Homework 11 Solution

P25.1

ANS: $1\mu A$ goes through $M_5, M_1, M_2, M_3, M_4, M_7, M_8$,

$2\mu A$ (I_{SS}) through M_6

$$g_{m1} = \sqrt{2 \times 50 \times 15/5 \times 1} = 17.32\ \mu A/V$$

$$g_{m7} = \sqrt{2 \times 17 \times \frac{70}{5} \times 1} = 21.82\ \mu A/V$$

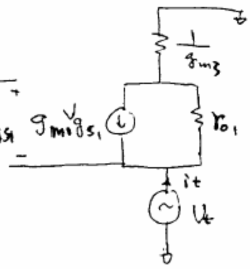
$$r_{o2} = r_{o4} = r_{o9} = r_{o8} = \frac{1}{0.06 \times 1\mu A} = 16.67\ M\Omega$$

$$A_{OL} = g_{m1}(r_{o2} \parallel r_{o4})(-g_{m7}(r_{o7} \parallel r_{o8})) = -17.32 \times \frac{16.67}{2} \times 21.82 \times \frac{16.77}{2}$$

$$= \boxed{-26{,}255\ V/V}$$

P25.3 ANS

$$R_{inM_1,S} = \left(\frac{1 + g_{m1} r_{o1}}{r_{o1} + \frac{1}{g_{m3}}}\right)^{-1} \approx g_{m1}^{-1} = \frac{1}{g_{m1}}$$



$$R_{inM_2,S} = \left(\frac{1 + g_{m2} r_{o2}}{r_{o2} + r_{o4}}\right)^{-1} = \left(\frac{g_{m2}}{2}\right)^{-1} = \frac{2}{g_{m2}}$$

$$\frac{5 - V_{GS5}}{0.88\ M} = \frac{1}{2} \times 50\ \mu A/V^2 \times \frac{15\mu}{5\mu}(V_{GS5} - 0.83)^2 \Rightarrow V_{GS} = 1.074V \quad I_{D5} = 4.4614\ \mu A \approx 4.$$

$$\Rightarrow I_{D5} = 4.5\ \mu A = I_{D1} = I_{D2} = I_{D3} = I_{D4} = I_{D7} = I_{D8}.$$

$$I_{D6} = 2 I_{D5} = 9\ \mu A$$

$$g_{m1} = \sqrt{2 \times 50 \times \frac{15}{5} \times 4.5} = 36.74\ \mu A/V = g_{m2}; \quad g_{m3} = \sqrt{2 \times 17 \times \frac{70}{5} \times 4.5} = 46.28\ \mu A/V = g_{m7}$$

$$r_{o1} = r_{o2} = r_{o3} = r_{o4} = r_{o5} = \frac{1}{0.06 \times 4.5} = 3.70\ M\Omega = r_{o7}; \quad r_{o6} = \frac{1}{0.06 \times 9} = 1.85\ M\Omega$$

$$\Rightarrow R_{inM_1,S} = \boxed{27.22\ k\Omega}$$

$$R_{inM_2,S} = \boxed{50.44\ k\Omega}$$

25.5

If the drain current of M6, in Fig. 25.11, is reduced to 5µA, what are the drain currents in M3, M4, M7, and M9?

$$I_{D3} = I_{D4} = \frac{1}{2} I_{D6} = \underline{2.5\mu A}$$

Since $\left(\frac{W}{L}\right)_4 = \left(\frac{W}{L}\right)_7$

$$I_{D7} = I_{D4} = \underline{2.5\mu A}$$

For I_{D9} first find V_{GS91}:

$$2.5\mu = \frac{50\mu}{2} \frac{15}{2} (V_{GS91} - 0.83)^2$$ ← neglecting bulk effect

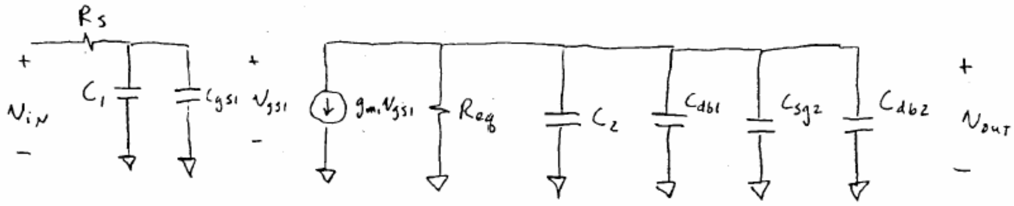
$$V_{GS91} = 0.945\ V$$

Due to symmetry $V_{GS91} = V_{GS9}$

$$I_{D9} = \frac{50\mu}{2} \frac{150}{2} (0.945 - .83)^2$$

$$I_{D9} = \underline{25\mu A}$$

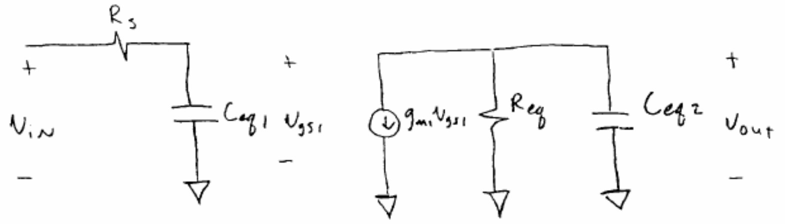
small signal model:



$$C_1 = C_{gd1}(1 + |A_v|) = 9.614\,fF$$

$$C_2 = C_{gd1}\left(1 + \frac{1}{|A_v|}\right) = 6.284\,fF$$

Simplify model



$$C_{eq1} = C_1 + C_{gs1}$$

$$C_{eq2} = C_2 + C_{db1} + C_{sg2} + C_{db2}$$

$$\frac{v_{out}}{v_{gs1}} = -g_{m1}\left(\frac{1}{\frac{1}{R_{eq}} + j\omega C_{eq2}}\right)$$

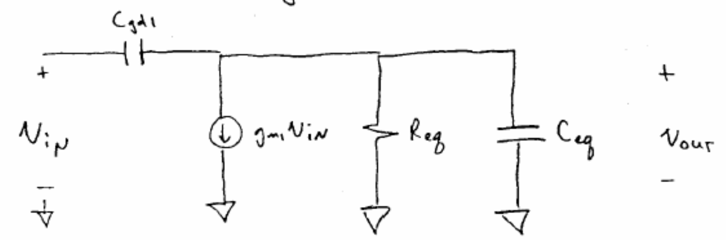
$$\frac{v_{gs1}}{v_{in}} = \frac{\frac{1}{j\omega C_{eq1}}}{\frac{1}{j\omega C_{eq1}} + R_s} = \frac{1}{1 + j\omega C_{eq1} R_s}$$

$$\frac{v_{out}}{v_{in}} = \frac{v_{out}}{v_{gs1}} \cdot \frac{v_{gs1}}{v_{in}} = -g_{m1}\left(\frac{1}{\frac{1}{R_{eq}} + j\omega C_{eq2}}\right)\left(\frac{1}{1 + j\omega C_{eq1} R_s}\right)$$

$$\frac{v_{out}}{v_{in}} = \left(\frac{-g_{m1} R_{eq}}{1 + j\omega C_{eq2} R_{eq}}\right)\left(\frac{1}{1 + j\omega C_{eq1} R_s}\right)$$

e) The location of the zero

To determine the location of the zero use the following small signal model:



$$R_{Leq} = r_{o1} \parallel \frac{1}{g_{m2}} \parallel r_{o2}$$

$$C_{eq} = C_{sg2} + C_{db1} + C_{db2}$$

$$V_{OUT} = \left[(V_{IN} - V_{OUT})\, j\omega C_{gd1} - g_{m1} V_{IN} \right] \frac{1}{\frac{1}{R_{Leq}} + j\omega C_{eq}}$$

$$V_{out}\left(1 + \frac{j\omega C_{gd1}}{\frac{1}{R_{Leq}} + j\omega C_{eq}}\right) = V_{IN}\left(j\omega C_{gd1} - g_{m1}\right) \frac{1}{\frac{1}{R_{Leq}} + j\omega C_{eq}}$$

$$\frac{V_{OUT}}{V_{IN}} = \frac{(j\omega C_{gd1} - g_{m1})\left(\frac{1}{\frac{1}{R_{Leq}} + j\omega C_{eq}}\right)}{\left(1 + \frac{j\omega C_{gd1}}{\frac{1}{R_{Leq}} + j\omega C_{eq}}\right)}$$

$$= \frac{j\omega C_{gd1} - g_{m1}}{\frac{1}{R_{Leq}} + j\omega C_{eq} + j\omega C_{gd1}}$$

$$= \frac{-g_{m1} R_{Leq}\left(j\omega \frac{C_{gd1}}{g_{m1}} - 1\right)}{1 + j\omega (C_{eq} + C_{gd1}) R_{Leq}}$$

$$\omega_z = \frac{g_{m1}}{C_{gd1}}$$