MIDTERM # 2

QUESTION 1)

a) $I_{D_1} = \frac{1}{2}\mu_n C_{ox} \left(\frac{W}{L}\right)_1 (V_{GS_1} - V_{tn})^2$

$I_{D_1} = I_{ref}$

} =>

$250^{\mu A} = \frac{1}{2} \times 100^{\mu A/V^2} \times 20 \times (V_{ref} - (-5) - 1)^2$

=> V_{ref} = → -3.5^V => $V_{GS_1} = 1.5^V > V_{tn}$ ✓

→ -4.5^V => $V_{GS_1} = 0.5^V < V_{tn}$ ✗

=> $V_{ref} = -3.5^V$

b) $R_1 = \frac{V_{DD} - V_{ref}}{I_{ref}} = \frac{5-(-3.5)}{250^{\mu}} = 34^{K\Omega}$

c) $I_{D_2} = \frac{1}{2}\mu_n C_{ox} \left(\frac{W}{L}\right)_2 (V_{GS_2} - V_{tn})^2$

$V_{GS_2} = V_{GS_1}$

} => $\frac{I_{D2}}{I_{D_1}} = \frac{\left(\frac{W}{L}\right)_2}{\left(\frac{W}{L}\right)_1}$

=> $\frac{1^{mA}}{250^{\mu A}} = \frac{\left(\frac{W}{L}\right)_2}{20}$

=> $\left(\frac{W}{L}\right)_2 = 80$

d) using symmetry :

$I_{D4} = I_{D3}$

$I_{D4} + I_{D3} = I_{D2}$

} => $I_{D4} = \frac{I_{D2}}{2} = 500^{\mu}$

e)
$$\begin{cases} I_{D6} = \frac{1}{2}\mu_p C_{ox} \left(\frac{W}{L}\right)_6 (V_{GS6} - V_{tp})^2 = I_{D4} \\ I_{D7} = \frac{1}{2}\mu_p C_{ox} \left(\frac{W}{L}\right)_7 (V_{GS7} - V_{tp})^2 \\ V_{GS6} = V_{GS7} \end{cases}$$

$$\Rightarrow \frac{I_{D7}}{I_{D6}} = \frac{\left(\frac{W}{L}\right)_7}{\left(\frac{W}{L}\right)_6}$$

$$V_{D7} = 1^V \Rightarrow I_{D7} = \frac{V_{D7} - (-V_{DD})}{R_3} = 1.5^{mA}$$

$$\Rightarrow \frac{1.5^{mA}}{0.5^{mA}} = \frac{\left(\frac{W}{L}\right)_7}{40}$$

$$\Rightarrow \left(\frac{W}{L}\right)_7 = 120$$

QUESTION 2)

a) first stage : input @ gate, output @ drain $\Rightarrow$ CSA

second stage : input @ gate, output @ source $\Rightarrow$ CDA

b) $I_{G_1} = 0 \Rightarrow V_{G_1} = 0$

$$I_{D_1} = \frac{1}{2}\mu_n C_{ox} \left(\frac{W}{L}\right)_1 (V_{GS_1} - V_t)^2 = I_S$$

$$\Rightarrow 500^{\mu A} = \frac{1}{2} \times 100^{\mu A/V^2} \times 40 \times (0 - V_{S_1} - 1)^2$$

$$\Rightarrow V_{S_1} = \begin{cases} -0.5^V \Rightarrow V_{GS_1} < V_{tn} \quad \times \\ -1.5^V \Rightarrow V_{GS_1} = 1.5 > V_{tn} \quad \checkmark \end{cases}$$

$$\Rightarrow V_{S_1} = -1.5^V$$

$I_{D_1} = 500^{\mu A} \Rightarrow V_1 = V_{DD} - R_D I_{D_1} = 3^V$

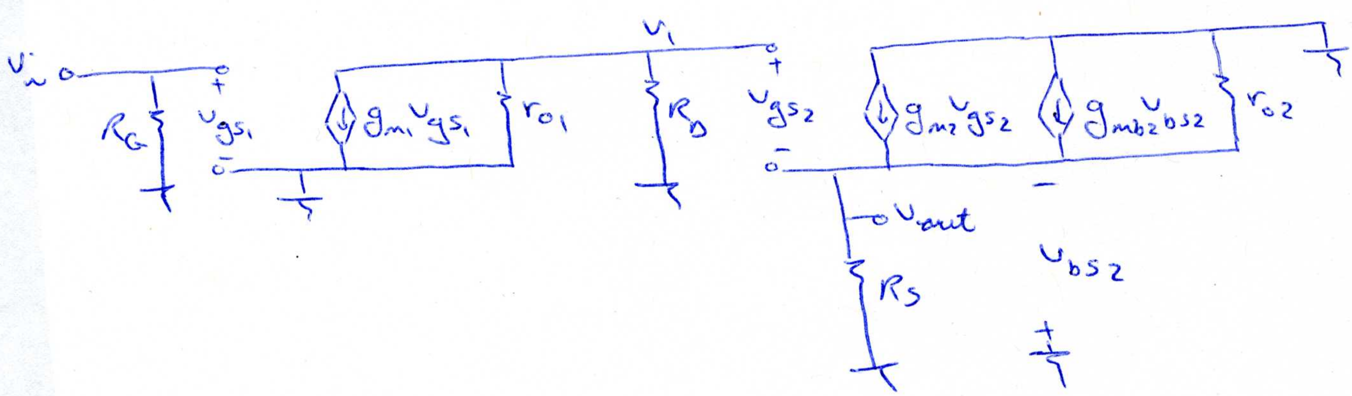
$I_{D_2} = I_S = \frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)_2 (V_{GS2} - V_{tn})^2$

$500^{\mu A} = \frac{1}{2} \times 100^{\mu A/V^2} \times 40 \times (V_1 - V_{S_2} - 1)^2$

$\Rightarrow V_{S2} = $
- $2.5^V \Rightarrow V_{GS_2} = 0.5^V < V_{tn}$ ✗
- $1.5^V \Rightarrow V_{GS_2} = 1.5^V > V_{tn}$ ✓

$\Rightarrow V_{out} = 1.5^V$

c) C is shorted $\Rightarrow v_{s_1} = 0 \Rightarrow v_{bs_1} = 0 \Rightarrow$ no AC body effect for M_1



d) $g_{m_1} = \frac{2I_{D_1}}{V_{GS_1} - V_{tn}} = \frac{2 \times 0.5^{mA}}{0.5^V} = 2^{mA/V}$

$g_{m2} = \frac{2I_{D2}}{V_{GS_2} - V_{tn}} = 2^{mA/V}$

$r_{o_1} = \frac{1}{\lambda I_{D_1}} = 80^{k\Omega}$

$r_{o2} = \frac{1}{\lambda I_{D2}} = 80^{k\Omega}$

e) $R_{in1} = R_G = 4^{k\Omega}$

$R_{in2} = \infty$

f) $V_{in} = V_{gs1}$

KCL @ v_1 : $\dfrac{v_1}{r_{o1} \| R_D} + g_{m1} V_{gs1} = 0$ } $\Rightarrow v_1 = -g_{m1}(r_{o1} \| R_D) V_{in}$

$$\Rightarrow \frac{v_1}{V_{in}} = -g_{m1}(r_{o1} \| R_D)$$

$$= -7.62 \ ^{V}/_{V}$$

$V_1 = V_{gs2} + V_{out} \Rightarrow V_{gs2} = v_1 - V_{out}$

$V_{out} = -V_{bs2}$

KCL @ output node :

$$\frac{V_{out}}{R_S} + \frac{V_{out}}{r_{o2}} = g_{m2} V_{gs2} + g_{mb2} V_{bs2}$$

$$= g_{m2}(v_1 - V_{out}) + \chi g_{m2}(-V_{out})$$

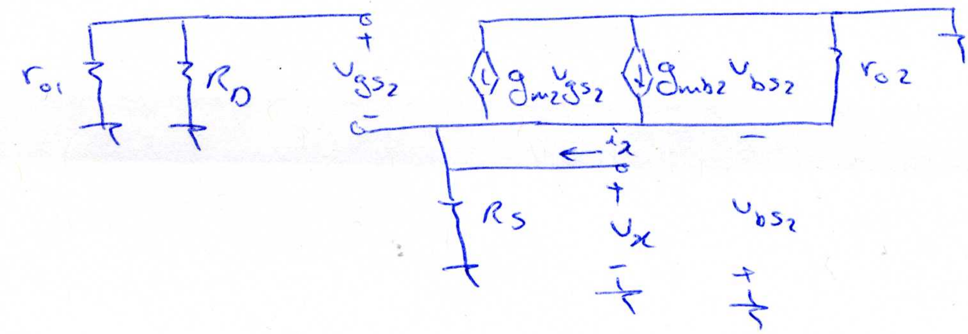
$$\Rightarrow V_{out}\left(\frac{1}{R_S} + \frac{1}{r_{o2}} + (1+\chi) g_{m2}\right) = g_{m2} v_1$$

$$\Rightarrow \frac{V_{out}}{v_1} = g_{m2}\left(R_S \| r_{o2} \| \frac{1}{(1+\chi) g_{m2}}\right) = 0.826 \ ^{V}/_{V}$$

$$\Rightarrow \frac{V_{out}}{V_{in}} = \frac{V_{out}}{v_1} \cdot \frac{v_1}{V_{in}} = -6.29 \ ^{V}/_{V}$$

g) finding R_{out} : - kill sources (v_{in})

- find $\frac{v_x}{i_x}$



$i_{g2} = 0 \Rightarrow v_{g2} = 0$

$\Rightarrow v_{gs2} = v_{bs2} = -v_x$

KCL @ output :

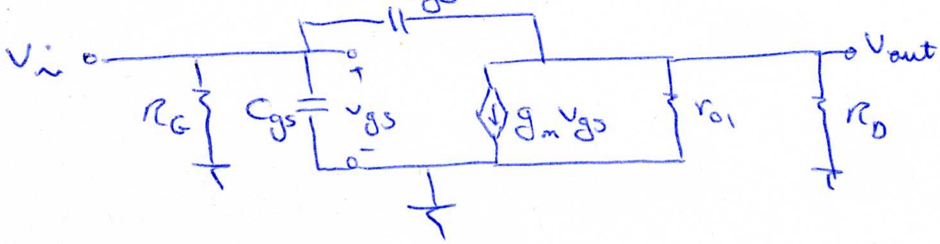
$$i_x = \frac{v_x}{R_S} + \frac{v_x}{r_{o2}} - g_{m2}v_{gs2} - \chi g_{m2} v_{bs2}$$

$$= v_x \left(\frac{1}{R_S} + \frac{1}{r_{o2}} + (1+\chi) g_{m2} \right)$$

$$\Rightarrow R_{out} = R_S \parallel r_{o2} \parallel \frac{1}{(1+\chi) g_{m2}} = 0.413 \ k\Omega$$

QUESTION 3)

a) high frequency equivalent circuit $\Rightarrow$ C_S and C_C are S.C.



b) mid-band gain : $\begin{cases} C_s \text{ and } C_c \rightarrow \text{S.C.} \\ C_{gs} \text{ and } C_{gd} \rightarrow \text{O.C.} \end{cases}$

$$\left.\begin{aligned} V_i &= V_{gs_1} \\ V_{out} &= -g_{m_1}(r_{o_1} \| R_D) V_{gs_1} \end{aligned}\right\} \Rightarrow V_{out} = -g_{m_1}(r_{o_1} \| R_D) V_i$$

$$\Rightarrow \frac{V_{out}}{V_i} = -g_{m_1}(r_{o_1} \| R_D)$$

c) $$\left.\begin{aligned} f_{C_S} &= \frac{1}{2\pi C_S R_{CS}} \\ R_{CS} &= \frac{1}{g_{m_1}} \| R_S \end{aligned}\right\} \Rightarrow f_{CS} = \frac{1}{2\pi C_S (\frac{1}{g_{m_1}} \| R_S)}$$

d) $$\left.\begin{aligned} f_{C_C} &= \frac{1}{2\pi C_C R_{CC}} \\ R_{CC} &= R_G \end{aligned}\right\} \Rightarrow f_{C_C} = \frac{1}{2\pi C_C R_G}$$

QUESTION 4)

PART I)

mode of operation	BE junction	BC junction
cutoff	reverse	reverse
active	forward	reverse
saturation	forward	forward
reverse active	reverse	forward

active mode is used in designing amplifiers.

Between the Base and the Emitter, there is a pn junction; thus looks like a diode. Across this junction in active mode, DC operating voltage is ~ 0.7V, just like a diode.
When the current begins to flow, a LARGE number of electrons from the emitter region enter the base region.
Between the Collector and the Base is a pn junction as well. In active mode, this junction is either reversed biased, or zero bias (VCB = 0).
Since the Base-region is so thin, the carriers from the emitter region are swept into the collector region.

PART II)

a) KVL :

$$\left.\begin{array}{l} V_{DD} - R_B I_B - V_{BE(on)} - R_E I_E = 0 \\ I_E = (\beta + 1) I_B \\ V_{BE(on)} = 0.7 \end{array}\right\} \Rightarrow$$

$$\Rightarrow \quad 5 - 200^k I_B - 0.7 - 2.3^k \times 101 \times I_B = 0$$

$$\Rightarrow \quad I_B = 9.9\mu A$$

$$I_C = \beta I_B = 0.99^{mA} \quad \Rightarrow \quad V_C = V_{DD} - R_C I_C = 4.01^V$$

b) $V_B = V_{DD} - 200^k I_B = 3.02^V$

$V_C = 4.01^V > V_B = 3.02^V \quad \Rightarrow$ active mode ✓