Analog Electronics
ENEE236

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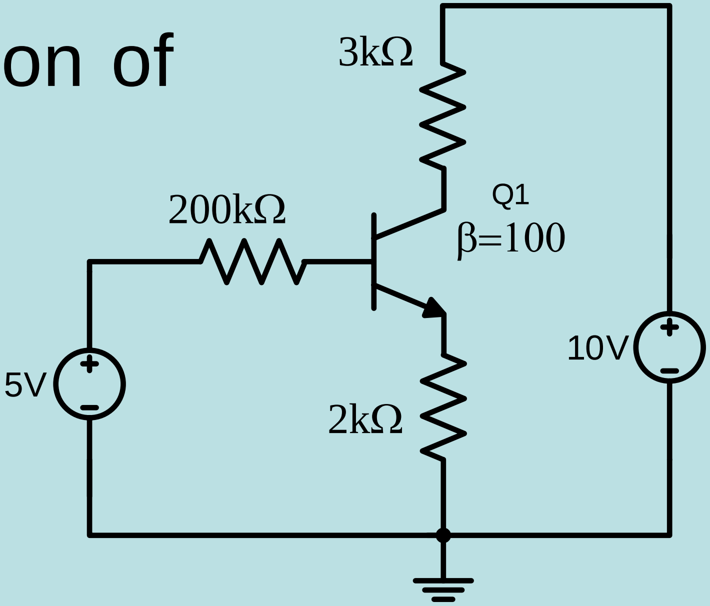
L8- DC Biasing - BJTs

Example

- Assume $V_{CE(sat)}$=0.2 V
- Find mode of operation of Q1 ?



Determine Mode of Operation of BJT?

- Solution:
- 1) Since BE junction is forward biased ==> Q1 can be either in Active (Linear) or Saturation mode
- Assume it is in Active Mode

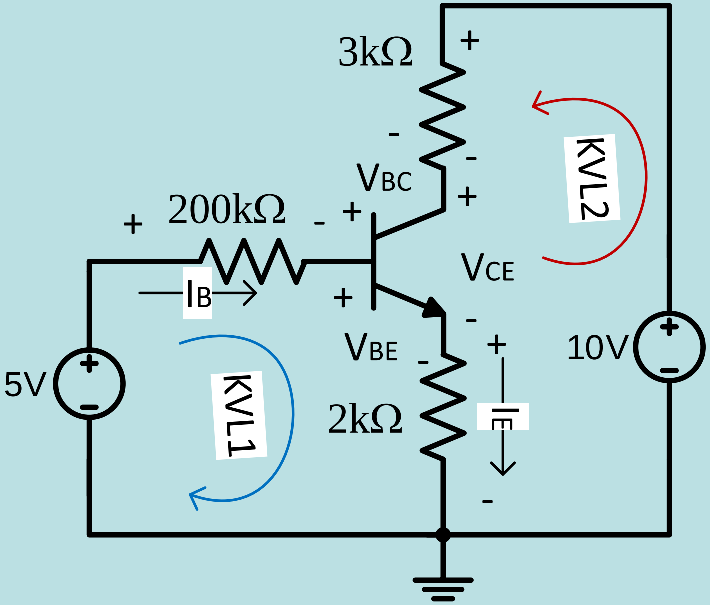
$$5 = 200\ \text{k}\Omega\,.\,I_B + V_{BE} + 2\ \text{k}\Omega.\,I_E$$

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

$$\text{Solve for } I_B = \frac{5 - V_{BE}}{200\ \text{k}\Omega + (1+\beta).\,2\ \text{k}\Omega}$$

$$I_B = \frac{5 - 0.7}{200\ \text{k}\Omega + (1+100).\,2\ \text{k}\Omega}$$

$$= \frac{4.3\ \text{V}}{402\ \text{k}\Omega} = 10.7\ \ \mu\text{A}$$



$$I_C = \beta I_B$$

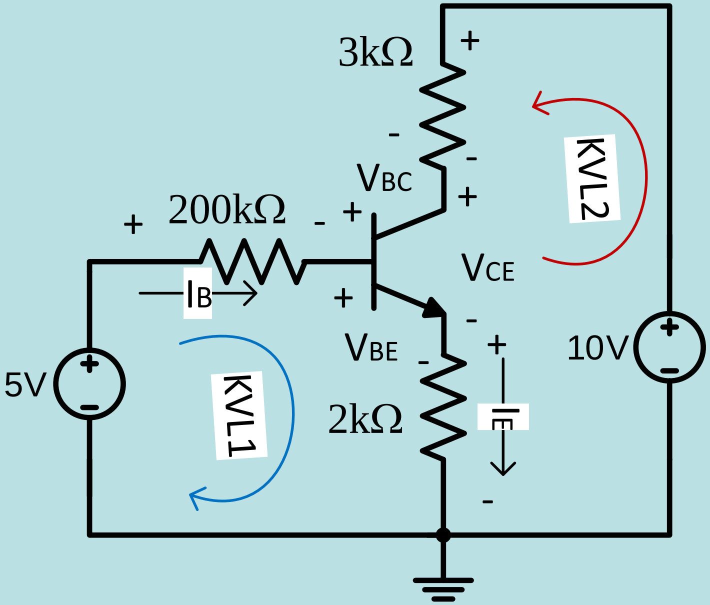
$$= (100).(10.7\,\mu A)$$

$$= 1.07\ \ mA$$

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

$$= 1.0807\ mA$$

Now we find V_{CE} from output circuit



$$10 - I_C\ .3\ k\Omega - I_E\ .2\ k\Omega = V_{CE}$$

$$\Rightarrow V_{CE} = 4.63\ V > V_{CE(sat)}$$

$\therefore$ Q1 is in active mode and the assumption is true

we can also verify that the BC junction is reverse

biassed which is required so that the BJT operates

in active mode

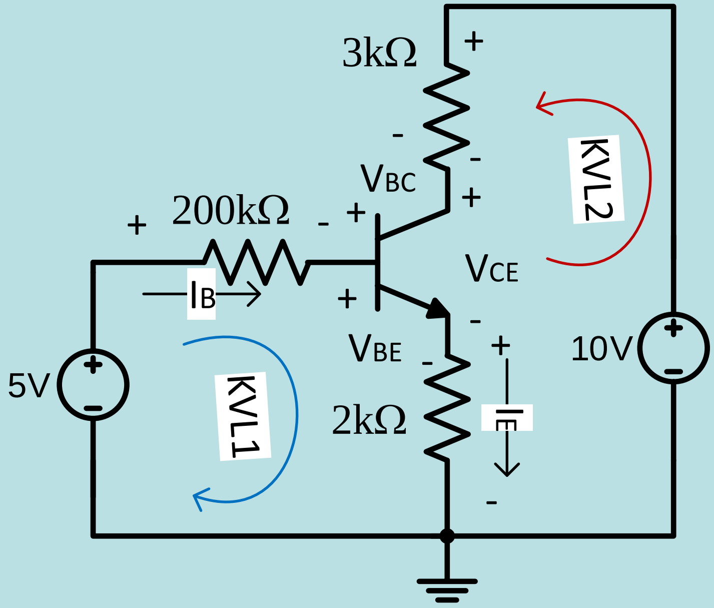
$$10 - I_C\,.3\,k\Omega - I_E\,.2\,k\Omega = V_{CE}$$

$$\Rightarrow V_{CE} = V_{CB} - V_{EB}$$

$$\Rightarrow V_{CB} = V_{CE} - V_{BE} = 4.63 - 0.7 = 3.93\,V$$

$$\therefore V_{BC} = -V_{CB} = -3.33\,V$$

BC junction is reverse biased



- Solution:
- 1) Since BE junction is forward biased ==> Q1 can be either in Active (Linear) or Saturation mode
- Assume it is in saturation mode:

$$10 - I_{C(sat)} .3k\Omega - I_{E(sat)} .2k\Omega = V_{CE(Sat)}$$

$$\text{assume} \quad I_{E(sat)} = I_{C(sat)}$$

$$\therefore I_{C(sat)} = \frac{10 - 0.2}{5k\Omega} = 1.96 \ \text{mA}$$

$$I_{B(min)} = \frac{I_{C(sat)}}{\beta} = 19.6 \ \mu\text{A}$$

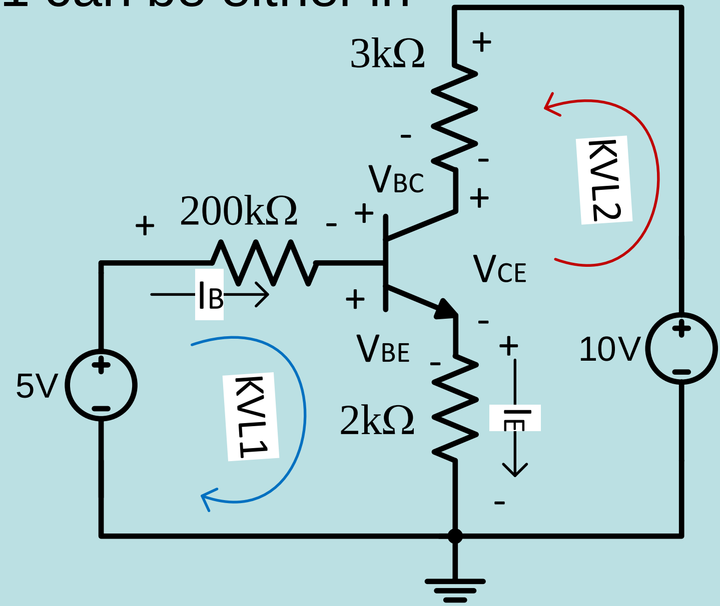
Now we find the actual value of IB

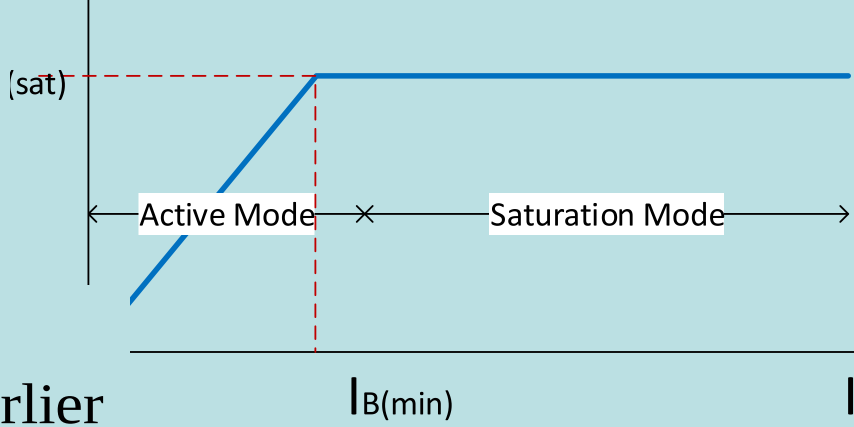
$I_{B(actual)} = 10.7\ \mu\text{A}$ (it was found previously)

since

$I_{B(actual)} < I_{B(sat)} \Rightarrow$ the assumption made earlier that BJT in saturation mode is wrong ,

and actually it is in active mode



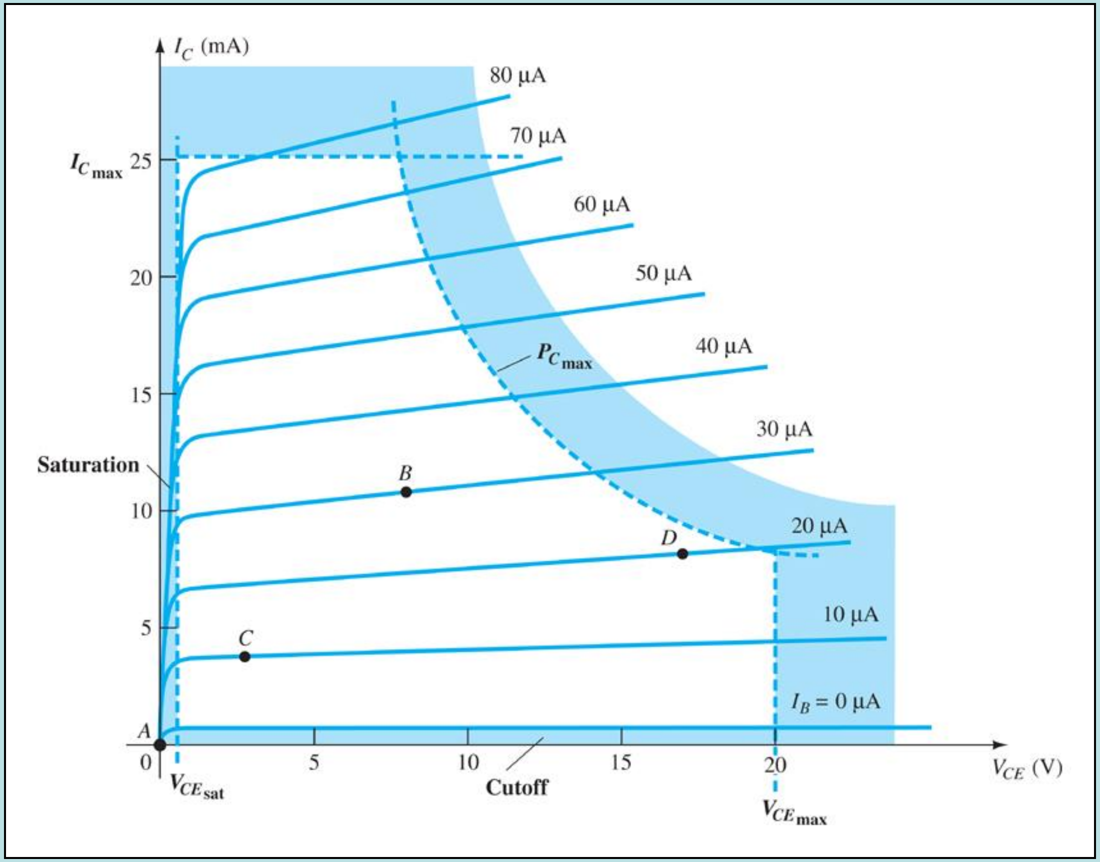


Biasing

Biasing: Applying DC voltages to a transistor in order to establish fixed level of voltage and current, for Amplifier mode, the resulting dc voltage and current establish the operation point to turn it on so that it can amplify AC signals.

Operating Point

The DC input establishes an operating or *quiescent point* called the ***Q-point***.



The Three Operating Regions

Active or Linear Region Operation

- Base–Emitter junction is forward biased
- Base–Collector junction is reverse biased

Cutoff Region Operation

- Base–Emitter junction is reverse biased

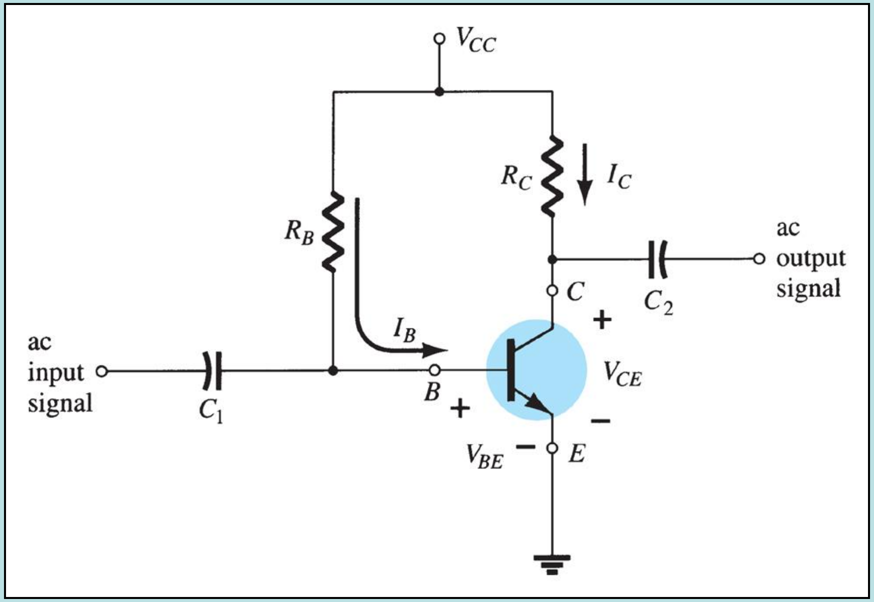
Saturation Region Operation

- Base–Emitter junction is forward biased
- Base–Collector junction is forward biased

DC Biasing Circuits

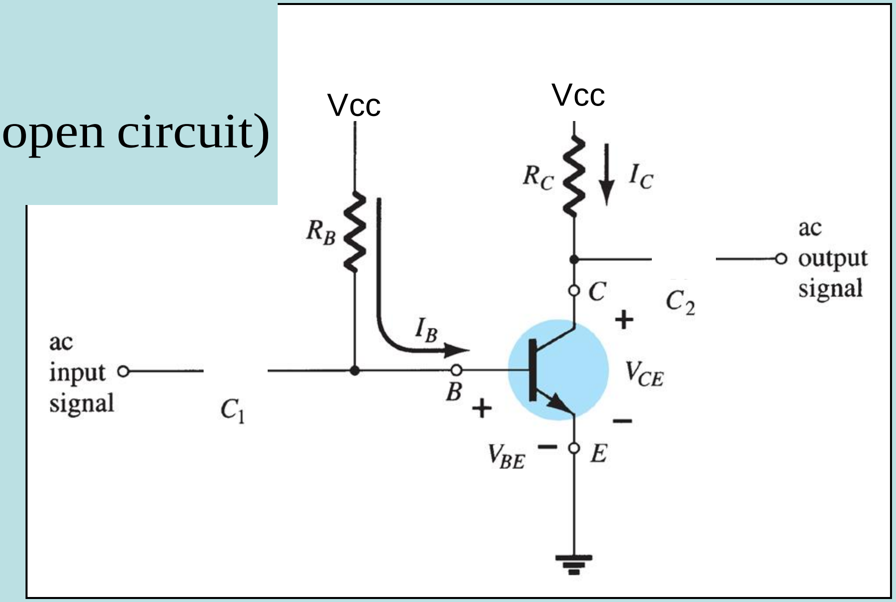
- Fixed-bias circuit
- Emitter-stabilized bias circuit
- Collector-emitter loop
- Voltage divider bias circuit
- DC bias with voltage feedback

1)Fixed Bias Configuration



DC equivalent circuit

$$f = 0 \Rightarrow Xc = \frac{1}{2\pi f C} \cong \infty \text{ (open circuit)}$$



The Base-Emitter Loop

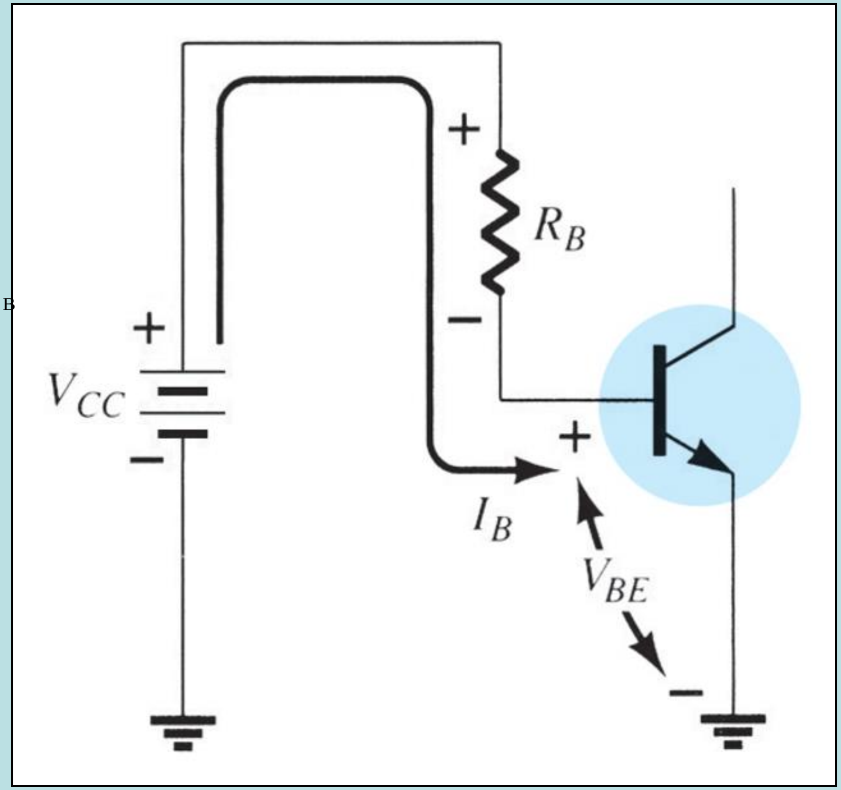
From Kirchhoff’s voltage law for Input:

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

Solving for base current:

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

Choosing R_B will establish the required level of I_B



Collector-Emitter Loop

Collector current:

$$I_C = \beta I_B$$

From Kirchhoff's voltage law:

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

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

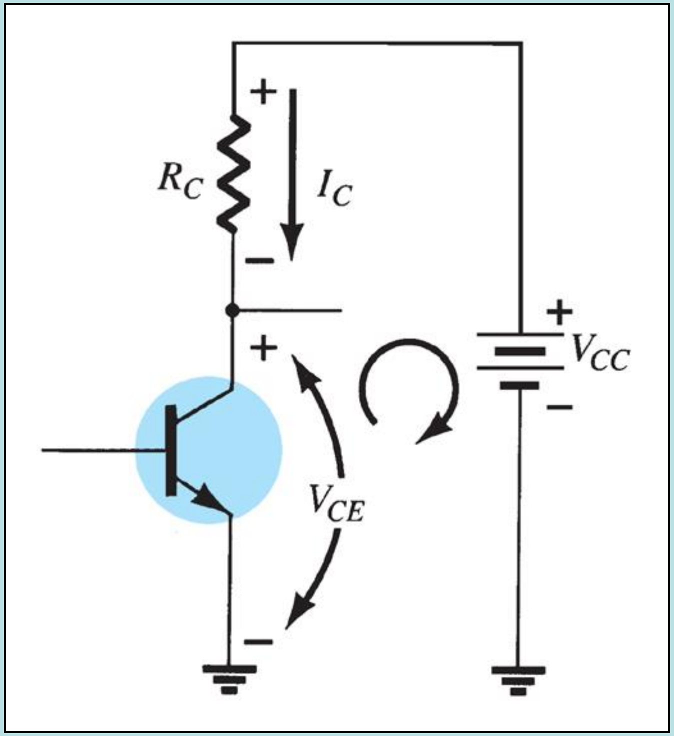
Since $V_E = 0$

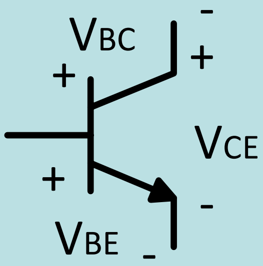
$$\therefore V_{CE} = V_C$$

Also

$$V_{BE} = V_B -$$

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





$$V_{BE} - V_{CE} - V_{BC} = 0$$

$$\therefore V_{BC} = V_{BE} - V_{CE}$$

Saturation

When the transistor is operating in **saturation**, current through the transistor is at its *maximum* possible value.

$$I_{Csat} = \frac{V_{CC}}{R_C}$$

$$V_{CE} \cong 0\ V$$

Load Line Analysis

The load line end points are:

I_{Csat}

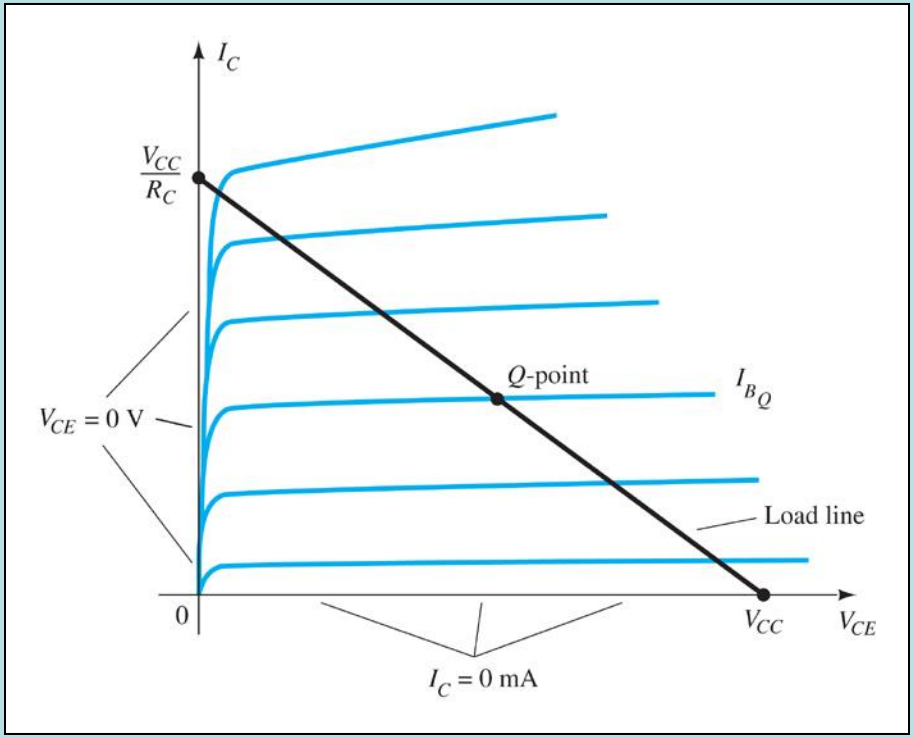
$I_C = V_{CC} / R_C$

$V_{CE} = 0$ V

$V_{CEcutoff}$

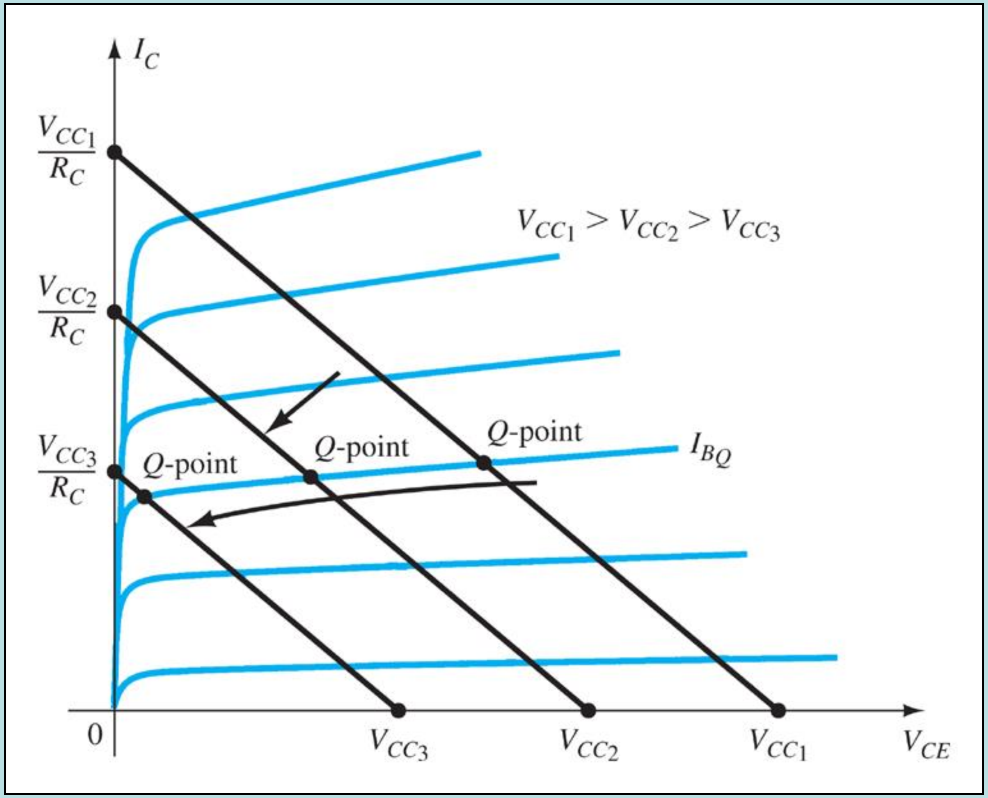
$V_{CE} = V_{CC}$

$I_C = 0$ mA

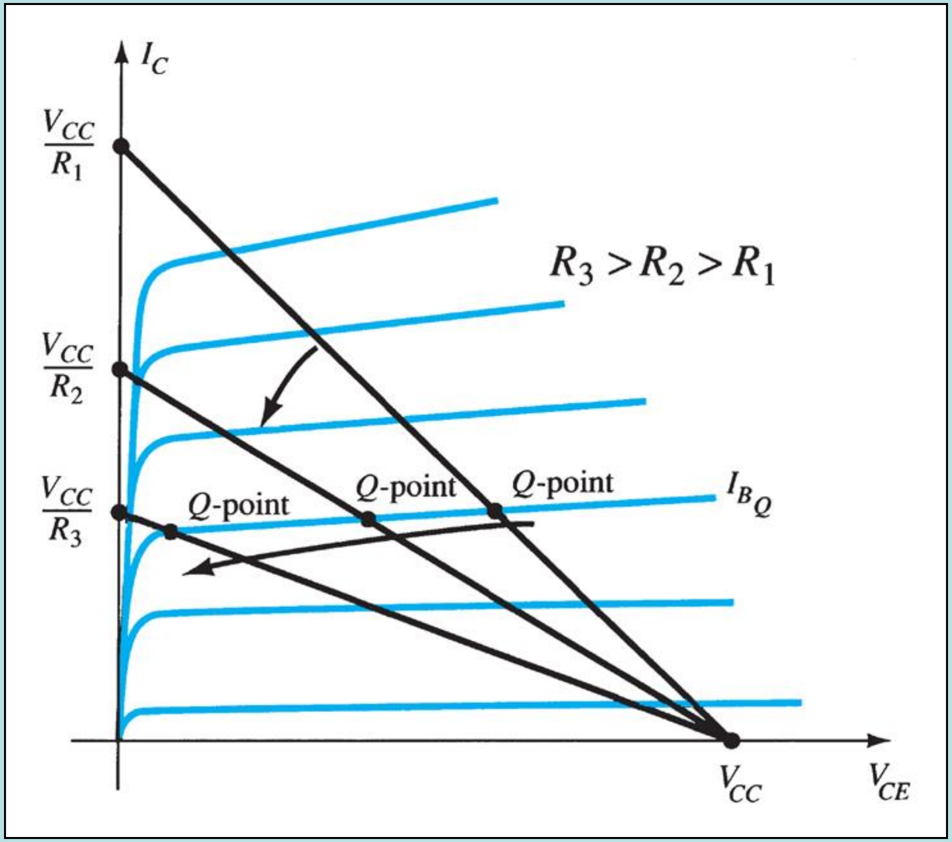


The *Q*-point is the operating point where the value of R_B sets the value of I_B that controls the values of V_{CE} and I_C .

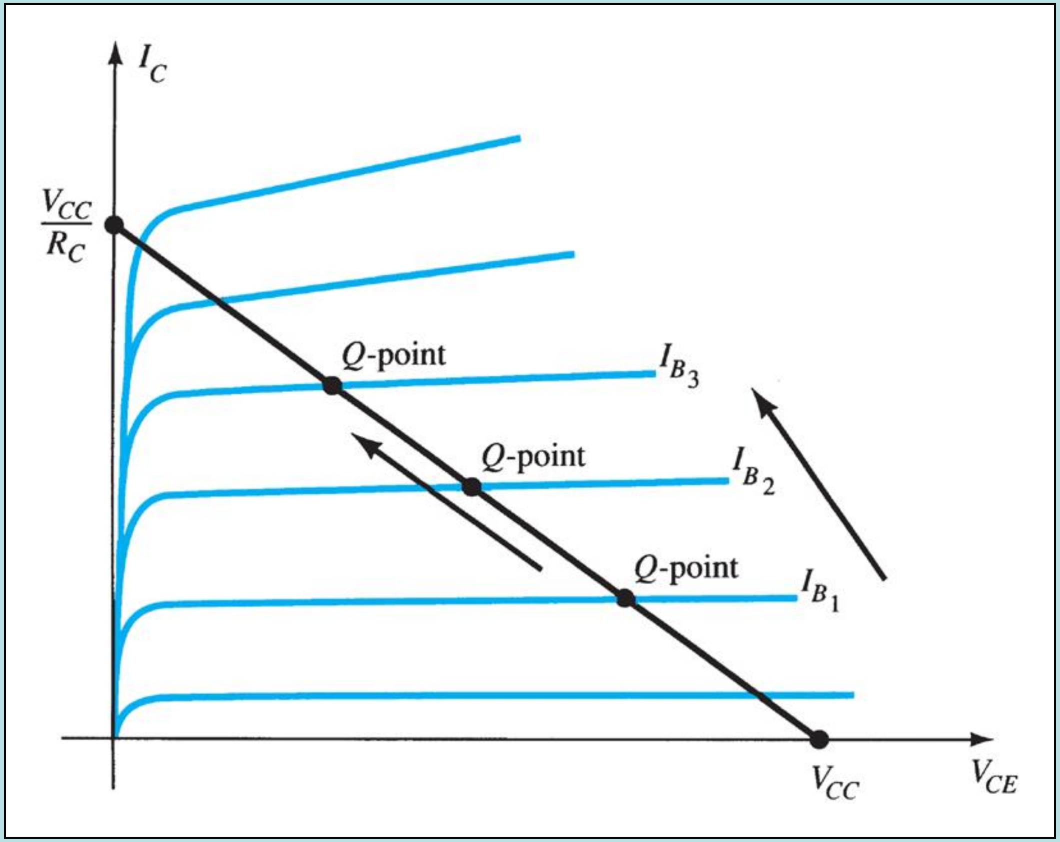
The Effect of V_{CC} on the Q-Point



The Effect of R_C on the Q-Point



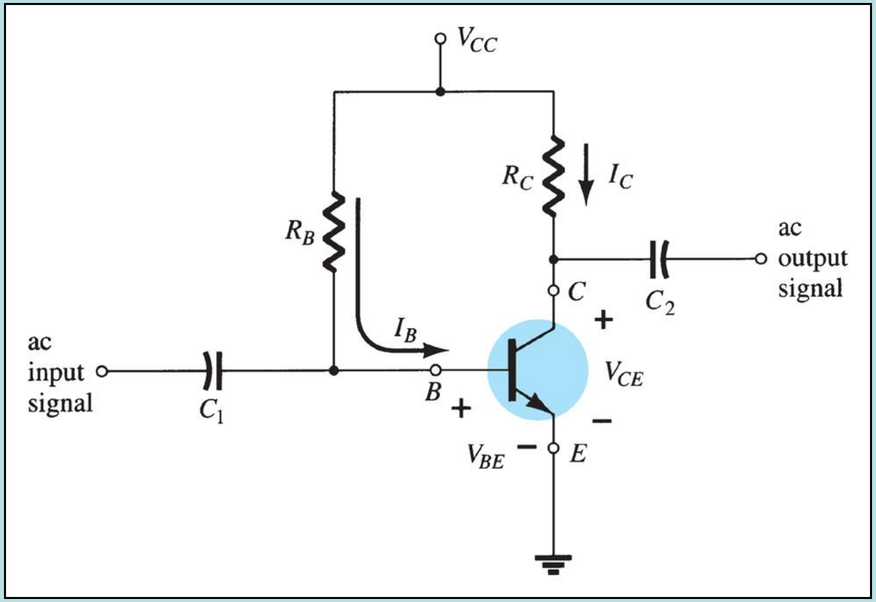
The Effect of I_B on the Q-Point



Design: Fixed bias

$$\text{Assume VCC} = 10\text{V}, \beta_{\text{nominal}} = 100, \beta_{\min} = 50, \beta_{\max} = 150$$

$$\text{Design for Q-point}: V_{CEQ} = 5\text{V}, I_{CQ} = 1\text{mA}$$



Solution

$$I_{BQ} = \frac{I_{CQ}}{\beta_{\text{nominal}}} = \frac{1\,\text{mA}}{100} = 10\,\mu\text{A}$$

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

$$R_B = \frac{V_{CC} - V_{BE}}{I_B} = \frac{10 - 0.7}{10\,\mu\text{A}}$$

$$= 930\,\text{k}\Omega$$

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

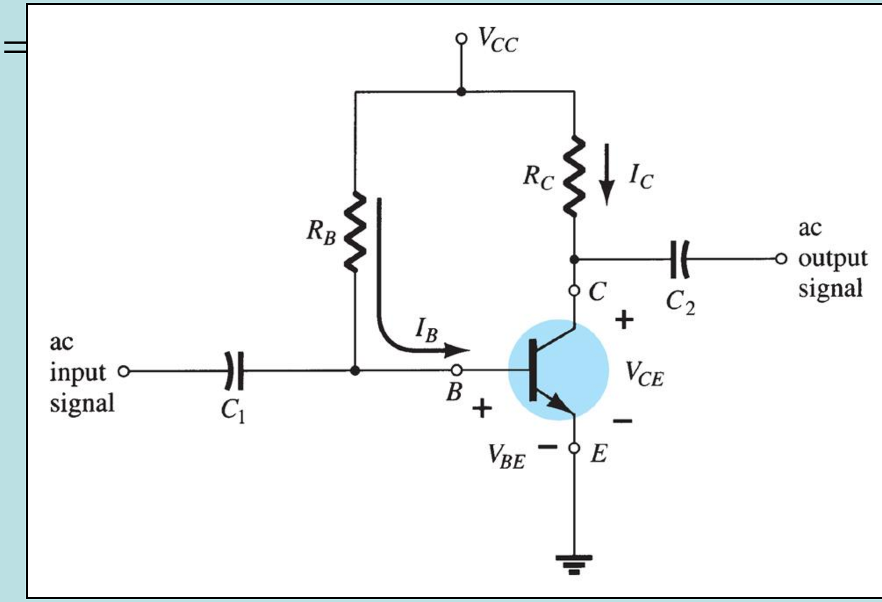
$$V_{CEQ} = 5 = 10 - I_C R_C$$

$$\therefore\ R_C = \frac{5}{1\,\text{mA}} = 5\,\text{k}\Omega$$

Fixed bias Stability

Assume $\text{VCC} = 10\text{V}, \beta_{\text{nominal}} = 100, \beta_{\min} = 50, \beta_{\max} =$

Design for Q - point : $V_{CEQ} = 5\text{V}, I_{CQ} = 1\text{mA}$



Solution

$$\text{If } \beta = \beta_{\min} = 50$$

$$I_B = 10\,\mu\text{A}$$

$$I_C = \beta I_B = (50)(10\,\mu\text{A}) = 0.5\,\text{mA}$$

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

$$V_{CEQ} = 10 - (0.5\,\text{mA})(5\,\text{k}\Omega) = 7.5\,\text{V}$$

$$\text{If } \beta = \beta_{\max} = 150$$

$$I_B = 10\,\mu\text{A}$$

$$I_C = \beta I_B = (150)(10\,\mu\text{A}) = 1.5\,\text{mA}$$

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

$$V_{CEQ} = 10 - (1.5\,\text{mA})(5\,\text{k}\Omega) = 2.5\,\text{V}$$

for

$$50 \le \beta \le 150$$

$$I_B = 10\,\mu\text{A} \ \text{ fixed}$$

$$0.5\,\text{mA} \le I_C \le 1.5\,\text{mA}$$

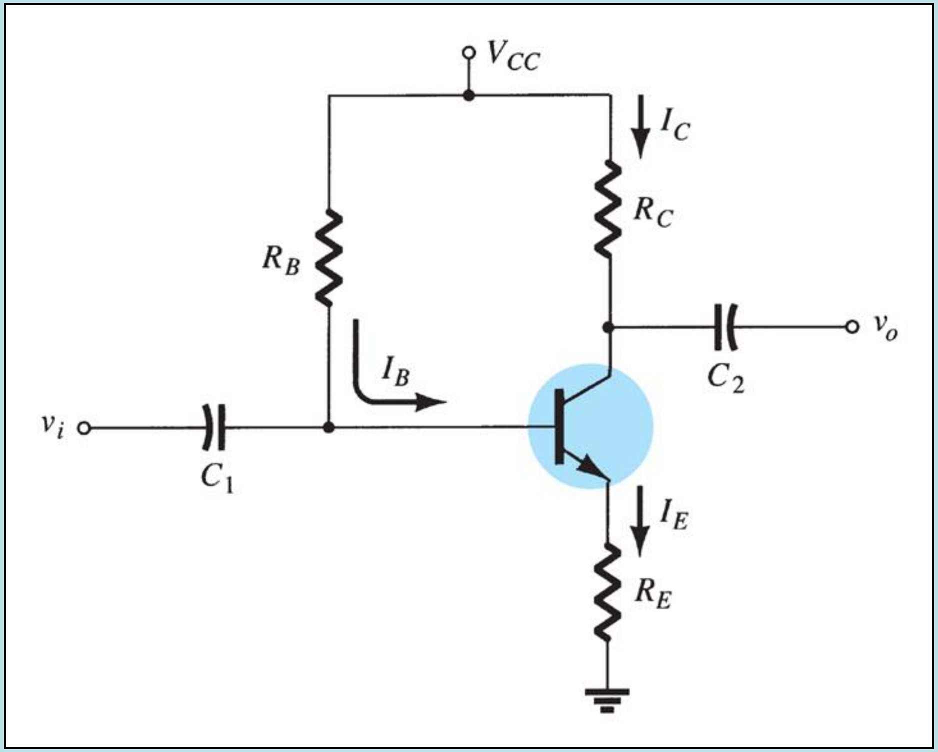
$$7.5\,\text{V} \ge V_{CE} \ge 2.5\,\text{V}$$

$$\therefore \frac{I_{C(\max)}}{I_{C(\min)}} = \frac{1.5\,\text{mA}}{0.5\,\text{mA}} = 3$$

Not very stable

Emitter-Stabilized Bias Circuit

Adding a resistor (R_E) to the emitter circuit stabilizes the bias circuit.



Base-Emitter Loop

From Kirchhoff’s voltage law:

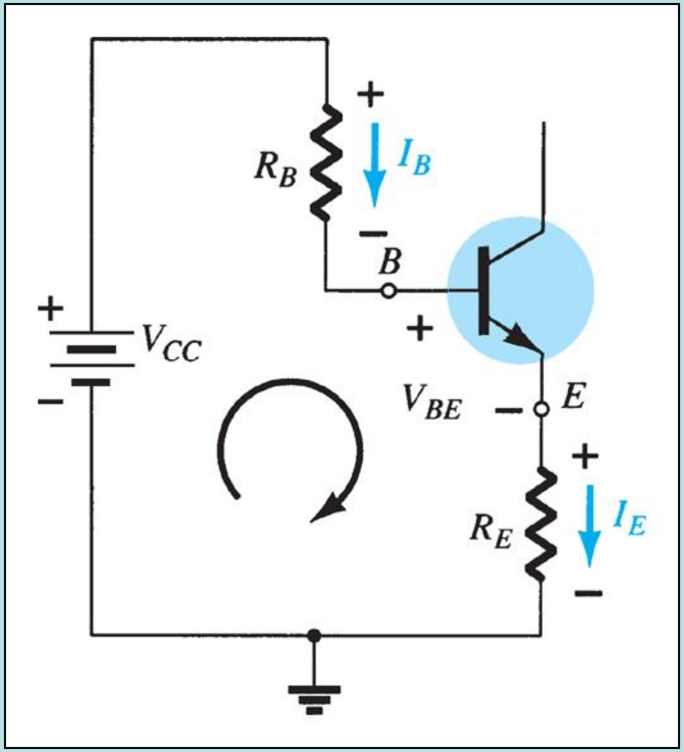
$$+V_{CC} - I_E R_E - V_{BE} - I_E R_E \; = \; 0$$

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

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

Solving for I_B:

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



Collector-Emitter Loop

From Kirchhoff’s voltage law:

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

Since $I_E \cong I_C$:

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

Also:

$$V_E = I_E R_E$$

$$V_C = V_{CE} + V_E = V_{CC} - I_C R_C$$

$$V_B = V_{CC} - I_R R_B = V_{BE} + V_E$$