

Lecture 05

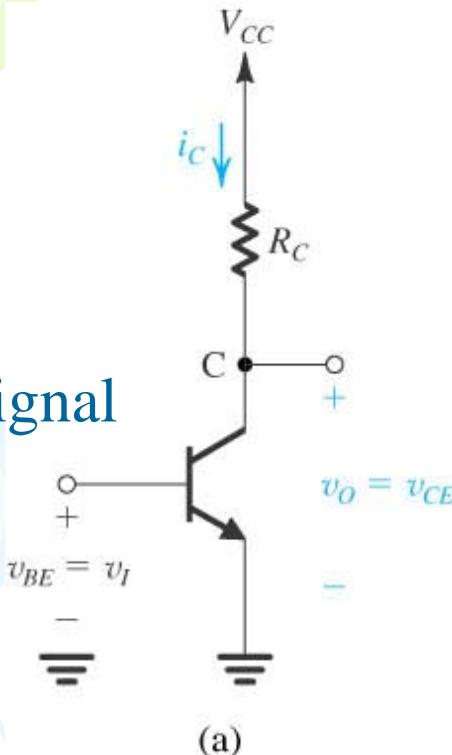
BJTs Circuits



topics

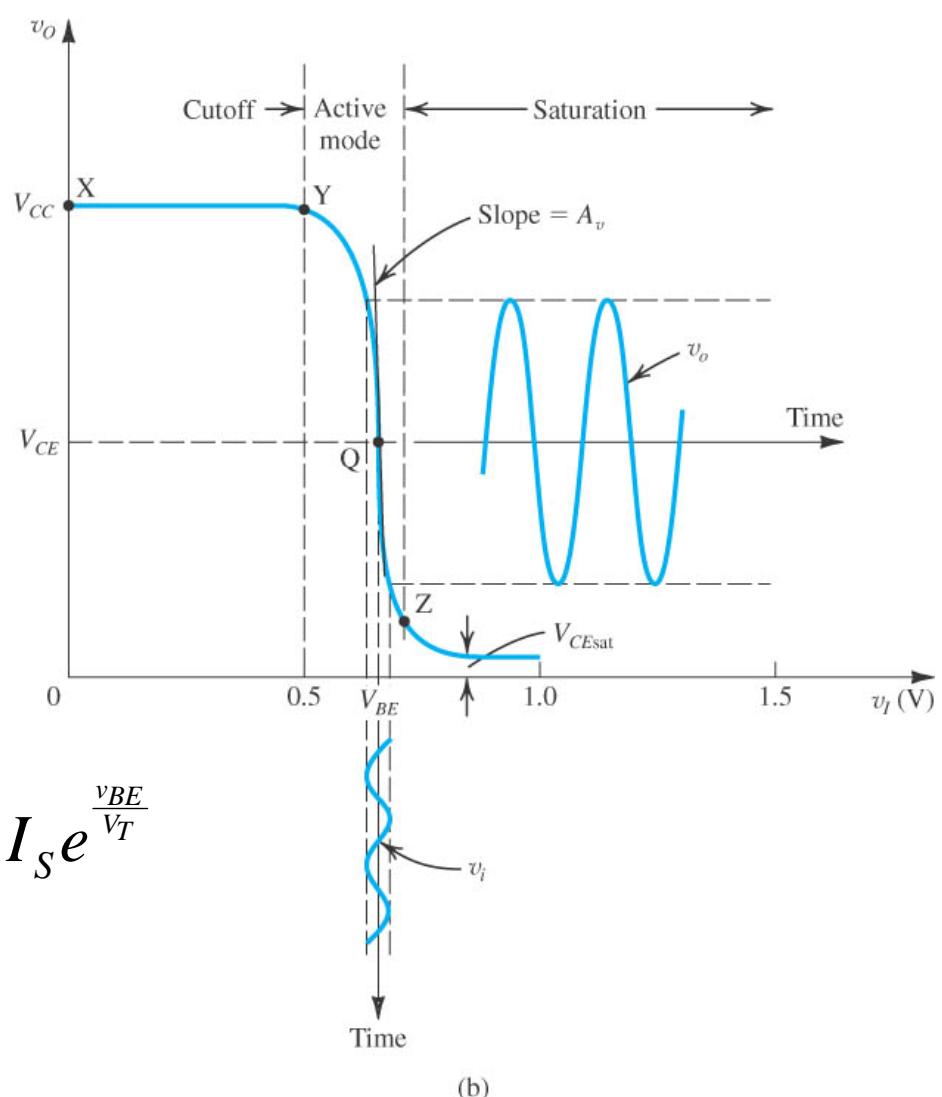
- Large-signal operation
- BJT circuits at DC
- BJT biasing schemes

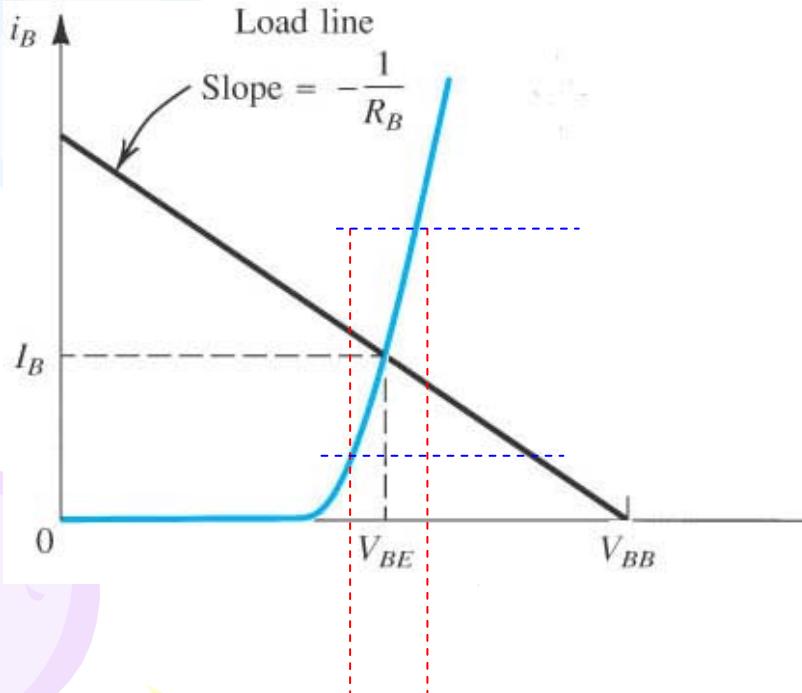
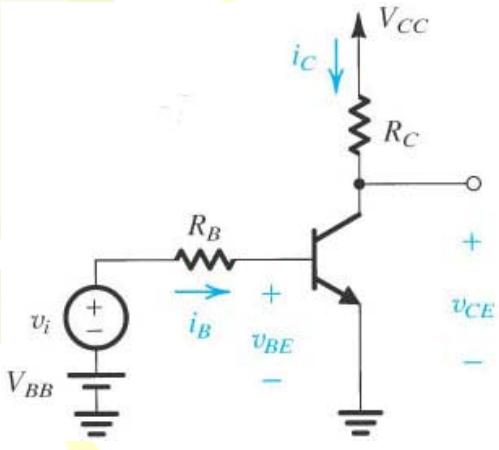
Large-signal \rightarrow Bias (DC) + signal (AC)



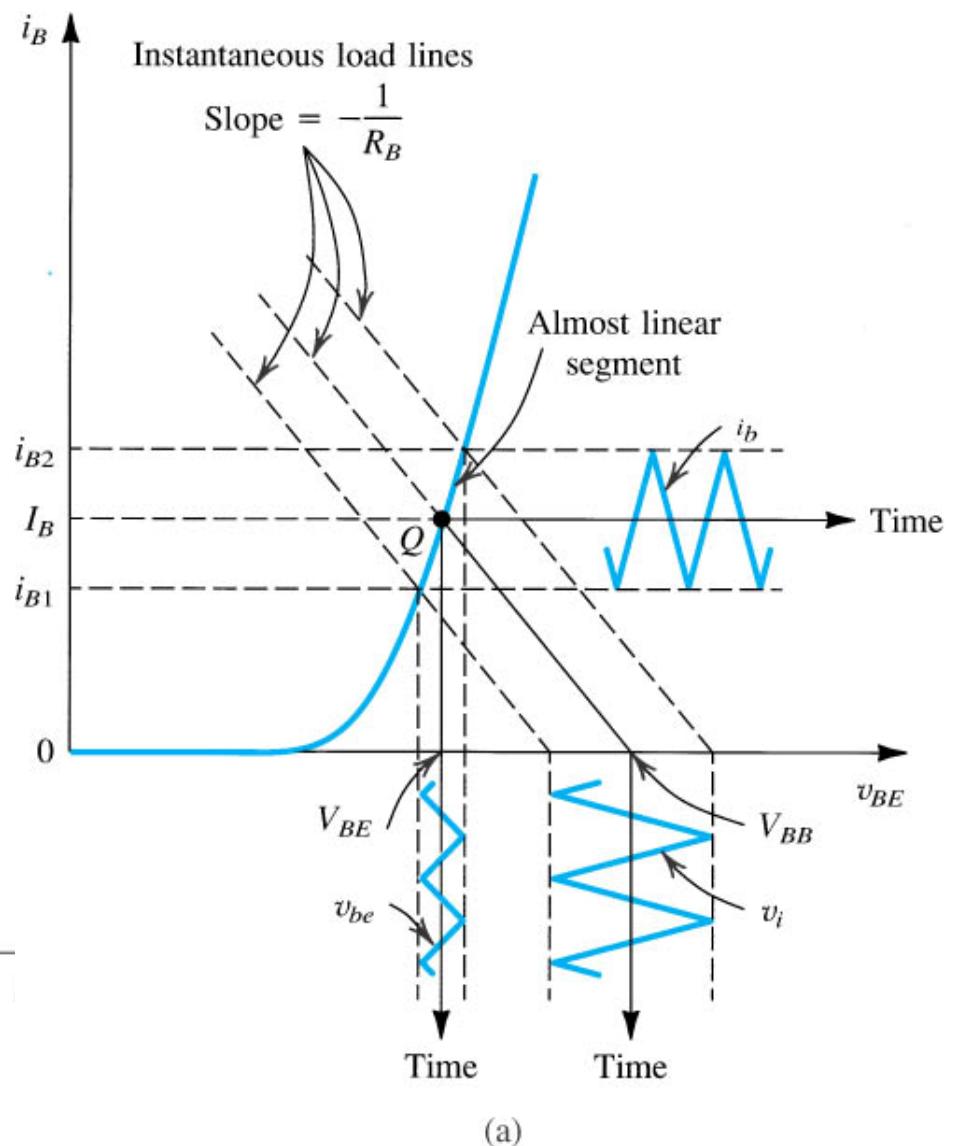
$$v_o = V_{cc} - i_C R_c = V_{cc} - R_c I_S e^{\frac{v_{BE}}{V_T}}$$

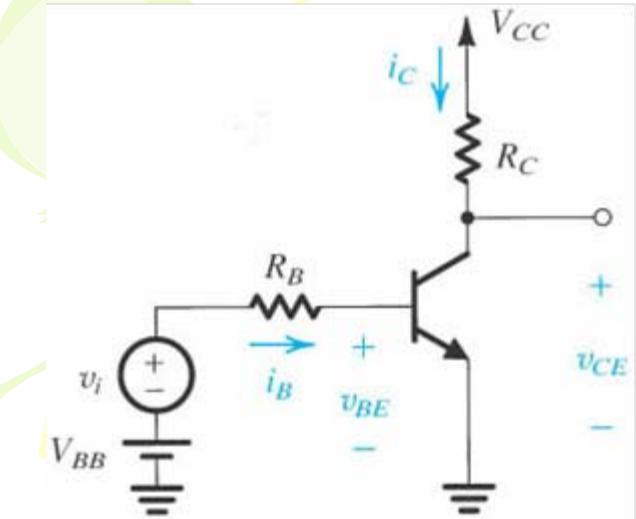
$$v_{BE} = V_{BE} + v_i$$



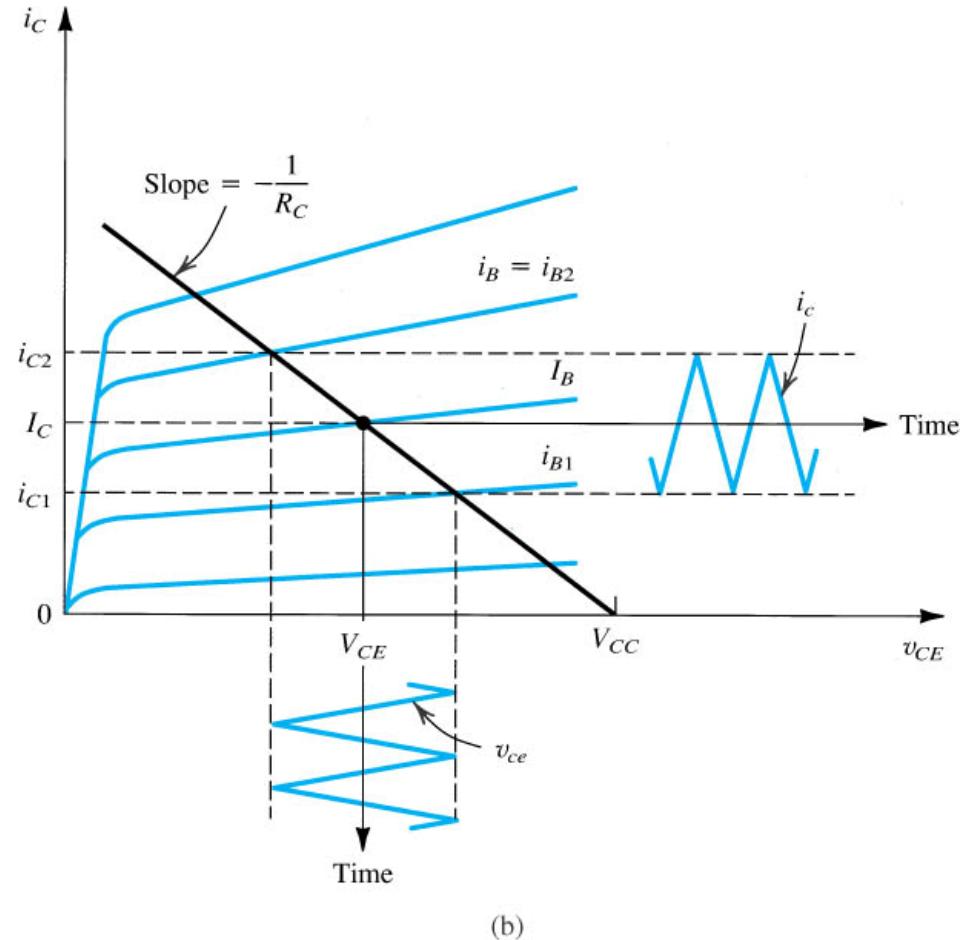
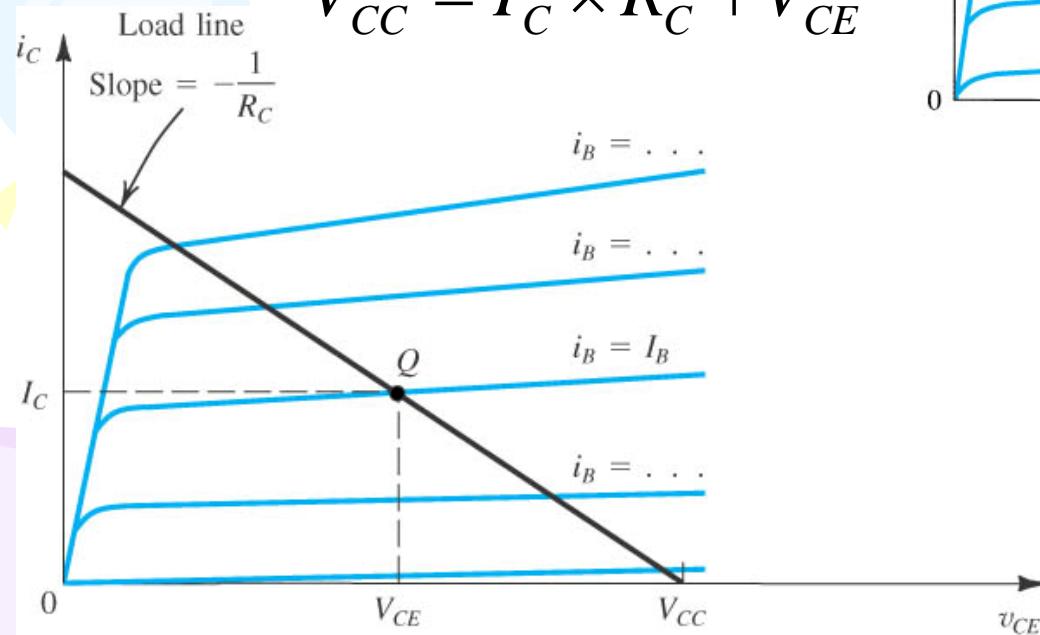


DC load line : $V_{BB} = I_B \times R_B + V_{BE}$

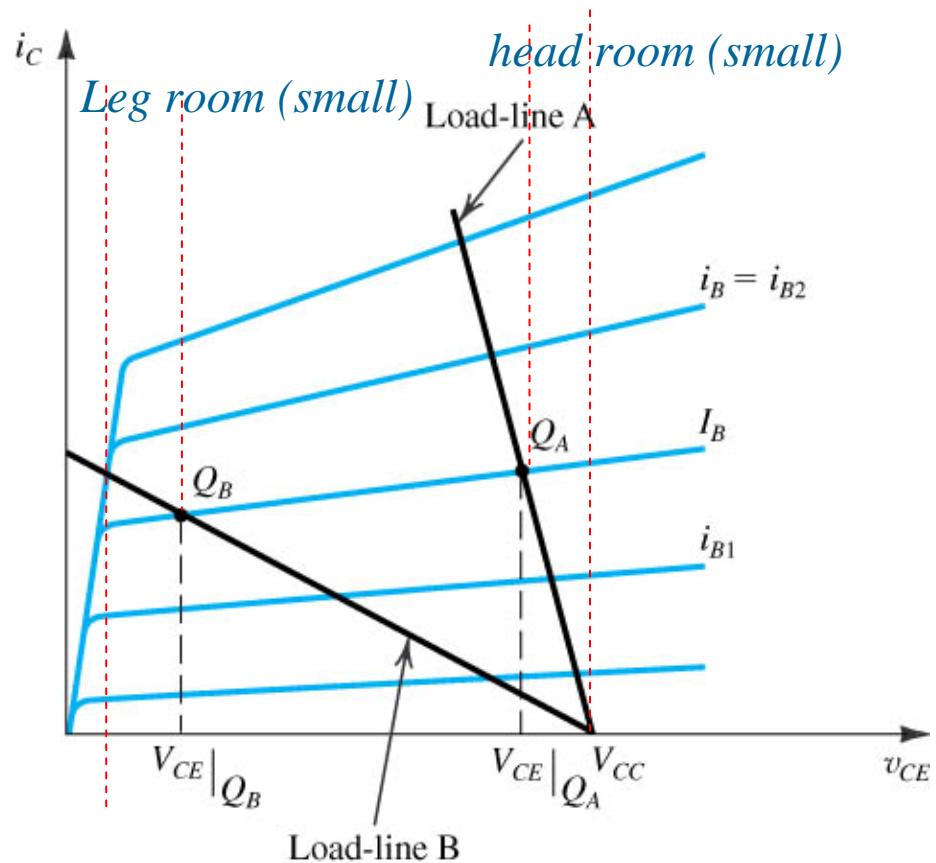
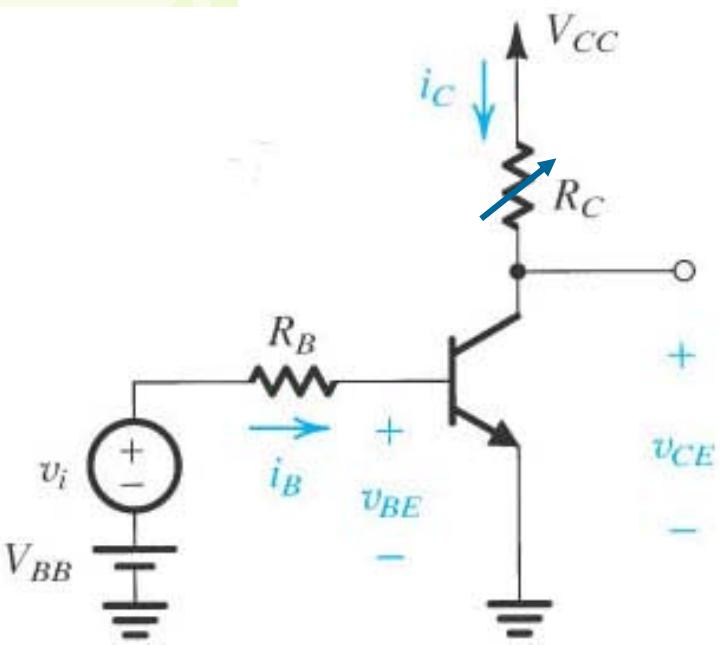




$$V_{CC} = I_C \times R_C + V_{CE}$$



(b)



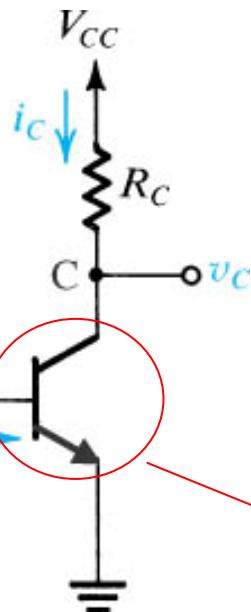
$$V_{CC} = I_C \times R_{CA} + V_{CE} \rightarrow Q_A$$

$$V_{CC} = I_C \times R_{CB} + V_{CE} \rightarrow Q_B$$

$$R_{CB} > R_{CA}$$

BJT operate as a switch

Switch off:

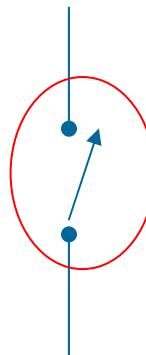


$$v_I < 0.5V \rightarrow i_B = 0 \rightarrow i_C = 0 \rightarrow v_C = V_{CC}$$

Switch on:

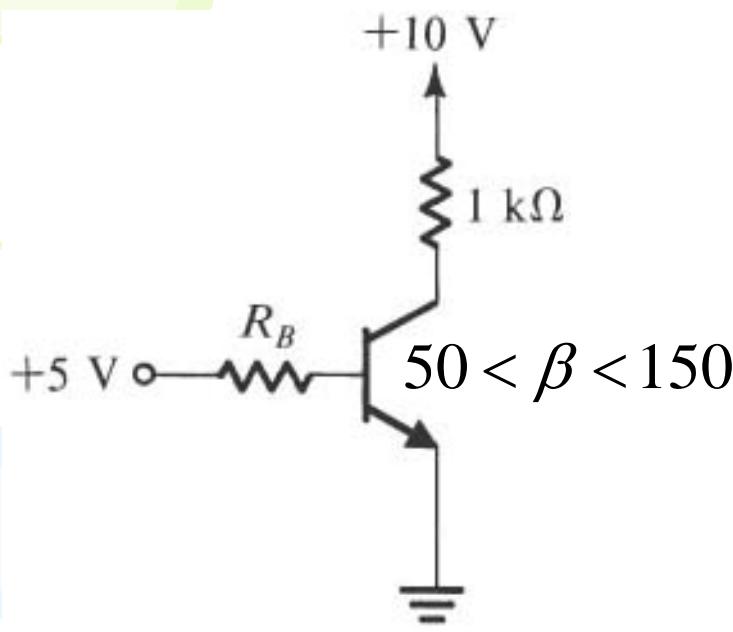
$$v_C = 0.2V \approx 0V$$

Switch on \rightarrow saturation mode
Switch off \rightarrow cut-off mode



Example 5.3

BJT work in saturation mode



$$V_C = V_{CE(sat)} = 0.2V$$

$$I_{C(sat)} = \frac{10 - 0.2}{1k} = 9.8mA$$

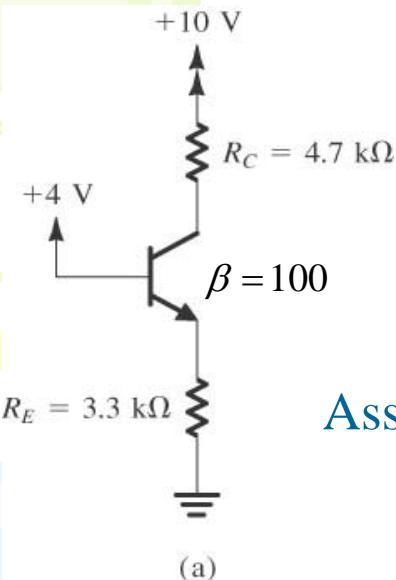
$$I_{B(max)} = \frac{I_{C(sat)}}{\beta_{min}} = \frac{9.8m}{50} = 0.196mA$$

$$I_{B(min)} = \frac{I_{C(sat)}}{\beta_{max}} = \frac{9.8m}{150} = 0.0653mA$$

$$I_B = I_{B(max)} \times \text{overdrive factor}$$

$$R_B = \frac{5 - 0.7}{I_B} = \frac{4.3}{1.96} = 2.2k$$

Example 5.4 (DC analysis)



Assume BJT in active mode :

$$V_E = 4 - 0.7V = 3.3V$$

(c)

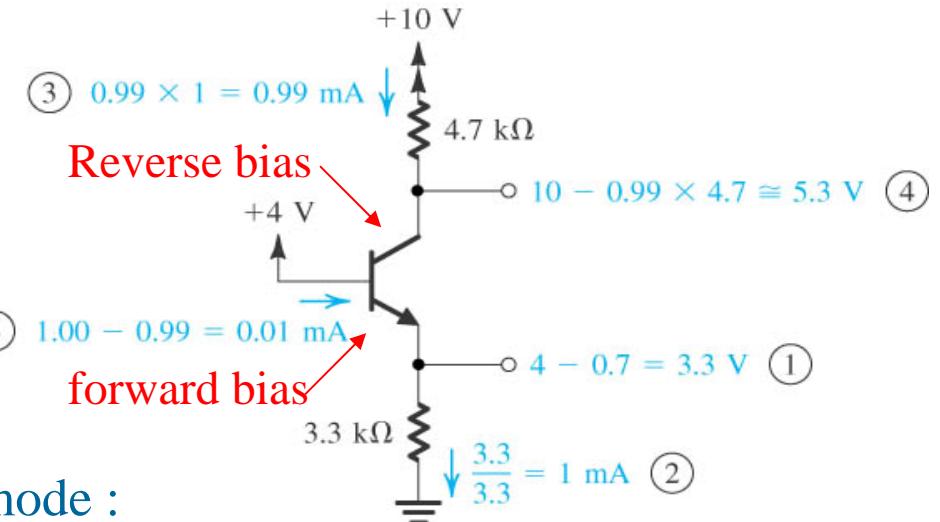
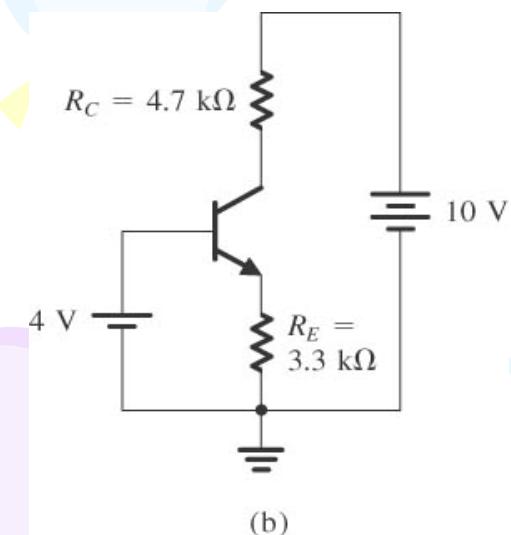
$$I_E = \frac{V_E}{R_E} = \frac{3.3}{3.3k} = 1mA$$

$$I_C = \alpha I_E = \frac{100}{100+1} \times 1mA = 0.99mA$$

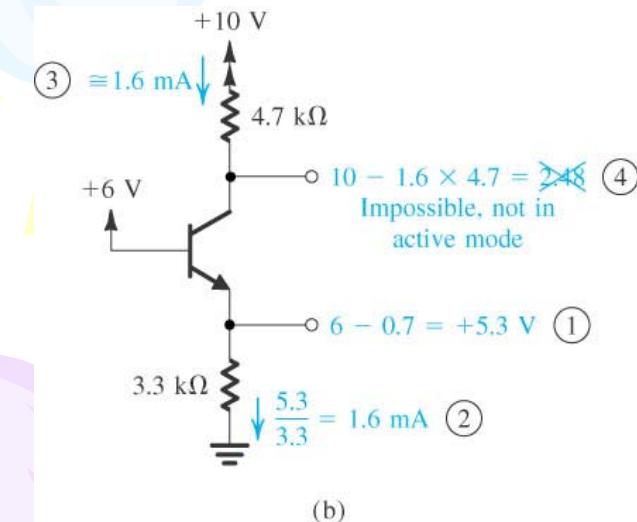
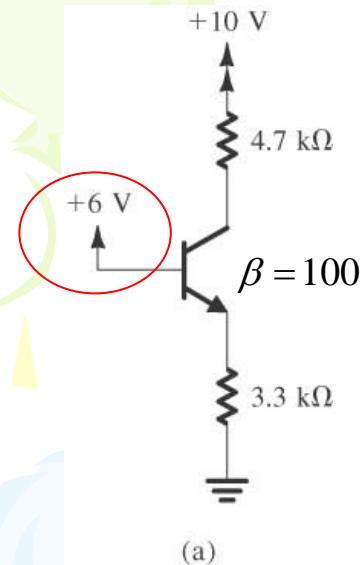
$$I_B = I_E - I_C = 0.01mA$$

$$V_C = 10 - I_C \times 4.7k = 5.3V$$

Active mode check



Example 5.5 (DC analysis)



Assume BJT in active mode :

$$V_E = 6 - 0.7V = 5.3V$$

$$I_E = \frac{V_E}{R_E} = \frac{5.3}{3.3k} = 1.6mA$$

$$I_C = \alpha I_E = \frac{100}{100+1} \times 1.6mA = 1.584mA$$

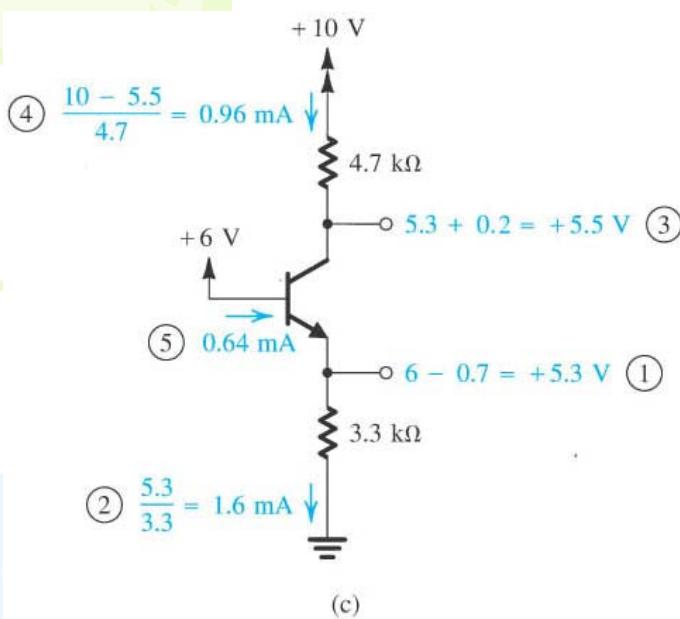
$$I_B = I_E - I_C = 0.016mA$$

$$V_C = 10 - I_C \times 4.7k = 2.48V$$

JC : forward bias
JE : forward bias

Not in active mode

Assume BJT in saturation mode :



$$V_E = 6 - 0.7V = 5.3V$$

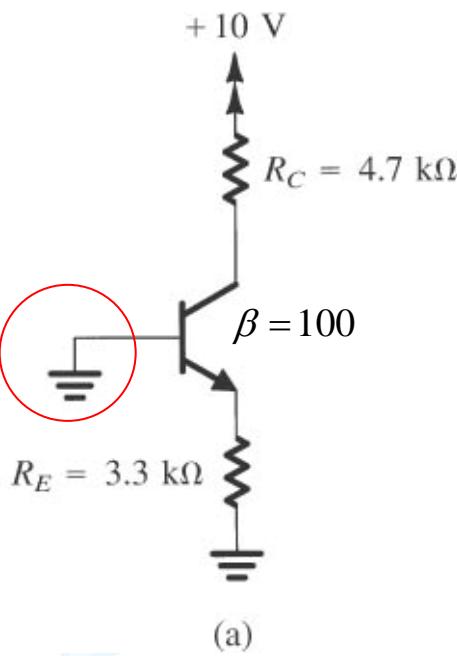
$$V_C = V_E + V_{CE(sat)} = 5.3 + 0.2 = 5.5V$$

$$I_E = \frac{V_E}{R_E} = \frac{5.3}{3.3k\Omega} = 1.6mA$$

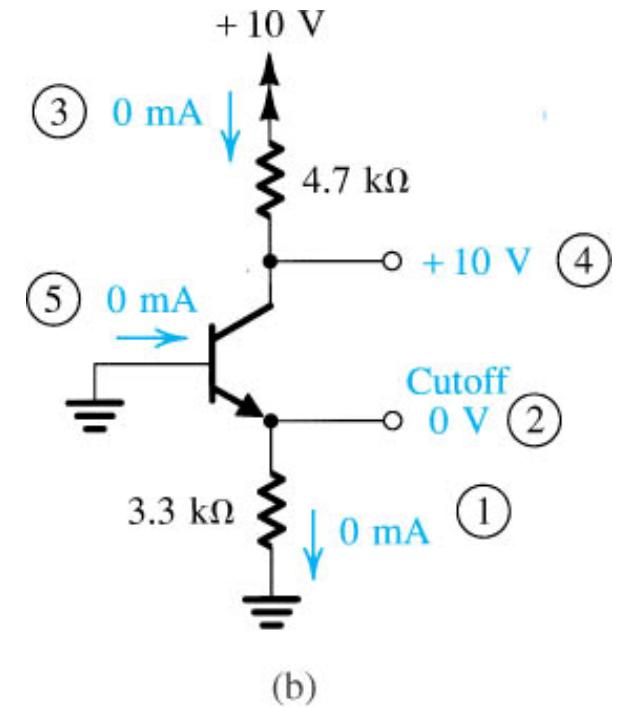
$$I_C = \frac{10 - 5.5}{4.7} = 0.96mA$$

$$I_B = I_E - I_C = 0.64mA$$

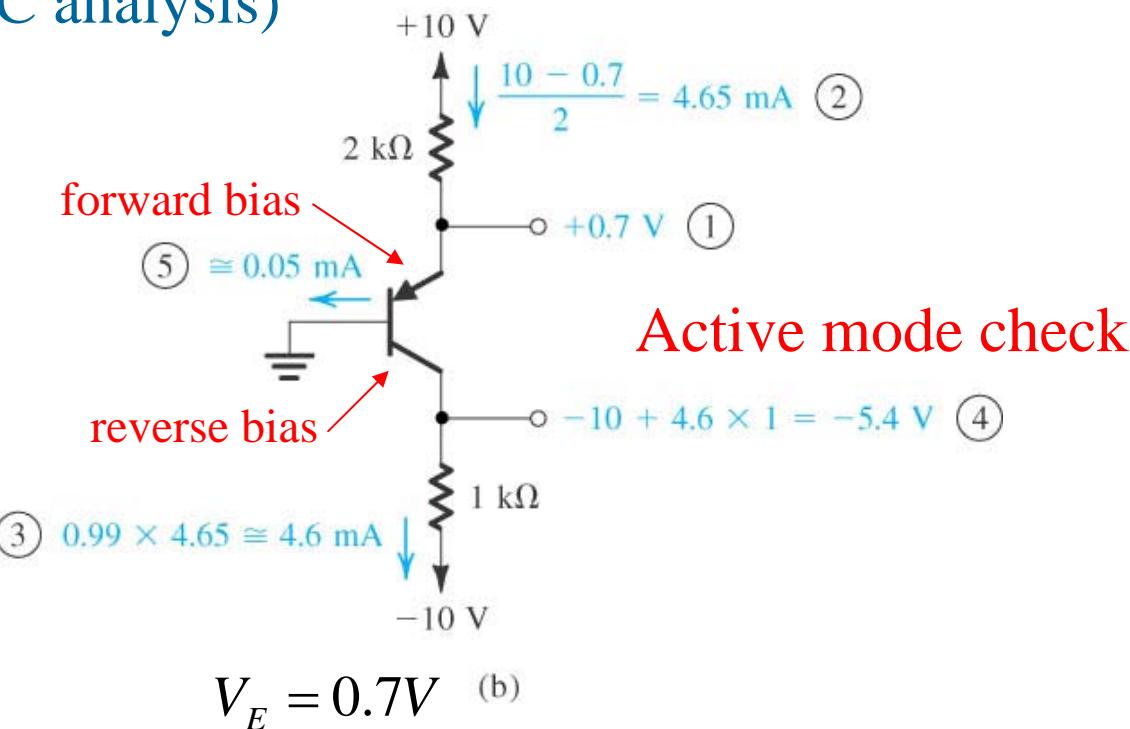
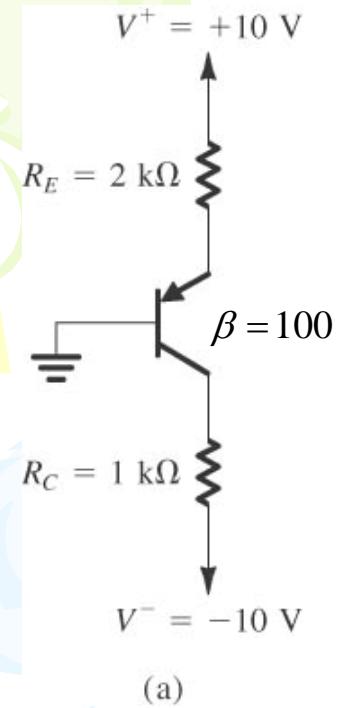
Example 5.6 (DC analysis)



$$V_{BE} = 0V$$
$$I_B = 0mA$$
$$I_E = 0mA$$
$$I_C = 0mA$$
$$V_C = V_{cc} = 10V$$



Example 5.7 (DC analysis)



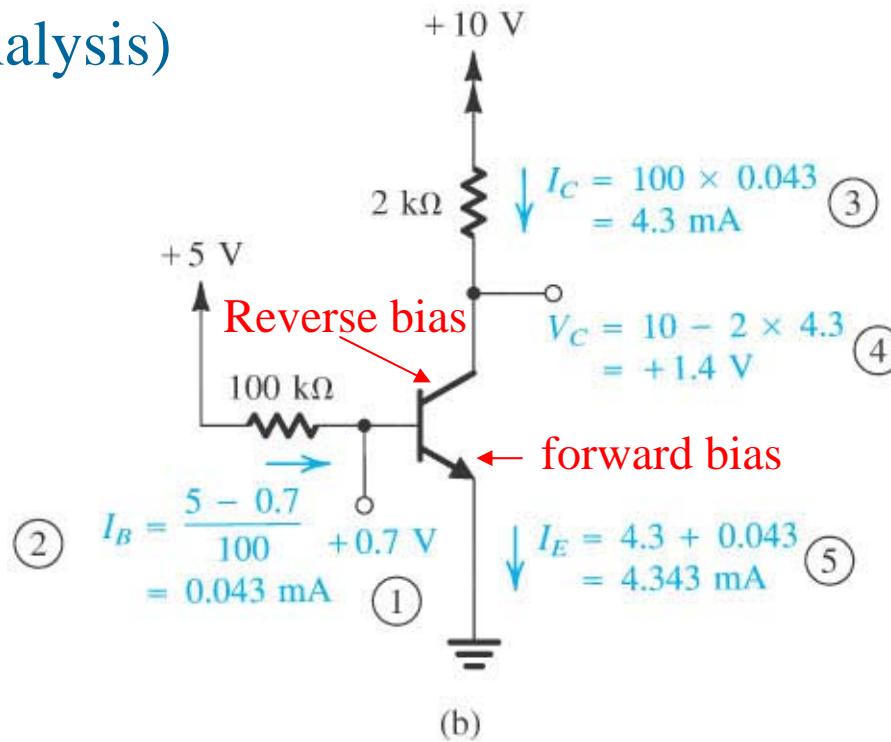
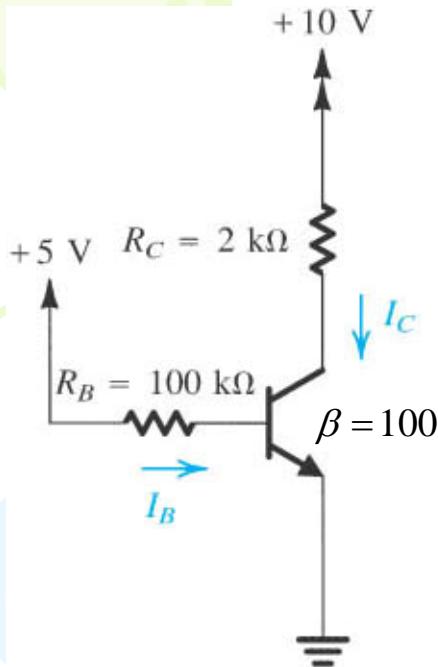
Assume BJT in active mode :

$$I_C = \alpha I_E = \frac{100}{101} \times 4.65m = 4.6mA$$

$$V_C = I_C \times R_C - 10V = 4.6m \times 1k - 10 = -5.4V$$

$$I_B = I_E - I_C = 0.05mA$$

Example 5.8 (DC analysis)



Assume BJT in active mode :

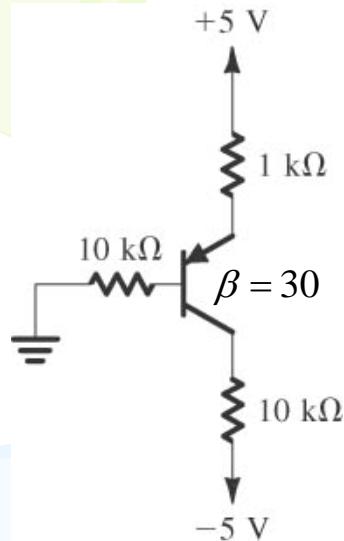
$$5V = 100k \times I_B + V_{BE} = 100k \times I_B + 0.7$$

$$\Rightarrow I_B = 0.043 \text{ mA}$$

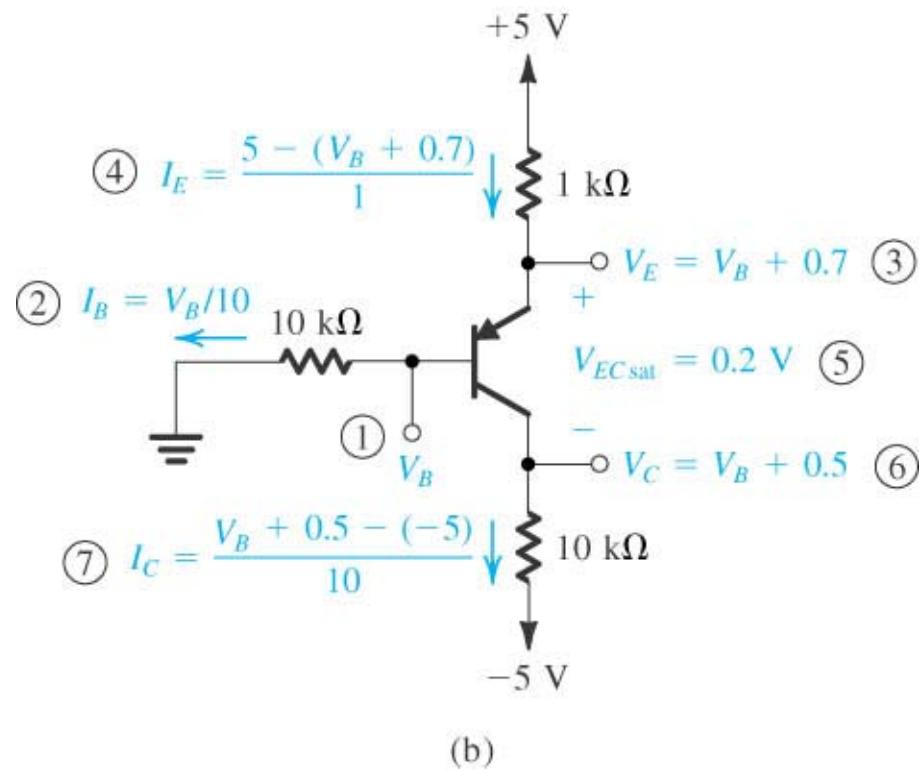
$$I_C = \beta I_B = 4.3 \text{ mA}$$

$$V_C = 10 - I_C R_C = 10 - 4.3m \times 2k = 1.4V$$

Example 5.9 (DC analysis)



(a)



(b)

Assume BJT in active mode :

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

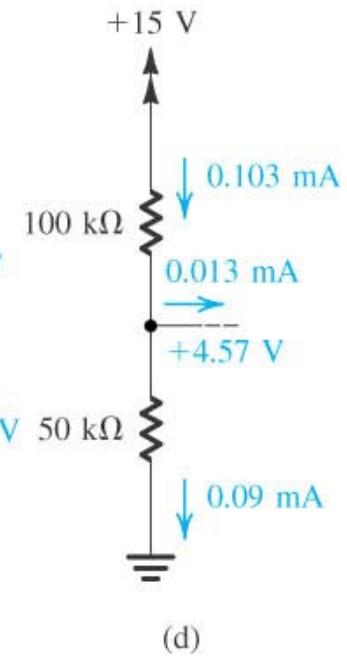
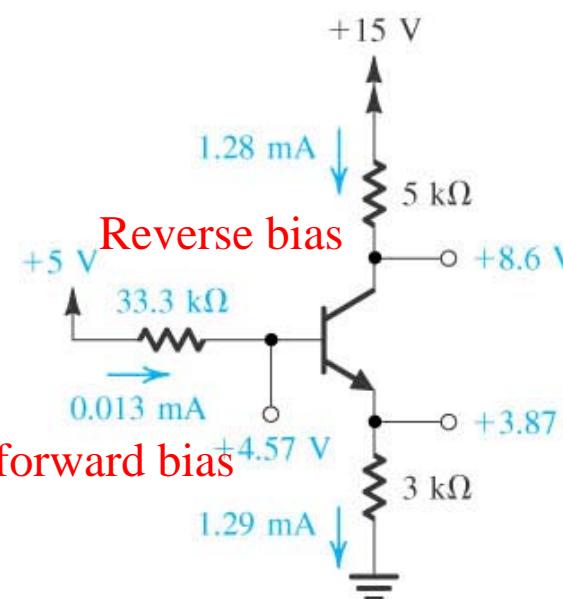
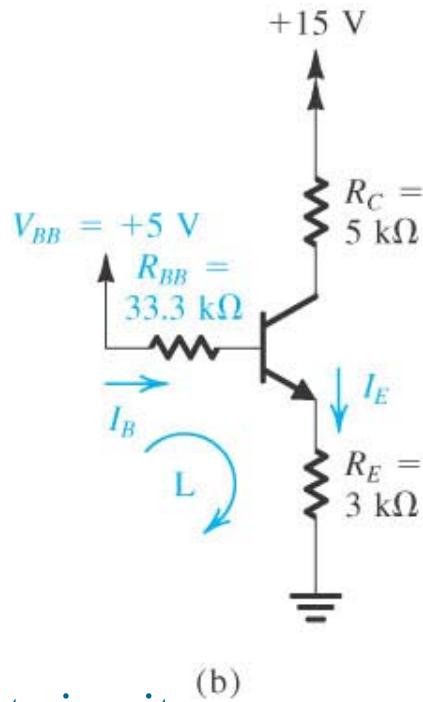
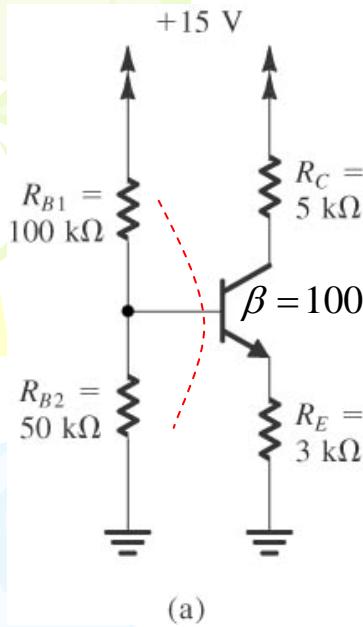
$$R_B \quad \text{large} \rightarrow I_B \approx 0$$

$$V_E \approx 0.7V \rightarrow I_E = \frac{5 - 0.7}{1k} = 4.3mA$$

$$I_C \approx I_E = 4.3V \rightarrow V_C = 10k \times 4.3m - 5V = 38V (\text{impossible})$$

$$I_{C(\max)} = 0.5mA \rightarrow V_C = 0V$$

Example 5.10 (DC analysis)



Thevenin's equivalent circuit

$$V_{BB} = 15V \frac{50k}{100k + 50k} = 5V$$

$$R_{BB} = 100k // 50k = 33.3k$$

Assume BJT in active mode :

$$V_{BB} = I_B R_{BB} + V_{BE} + I_E R_E$$

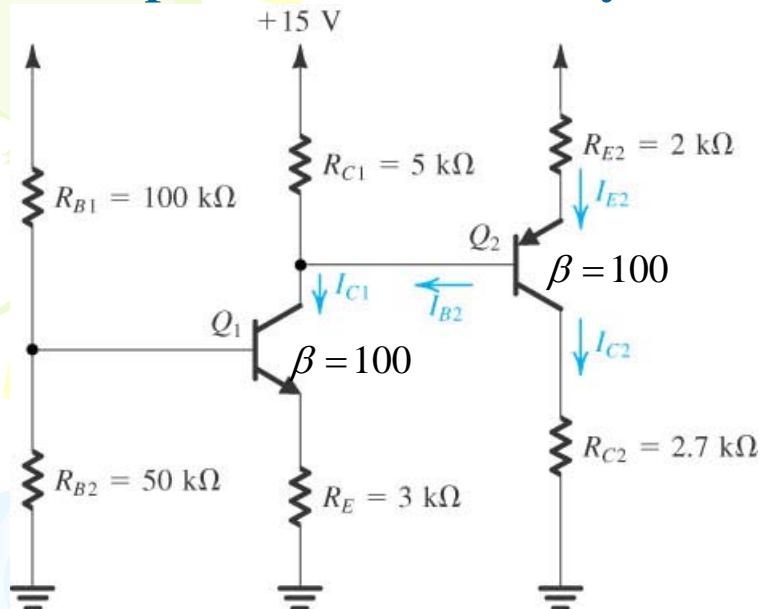
$$V_{BB} = I_B R_{BB} + V_{BE} + (\beta I_B + I_B) R_E$$

$$\Rightarrow I_B = 0.0128mA$$

$$\Rightarrow I_E = 101 \times I_B = 1.29mA$$

$$\Rightarrow I_C = 1.28mA$$

Example 5.11 (DC analysis)



$$15V = (I_{C1} + I_{B2})R_{C1} + V_{C1} \approx I_{C1}R_{C1} + V_{C1}$$

$$\Rightarrow V_{C1} \approx 8.6V$$

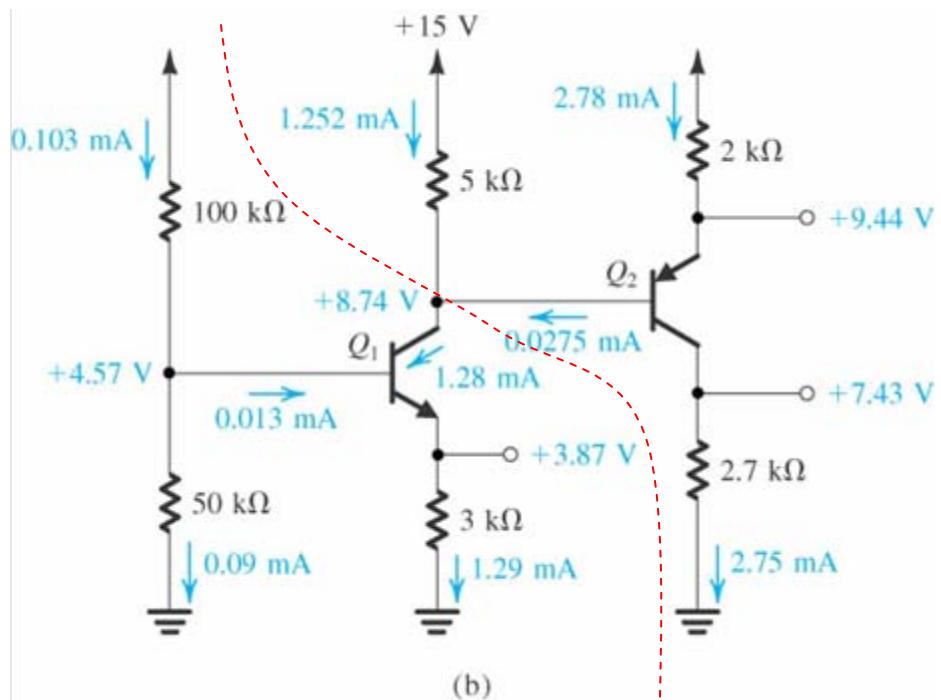
$$V_{E2} = V_{C1} + 0.7V \approx 9.3V$$

$$I_{E2} = \frac{15 - 9.3}{2k} \approx 2.85mA$$

$$I_{C2} = \alpha I_{E2} \approx 2.82mA$$

$$V_{C2} = I_{C2} \times 2.7k \approx 7.62V$$

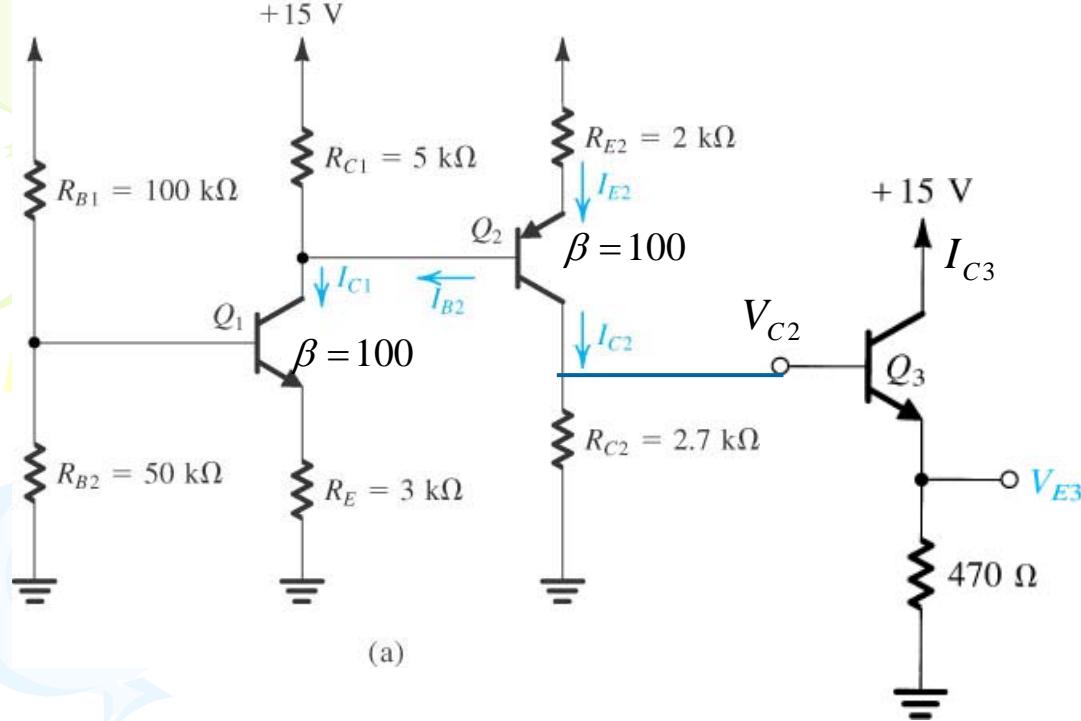
$$I_{B2} = \frac{I_{E2}}{101} \approx 0.028mA$$



start with $I_{B2} = 0.028mA$

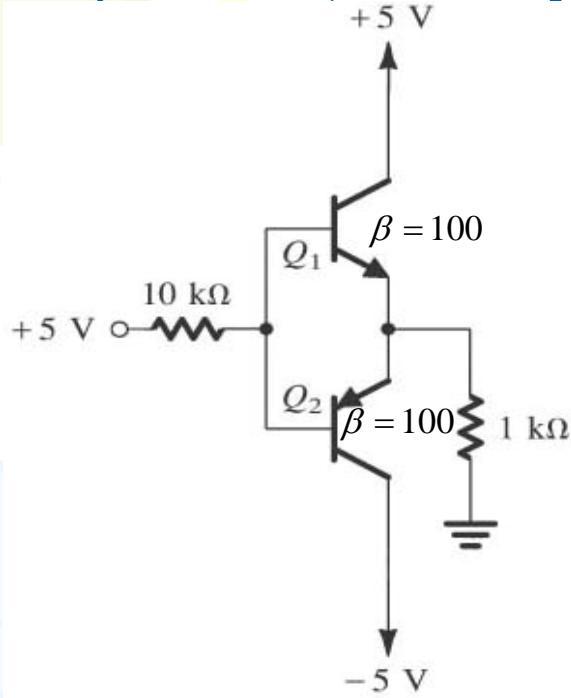
Find correct current
by iteration

Exercise 5.30 (DC analysis)



(a)

Example 5.12 (DC analysis)

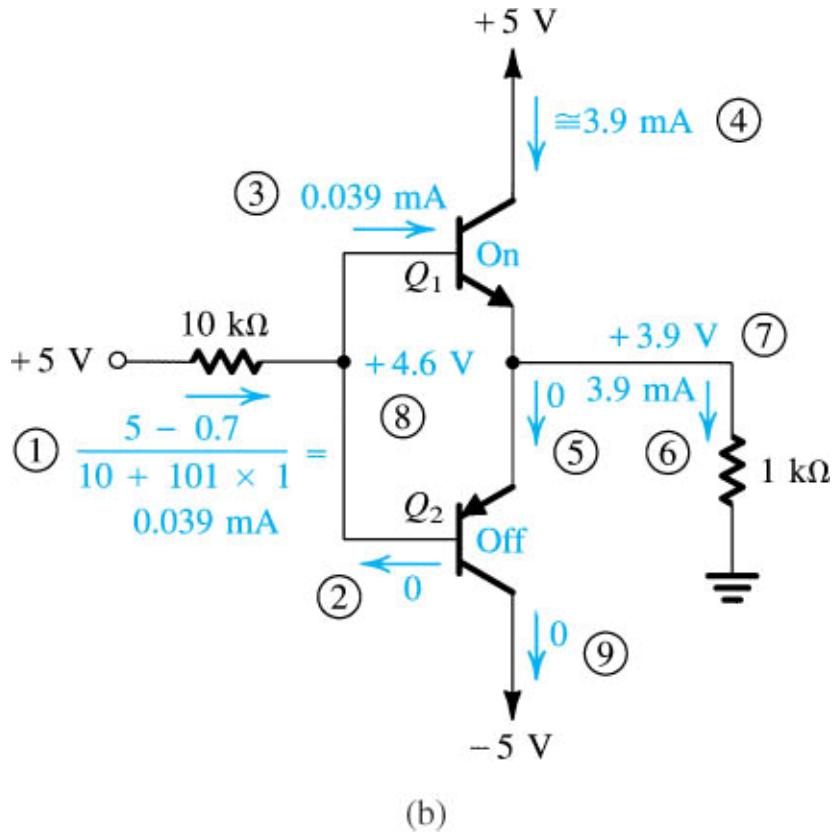


(a)

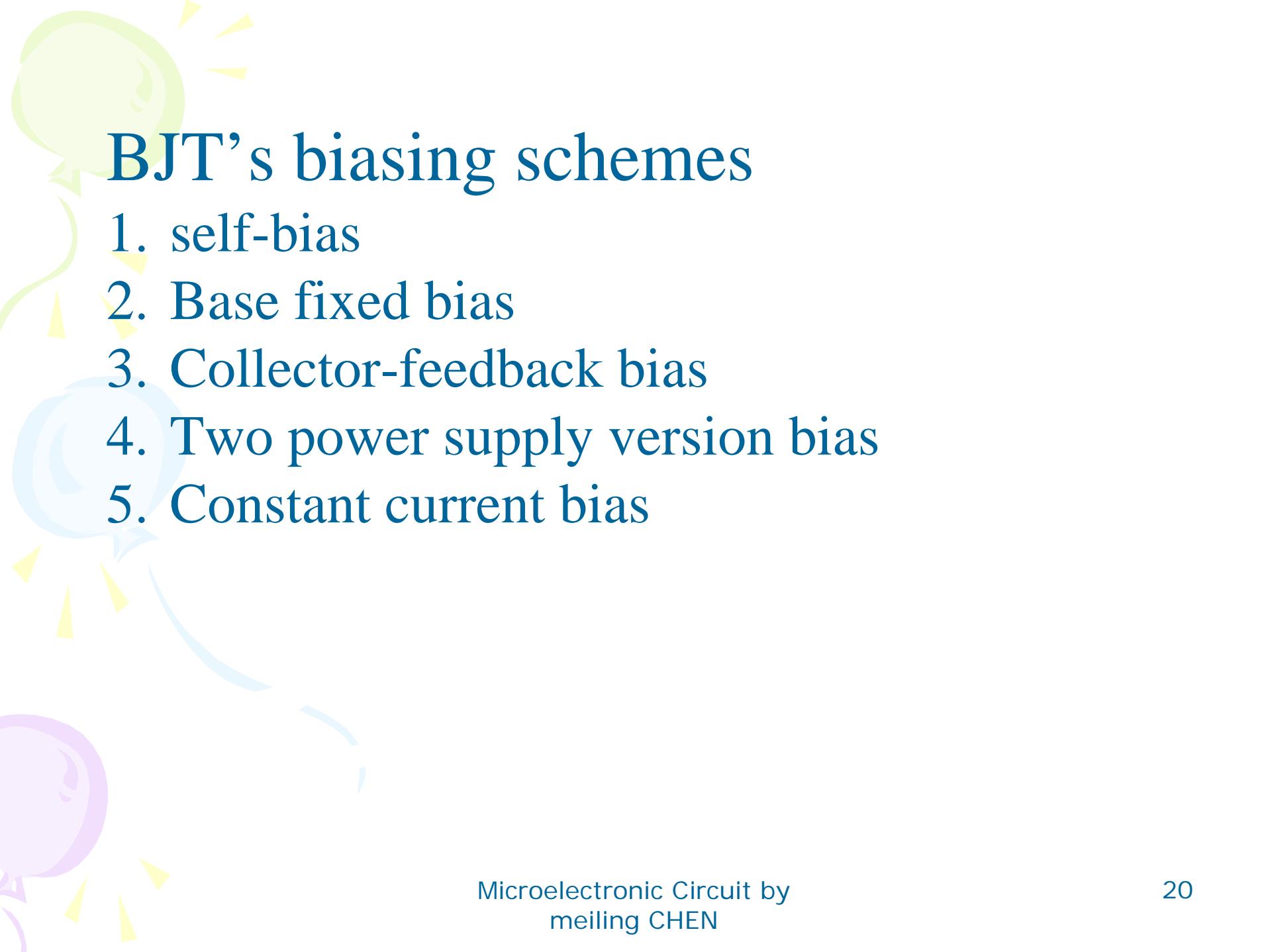
Q_1 and Q_2 cannot be conducting at same time.

If Q_1 ON than Q_2 OFF, and vice versa.

Assume Q_1 on and Q_2 off :



(b)

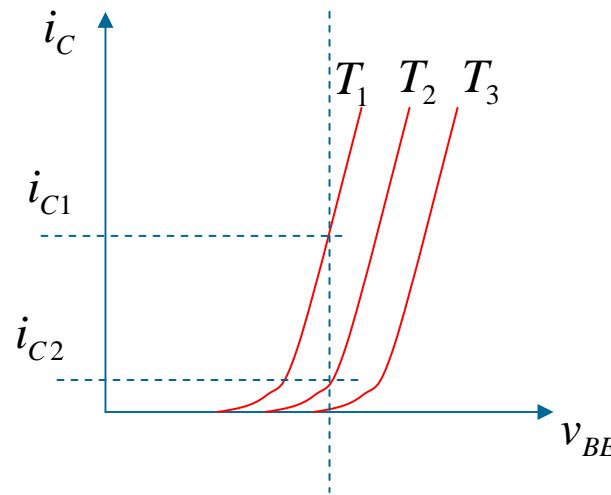


BJT's biasing schemes

1. self-bias
2. Base fixed bias
3. Collector-feedback bias
4. Two power supply version bias
5. Constant current bias

Why we need good biasing scheme?

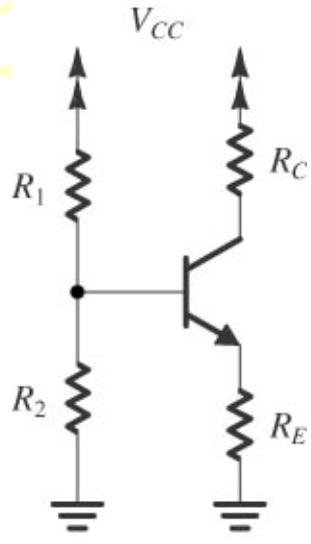
- 1.Temperature change → Collector biasing current change
- 2.Device change → biasing current change



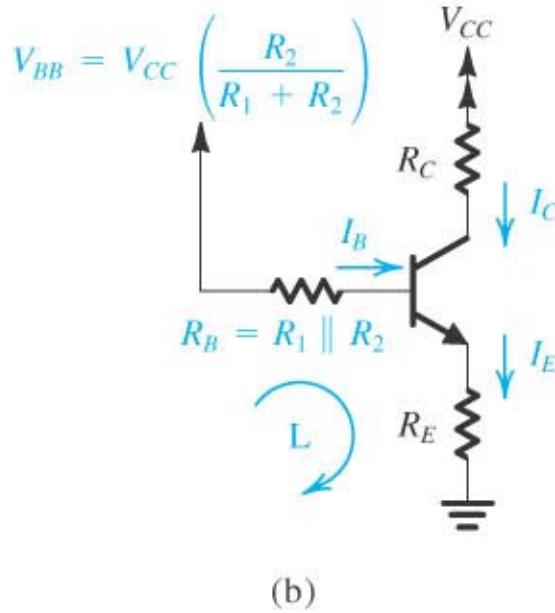
$$i_C = I_s e^{\frac{V_{BE}}{V_T}}$$

$$V_T = \frac{KT}{q} = \frac{1.38 \times 10^{-23} (\text{°K})}{1.6 \times 10^{-19}}$$

1. Self-Bias



(a)



(b)

Voltage-divider :

$$R_E \gg \frac{R_B}{1+\beta}$$

$$\therefore R_B = \frac{R_1 R_2}{R_1 + R_2}$$

$\therefore R_1, R_2 \text{ small} \rightarrow I_B \uparrow$

Trade-off

Suggestion:

$$(R_1 + R_2) \times 0.1 \times I_E = V_{CC}$$

$$I_E = \frac{V_{BB} - V_{BE}}{R_E + \frac{R_B}{1+\beta}}$$

In insensitive to T and β

Constraints:

$$V_{BB} \gg V_{BE}$$

$$R_E \gg \frac{R_B}{1+\beta}$$

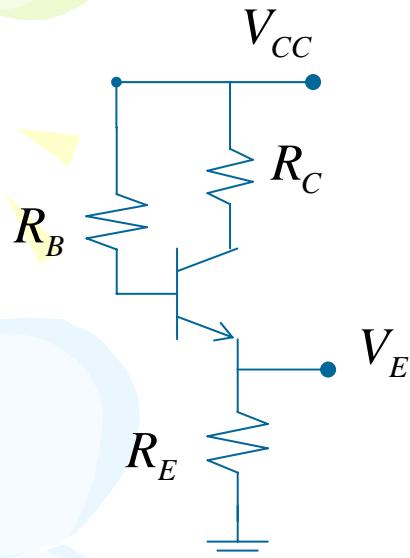
The rule of thumb :
(經驗法則)

$$V_{BB} = \frac{1}{3} V_{CC}$$

$$I_C R_C = \frac{1}{3} V_{CC}$$

$$V_{CE} (\text{or } V_{CB}) = \frac{1}{3} V_{CC}$$

1. Self-Bias (emitter feedback bias)



$$I_E = \frac{V_{CC} - V_{BE}}{R_E + \frac{R_B}{1+\beta}}$$

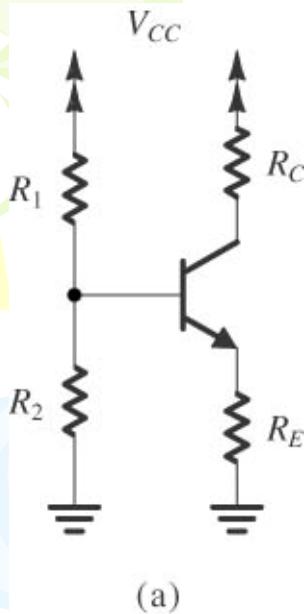
The rule of thumb :

$$V_{BB} = \frac{1}{3}V_{CC}$$

$$I_C R_C = \frac{1}{3}V_{CC}$$

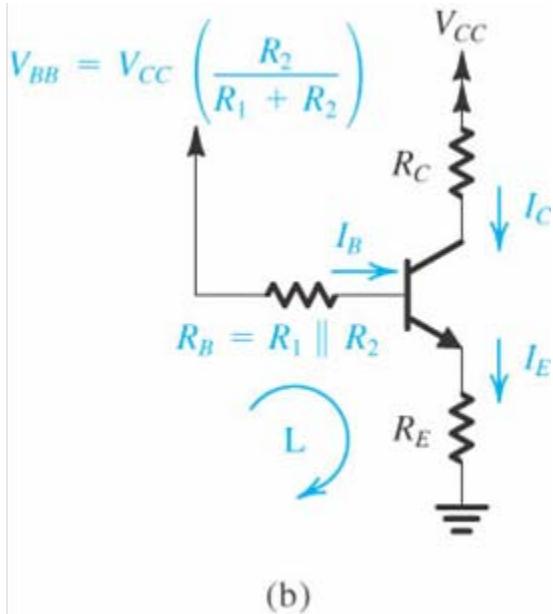
$$V_{CE} (\text{or } V_{CB}) = \frac{1}{3}V_{CC}$$

Example 5.13 design the following self bias circuit



(a)

given
 $I_E = 1mA$
 $V_{CC} = 12V$
 $\beta = 100$



(b)

$$(R_1 + R_2) \times 0.1 \times I_E = V_{CC}$$

$$\Rightarrow (R_1 + R_2) \times 0.1 \times 1 = 12 \cdots (a)$$

$$V_B = 4V \Rightarrow \frac{R_2}{R_1 + R_2} V_{CC} \cdots (b)$$

$$(a), (b) \Rightarrow \begin{aligned} R_1 &= 80k \\ R_2 &= 40k \end{aligned}$$

$$I_E = \frac{V_{BB} - V_{BE}}{R_E + \frac{R_B}{1+\beta}}$$

The rule of thumb :

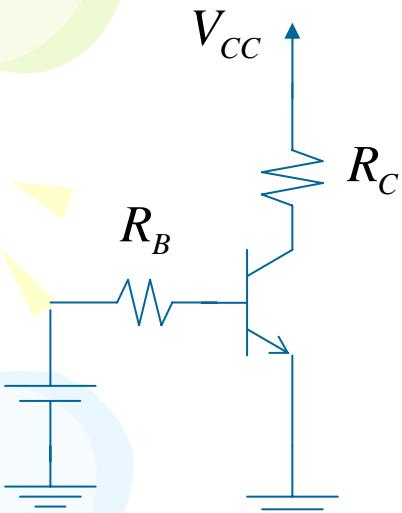
$$V_B = \frac{1}{3} 12 = 4V$$

$$V_E = 4 - V_{BE} = 3.3V$$

$$R_E = \frac{V_E}{I_E} = \frac{3.3}{1m} = 3.3k$$

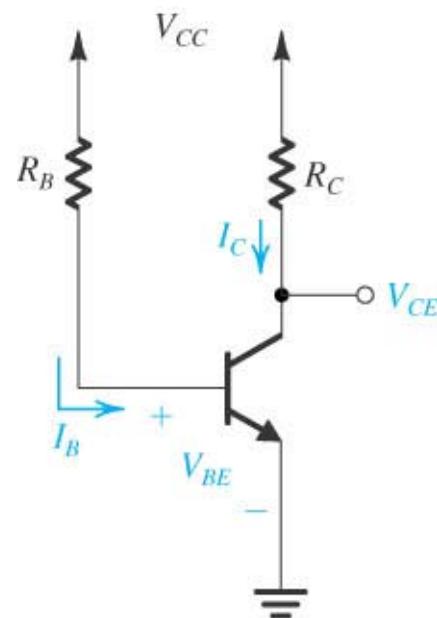
$$R_C = \frac{\frac{1}{3} 12}{\alpha I_E} = \frac{4}{0.99 \times 1m} \approx 4k$$

2. Base fixed bias



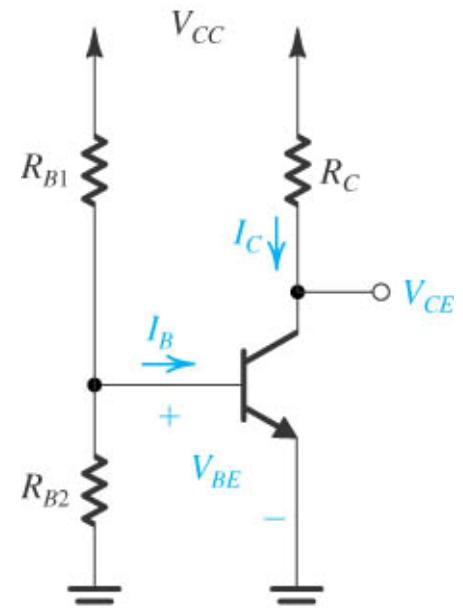
Type 1

$$I_C = \frac{\beta(V_{BB} - V_{BE})}{R_B}$$



Type 2

$$I_C = \frac{\beta(V_{CC} - V_{BE})}{R_B}$$



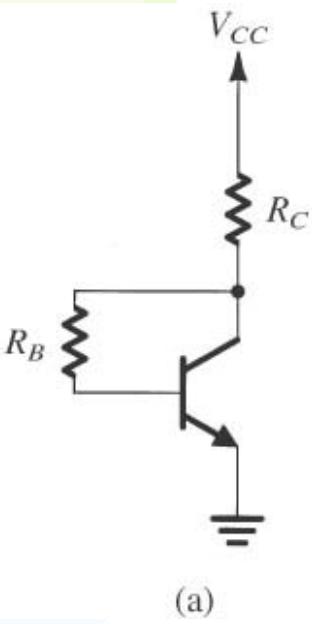
(a)
Type 3

$$I_C = \frac{\beta(V_{BB} - V_{BE})}{R_B}$$

$$R_B = R_{B1} // R_{B2}$$

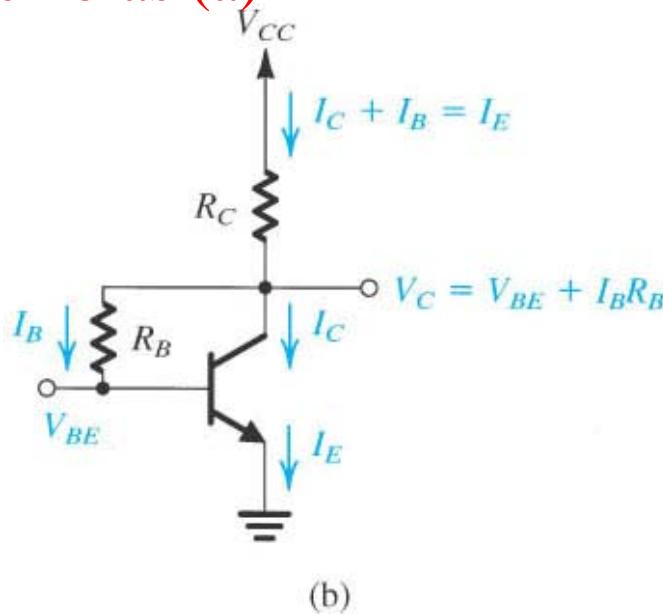
$$V_{BB} = \frac{R_{B2}}{R_{B1} + R_{B2}} V_{CC}$$

3. Collector-feedback bias (a)



$$V_{CC} = I_E R_C + I_B R_B + V_{BE}$$

$$I_E = I_B + I_C = \frac{V_{CC} - V_{BE}}{R_C + \frac{R_B}{1+\beta}}$$



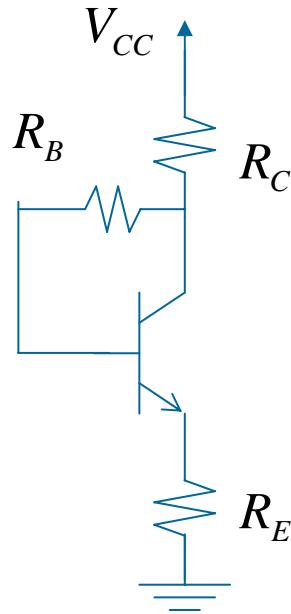
Constraints:

$$R_C \gg \frac{R_B}{1+\beta}$$

$$\begin{aligned} T \uparrow &\Rightarrow I_C \uparrow \Rightarrow I_C R_C \uparrow \\ &\Rightarrow V_{CE} \downarrow \Rightarrow I_B \downarrow \Rightarrow I_C \downarrow \end{aligned}$$

Good biasing scheme

3. Collector-feedback bias (b)



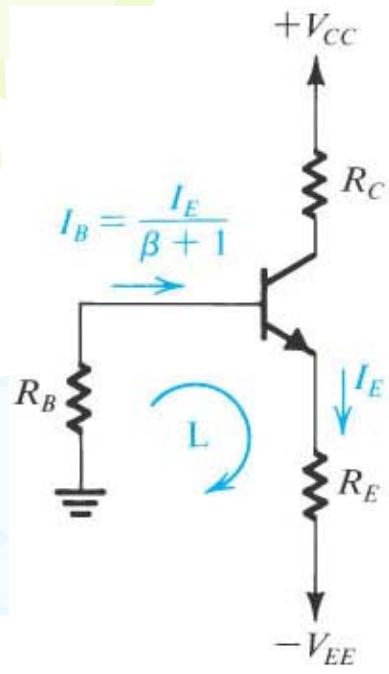
$$V_{CC} = (I_B + I_C)R_C + I_B R_B + V_{BE} + (I_B + I_C)R_E$$

$$I_E = I_B + I_C = \frac{V_{CC} - V_{BE}}{R_C + R_E + \frac{R_B}{1+\beta}}$$

$T \uparrow \Rightarrow I_C \uparrow \Rightarrow I_E \uparrow$
 $\Rightarrow V_{CE} \downarrow \Rightarrow I_B \downarrow \Rightarrow I_C \downarrow$

Good biasing scheme

4. Two-power supply version



$$I_B R_B + V_{BE} + I_E R_E = V_{EE}$$

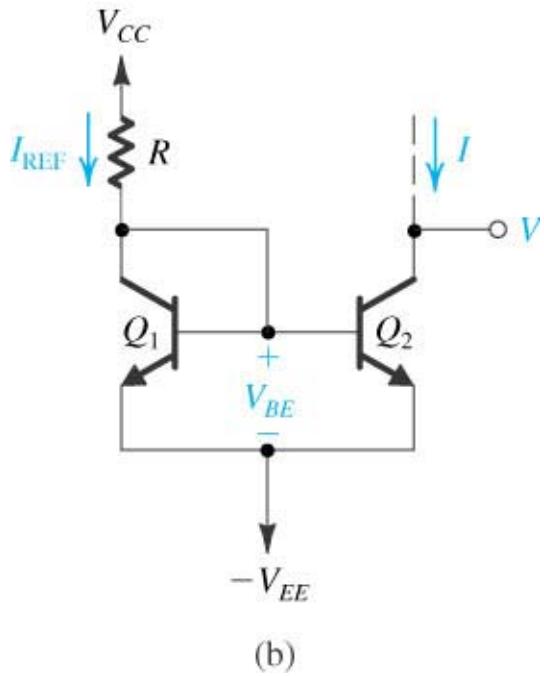
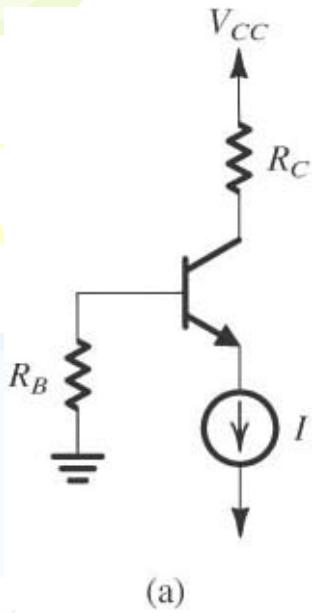
$$\Rightarrow I_E = \frac{V_{EE} - V_{BE}}{R_E + \frac{R_B}{1+\beta}}$$

Constrains:

$$V_{BB} \gg V_{BE}$$

$$R_E \gg \frac{R_B}{1+\beta}$$

5. Constant current bias by Current mirror



$$I_{Ref} = \frac{V_{CC} - (-V_{EE}) - V_{BE}}{R}$$

$$I = I_{Ref} = \frac{V_{CC} + V_{EE} - V_{BE}}{R}$$

$$I_{REF} = I_{C1} + I_{B1} + I_{B2}$$

$$\because Q_1 \equiv Q_2$$

$$\therefore I_{B1} = I_{B2} = I_B$$

$$I_{REF} = I_{C1} + 2I_B = (\beta + 2)I_B$$

$$I = I_{C2} = I_{C1} = (\beta + 2)I_B$$

$$\frac{I}{I_{REF}} = \frac{\beta}{(\beta + 2)} \approx \beta$$