Question #1 (Solution)

(a)

$$\left.\begin{aligned} I_{REF} &= I_{D1} = \frac{\mu_n C_{ox}}{2}(\frac{W}{L})_1 (V_{GS1} - V_{T0n})^2 \\ I_2 &= I_{D2} = \frac{\mu_n C_{ox}}{2}(\frac{W}{L})_2 (V_{GS2} - V_{T0n})^2 \\ V_{GS1} &= V_{GS2} \end{aligned}\right\} \Rightarrow I_2 = \frac{(\frac{W}{L})_2}{(\frac{W}{L})_1} I_{REF} = 2I_{REF}$$

$$I_{D4} = I_2 = 2I_{REF}$$

$$\left.\begin{aligned} 2I_{REF} &= I_{D4} = \frac{\mu_P C_{ox}}{2}(\frac{W}{L})_4 (|V_{GS4}| - |V_{T0P}|)^2 \\ I_{D5} &= \frac{\mu_P C_{ox}}{2}(\frac{W}{L})_5 (|V_{GS5}| - |V_{T0P}|)^2 \\ I_{D6} &= \frac{\mu_P C_{ox}}{2}(\frac{W}{L})_6 (|V_{GS6}| - |V_{T0P}|)^2 \\ I_{D7} &= \frac{\mu_P C_{ox}}{2}(\frac{W}{L})_7 (|V_{GS7}| - |V_{T0P}|)^2 \\ I_{D8} &= \frac{\mu_P C_{ox}}{2}(\frac{W}{L})_8 (|V_{GS8}| - |V_{T0P}|)^2 \\ V_{GS4} &= V_{GS5} = V_{GS6} = V_{GS7} = V_{GS8} \end{aligned}\right\} \Rightarrow I_{D5} = I_{D6} = I_{D7} = I_{D8} = \frac{(\frac{W}{L})_5}{(\frac{W}{L})_4} I_{D4} = 2I_{REF}$$

$$\Rightarrow \begin{cases} I_9 = I_{D5} + I_{D6} = 4I_{REF} \\ I_{10} = I_{D7} + I_{D8} = 4I_{REF} \end{cases}$$

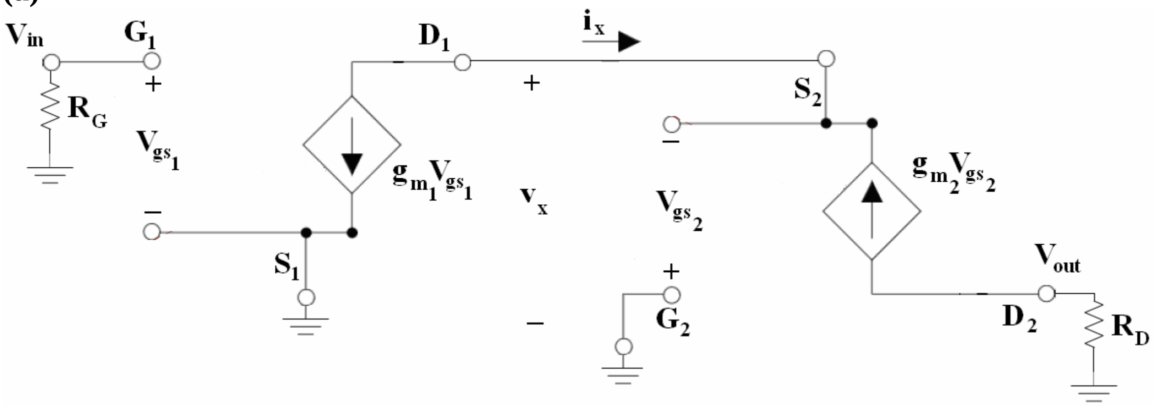
(b)

$$\left.\begin{aligned} I_{REF} &= I_{D1} = \frac{\mu_n C_{ox}}{2}(\frac{W}{L})_1 (V_{GS1} - V_{T0n})^2 \\ I_3 &= I_{D3} = \frac{\mu_n C_{ox}}{2}(\frac{W}{L})_3 (V_{GS2} - V_{T0n})^2 \\ V_{GS1} &= V_{GS3} \\ I_3 &= I_9 + I_{10} = 8I_{REF} \end{aligned}\right\} \Rightarrow I_3 = 8I_{REF} = \frac{(\frac{W}{L})_3}{(\frac{W}{L})_1} I_{REF}$$

$$\Rightarrow (\frac{W}{L})_3 = 8(\frac{W}{L})_1$$

Question #2 (Solution)

(a)



T model can be also used for M2.

(b)

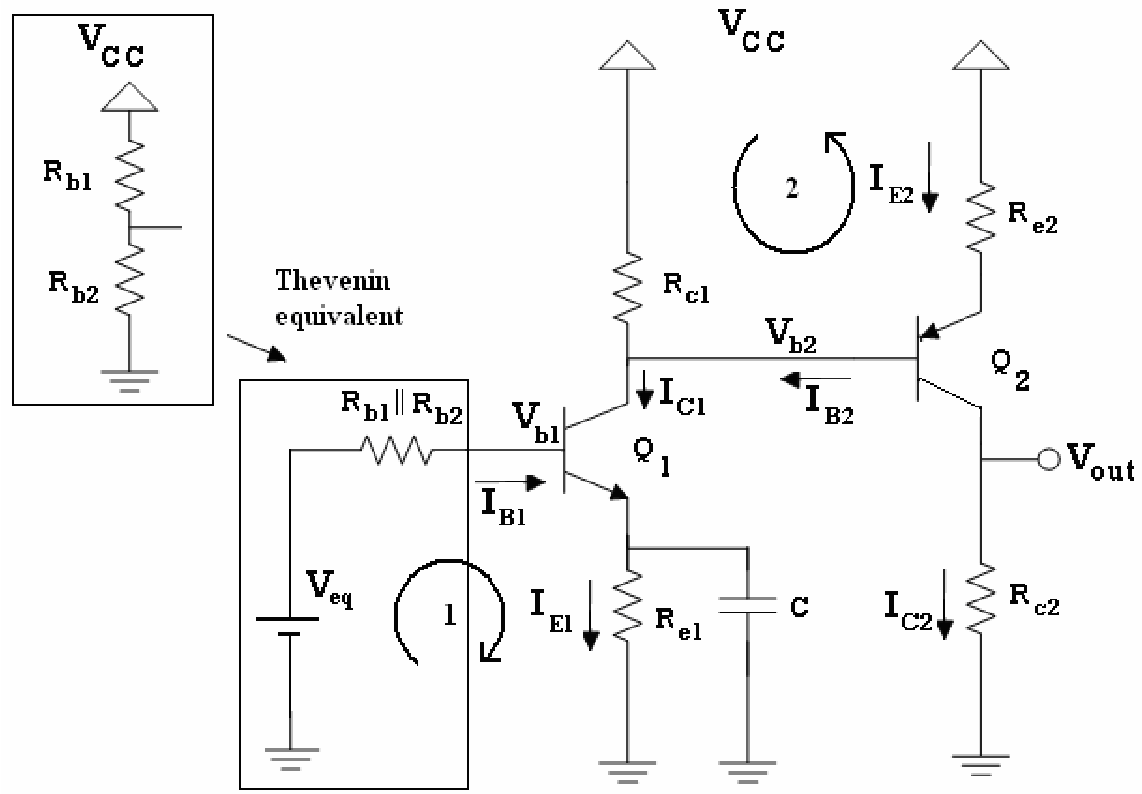
$$\left.\begin{aligned} R_{eq} &= \frac{v_X}{i_X} \\ V_{gs2} &= -v_X \\ i_X &= -g_{m2}V_{gs2} = g_{m2}v_X \end{aligned}\right\} \Rightarrow R_{eq} = \frac{1}{g_{m2}}$$

(c)

$$\left.\begin{aligned} i_{D1} &= g_{m1}V_{gs1} = g_{m1}V_{in} \\ V_{gs2} &= i_{D1}R_{eq} \\ V_{out} &= -i_{D2}R_D = -g_{m2}V_{gs2}R_D \end{aligned}\right\} \Rightarrow V_{out} = -g_{m1}R_D V_{in}$$

$$\Rightarrow A_V = \frac{V_{out}}{V_{in}} = -g_{m1}R_D$$

Question #3 (Solution)



(a)

$$V_{eq} = \frac{R_{b2}}{R_{b2}+R_{b1}}V_{cc} = \frac{30}{30+70}10 = 3V$$

$$R_{b1} \parallel R_{b2} = 30 \parallel 70 = 21K\Omega$$

Assume Q_1 is operating in active mode and write the KVL at loop 1

$$V_{eq} - (R_{b1} \parallel R_{b2})I_{B1} - V_{BE1(on)} - R_{e1}I_{E1} = 0$$

$$\Rightarrow 3 - 21 \times I_{B1} - 0.7 - 2I_{B1}(100+1) = 0$$

$$\Rightarrow I_{B1} = 0.0103mA$$

$$\Rightarrow I_{C1} = 100 \times I_{B1} = 1.03mA$$

$$V_{B1} = V_{eq} - (R_{B1} \parallel R_{B2})I_{B1} = 2.78V$$

$$V_{C1} = V_{B2} \quad V_{C1} - V_{B1} \geq 0 \quad Active \text{ mod} e$$

Assume Q_2 is operating in active mode and write the KVL at loop 2

$-(I_{C1} - I_{B2})R_{C1} + V_{BE2(on)} + I_{E2}R_{e2} = 0$

$\Rightarrow -(1.03 - I_{B2})4 + 0.7 + 3(100+1)I_{B2} = 0$

$\Rightarrow I_{B2} = 0.011mA$

$\Rightarrow I_{C2} = 100 \times I_{B2} = 1.1mA$

$V_{B2} = V_{CC} - R_{C1}(I_{C1} - I_{B2}) = 5.924V$

$V_{C2} = R_{C2}I_{C2}$

$V_{B2} - V_{C2} \geq 0 \quad Active \text{ mod}e$

$V_{CE1} = V_{B2} - R_{e1}I_{E1} = 5.924 - 2.08 = 3.844V \Rightarrow Again\ we\ can\ conclude\ that\ Q_1\ \ is\ \ in\ \ active\ \ \text{mod}e$

$|V_{CE2}| = V_{B2} + 0.7 - R_{c2}I_{C2} = 6.624 - 4.4 = 2.224V \Rightarrow Again\ we\ can\ conclude\ that\ Q_2\ is\ \ in\ \ active\ \text{mod}e$

(b)

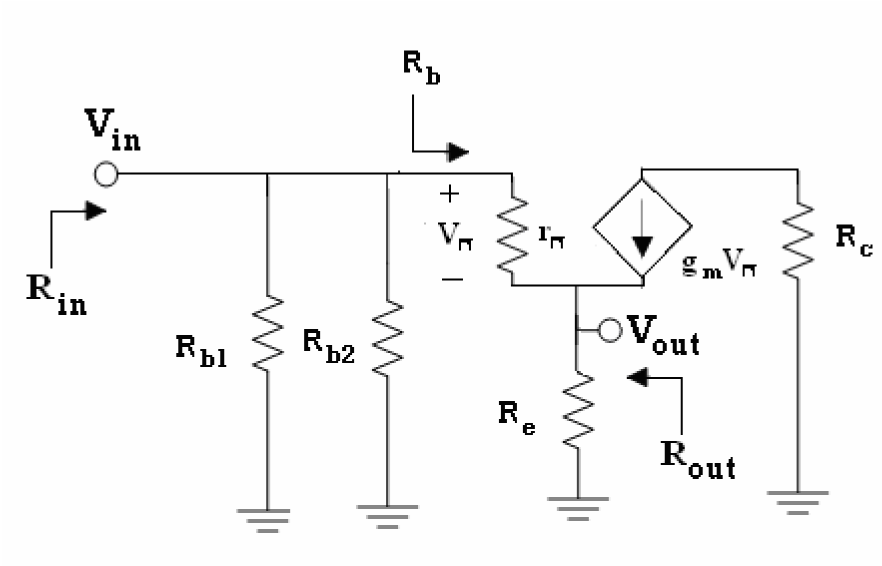
In order for Q_2 to turn off $|V_{CE}|$ must equal $|V_{CE(sat)}|$

$6.624\text{-}R_{c2}I_{C2}=6.624\text{-}1.1R_{c2}=0$

$R_{c2}=6.02\ K\Omega$

Question #4 (Question)

(a)



(b)

$R_b = r_\pi + (1+\beta)R_e$

$$i_b = \frac{v_{in}}{R_b} = \frac{v_{in}}{r_\pi + (1+\beta)R_e}$$

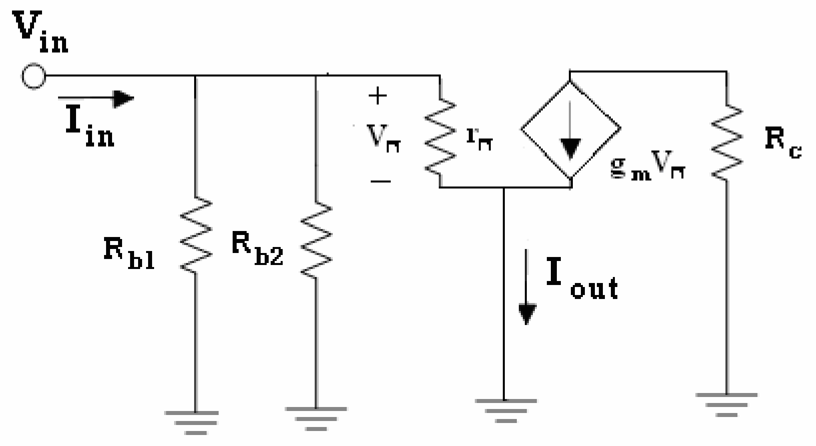
$$i_c = \beta \quad i_b = \frac{v_{in}}{\frac{r_\pi}{\beta} + (1+\frac{1}{\beta})R_e} = \frac{v_{in}}{r_e + (1+\frac{1}{\beta})R_e}$$

$$i_e = \frac{\beta+1}{\beta} i_c$$

$$v_{out} = i_e R_e = \frac{\beta+1}{\beta} \frac{R_e}{r_e + (1+\frac{1}{\beta})R_e} v_{in}$$

$$A_v = \frac{v_{out}}{v_{in}} = \frac{\beta+1}{\beta} \frac{R_e}{r_e + (1+\frac{1}{\beta})R_e} \cong \frac{R_e}{R_e + r_e}$$

(c) Short circuit the output to find A_{IS}



$$i_{in} = \frac{v_{in}}{R_{b1} \parallel R_{b2}} + \frac{v_{in}}{r_\pi}$$

$$i_{out} = \frac{v_{in}}{\frac{r_\pi}{1+\beta}} = \frac{v_{in}}{r_e}$$

$$\Rightarrow A_{IS} = \frac{i_{out}}{i_{in}} = \frac{\frac{1}{r_e}}{\frac{1}{(\beta+1)r_e} + \frac{1}{R_{b1} \parallel R_{b2}}} = \frac{(\beta+1)(R_{b1} \parallel R_{b2})}{(\beta+1)r_e + R_{b1} \parallel R_{b2}}$$

(d)

$R_{in}=R_{b1}||R_{b2}||R_b= R_{b1}||R_{b2}|| (r_\pi+(1+\beta)R_e)$

$$R_{out} = \frac{v_{out}}{i_{out}}\Big|_{Vin=0} = R_e \parallel r_e$$