Analog Circuits : Assignment -2

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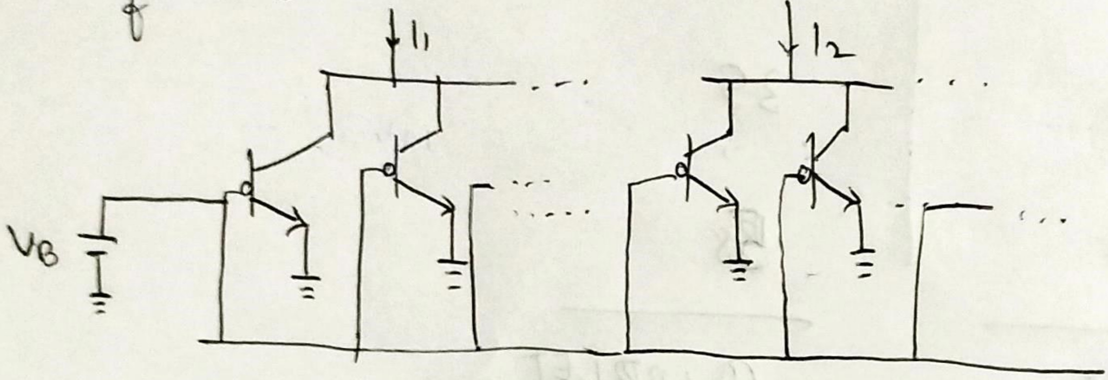
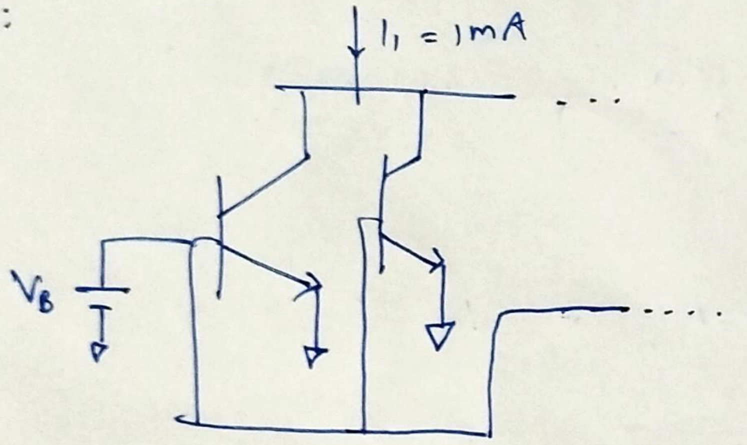
Q1) An IC uses $I_1 = 1mA$ & $I_2 = 1.5mA$. Assuming only integer multiples of a unit BJT, < $i_S = 3 \times 10^{-16} A$ > can be placed in ||, & only V_B is available, make the req. circuit with min. no. of BJTs

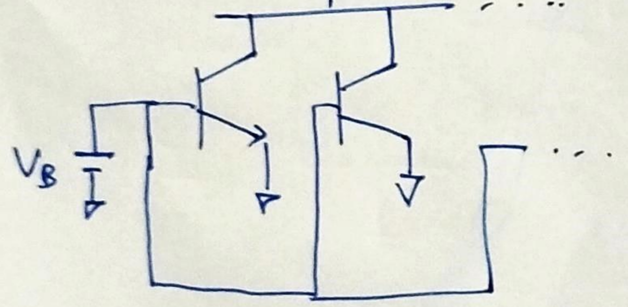


< Assume all BJTs have same i_s, $V_A = \infty$ >
$V_T = 26mV$

Ans:



=> assume n BJTs



=> assume m BJTs

=> For I_1:

$$I_1 = n(I_c) = n\left(i_s e^{V_{BE}/V_T}\right) \quad -①$$

$$I_2 = m(I_c) = m\left(i_s e^{V_{BE}/V_T}\right) \quad -②$$

$\Rightarrow$ Divide ① & ②

$$\frac{1}{1.5} = \frac{n}{m} \cdot \frac{i_s}{i_s} \cdot \frac{e^{V_{BE}/V_T}}{e^{V_{BE}/V_T}} = \frac{n}{m}$$

< common V_{BE}, same type of BJTs>

$$\rightarrow \frac{n}{m} = \frac{1}{1.5} = \frac{1}{3/2} = \frac{2}{3}$$

$\therefore$ $\boxed{n = 2,\ m = 3 \quad \text{< Assuming integral of BJTs>}}$

$\Rightarrow$ t.f. V_{BE} : use ① or ②

$$\Rightarrow 10^{-3} \times 1 = 2 \times e^{(V_{BE}/V_T)} \times i_s$$

$$\Rightarrow 10^{-3} \times 1/2\, i_s = e^{V_{BE}/V_T}$$

$$\Rightarrow V_T = 26\,mV \ ; \ V_{BE} = V_T \ln\left(\frac{10^{18}}{2\times 3}\right)$$

< $1mA = 2 \times e^{V_{BE}/V_T}$ —①, $V_T = 26\,mV$ >

$\therefore$ $\boxed{V_{BE} = 731.69\,mV}$ (0.73 V approx)

Q2> BJT's relation b/w $I_C - V_{BE}$ is as follows:

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

<same assumptions>

→ η is a constant < like I_S, V_T >

→ Given: $I_C = \beta I_B$. Find small signal model.

Ans: Given:

$$I_C = i_s e^{V_{BE}/\eta V_T}$$

$$= \beta I_B$$

Q2>

=> For small signal model (π model):

find r_π, r_o, r_μ, g_m

↳ ignored generally.

=> We know that:

$$g_m = \frac{\partial i_C}{\partial V_{BE}} \quad , \quad 1/r_\pi = \frac{\partial i_B}{\partial V_{BE}} = \frac{1}{\beta}\frac{\partial i_C}{\partial V_{BE}}$$

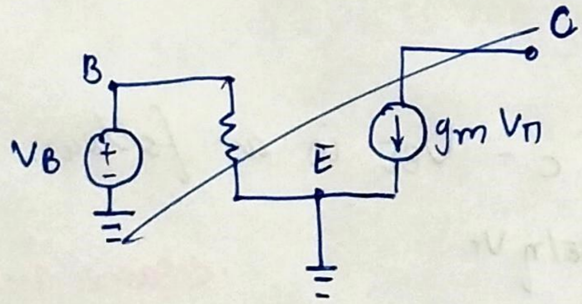
$$\Rightarrow r_\pi = \beta / g_m$$

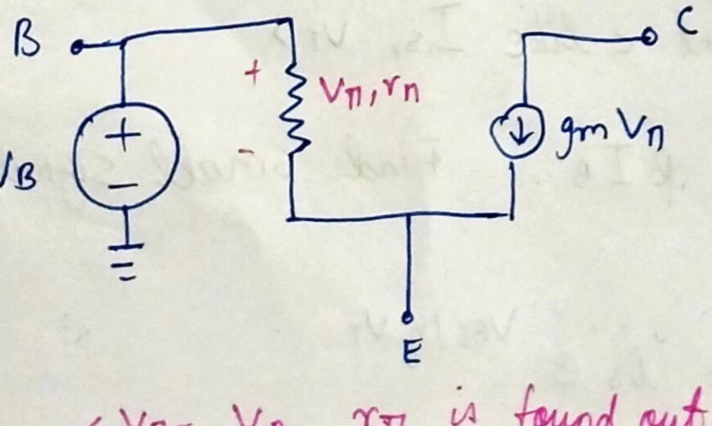
$$\Rightarrow g_m = \frac{\partial}{\partial V_{BE}}\left(i_s e^{V_{BE}/\eta V_T}\right) = \frac{i_s e^{V_{BE}/\eta V_T}}{(\eta V_T)} = \frac{i_c}{\eta V_T}$$

$$\Rightarrow r_\pi = \frac{\beta \cdot \eta V_T}{i_c} = \beta\eta\left(\frac{V_T}{i_c}\right)$$

=> ~~Assume~~ Assuming $V_A = \infty$: ~~$r_o \to \infty$~~ $r_o \to \infty$, so it is ignored

=> Small Signal Model:





(V_E can be 0 due to ground)

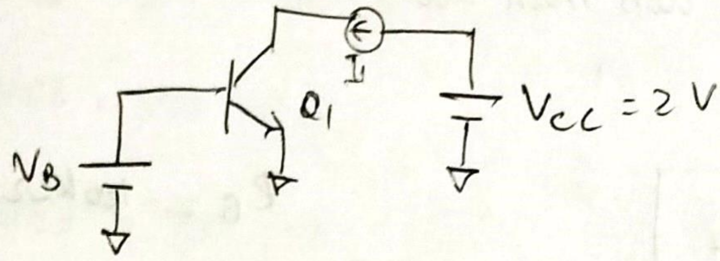
<$V_\pi = V_B$, r_π is found out>

<Not assuming R_L, R_C here>

Q3) $I_1 = 1mA$, $i_s = 3\times10^{-17} A$

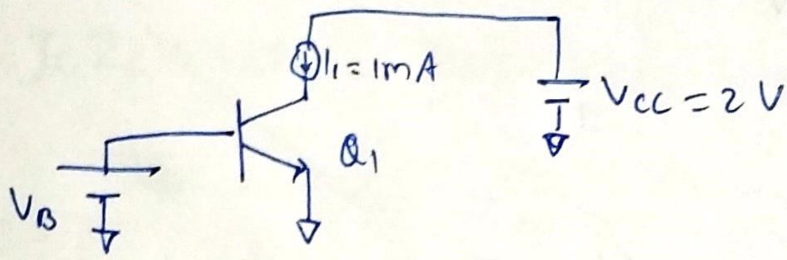
a) $V_A = \infty$, V_B s.t. $i_C = 1mA$

b) $V_A = 5V$, make V_B s.t. $i_C = 1mA$, $V_{CE} = 3/2\ V$



Ans:

a)



$(V_A = \infty)$

$\Rightarrow$ If $V_A = \infty$, it is an ideal BJT:

$$I_1 = I_C = 1mA$$

$$\Rightarrow V_{BE} = V_T \ln\left(\frac{I_C}{I_S}\right)$$

$$= 26\times10^{-3} \times \ln\left(\frac{10^{-3}}{3\times10^{-17}}\right)$$

$$\boxed{V_{BE} = 809.577\ mV \approx 0.81\ V}$$

b) now $V_A = 5V$

$\Rightarrow I_1 = I_C = 1mA$

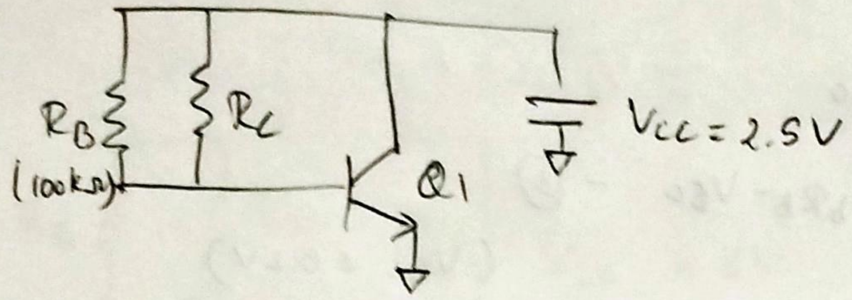
$\Rightarrow I_C = i_S\left(e^{\frac{V_{BE}}{V_T}}\right)\left[1 + \frac{V_{CE}}{V_A}\right]$ // Due to Early Effect

$\Rightarrow V_{CE} = 3/2\ V$, $V_A = 5V$

$\Rightarrow 10^{-3} = (3\times10^{-17}) \times \left(e^{V_{BE}/V_T}\right) \times \left(1 + \frac{3}{10}\right)$

$\Rightarrow V_{BE} = 26\times10^{-3} \times \ln\left(10^{14}/3.9\right) \Rightarrow \boxed{V_B = 802.76\ mV \approx 0.8\ V}$

Q4) $V_A = \infty$, $i_s = 2 \times 10^{-17} A$, $\beta = 100$. Max value of R_C s.t. collector-base must experience a forward bias < 200 mV.



Ans: Given;

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

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

$V_{CE} = V_{BE} - 0.2V \qquad (V_{BC} \le 0.2V)$

$\Rightarrow \quad I_C / I_B = 100, \; R_B = 100k\Omega$

$\Rightarrow \quad 2.5 = \frac{I_C}{100} \times 100 \times 10^3 + V_{BE} = 1000 I_C + V_{BE}$

$2.5 = I_C R_C + V_{CE}$

$\Rightarrow$ Also, $V_{BE} = V_T \ln\left(\frac{I_C}{V_S}\right)$

$\cancel{V_{BE} = 26 \times 10^{-3} \times \ln} \left(\frac{I_C}{V_S}\right)$

$\Rightarrow \quad 2.5 = 1000\left[i_S e^{V_{BE}/V_T}\right] + V_{BE}$

//cross verify with $V_{BE} = \cancel{2.80}$ 0.8335 V ≈ 833.5 mV

$\Rightarrow V_{BE} = 833.5 mV$, $\quad I_C = 2 \times 10^{-17} \times e^{(0.8335/0.026)}$

$= 0.00167305$

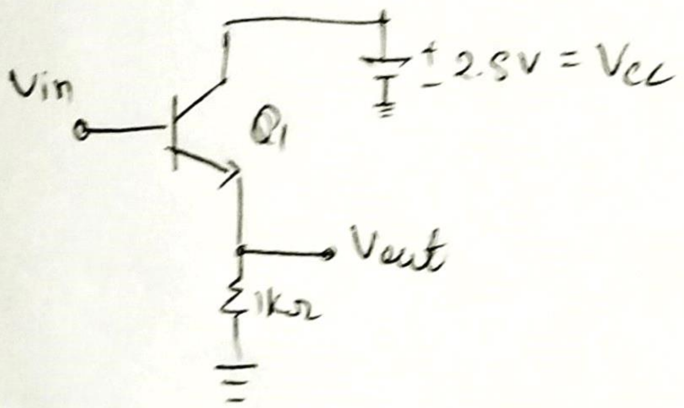
$V_{CE} = 633.5 mV$

$\Rightarrow \quad R_C = \frac{V_{CC} - V_{CE}}{I_C} = \frac{2.5 - 0.6335}{\cancel{2\times10}\; 0.0167305} = 1115.63\,\Omega$

$\approx \boxed{1.12\,k\Omega}$

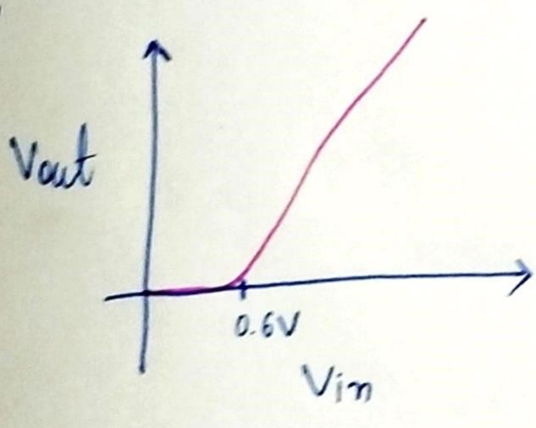
Q5) $V_{in} \in (0, 2.5)$ V. What value of V_{in} places transistor at the edge of saturation?

Value of V_{in} s.t. Q_1 has $i_c = 1mA$

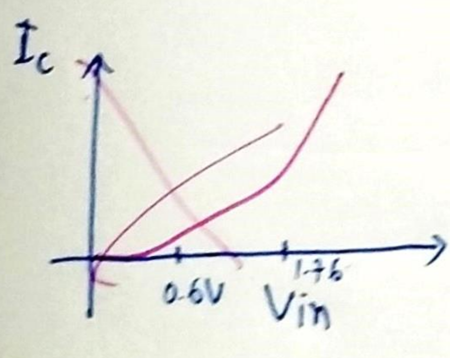


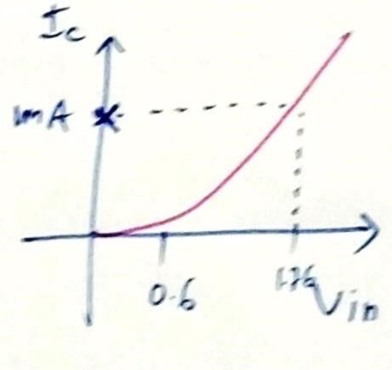
< Assume: $i_s = 5 \times 10^{-16}$ A, $\beta = 100$, $V_A = 5V$ >

Ans:



$V_{in} = 0.6V$: edge of saturation





$V_{in} = 1.76$ V , $I_C = 1mA$