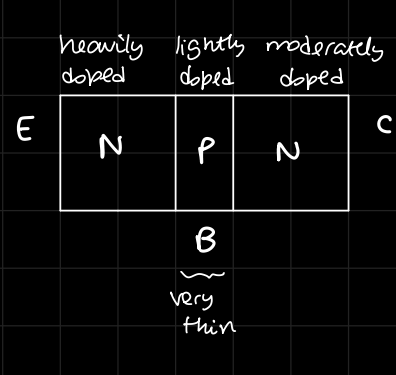
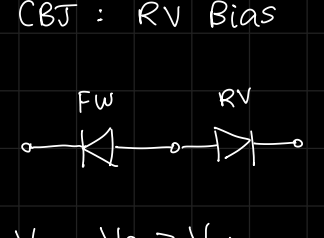
* # Bipolar Junction Transistor



Active Region ≡ Amplifier
EBJ : FW Bias
CBJ : RV Bias



$V_C > V_B > V_E$

Cutoff Region ≡ Switch
EBJ : RV , CBJ : RV

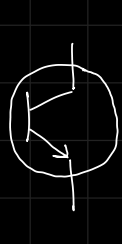
$V_E > V_B$ and $V_C > V_B$

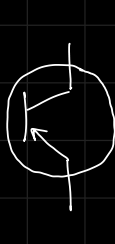
Saturation Region ≡ Switch
EBJ : FW , CBJ : FW

$V_B > V_E$ and $V_B > V_C$

Inverted Region ≡ useless (gain very low)
EBJ : RV and CBJ : FW

$V_E > V_B > V_C$


npn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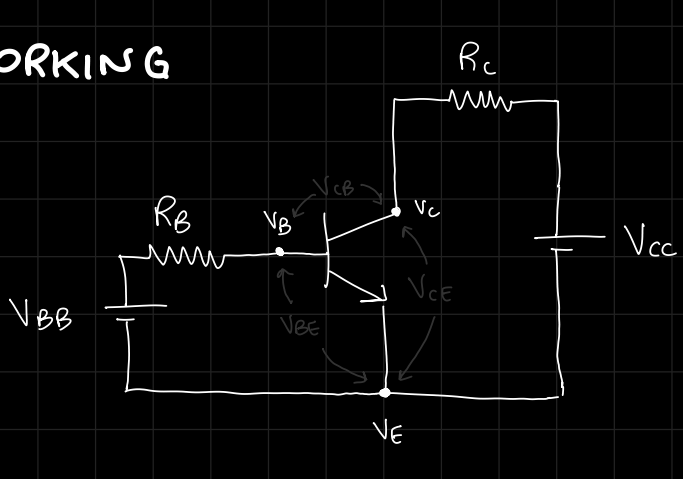
WORKING



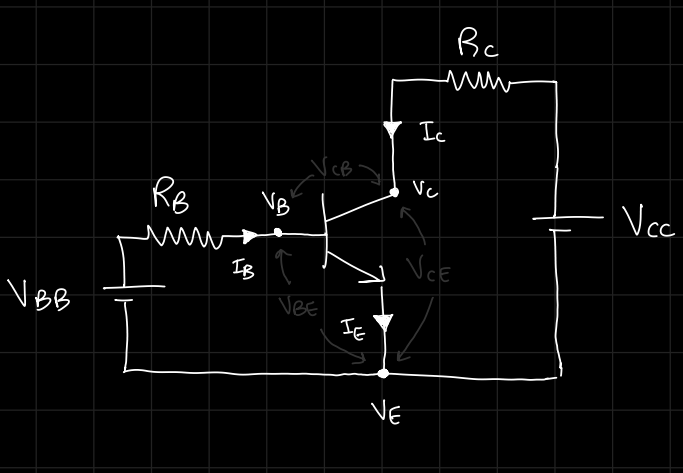
$V_{BE} \sim 0.7V$

We know that Emitter region is heavily doped and since it is n type, the majority carriers are e^-.

When we power the circuit, the e^- from the -ve terminal of V_{BB} will repel the e^- in Emitter and they will move towards the base which is lightly doped so it has less concentration of holes.

Now, in the Base, the e^- have 2 routes they can take; either towards the +ve terminal of V_{BB} as I_B or towards the Collector region.

Majority of the e^- from the emitter will go in the collector and some of them will merge with the holes in Base and go towards +ve terminal of V_{BB} because B is lightly doped and the width of the Base is very small.



$I_E = I_B + I_C$

Since very less e^- flow out from the Base,
$I_E \simeq I_C$

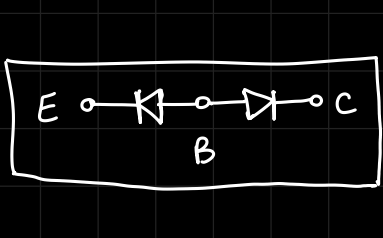
$I_C = \alpha I_E$

$\frac{I_C}{\alpha} = I_B + I_C \rightarrow I_B = I_C\left(\frac{1-\alpha}{\alpha}\right)$

$I_C = \left(\frac{\alpha}{1-\alpha}\right) \times I_B$

let $\beta = \frac{\alpha}{1-\alpha} \Rightarrow \frac{1}{\beta} = \frac{1}{\alpha} - 1 \rightarrow \alpha = \frac{\beta}{\beta+1}$

$I_C = \beta I_B$



active mode : $V_{BE} > 0$, $V_{CB} > 0$ FW, RV

cutoff mode : $V_{BE} > 0$, $V_{CB} < 0$ FW, FW

saturation mode : $V_{BE} < 0$, $V_{CB} > 0$ RV, RV

eg} $I_B = 10\mu A$, $I_C = 600\mu A$

$\beta = \frac{I_C}{I_B}$, $\alpha = \frac{I_C}{I_E}$

$\beta = \frac{600}{10} = 60$

$\alpha = \frac{\beta}{\beta+1} = \frac{60}{61} = 0.9836$

eg} $V_{BE} = 0.76V$ $I_C = 10mA$

$I_C = I_S e^{V_{BE}/V_T}$

at room temperature, $V_T = 25mV$

$10 \times 10^{-3} = I_S e^{760/25}$

$\log_e 10^{-2} = \frac{760}{25} + \log_e I_S$

$\log_e I_S = 4.6 - \frac{76 \times 4}{10}$

$= 4.6 - 30.4 = -25.8$

$I_S = e^{-25.8}$ ✗

$I_S = \frac{1}{159.42 \times 10^{13}} = 0.627 \times 10^{-15} A$

$= 6.27 \times 10^{-16} A$

$I_C = ?$ at $V_{BE} = 0.7V$

$I_C = I_S e^{V_{BE}/V_T}$

$I_C = 6.27 \times 10^{-16} e^{700/25}$

$I_C = 6.27 \times 10^{-16} \times 1.44 \times 10^{12} = 0.9mA$

$V_{BE} = ?$ at $I_C = 10\mu A$

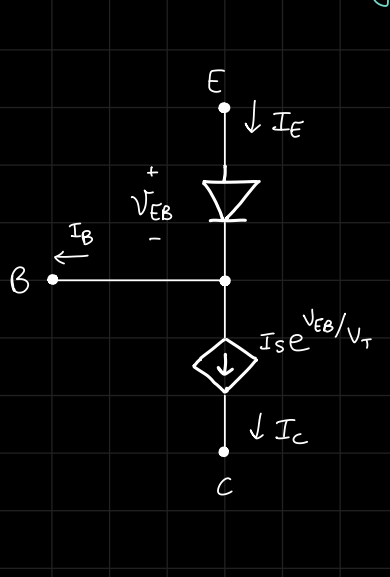
$10 \times 10^{-6} = 6.27 \times 10^{-16} \times e^{V_{BE}/V_T}$

$V_{BE} = 25 \times 10^{-3} \times \ln\left(\frac{10^{11}}{6.27}\right)$

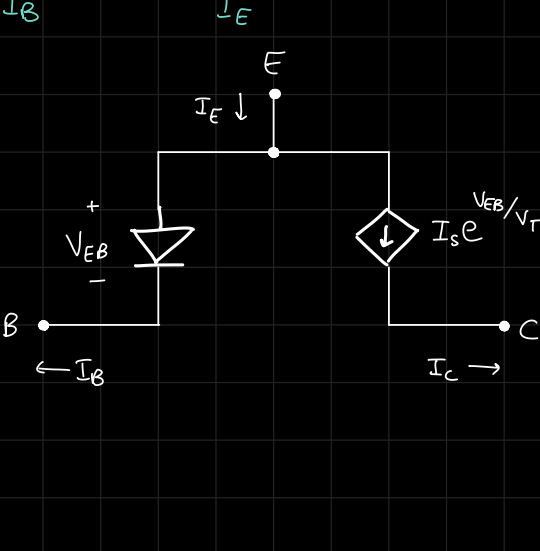
$V_{BE} = 25 \times 10^{-3} \times 23.5$

$V_{BE} = 0.587V$

$I_C = I_S e^{V_{BE}/V_T}$ $\beta = \frac{I_C}{I_B}$ $\alpha = \frac{I_C}{I_E}$

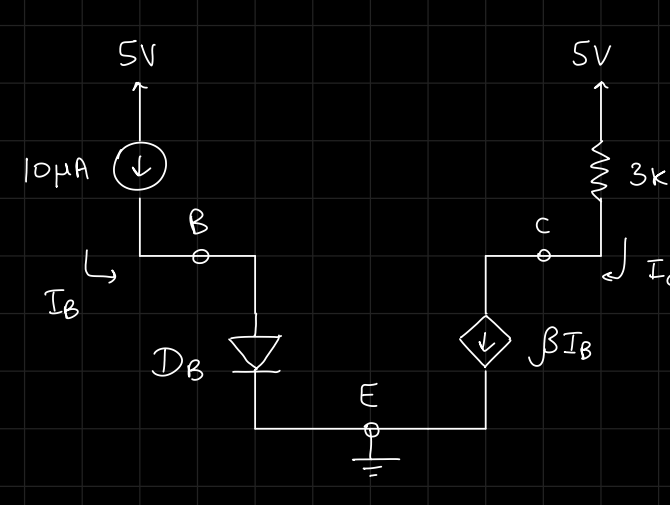


T Model



π - Model

eg}



given: $I_S = 10^{-15} A$, $\beta = 100$, $I_B = 10\mu A$

find : I_C, V_{BE} , V_{CE}

$I_C = \beta I_B = 1mA$

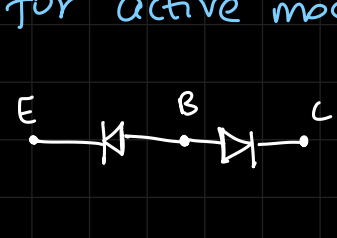
$I_C = I_S e^{V_{BE}/V_T} \Rightarrow 10^{-3} = 10^{-15} e^{V_{BE}/V_T}$

$\Rightarrow V_{BE} = 25 \cdot 10^{-3} \cdot \ln(10^{12}) = 25 \times 10^{-3} \times 27.63$
$= 0.69V$

$-5 + 3000 I_C + V_{CE} = 0$

$V_{CE} = 2V$

for active mode (npn) → $V_{CB} \geq 0$



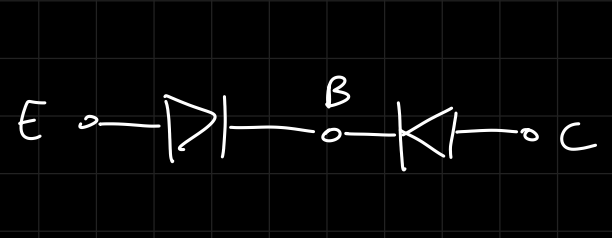
$V_{CB} \geq 0$
CBJ : Reverse

base current in the saturation region $\Rightarrow i_B = \underbrace{\frac{I_S}{\beta} e^{V_{BE}/V_T}}_{EBJ} + \underbrace{I_{SC} e^{V_{BE}/V_T}}_{CBJ}$

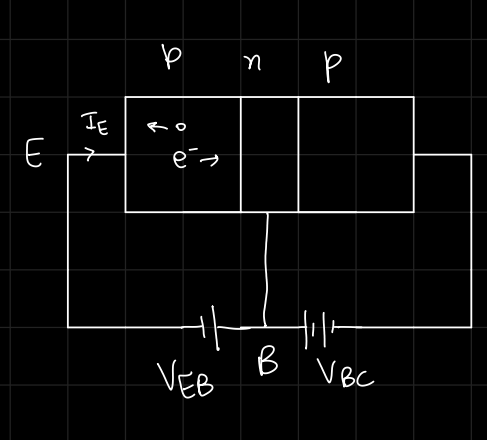
$\beta_{forced} = \left.\frac{i_C}{i_B}\right|_{saturation} \leq \beta$

$V_{CE_{saturation}} = V_{BE} - V_{BC}$

pnp →



Active mode : $V_{EB} > 0$ and $V_{CB} < 0$

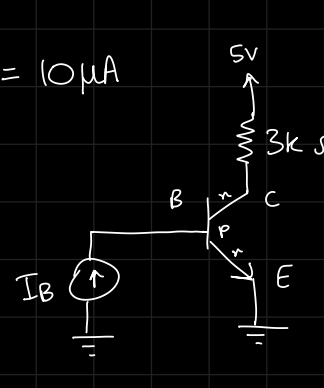


$\beta = \frac{I_C}{I_B}$ → common emitter current gain

$\alpha = \frac{I_C}{I_E}$ → common base current gain

eg 6.1) npn, $I_S = 10^{-15} A$, $\beta = 100$

$I_B = 10\mu A$



assumption (s):
active mode
↳ EBJ : FW
CBJ : RV

$V_{BE} > 0$ and $V_{CB} < 0$

$I_C = \beta I_B = 1mA$

$I_C = I_S e^{V_{BE}/V_T}$

$10^{-3} = 10^{-15} e^{V_{BE}/V_T}$

$\ln(10^{12}) = \frac{V_{BE}}{25 \times 10^{-3}}$

$V_{BE} = 27.63 \times 25 \times 10^{-3} = 0.69V$ → FW

$-5 + 3000 I_C + V_{CE} = 0$
$V_{CE} = 2V$

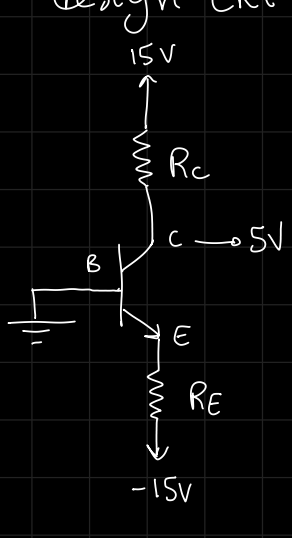
$\left.\begin{aligned} V_{CE} &= V_C - V_E \\ V_{BE} &= V_B - V_E \end{aligned}\right\} V_{CB} = V_{CE} - V_{BE} = -1.31V$ → RV

$R_B = \frac{5}{I_B} = \frac{5}{10} \times 10^{6} = 500k\Omega$ ✗

$\frac{5 - 0.69}{I_B} = 431k\Omega$ ✓

eg2) $\beta = 100$ $v_{BE} = 0.7V$ $i_C = 1mA$

design ckt so that $i_C = 2mA$ and $V_C = 5V$



$-15 + 10^{-3} \cdot R_C + V_{CE} + I_E R_E - 15 = 0$

$\alpha = \frac{\beta}{\beta+1} = \frac{100}{101} = 0.99$

$\frac{I_C}{I_E} = \alpha \rightarrow I_E = \frac{10^{-3}}{0.99} = 1.01mA$

$10^{-3} \cdot R_C + V_{CE} + I_E R_E = 30$

$-15 - 1.01 \cdot 10^{-3} \cdot R_E - V_{BE} = 0$
$R_E = \frac{15.7}{1.01} k\Omega = 15.5k\Omega$

$-15 + 10^{-3} \cdot R_C + V_{CB} = 0$

$10^{-3} \cdot R_C = 15 - V_{CB}$

$I_B = \frac{I_C}{\beta} = \frac{10^{-3}}{100} = 10^{-5} A$

$R_C = \frac{15 - 5}{10^{-3}} = 5k\Omega$

* Tutorial 4

Q1)

1. In the amplifier circuit shown in figure 1, the values of R_1 and R_2 are such that the transistor is operating at $V_{CE} = 3$ V and $I_C = 1.5$ mA when β is 150. For a transistor with β of 200, find the operating point (V_{CE}, I_C). (Assume R_1&R_2 are fixed)

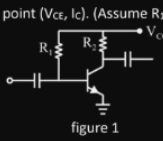
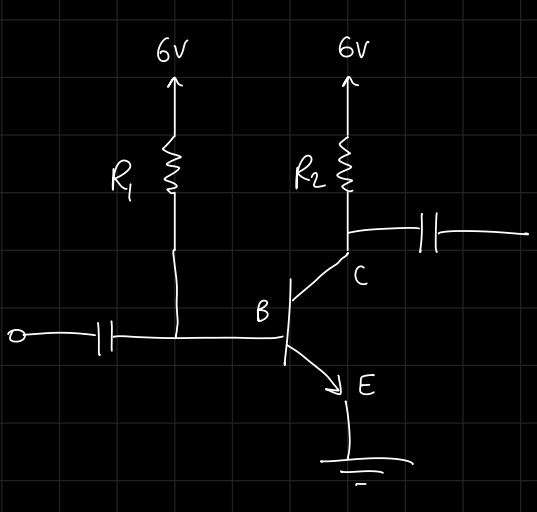


figure 1



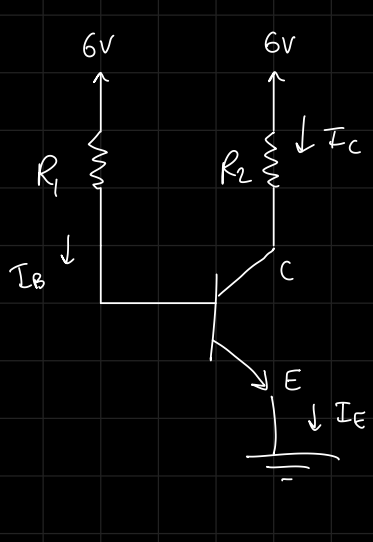
Since there is no AC source, we open circuit all the capacitors

NOTE: No AC →

Capacitor ≡ OC

Inductor ≡ SC

$V_{AC} = 0$



KVL: $-6 + I_C R_2 + V_{CE} = 0$

I_C: 1.5mA (given), V_{CE}: 3V (given)

$$R_2 = \frac{6-3}{1.5}\ k\Omega = 2k\Omega$$

$$-6 + R_1 I_B + V_{BE} = 0$$

$$\beta = 150, \quad I_B = \frac{I_C}{\beta} = \frac{1.5}{150}\ mA$$

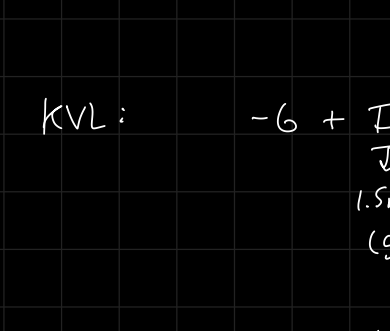
$$= 10\mu A$$

$$R_1 = \frac{6-0.7}{10} \times 10^6\ \Omega$$

$$R_1 = 530\ k\Omega$$

So $R_1 = 530k\Omega$ and $R_2 = 2k\Omega$

(b) for $\beta = 200$, find V_{CE} and I_C



operating point

$$-6 + I_C \cdot 2k + V_{CE} = 0$$

$$-6 + 530k \cdot I_B + V_{BE} = 0$$

$$I_B = \frac{6-0.7}{530}\ mA$$

$$= \frac{5.3}{530}\ mA$$

$$= 10\mu A$$

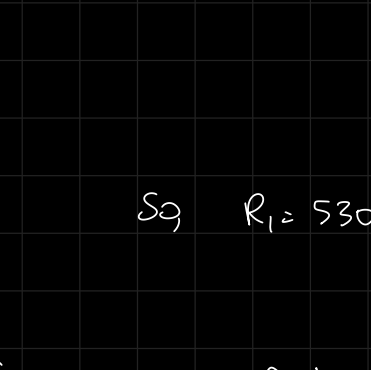
$$I_C = 200 \times I_B = \underline{2\ mA}$$

$$V_{CE} = 6 - 2 \cdot 2 = \underline{2V}$$

Q2)

2. For a silicon based BJT shown in figure 2, find R_B to establish $V_{CE} = 2$V, Assume $V_{BE} = 0.7$ V.

figure 2



$\beta = 50$

$$-12 + I_C \cdot 5k + V_{CE} = 0$$

$$-12 + I_C \cdot 5k + 2 = 0$$

$$I_C = 2mA$$

$$I_B = \frac{2mA}{50} = 40\mu A$$

$$-12 + R_B \cdot 40\mu A + 0.7 = 0$$

$$R_B = \frac{11.3}{40}\ M\Omega = 282.5k\Omega$$

Q3)

3. Determine the voltages at all nodes and the currents through all branches in given figure3. Assume $\beta = 100$.

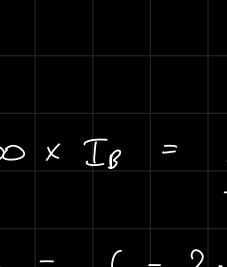
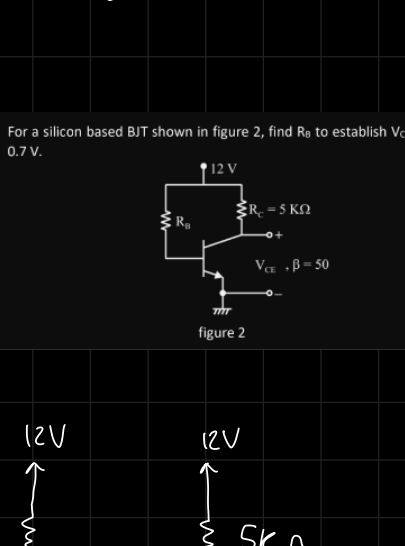


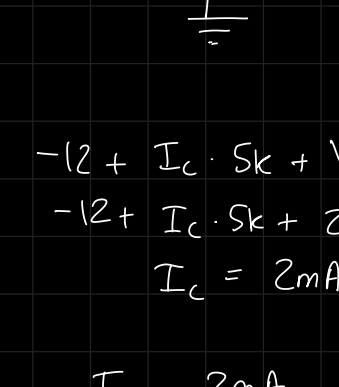
figure 3



$\beta = 100$

$$-15 + 5k\, I_C + V_{CE} + 3k I_E = 0$$

Using Thevenin's Theorem, we can simplify the ckt on the left



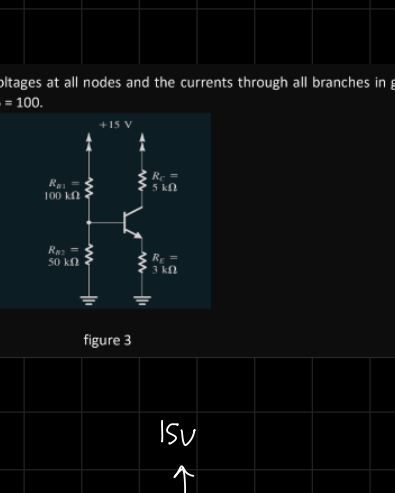
$$V_{Th} = \frac{50k}{150k} \cdot 15 = \frac{15}{3} = 5V$$

R_{Th} → SC all V sources

So, $R_{Th} = 100k \parallel 50k$

$$\left(\frac{1}{100k} + \frac{1}{50k}\right)^{-1}$$

$$= \frac{5 \cdot 10^{9} \cdot 6}{150k} = \frac{500 \cdot 10^3}{15} = \frac{100}{3} = 33.3k\Omega$$



$$-5 + 33.3k I_B + 0.7 + I_E \cdot 3k = 0$$

$$-15 + 5k\, I_C + V_{CB} - 33.3k I_B + 5 = 0$$

$$\frac{5-0.7}{33.3} = I_B = 0.129\ mA$$

$$I_C = 12.9\ mA$$

$$\alpha = \frac{\beta}{\beta+1} = \frac{100}{(0)} = 0.99$$

$$I_E = \frac{I_C}{\alpha} = 13.03\ mA$$