Problem 9.1

a) The transconductance of the cascode amplifier is apporximatly the transconductance of M_1. To make

$$g_{m1} = \sqrt{2k_n I_D} \approx 1mS. \Rightarrow W_1 = 200\mu m$$

b)

M_1: $R_{out} \approx r_{o1} = (\lambda_n I_D)^{-1} = 200k\Omega$

M_2: $R_{out} \approx g_{m2} r_{o1} r_{o2}$

M_3: $R_{out} \approx g_{m3} r_{o3} r_{o8}$

M_8: $R_{out} \approx r_{o8} = (\lambda_p I_D)^{-1} = 500k\Omega$

c) $R_{out} \approx g_{m2} r_{o1} r_{o2} = 20 M\Omega \Rightarrow g_{m2} = 0.5mS$

d) $g_{m2} = \sqrt{2k_n I_D} = 0.5mS \Rightarrow W_2 = 50\mu m$

e) $R_{out} = g_{m3} r_{o3} r_{o8} = 100M\Omega \Rightarrow g_{m3} = 0.4mS$

f) $g_{m3} = \sqrt{2k_p I_D} = 0.4mS \Rightarrow W_3 = 64\mu m$

g) $W_4 = W_3 = 64\mu m$, $W_5 = W_2 = 50\mu m$, $W_9 = W_8 = W_3 = 64\mu m$

i) V_1: $-I_{D1} = -\frac{W_9}{2L}\mu_p C_{ox}(V_1 - V_{DD} - V_{TP})^2 \Rightarrow V_1 = 3.5V$

V_2: $-I_{D1} = -\frac{W_4}{2L}\mu_p C_{ox}(V_2 - V_1 - V_{TP})^2 \Rightarrow V_2 = 2V$

$V_3 = V_2 = 2V$

j) $V_4 = V_1 = 3.5V$.

For V_6:

$$I_{D1} = \frac{W_5}{2L}\mu_n C_{ox}(V_3 - V_6 - V_{TN})^2 \Rightarrow V_6 = 0.6V$$

For V_7:

$$I_{D1} = \frac{W_6}{2L}\mu_n C_{ox}(V_7 - V_{TN})^2 \Rightarrow V_7 = 1.2V$$

h) $$I_{D1} = \frac{W_7}{2L}\mu_n C_{ox}(V_7 - V_{TN})^2 \Rightarrow W_7 = W_6 = W_1 = 200\mu m$$

k) $V_{BIAS} = V_7 = 1.2V$

l) $$R = \frac{V_{DD} - V_7}{I_{REF}} = \cancel{3800}\,\Omega$$

Problem 9.2

a) CG, CS

b) $$I_{BIAS1} = \frac{W_1}{2L}\mu_n C_{ox}(1.5 - V_2 - V_{TN})^2.\ V_2 = 0.5V \Rightarrow W_1 = 355\mu m$$

c) $$-I_{BIAS3} = -\frac{W_2}{2L}\mu_p C_{ox}(V_1 - V_{DD} - V_{TP})^2.\ V_1 = 2.0V \Rightarrow W_2 = 160\mu m$$

d) The input resistance is the input resistance of CG amplifier with infinite load resistance.

$$R_{in} = \frac{1}{g_m}\left(1 + \frac{r_{oc1}}{r_o}\right)$$ according to the lecture notes.

e) The output resistance is the output resistance of CS amplifier.

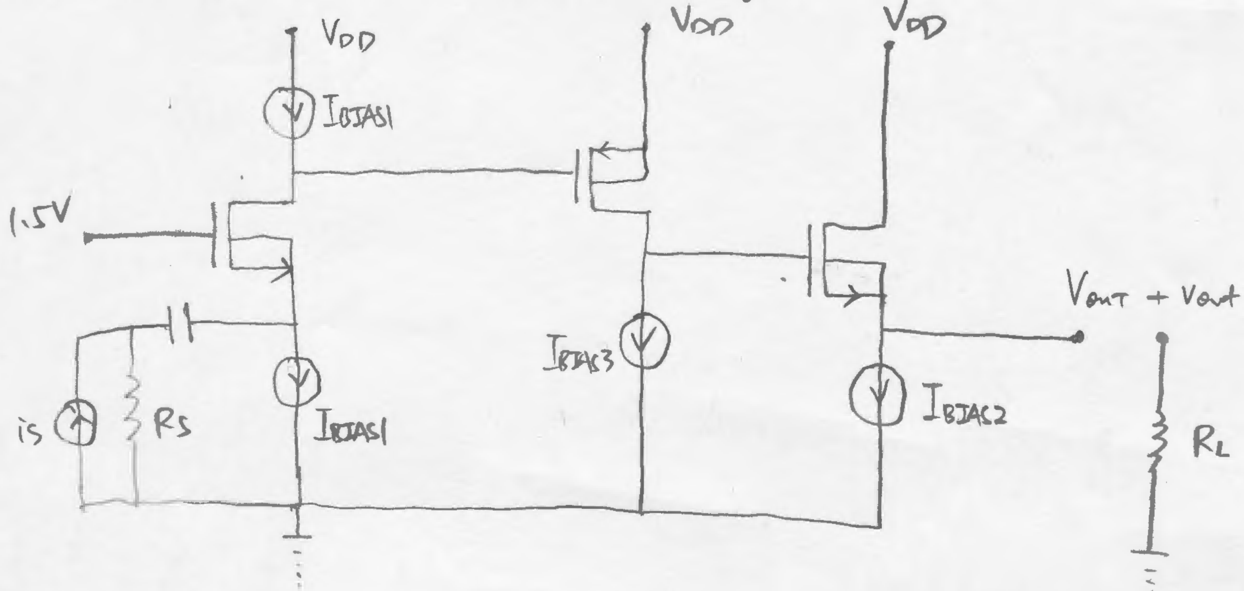
$$R_{out} = r_{o2} \,//\, r_{oc3}$$

f)

$$R_m = \frac{v_{out}}{i_s} = R_{m1} \times A_{v2} = A_{i1} \times R_{out1} \times A_{v2} \approx r_{oc1}\left(-g_{m2}\left(r_{o2} // r_{oc3}\right)\right)$$

$$= -g_{m2} r_{oc1} \left(r_{o2} // r_{oc3}\right)$$

g) Consider another CD cascade stage



Because $V_{OUT} = 1.5V$, $V_{GS} = 2.5V - 1.5V = 1V$, NFET is needed.

$$A_v = \frac{g_m R_o}{1 + g_m R_o}, \qquad R_o = r_{oc2}$$

$$R_{out} = \frac{R_o}{1 + g_m R_o}, \qquad V_{OUT} = R_o I_{BIAS2}$$

For $A_v \sim 1$, $R_{out} \sim 5k\Omega$, $g_m \sim 0.2mS$. $g_m = \sqrt{2 k_n I_{BIAS2}}$.

If we have similar current sources, choose $I_{BIAS2} = 200\mu A$, then $W_n = 8\mu m$

For $V_{OUT} = 1.5V$, $R_o \sim 7.5k\Omega$, on the order of R_s.

Problem 9.3

a) Considering the symmetry of the circuit and devices, the current throug

each leg is the same as $I_{REF} = 100\mu A$

b) Power $= 5 \times 5V \times 100\mu A = 2.5mW$

c) $V_{BIAS} = V_5$

$$I_{REF} = \frac{W_n}{2L}\mu_n C_{ox}(V_5 - V_{TN})^2 \Rightarrow V_{BIAS} = V_5 = 1.5944V$$

d) M_1 & Q_2 : CS & CB . transconductance amplifier

M_3 : CD . Voltage buffer

Q_4 : CC , Voltage buffer

e) For V1 :

$$-I_{REF} = -\frac{W_P}{L}\mu_P C_{ox}(V_1 - V_{DD} - V_{TP})^2 \Rightarrow V_1 = 3.6675V$$

For V2 :

$$-I_{REF} = -\frac{W_P}{L}\mu_P C_{ox}(V_2 - V_1 - V_{TP})^2 \Rightarrow V_2 = 2.3351$$

For V3 :

$$V_3 = V_2 - V_{BE\_ON} = 2.3351 - 0.7V = 1.6351V$$

For V4 :

$$V_4 = V_1 = 3.6675V$$

For V_5 :

$$V_5 = 1.5944V$$

For VX :

$$VX = V_2 = 2.3351V$$

For V_{OUT} :

$$V_{OUT} = V_4 - V_{BE\_ON} = 3.6675V - 0.7V = 2.9675V$$

f) & g)
M10:

$$V_5 - V_{OUT} < V_{TN} \Rightarrow V_{OUT} > V_5 - V_{TN} = 0.8944V$$

Q4:

$$V_{CE} > V_{CE\_SAT} \Rightarrow V_{DD} - V_{OUT} > V_{CE\_SAT} \Rightarrow V_{OUT} < V_{DD} - V_{CE\_SAT}$$
$$= 4.8V$$

h) The circuit voltage gain is appoximatly the gain of the cascode of M_1 and Q_2.

$R_{out1} = r_{o1}$, $\quad R_{in2} : \dfrac{r_{\pi 2}}{1 + \beta_F r_{o2}/(r_{o2}+R)}$, here $R = g_{m6} r_{o6} r_{o7} + r_{o6} + r_{o7}$

$A_{v1} = -g_{m1} r_{o1}$

$A_{v2} : g_{m2} (R \,//\, r_{o2})$.

$r_{o1} = (\lambda_n I_D)^{-1}$, $I_D = I_{REF}$ $\quad g_{m1} = \sqrt{2 k_n I_D}$.

$r_{\pi 2} = \dfrac{kT}{q I_B} = \dfrac{kT}{q I_C}\beta_F$, $\quad I_C \approx I_{REF}$ $\quad \beta_F = \beta_{F0} e^{\frac{V_{CE}}{V_A}}$, $\quad V_{CE} = V_X - V_3$

$r_{o2} = \dfrac{V_A}{I_D}$, $\quad g_{m2} = \dfrac{q I_C}{kT}$

$g_{m6} = g_{m1}$, $\quad r_{o6} = r_{o7} = r_{o1}$

$$A_v = A_{v2} A_{v1} \frac{R_{in2}}{R_{out1} + R_{in2}} = -5.8 \times 10^3$$