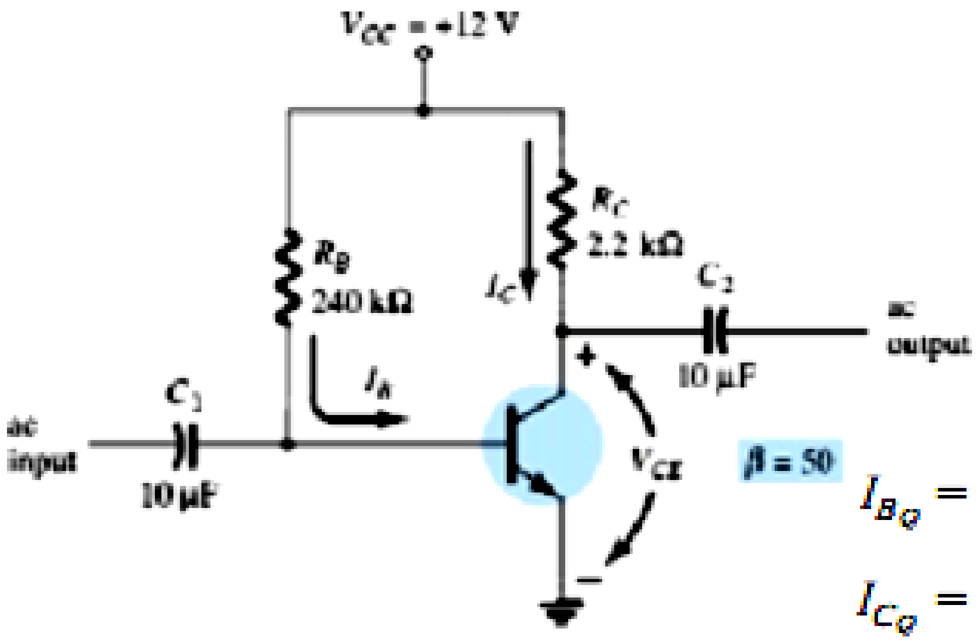
I_C
$\frac{V_{CC}}{R_C}$
Q-point
I_{B_Q}
$V_{CE} = 0$ V
Load line
0
V_{CC}
V_{CE}
$I_C = 0$ mA



I_C
$\frac{V_{CC}}{R_1}$
$R_3 > R_2 > R_1$
$\frac{V_{CC}}{R_2}$
$\frac{V_{CC}}{R_3}$
Q-point
Q-point
Q-point
I_{B_Q}
V_{CC}
V_{CE}

Prob:

- Determine I_{BO}, I_{CO} and V_{CEQ}.



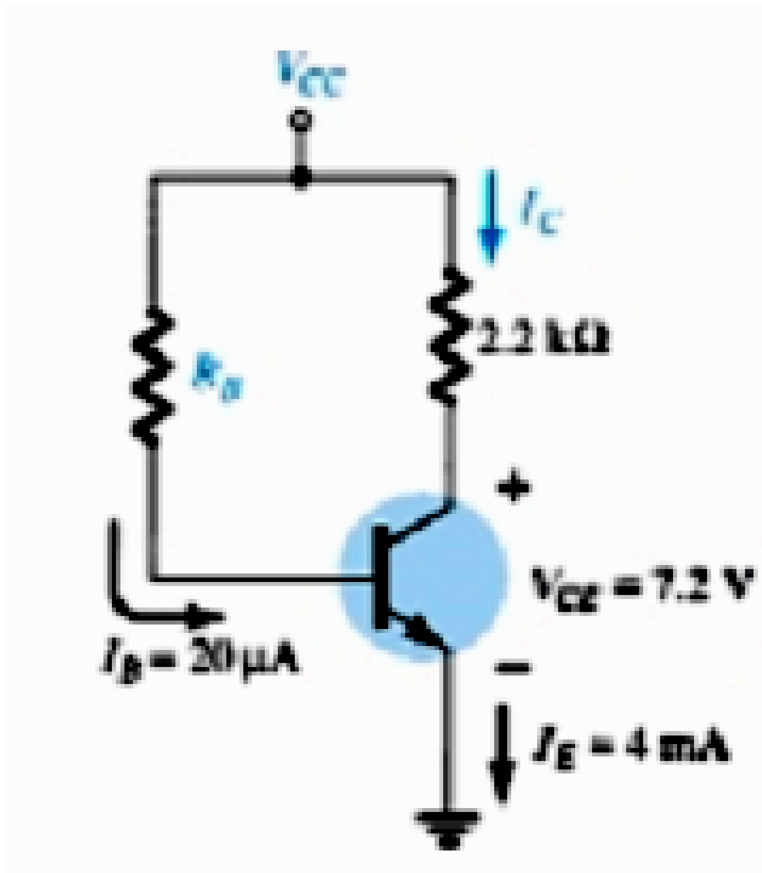
$$I_{B_Q} = \frac{V_{CC} - V_{BE}}{R_B} = \frac{12\text{ V} - 0.7\text{ V}}{240\text{ k}\Omega} = \mathbf{47.08\ \mu A}$$

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

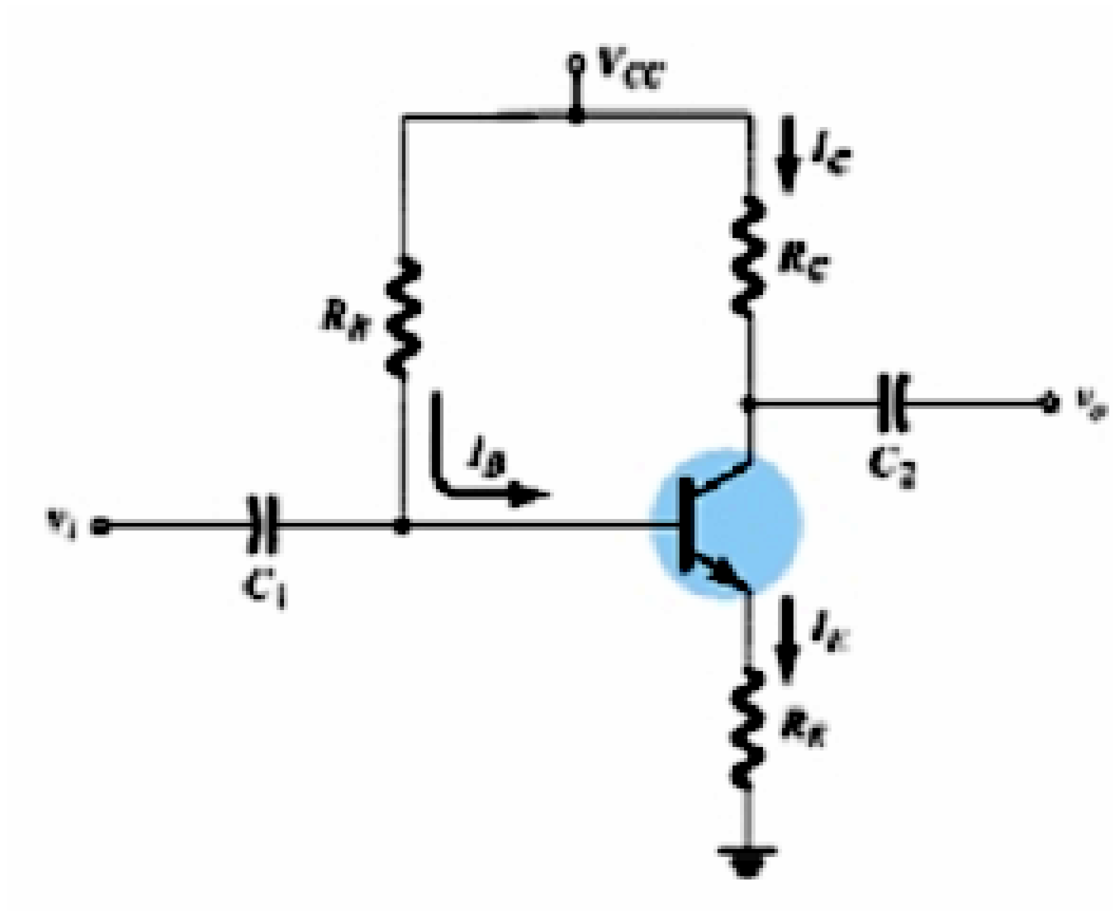
$$\begin{aligned} V_{CE_Q} &= V_{CC} - I_C R_C \\ &= 12\text{ V} - (2.35\text{ mA})(2.2\text{ k}\Omega) \\ &= \mathbf{6.83\ V} \end{aligned}$$

Seatwork:

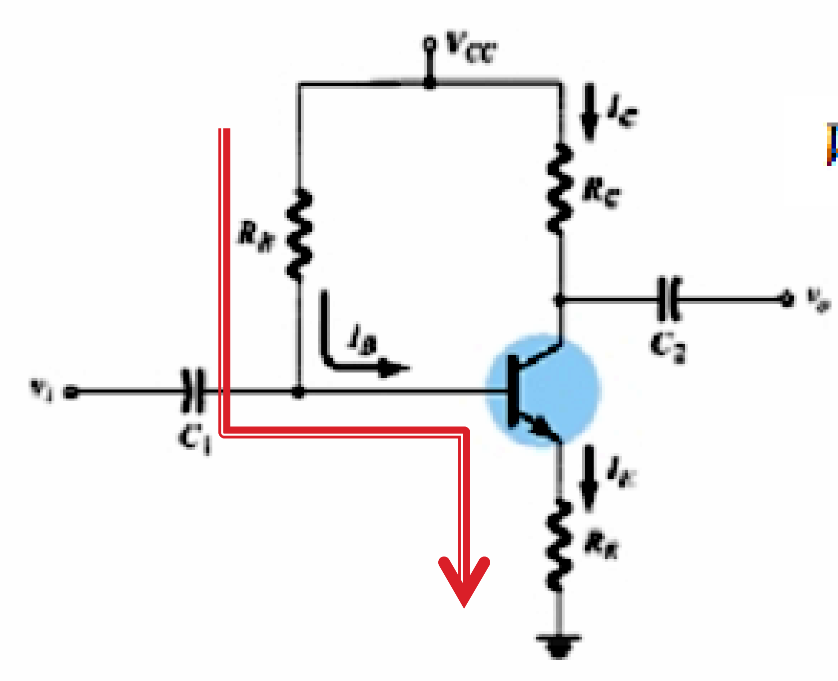
- Determine I_C, V_{CC}, β, and R_B.



Emitter-Stabilized Bias



Input Side



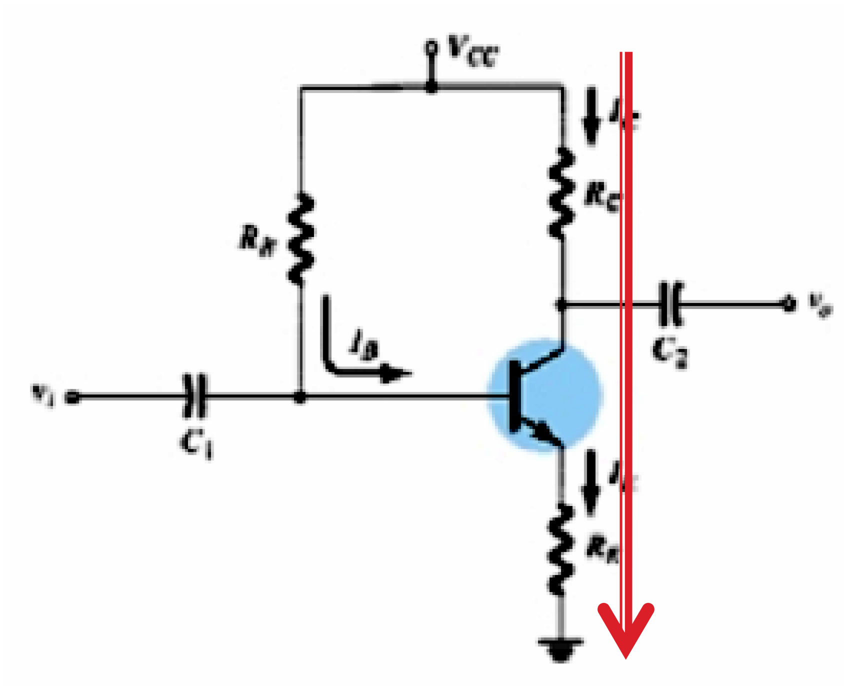
$$+V_{CC} - I_B R_B - V_{BE} - I_E R_E = 0$$

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

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

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

Output Side



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

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

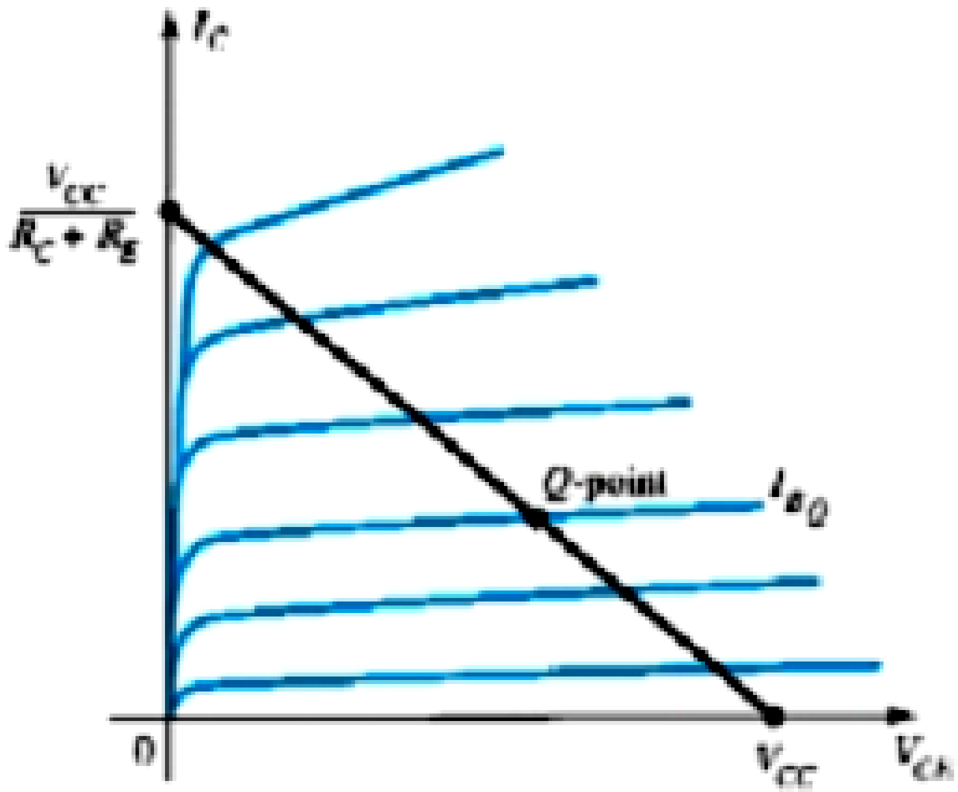
$$\boxed{V_E = I_E R_E}$$

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

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

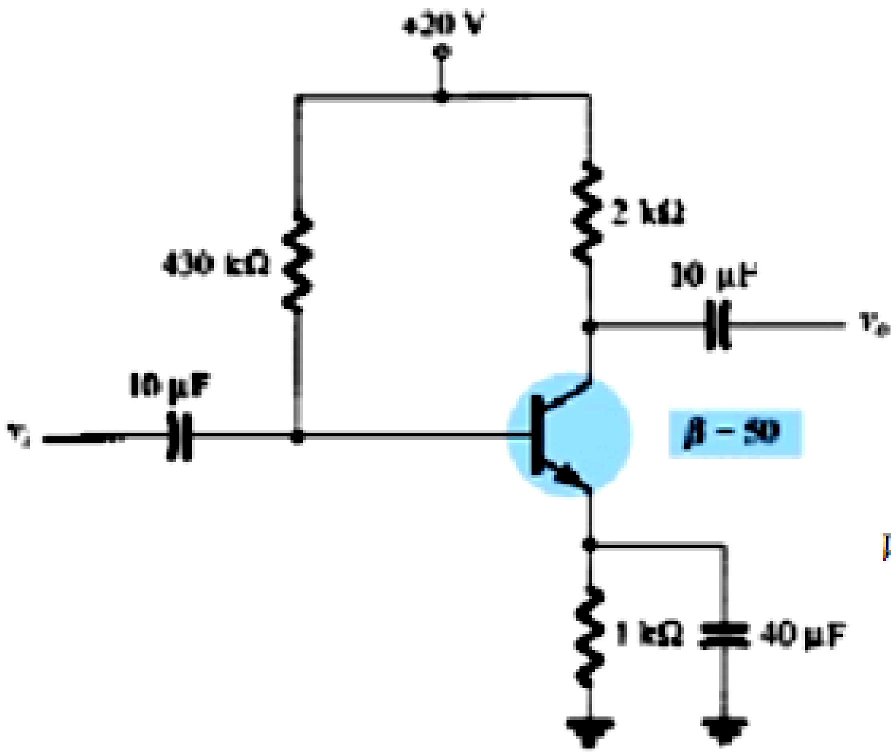
$$\boxed{V_C = V_{CC} - I_C R_C}$$

Loadline



Problem:

- Determine I_B, I_C, V_{CE} and V_C.



$$I_B = \frac{V_{CC} - V_{BE}}{R_B + (\beta + 1)R_E} = \frac{20\text{ V} - 0.7\text{ V}}{430\text{ k}\Omega + (51)(1\text{ k}\Omega)}$$

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

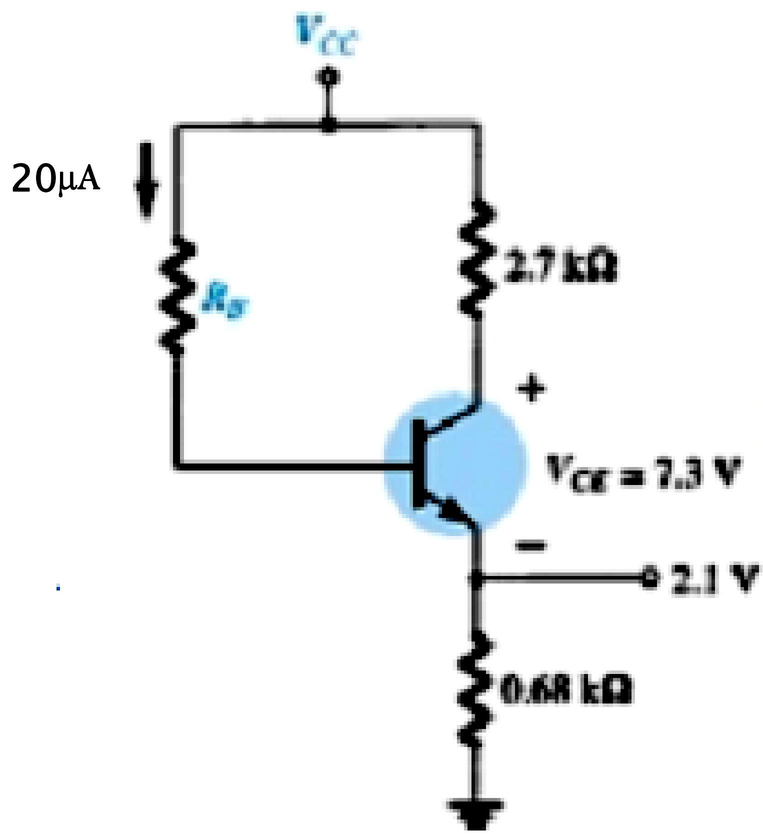
$$I_C = \beta I_B$$
$$= (50)(40.1\ \mu\text{A})$$
$$\cong \mathbf{2.01\ mA}$$

$$V_{CE} = V_{CC} - I_C(R_C + R_E)$$
$$= 20\text{ V} - (2.01\text{ mA})(2\text{ k}\Omega + 1\text{ k}\Omega) = 20\text{ V} - 6.03\text{ V}$$
$$= \mathbf{13.97\ V}$$

$$V_C = V_{CC} - I_C R_C$$
$$= 20\text{ V} - (2.01\text{ mA})(2\text{ k}\Omega) = 20\text{ V} - 4.02\text{ V}$$
$$= \mathbf{15.98\ V}$$

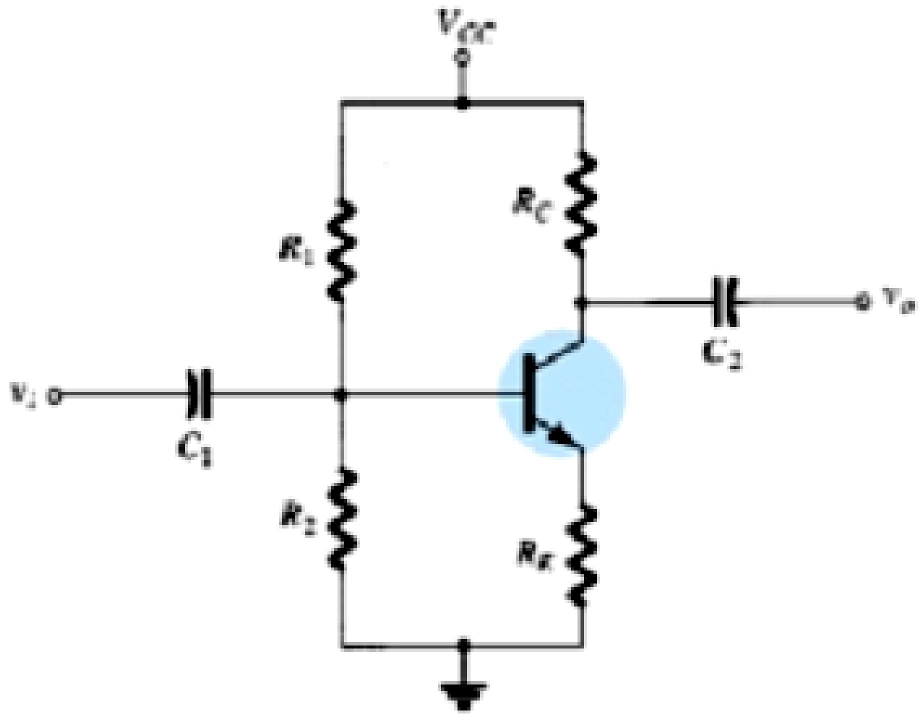
Seatwork:

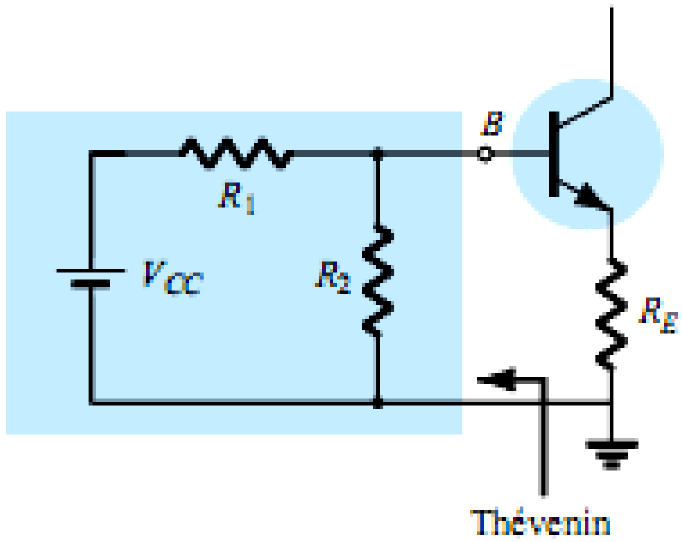
- Determine β, V_{CC} and R_B.



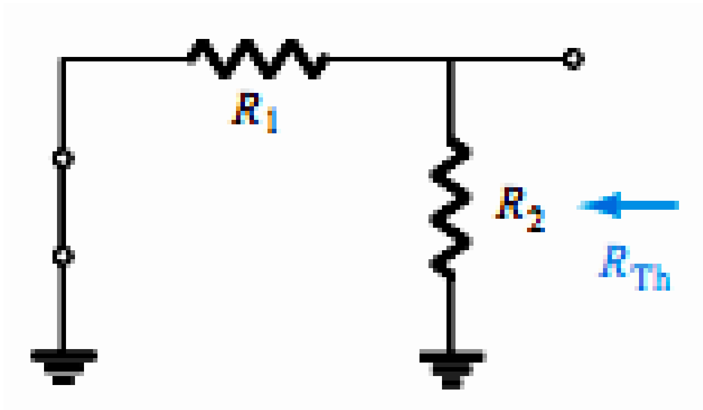
Voltage-Divider Bias

- Exact Analysis

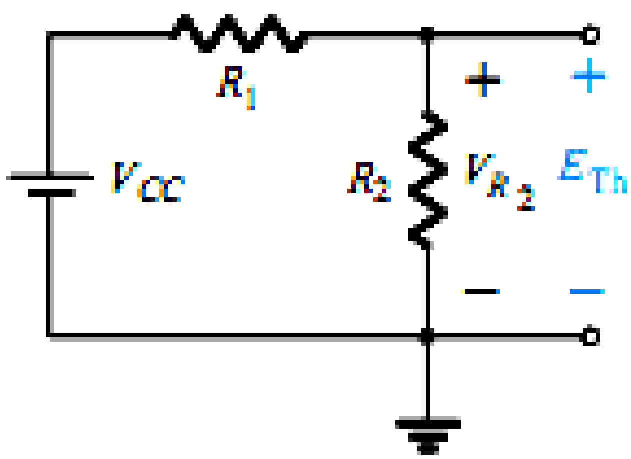




R_{Th} and E_{Th}

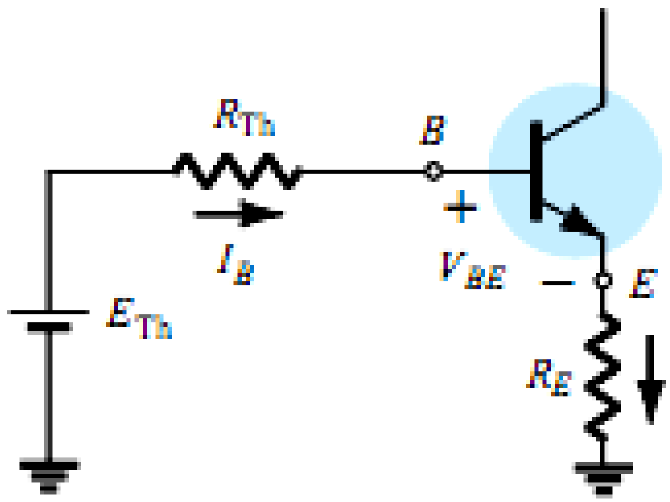


$$R_{Th} = R_1 \| R_2$$



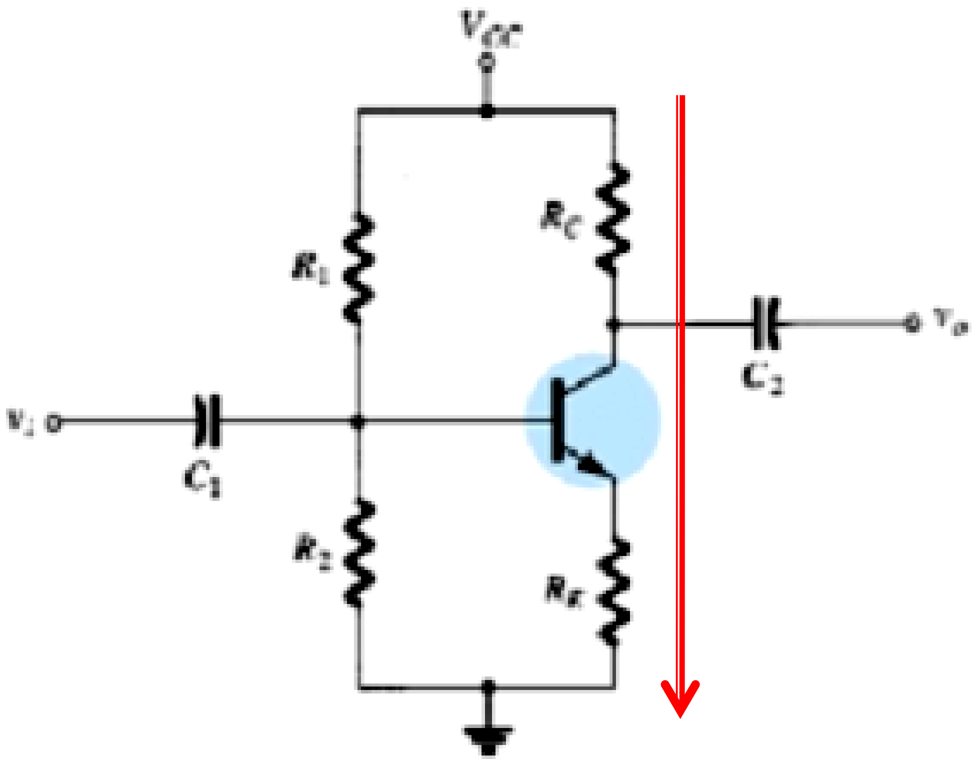
$$E_{Th} = V_{R_2} = \frac{R_2 V_{CC}}{R_1 + R_2}$$

Thevenin's Circuit



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

Output Side



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

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

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

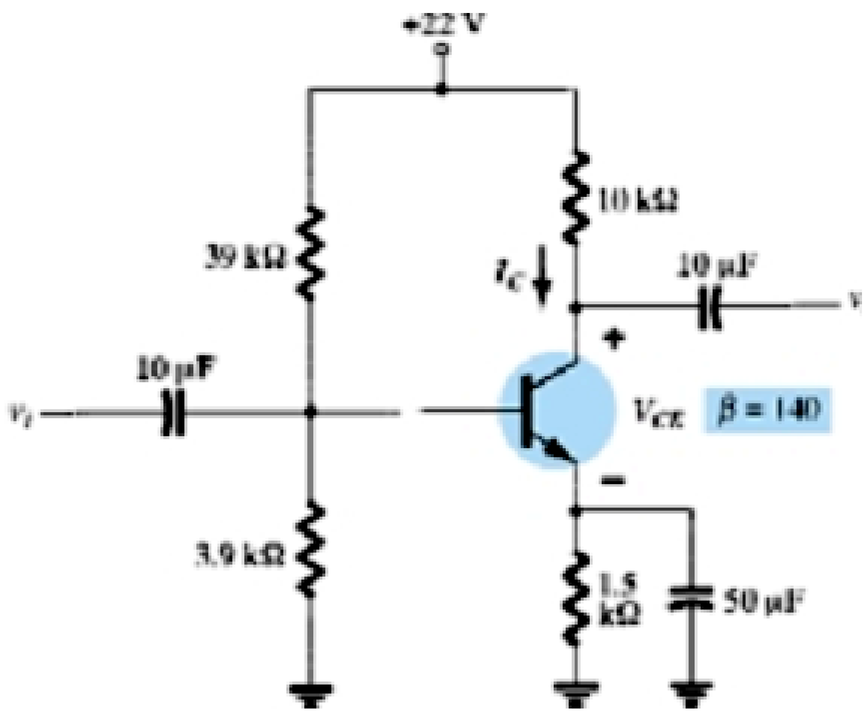
$$V_{CE} = V_C - V_E$$

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

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

Problem:

- Determine I_C and V_{CE}.



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

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

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

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

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

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

$$= 6.05\ \mu A$$

$$I_C = \beta I_B$$

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

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

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

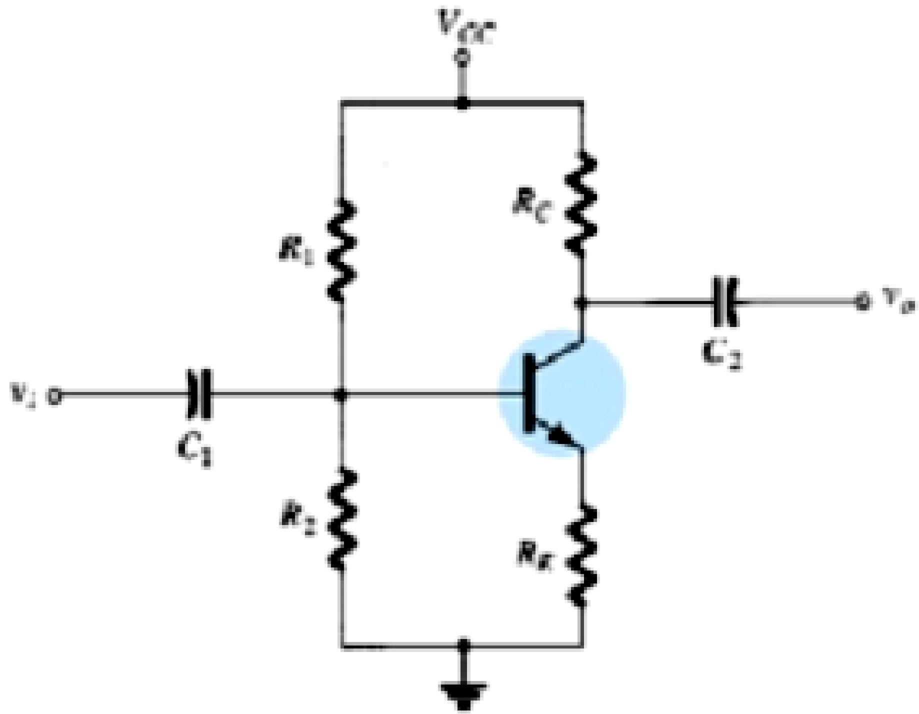
$$= 22\text{ V} - (0.85\text{ mA})(10\text{ k}\Omega + 1.5\text{ k}\Omega)$$

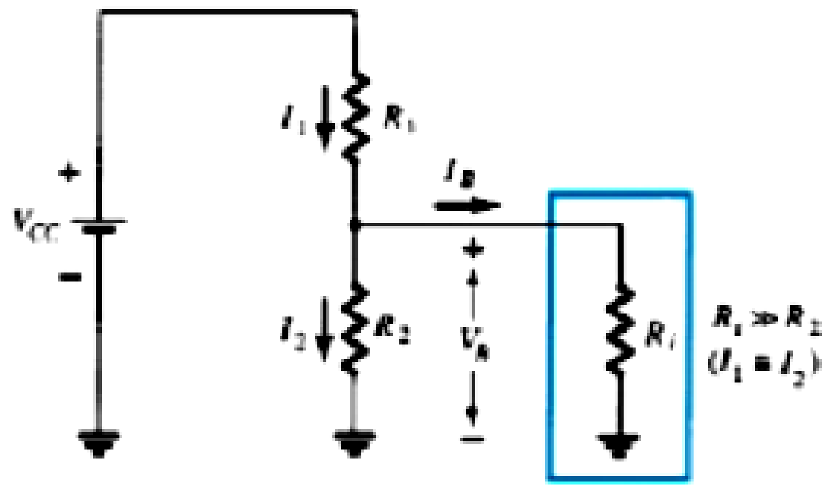
$$= 22\text{ V} - 9.78\text{ V}$$

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

Voltage-Divider Bias

- Approximate Analysis





$$\boxed{\beta R_E \geq 10R_2}$$

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

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

$$I_E = \frac{V_E}{R_E}$$

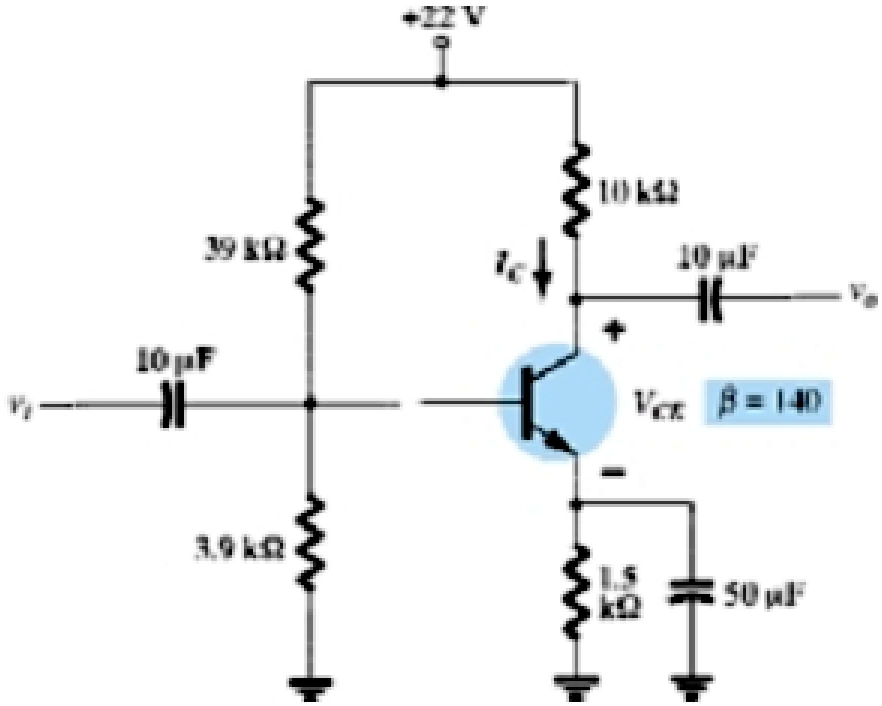
$$I_{C_Q} \cong I_E$$

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

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

Problem:

- Determine I_C and V_{CE}.



$$\beta R_E \geq 10R_2$$

$$(140)(1.5\ \text{k}\Omega) \geq 10(3.9\ \text{k}\Omega)$$

$$210\ \text{k}\Omega \geq 39\ \text{k}\Omega\ (\textit{satisfied})$$

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

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

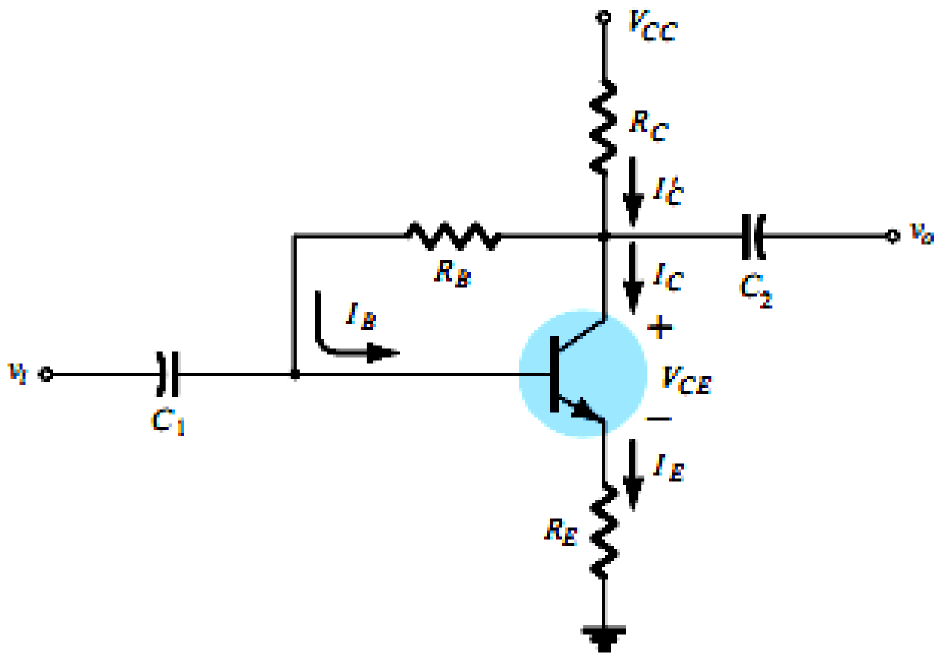
$$= 2\ \text{V}$$

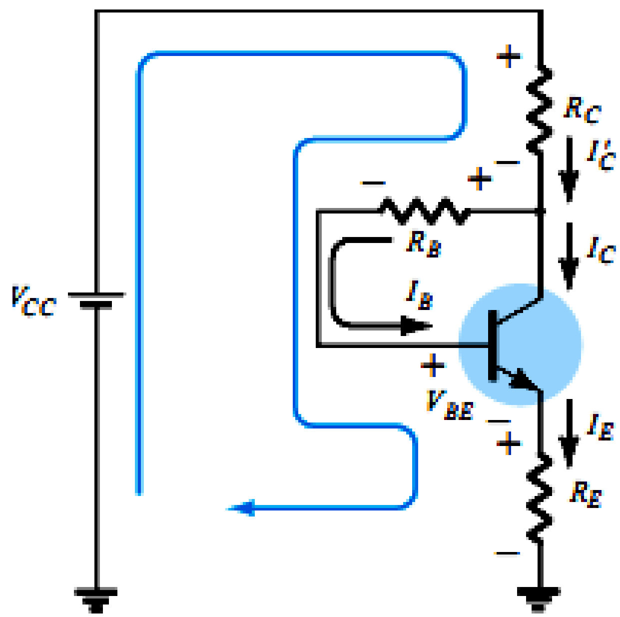
$$V_E = V_B - V_{BE}$$
$$= 2\text{ V} - 0.7\text{ V}$$
$$= 1.3\text{ V}$$

$$I_{CQ} \cong I_E = \frac{V_E}{R_E} = \frac{1.3\text{ V}}{1.5\text{ k}\Omega} = \mathbf{0.867\text{ mA}}$$

$$V_{CE_Q} = V_{CC} - I_C(R_C + R_E)$$
$$= 22\text{ V} - (0.867\text{ mA})(10\text{ kV} + 1.5\text{ k}\Omega)$$
$$= 22\text{ V} - 9.97\text{ V}$$
$$= \mathbf{12.03\text{ V}}$$

DC Bias with Voltage Feedback



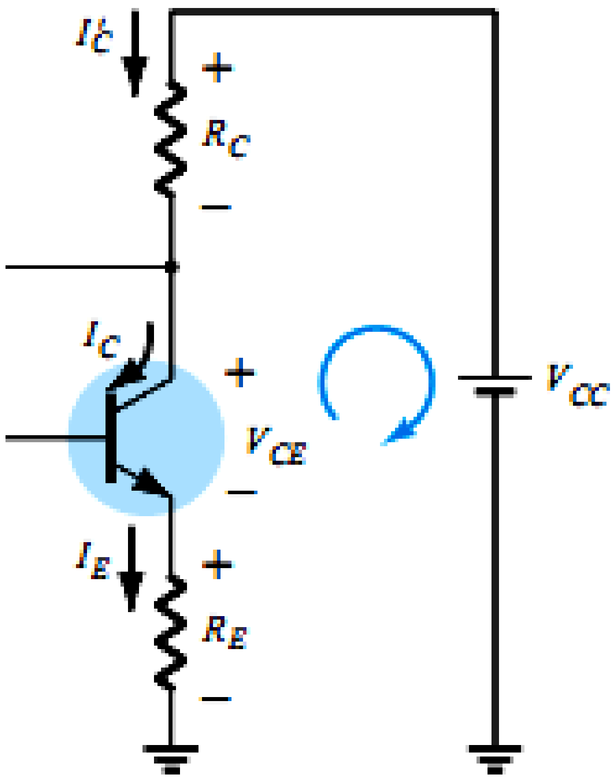


$$V_{CC} - I'_C R_C - I_B R_B - V_{BE} - I_E R_E = 0$$

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

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

Output Side



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

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

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

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

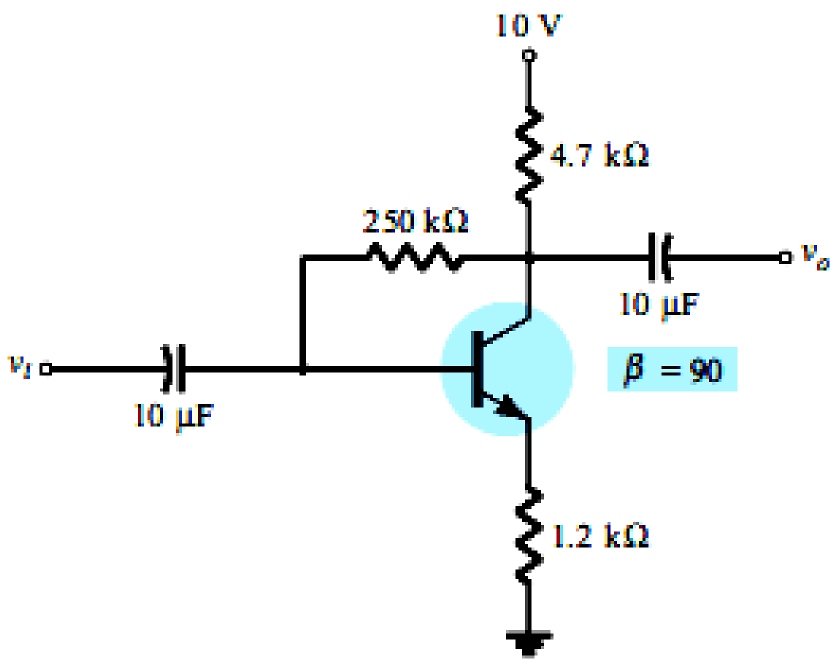
$$V_{CE} = V_C - V_E$$

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

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

Problem:

- Determine I_{CQ} and V_{CEQ}.



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

$$= \frac{10\text{ V} - 0.7\text{ V}}{250\text{ k}\Omega + (90)(4.7\text{ k}\Omega + 1.2\text{ k}\Omega)}$$

$$= \frac{9.3\text{ V}}{250\text{ k}\Omega + 531\text{ k}\Omega} = \frac{9.3\text{ V}}{781\text{ k}\Omega}$$

$$= 11.91\ \mu\text{A}$$

$$I_{C_Q} = \beta I_B = (90)(11.91\ \mu\text{A})$$

$$= \mathbf{1.07\ mA}$$

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

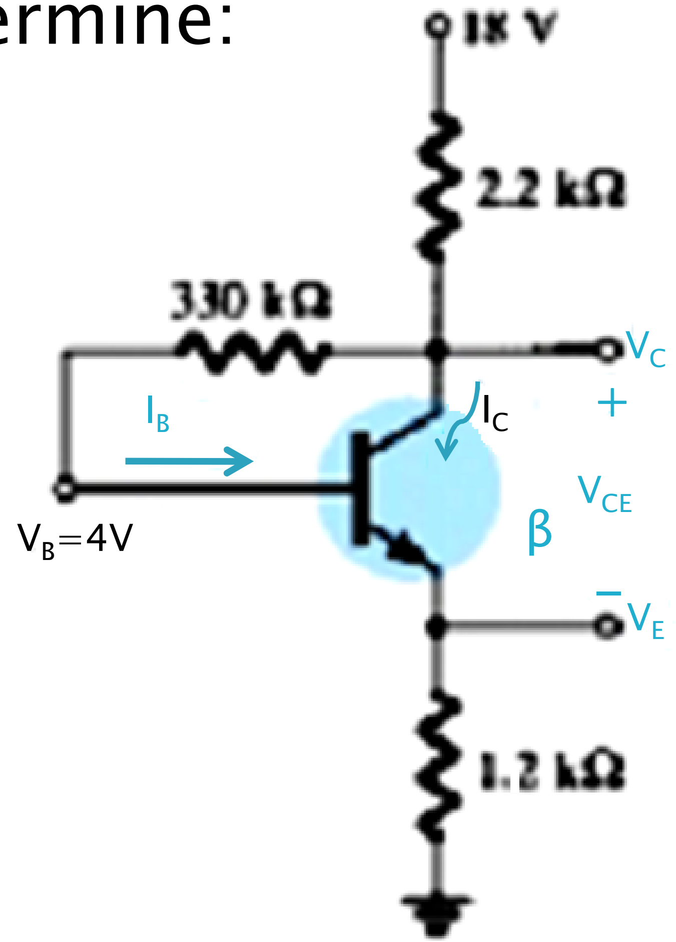
$$= 10\text{ V} - (1.07\text{ mA})(4.7\text{ k}\Omega + 1.2\text{ k}\Omega)$$

$$= 10\text{ V} - 6.31\text{ V}$$

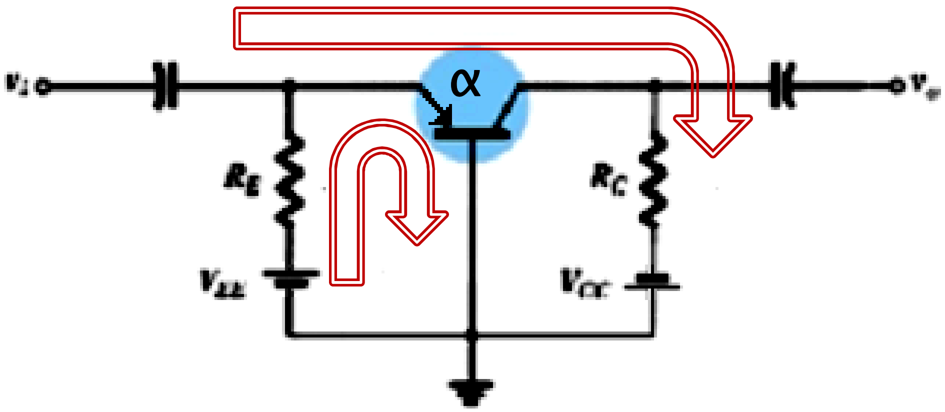
$$= \mathbf{3.69\ V}$$

Seatwork:

- Given $V_B = 4V$, determine:
  - V_E
  - I_C
  - V_{CE}
  - I_B



Common-Base Bias



$$V_{EE} - I_E R_E - V_{EB} = 0$$

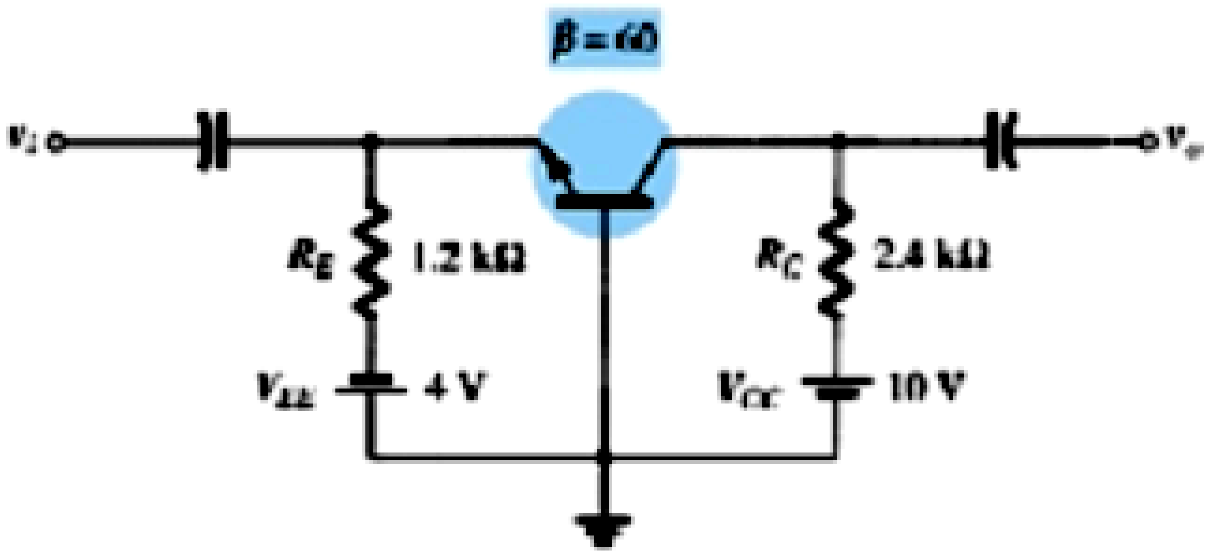
$$I_E = \frac{V_{EE} - V_{EB}}{R_E}$$

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

$$V_{EC} = V_{EE} + V_{CC} - I_E R_E - I_C R_C$$

Problem:

- Determine V_{CB} and I_B.



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

$$V_{CB} = V_{CC} - I_C R_C \text{ with } I_C \cong I_E$$

$$= 10\text{ V} - (2.75\text{ mA})(2.4\text{ k}\Omega)$$

$$= \mathbf{3.4\text{ V}}$$

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

$$= \frac{2.75\text{ mA}}{60}$$

$$= \mathbf{45.8\ \mu A}$$

$$-V_{EE} + I_E R_E + V_{BE} = 0$$

$$I_E = \frac{V_{EE} - V_{BE}}{R_E} \qquad I_E = \frac{4\text{ V} - 0.7\text{ V}}{1.2\text{ k}\Omega} = 2.75\text{ mA}$$

Seatwork:

- Find V_C if $RE=1k\Omega$, $R_C=5k\Omega$, $V_{EE}=2V$, $V_{CC}=8V$ and $\alpha=0.98$.