

Q.1. (25 points)

a) (2p) Indicate the region of operation in the following table for an NPN BJT.

	$V_{BC} = 0.7V$	$V_{BC} = -5V$
$V_{BE} = -5V$	REVERSE ACT.	OFF
$V_{BE} = 0.7V$	SATURATION	FORWARD ACT.



b) (3p) Indicate the region of operation in the following table for an PNP BJT.

	$V_{CB} = 0.7V$	$V_{CB} = -5V$
$V_{EB} = -5V$	REVERSE ACT.	OFF
$V_{EB} = 0.7V$	SATURATION	FORWARD ACT.



c) (10p) Find I_C , I_C , I_B and V_{CE} for the following circuit where $\beta_F = 100$, $V_{BE_{ON}} = V_{D_{ON}} = 0.5V$, $V_Z = 4.5V$.

* KVL on Loop ①. (5p)

$$V_{CE} = (I_C + I_B)R_C + V_Z + V_{D_{ON}} + V_{BE_{ON}}$$

$$\Rightarrow 12 = 0.5 I_E + 5.5$$

$$6.5 = 0.5 I_E$$

$$\Rightarrow \boxed{I_E = 13 \text{ mA}}$$

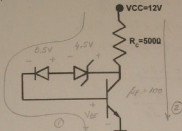
$$\Rightarrow I_C = \frac{I_E}{\beta_F + 1} = I_E \frac{\beta_F}{\beta_F + 1} \quad (1p)$$

$$\approx I_E$$

$$\Rightarrow \boxed{I_C = 13 \text{ mA}}$$

$$I_B = \frac{I_C}{\beta_F} \quad (1p)$$

$$\Rightarrow \boxed{I_B \approx 0.13 \text{ mA}}$$



* KVL on Loop ② (3p)

$$V_{CE} = (I_C + I_B)R_C + V_{CE}$$

$$\Rightarrow V_{CE} = 12 - 0.5 I_E$$

$$\Rightarrow \boxed{V_{CE} = 5.5 \text{ V}}$$

* OR;

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

$$V_C = V_{D_{ON}} + V_{Z} + V_E = 5.5 \text{ V}$$

$$\Rightarrow \boxed{V_{CE} = 5.5 \text{ V}}$$

Q.2. (25 points) Calculate the value of β_R for the following circuit by using the Transport Model Equations.

$$I_C \approx -I_S e^{0.7/V_T} - \frac{I_S}{\beta_R} e^{0.7/V_T}$$

$$I_E \approx -I_S e^{0.7/V_T}$$

$$I_B \approx \frac{I_S}{\beta_R} e^{0.7/V_T}$$

$$\Rightarrow \beta_R = \frac{I_S e^{0.7/V_T}}{I_B}$$

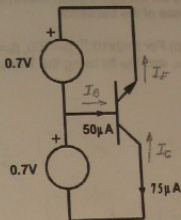
$$I_C = -I_S e^{0.7/V_T} - I_B$$

$$-75\mu A + 50\mu A = -I_S e^{0.7/V_T}$$

$$25\mu A = I_S e^{0.7/V_T}$$

$$\Rightarrow \beta_R = \frac{25\mu A}{50\mu A}$$

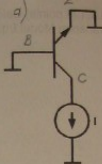
$$\boxed{\beta_R = 0.5}$$



Q.3. (25 points)

a) (2p) On the figure given below, label the collector, emitter and base of the transistor.

b) (23p) For $I_s = 2 \times 10^{-15}$, $\beta_F = 100$, $\beta_R = 0.25$, $I = 150 \mu A$, calculate I_E , I_B , I_C , and V_{BC} by using the Transport Model Equations.



$$b) \quad I_C = I_S \left(1 - e^{V_{BC}/V_T} \right) - \frac{I_S}{\beta_R} \left(e^{V_{BC}/V_T} - 1 \right)$$

$$I_E = I_S \left(1 - e^{V_{BC}/V_T} \right)$$

$$I_B = \frac{I_S}{\beta_R} \left(e^{V_{BC}/V_T} - 1 \right)$$

$$\text{Since } e^{V_{BC}/V_T} \gg 1;$$

$$I_C \approx -I_S e^{V_{BC}/V_T} - \frac{I_S}{\beta_R} e^{V_{BC}/V_T} = -I_S e^{V_{BC}/V_T} \left(1 + \frac{1}{\beta_R} \right)$$

$$I_E \approx -I_S e^{V_{BC}/V_T}$$

$$I_B = \frac{I_S}{\beta_R} e^{V_{BC}/V_T}$$

$$I_C = -I = -150 \times 10^{-6} = -I_S e^{V_{BC}/V_T} (5) \quad , \quad \boxed{I_C = -150 \mu A}$$

$$\Rightarrow I_S e^{V_{BC}/V_T} = 30 \times 10^{-6}$$

$$\Rightarrow \boxed{I_E = -30 \mu A}$$

$$\Rightarrow I_B = \frac{30 \mu A}{0.25}$$

$$\boxed{I_B = 120 \mu A}$$

$$e^{V_{BC}/V_T} = \frac{30 \times 10^{-6}}{2 \times 10^{-15}} = 15 \times 10^9$$

$$V_{BC} = V_T \ln 15 \times 10^9 \quad \text{where } V_T \approx 25 \text{ mV}$$

$$\Rightarrow V_{BC} \approx 0.59 \text{ V}$$

d) (10p) In the following circuit, $R_1=500\Omega$, $R_2=100\Omega$, $\beta_F=100$, $V_{EB,ON}=0.7V$. Find R_3 in order to have $I_{R_1}=10mA$.

$$I_{R_1} = 10mA$$

$$\Rightarrow V_C = V_{BE} + I_{R_1} \cdot R_1$$

$$= -5 + 10 \times 0.5$$

$$\Rightarrow \underline{V_C = 0V}$$

$$I_{R_1} = I_C + I_B = I_E$$

$$\Rightarrow V_B = V_{CC} - I_E R_2 - V_{EB,ON}$$

$$= 5 - 10 \times 0.1 - 0.7$$

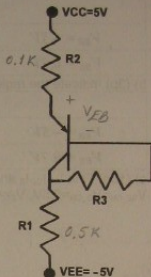
$$\underline{V_B = 3.3V}$$

$$R_3 = \frac{V_B - V_C}{I_B}$$

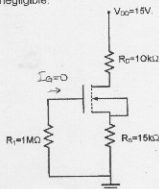
$$= \frac{3.3 - 0}{I_E / (\beta_F + 1)}$$

$$\Rightarrow R_3 = \frac{3.3}{0.1mA}$$

$$\boxed{R_3 = 33k\Omega}$$



Q.4. (25 points) Consider the following MOSFET circuit. MOSFET has parameters, $K_n = 1 \text{ mA/V}^2$ and $V_{TN} = -5 \text{ Volts}$. Channel length modulation effect is negligible.



- a) Is this a n-channel or a p-channel MOSFET based on the symbol used? (2 points)

It is a n-channel MOSFET

- b) Is this MOSFET an enhancement mode or a depletion mode MOSFET (5 points) based on the MOSFET device parameters? Explain why?

This is a n-channel depletion mode MOSFET.

Since it has a negative threshold voltage it has a built in channel.

- c) Determine the operating point of the MOSFET. (18 points)

Let's assume that the MOSFET is at SATURATION,

$$I_{DS} = \frac{K_n}{2} (V_{GS} - V_{TN})^2 \quad \text{for } V_{DS} \geq V_{GS} - V_{TN} \text{ and } \lambda = 0$$

$$I_G = 0 \Rightarrow V_{GS} = -I_{DS} \cdot R_3$$

$$V_{GS} = -\frac{K_n}{2} (V_{GS} - V_{TN})^2 \cdot R_3 = -\frac{10^{-3}}{2} (V_{GS} + 5)^2 \cdot 10^4$$

$$V_{GS} = -5(V_{GS}^2 + 10V_{GS} + 25)$$

$$0 = 5V_{GS}^2 + 51V_{GS} + 125 \longrightarrow V_{GS} = -6.105 \text{ V}$$

$$V_{GS} = -4.095 \text{ V}$$

$V_{GS} = -6.105 \text{ V}$ does not satisfy the SAT. condition since $V_{GS} < V_{TN}$, channel is not pinched off

Therefore, $V_{GS} = -4.095 \text{ V}$ must be the solution

Here, continue from Q.4 part (c):

$$V_{gs} = -4.095 \text{ V.} \Rightarrow I_{DS} = \frac{-V_{gs}}{R_3} = \frac{4.095 \text{ V}}{10 \text{ k}} = 0.4095 \text{ mA} \\ = 409.5 \mu\text{A}$$

$$V_{DS} = 15 \text{ V} - 15 \text{ k} \cdot I_{DS} = 15 \text{ V} - 15 \text{ k} \cdot 409.5 \mu\text{A} \\ = 8.8575 \text{ V.}$$

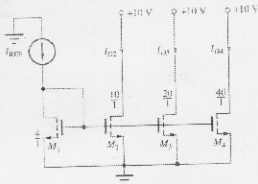
$$V_{DS} > V_{gs} - V_{TN}$$

$$8.8575 \text{ V} > \underbrace{-4.095 + 5 \text{ V}}_{0.905 \text{ V}} \Rightarrow \text{SAT condition is satisfied}$$

$$\text{Q-point: } I_{DS} = 409.5 \mu\text{A}$$

$$V_{DS} = 8.8575 \text{ Volts.}$$

Q.5. (25 points) Following current mirror (source) circuit is composed of MOSFET's with identical values of $K_n' = 25 \mu A/V^2$ and $V_{th} = 0.75V$. The W/L ratios of the MOSFET's are 4/1, 10/1, 20/1 and 40/1 for M1, M2, M3 and M4 respectively. The current source is $I_{REF} = 30 \mu A$ and the channel length modulation effect is negligible. Calculate the output currents: I_{D2} , I_{D3} and I_{D4} .



for M₁ $V_{DS1} = V_{GS1} \Rightarrow V_{DS1} > V_{GS1} - V_{TN} \Rightarrow \text{saturation}$

$$V_{GS1} = V_{GS2} = V_{GS3} = V_{GS4}$$

$$V_{DS2} = V_{DS3} = V_{DS4} = 10V.$$

$10V > V_{GS1} - V_{TN} \Rightarrow \text{saturation for } M_2, M_3 \text{ and } M_4$

$$I_D = K_n' \frac{W}{L} (V_{GS} - V_{TN})^2 (1 + \lambda V_{DS})$$

$$\lambda \approx 0$$

$$\frac{I_{D1}}{I_{D2}} = \frac{I_{REF}}{I_{D2}} = \frac{\left(\frac{W}{L}\right)_1}{\left(\frac{W}{L}\right)_2} = \frac{30 \mu A}{I_{D2}} = \frac{4/1}{10/1}$$

$$\Rightarrow I_{D2} = 75 \mu A$$

Similarly,

$$I_{D3} = \frac{30 \mu A \cdot 20}{4} = 150 \mu A$$

$$I_{D4} = \frac{30 \mu A \cdot 40}{4} = 300 \mu A$$