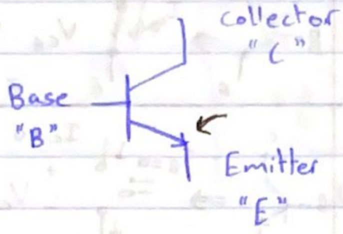
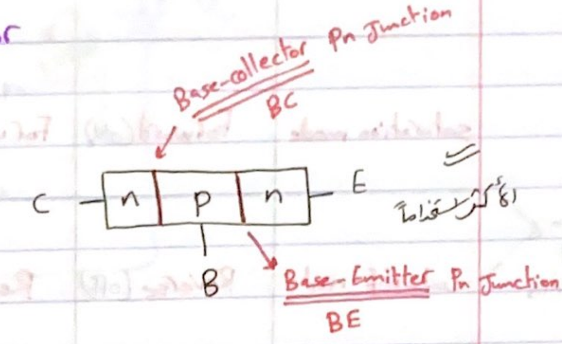
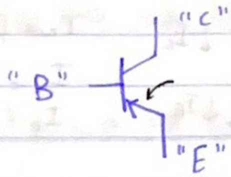
· T_6 : BJT Construction & Operation

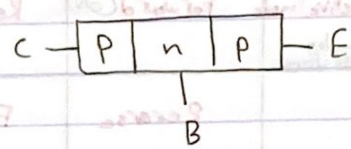
* Bipolar Junction Transistor





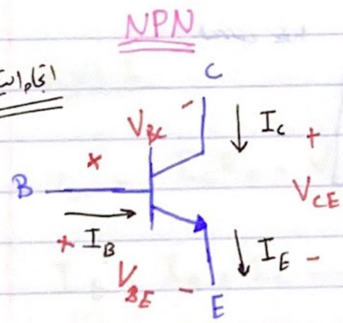
الأكثر استخداماً

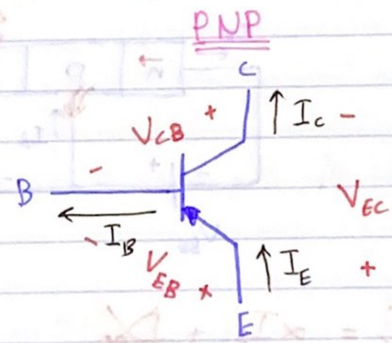




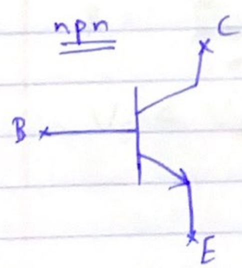
⟹ Transistor structure

اتجاه التيارات إجباري





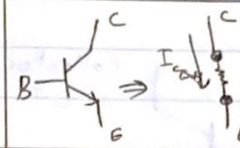
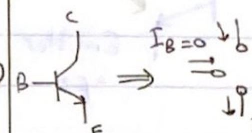
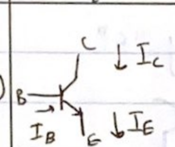
⟹ Transistor Biasing



Pn junction → BE → ON / OFF

Pn junction → BC → ON / OFF

4 possible combination
⇓
4 possible modes of operation

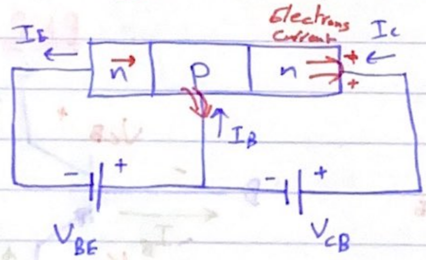
Junction/Mode	BE	BC	
saturation mode	Forward (ON)	Forward (ON)	 $I_{C(sat)}$ $V_{CE} = V_{CE(sat)} \cong 0 - 0.2V$ closed switch
cut-off mode	Reverse (OFF)	Reverse (OFF)	 $I_B = 0$, $I_C = 0$, $+\ V_{CE}$?? $-$, $I_E = 0$ open switch
** linear (Active) mode	Forward (ON)	Reverse (OFF)	 $I_C = \beta I_B$ $I_C = \alpha I_E$ $I_E = I_B + I_C$
	Reverse	Forward	

used in digital Electronics (saturation mode, cut-off mode)

Amplifiers ⇒ used in analog electronics (linear (Active) mode)

$V_{CE(sat)} < V_{CE} < V_{CE(max)}$

⇒ In active region → BE (ON), BC (OFF)



$$I_C = \underbrace{\alpha I_E}_{\text{majority}} + \underbrace{\cancel{I_{CBQ}}}_{\text{minority}} \quad \text{—(1)}$$

$0.998 > \alpha > 0.9$

$$I_E = I_B + I_C \quad \text{—(2)}$$

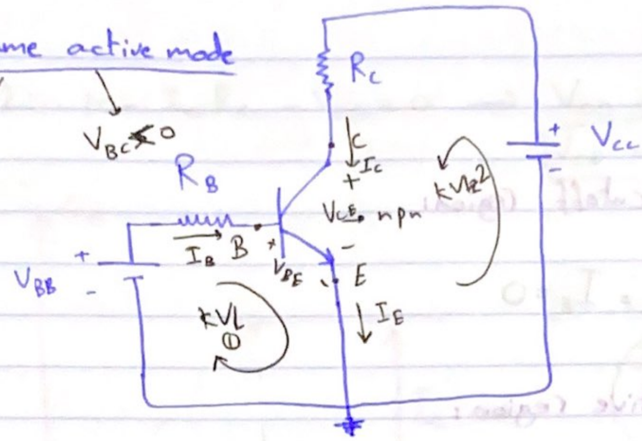
Put (2) in (1)

$$I_C = \frac{\alpha}{1-\alpha} I_B, \quad B = \frac{\alpha}{1-\alpha}$$

$$\Rightarrow I_C = \beta I_B$$

assume active mode

$V_{BE} > 0$ $\qquad$ $V_{BC} < 0$



$V_{BE} > 0 \Rightarrow BE \rightarrow ON$

$V_{BC} < 0 \Rightarrow BC \rightarrow OFF$

<u>KVL 1</u>

$$V_{BB} = I_B R_B + V_{BE} \quad —① $$

<u>KVL2</u>

$$V_{CC} = I_C R_C + V_{CE} \quad —② $$

$$I_E = I_B + I_C \quad —③ $$

$$\alpha = \frac{I_C}{I_E} \quad —④ \qquad \beta = \frac{I_C}{I_B} \quad —⑤ $$

$$\beta = \frac{\alpha}{1-\alpha} \quad —⑥ $$

$$V_E < V_B < V_C$$

* Summary

- In the cutoff region:

$$I_B = I_C = I_E = 0$$

- In the active region:

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

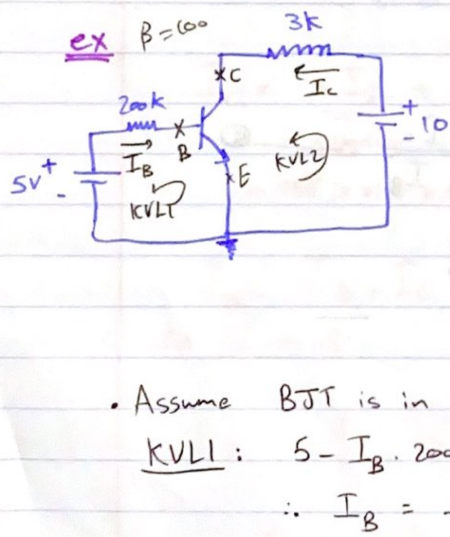
npn, Si $\Rightarrow$ $V_{BE} = 0.7V$

pnp, Si $\Rightarrow$ $V_{BE} = -0.7V$

$V_{CE} > V_{CE,sat} = 0.2 V$, npn

$V_{CE} < V_{CE,sat} = -0.2V$, pnp

ex $\beta = 100$



Find mode of operation of BJT, I_{CQ}, V_{CEQ}.

BE $\longrightarrow$ FW

BC (FW) $\downarrow$ saturation

BC (BW) $\downarrow$ Active

- Assume BJT is in active mode:

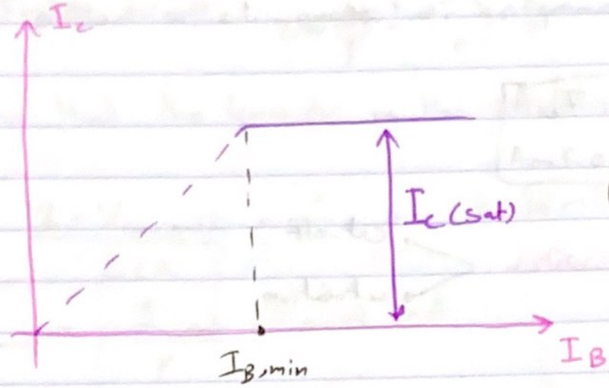
KVL1: $5 - I_B \cdot 200k - V_{BE} = 0$ $\longrightarrow$ $V_{BE} = 0.7$ $\leftarrow$ active

$$\therefore I_B = \frac{5 - 0.7}{200k} = 21.5 \mu A$$

$$\boxed{I_C = \beta I_B = 2.15 mA}$$

KVL2: $10 - I_C R_C - V_{CE} = 0 \longrightarrow V_{CE} = 10 - 2.15m \times 3k$

$\boxed{V_{CE} = 3.55V}$



saturation mode

$I_c = I_{c(sat)}$

$I_c \neq \beta I_B$

$V_{CE} = V_{cc} - I_c R_c$

$\therefore \quad I_{c(sat)} = \dfrac{V_{cc} - V_{CE(sat)}}{R_C}$

$I_{B(min)} = \dfrac{I_{c(sat)}}{\beta}$

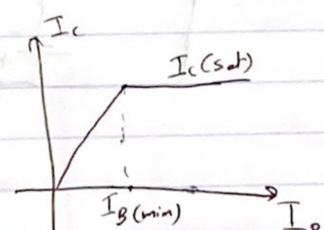
$\Rightarrow$ If $I_B > I_{B(min)} \Rightarrow$ saturation mode

$\Rightarrow$ If $I_B < I_{B(min)} \Rightarrow$ Active region

- Assume saturation mode:

$V_{CE} = V_{CE(sat)} = 0.2V \quad , \quad I_c = I_{c(sat)} = ?$

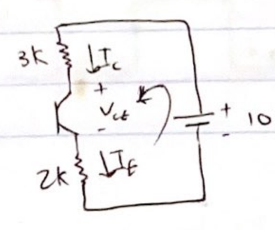
$10 = I_c \cdot 3k + I_b \cdot 2k$



in saturation:

$I_c \simeq I_E = I_c(sat), \; V_{CE} = V_{CE(sat)} = 0.2$

$\therefore \quad I_{c(sat)} = \dfrac{10 - 0.2}{3k + 2k} = 1.96\ mA$



$I_{B(min)} = \dfrac{I_{c(sat)}}{\beta} = 19.6\ \mu A$

→ Find $I_{B(actual)} = \frac{5-0.7}{200k + 2k(101)} = 10.7\ \mu A < \underline{\underline{I_{B(min)}}}$

شي خاطئة

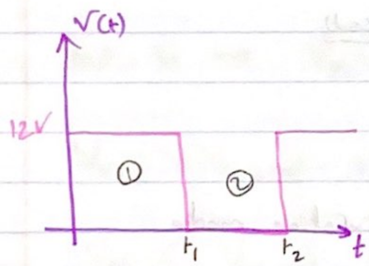
⇒ The assumption is wrong, its in active mode.

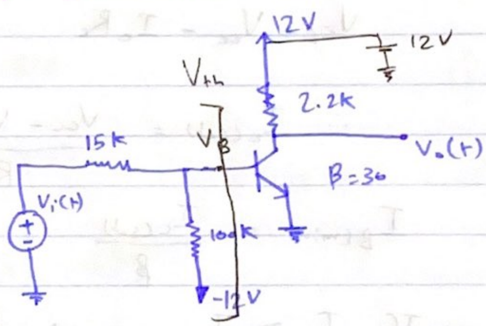
$\boxed{\begin{aligned} I_B &= 10.7\,\mu A \\ I_C &= 1.07\,mA \end{aligned}}$

17:01

⇒ BJT as switch → cut-off / saturation

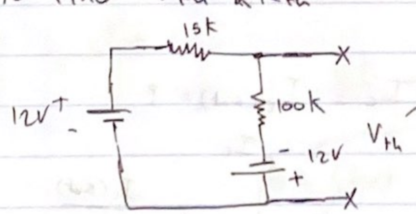
ex Find $V_o(t)$ for the input given below:





① $0 - t_1 \Rightarrow V_i = 12V$

· To Find V_{th} & R_{th}



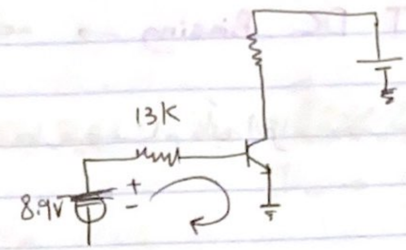
super position

$V'_{th}\Big|_{12V \to 0} = \frac{15k}{(15 \times 100)k} \times -12$

$V''_{th}\Big|_{-12V \to 0} = \frac{100k}{(15+100)k} \times 12$

$V_{th} = V'_{th} + V''_{th} = 8.9V$

$R_{th} = 100k // 15k = 13k$



Base-Emitter : Forward

. Assume that the transistor in the saturation mode

$$\frac{12 - V_{CE(sat)}}{2.2k} = I_{c,sat} = 5.36\,mA$$

$$I_{B(min)} = \frac{I_{C,sat}}{\beta} = 0.18\ mA$$

$$I_{B(actual)} = \frac{V_{th} - V_{BE}}{13k} = \frac{8.9 - 0.7}{13k} = 0.63\ mA$$

Since $I_B > I_{B(min)}$, our assumption is right

$V_{CE(sat)} = V_o = 0.2\,V$

$I_c = 5.36\ mA$

② $t_1 - t_2 \Rightarrow V_i = 0$ Volt

$$V_{th} = \frac{15}{15+100} \times -12 = -1.56\ V$$

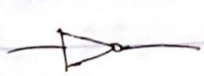
$R_{th} = 13k$

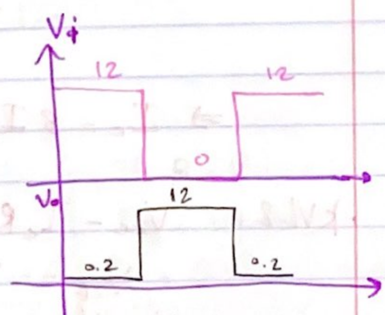
Base - Emitter : Reverse

cutoff region

$I_B = 0 \Rightarrow V_o = V_{CE} = 12V$

inverter / not gate

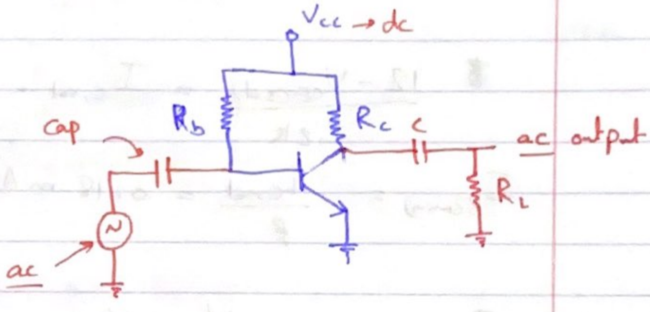




. T_7 : BJT DC Biasing → active/linear mode

الـBiasing هي مصادر ڤولتية خارجية عشان نخلي الترانزيستور يشتغل بالمود الي إحنا بدنا اياها.

① Fixed-bias circuit



dc Analysis

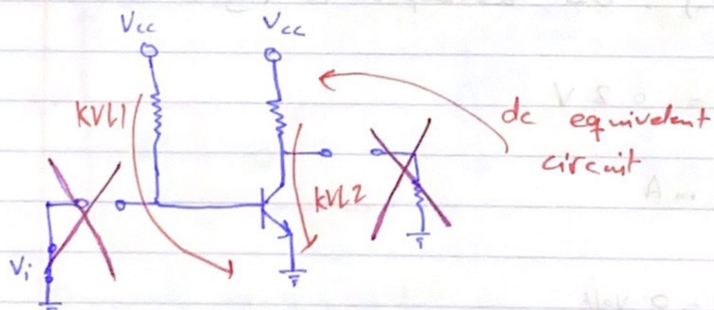
⇒ ac sources killed

⇒ $f = 0$

$X_c = \frac{1}{2\pi f c} \cong \infty$

caps are treated as open circuit

open



. KVL1 : $V_{cc} - I_B R_B - V_{BE} = 0$

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

. اختيار قيمة R_B هو الي رح يحددلنا قيمة I_B

. قيمة I_B رح تحدد قيمة I_c

$$\Rightarrow I_c = \beta I_B$$

. KVL2 : $V_{cc} - I_c R_c - V_{CE} = 0$

$$V_{CE} = V_{cc} - I_c R_c$$

$$V_c - V_E = V_{cc} - I_c R_c$$

$V_E = 0$

$\Rightarrow V_c = V_{cc} - I_c R_c \rightarrow$

$$I_c = \frac{V_{cc} - V_{CE}}{R_c}$$

$V_{BE} = V_B - V_E$

$V_E = 0$

$\therefore V_{BE} = V_B$

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

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

ex $V_{cc} = 10V$, $\beta_{nominal} = 100$, $\beta_{min} = 50$, $\beta_{max} = 150$

$V_{CEQ} = 5V$, $I_{CQ} = 1\,mA$

Find R_B & R_c

$$I_B = \frac{I_c}{\beta} = \frac{1\,mA}{100} = 10\,\mu A$$

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

$$10\mu = \frac{10 - 0.7}{R_B}$$

$$\boxed{R_B = 930\,k\Omega}$$

$$V_{CE} = V_{cc} - I_c R_c$$

$$R_c = \frac{V_{cc} - V_{CE}}{I_c} = \frac{10 - 5}{1m} = 5\,k\Omega$$

$$\boxed{R_c = 5\,k\Omega}$$

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

  $I_B = 10\,\mu A$ (ما بتعتمد على β)

  $I_c = \beta I_B = 50(10\,\mu A) = 0.5\,mA$

  $V_{CE} = V_{cc} - I_c R_c \Rightarrow \boxed{V_{CE} = 7.5V}$

- If $\beta = \beta_{max}$

  $I_B = 10\,\mu A$

  $I_c = \beta I_B = 1.5\,mA$

  $\boxed{V_{CE} = 2.5V}$

$\Rightarrow$ for $50 \leq \beta \leq 150$

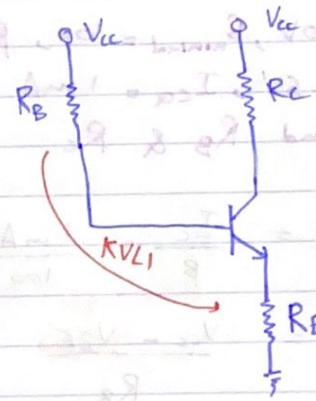
$I_B = 10\,\mu A$ <u>fixed</u>

$0.5\,mA \leq I_c \leq 1.5\,mA$

$2.5\,V \leq V_{CE} \leq 7.5\,V$

$\therefore \dfrac{I_{c\,(max)}}{I_{c\,(min)}} = \dfrac{1.5\,mA}{0.5\,mA} = 3$ <u>not very stable</u>

② Emitter - Stabilized Bias Circuit



* KVL①:

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

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

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

$$\Rightarrow I_E = \frac{V_{cc} - V_{BE}}{\frac{R_B}{\beta+1} + R_E}$$ (احنا ما بدنا تكون المعادلة معتمدة على β)

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

$$I_E = \frac{V_{cc} - V_{BE}}{R_E}$$ *

Design rule / Assumption : $0.1\, V_{cc} \leq V_E < 0.2\, V_{cc}$

(في حال إنه R_E مش معروفة وبدنا نعمل Design بكل)

* KVL②

$-V_{cc} + I_c R_c + V_{CE} + I_B R_B = 0$

since $I_E \cong I_c \Rightarrow V_{CE} = V_{cc} - I_c (R_c + R_E)$

ex $V_{cc} = 10V$, $\beta_{nominal} = 100$, $\beta_{min} = 50$, $\beta_{max} = 150$

$V_{CE} = 5V$, $I_c = 1mA$

- Assumption to be used in design problem only if R_E is unknown

$$0.1\,V_{cc} \le V_E \le 0.2\,V_{cc}$$

① let $V_E = 0.1\,V_{cc} = 1V$

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

$$R_E = \frac{1V}{0.99mA} \cong \boxed{1\,k\Omega = R_E}$$

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

$$\boxed{R_B = 829\,k\Omega}$$

$$R_c = \frac{V_{cc} - V_{CE} - V_E}{I_c} = \frac{10-5-1}{1m} = \boxed{4\,k\Omega = R_c}$$

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

$$I_B = \frac{10 - 0.7}{829k + (51)(1k)} = 10.56\,\mu A$$

$$I_c = \beta I_B = 0.528\,mA$$

$$V_{CE} = V_{cc} - I_c R_c - V_E = 10 - (0.258m)(4k) - 1$$

$$= \boxed{6.89V = V_{CE}}$$

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

$I_B = 9.489\,\mu A$

$I_c = 1.423\,mA$

$V_{CE} = 3.31V$

for $50 \le \beta \le 150$

$10.56\mu \ge I_B \ge 9.489\mu$

$1.423m \ge I_c \ge 0.528m$

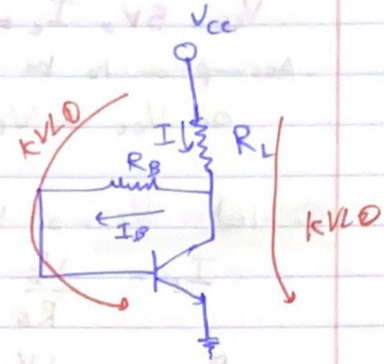
$6.89V \ge V_{CE} \ge 3.31V$

$$\frac{I_{c\,max}}{I_{c\,min}} = \frac{1.423}{0.528} \cong 2.7$$

Improved but not very stable

③ DC Bias with voltage feedback

* KVL ①



$$V_{cc} - IR_L - I_BR_B - V_{BE} = 0$$

$$I = I_c + I_B$$
$$I_c = \beta I_B$$

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

$$\Rightarrow \quad I_B = \frac{V_{cc} - V_{BE}}{R_L(\beta+1) + R_B}$$

* KVL ②

$$V_{cc} = IR_L + V_{CE}$$

$$V_{CE} = V_{cc} - (I_c + I_B)R_L$$

ex $V_{cc} = 10\,V$, $\beta_{nominal} = 100$, $\beta_{min} = 50$, $\beta_{max} = 150$
$V_{CE} = 5V$, $I_c = 1mA$

$$R_L = \frac{V_{CC} - V_{CE}}{I} = \frac{V_{CC} - V_{CE}}{I_B + I_c} = \frac{10-5}{1m + \frac{1m}{100}}$$

$$\Rightarrow \boxed{R_L = 4.95k\Omega}$$

$$I_B = \frac{V_{cc} - V_{BE}}{R_L(\beta+1) + R_B} \Rightarrow \boxed{430\ k\Omega} = R_B$$

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

$I_B = 0.013627 \, mA$

$I_C = 0.68 \, mA$

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

$I_B = 0.00793 \, mA$

$I_C = 1.19 \, mA$

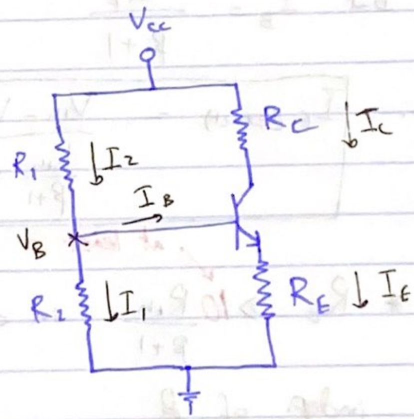
for $50 \le \beta \le 150$

$0.68 \, mA \le I_C \le 1.19 \, mA$

$\therefore \dfrac{I_{C(max)}}{I_{C(min)}} = \dfrac{1.19m}{0.68m} \simeq 1.75$ Better Q-point stability

④ Voltage Divider Bias

. Approximate Analysis



$I_B \ll I_1$

$I_2 = I_B + I_1 \Rightarrow I_2 = I_1$

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

$I_{E(approximate)} = \dfrac{V_E}{R_E} = \boxed{\dfrac{V_B - V_{BE}}{R_E}}$ ← لا تعتمد على β

KVL

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

$I_E \simeq I_C$

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

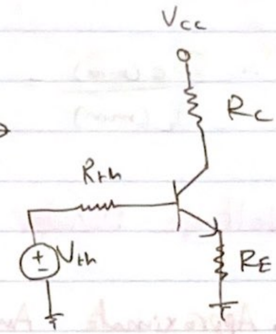
• Exact Analysis

Therinin Equivelat circuit for the circuit left

$$V_{th} = \frac{R_1 V_{cc}}{R_1 + R_2}$$

$$R_{th} = R_1 // R_2 = \frac{R_1 R_2}{R_1 + R_2}$$

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



but $I_B = \frac{I_E}{\beta + 1}$

$$\therefore \boxed{I_{E\,(exact)} = \frac{V_{th} - V_{BE}}{\frac{R_{th}}{\beta+1} + R_E}}$$

at least 10

* $R_E \gg 10 \frac{R_{th}}{\beta + 1}$ in order to get I_E almost indep. of β

ex $V_{cc} = 10\,V$, $\beta_{nominal} = 100$, $\beta_{min} = 50$, $\beta_{max} = 150$
$V_{CE} = 5V$, $I_E = 1mA$

① let $V_E = 0.1\, V_{cc} \Rightarrow V_E = 1V$

$$I_E = \frac{V_E}{R_E} \Rightarrow R_E = \frac{1\,V}{1.01\,mA} \cong 1\,K\Omega$$

② let $R_{th} = \frac{R_E \cdot \beta_{(nominal)}}{50} = \frac{1K\,(100)}{50} = 2K\Omega$

③ $V_{cc} = R_c I_c + R_E I_E + V_{CE}$