EE140 HW#8 Solution ①

1.

a) At the operation frequency ω_0 of 10G rad/s

L_g, C_{gs} & L_s is resonant The gate to sonce voltage is Q times as large as the input voltage So the overall stage transconductance G_m under this condition is :

$$G_m = Q \cdot g_{m1} = \frac{\frac{1}{\omega_0 C_{gs}}}{R_s + \frac{g_m}{C_{gs}}(L_g + L_s)} \cdot g_{m1}$$

$$= \frac{\frac{1}{10G \times 0.67P}}{100\Omega} \times 23.45mS$$

$$= 35mS$$

$\therefore A_{vo} = G_m \cdot Z_{out}$.

At ω_0, L_p & C_L in resonant $\therefore Z_{out} = R_{out} = 100\Omega$

$\therefore A_{vo} = G_m \cdot R_{out} = 3.5$

b) $Z_{in} = SL_s + \frac{1}{SC_{gs}} + \frac{g_m}{C_{gs}} \cdot L_s + S \cdot L_g$ ②

Substitute $S = 10\,Grad/s$ $g_m = 23.45\,mS$

$C_{gs} = 0.67\,pF$

$Z_{in} = 50\Omega$

2.

For M1 & M6 :

$$I_D = \frac{1}{2} \mu C_{ox} \frac{W}{L} (V_{GS} - V_t)^2$$

$$100\mu = 15\mu \times 50 \times (V_{GS} - V_t)^2$$

$$\therefore V_{GS} = -1.065V$$

For M3, M5, & M7.

$$100\mu = 30\mu \times 50 \times (V_{GS} - V_t)^2$$

$$V_{GS} = 0.958V$$

$$\therefore V_{SG2} = 5V - 1.065V - 0.958V = 2.977V$$

$$\therefore 100\mu = 15\mu \cdot \left(\frac{W}{L}\right)_2 (2.977 - 0.7)^2$$

$$\therefore \left(\frac{W}{L}\right)_2 = 1.286 = \frac{2.57\mu}{2\mu}$$

$$2.5V = V_{GS4} + V_{GS7}$$

$$\therefore 2.5V - 0.958V = 1.542V = V_{GS4}$$

$$V_{t4} = V_{t0} + \gamma\left(\sqrt{2\phi_f + V_{SB}} - \sqrt{2\phi_f}\right)$$

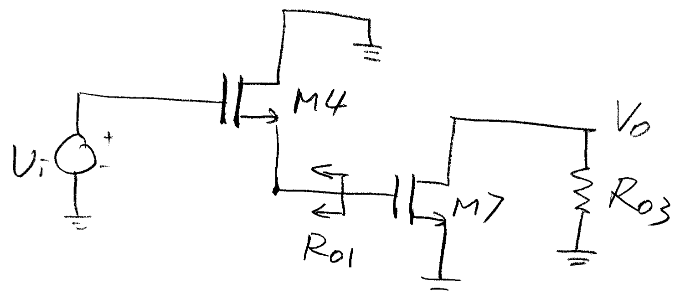
$$= 0.7V + 0.4 \times \left(\sqrt{0.6 + 0.958} - \sqrt{0.6}\right)$$

$$= 0.89V$$

$$I_{D4} = 100\mu = 30\mu \times \left(\frac{W}{L}\right)_4 (1.542 - 0.89)^2$$

$$\therefore \left(\frac{W}{L}\right)_4 = 7.83 = \frac{15.7\mu}{2\mu}$$

Signal path:



$$R_{o1} = \frac{1}{g_{m4} + g_{mb4}}$$

$$g_{m4} = \sqrt{2 I_D \mu C_{ox} \frac{W}{L}} = \sqrt{200\mu \times 60\mu \times 7.83} = 307\mu A/V$$

$$g_{mb4} = g_{m1} \cdot \frac{\gamma}{2\sqrt{2\phi_f + V_{SB}}} = 307\mu \times \frac{0.4}{2\sqrt{0.6 + 0.958}} = 49.2\mu A/V$$

$$\therefore R_{o1} = 2811\,\Omega$$

$$g_{m7} = \sqrt{200\mu \times 60\mu \times 50} = 775\mu A/V$$

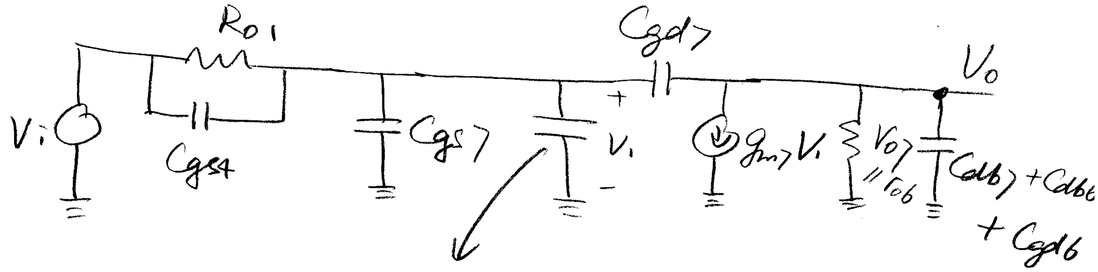
$$R_{o3} = r_{o7} // r_{o6} = \frac{1}{0.03 \times (100\mu)} // \frac{1}{0.03 \times (100\mu)} = 167k\Omega$$

$$\therefore \text{gain}: \frac{v_o}{v_i} = \frac{g_{m4} R_S}{1 + g_{m4} R_S} \cdot -g_{m7} \cdot R_{o3}$$

$R_s = r_{o7} = 333K$

$$\therefore \frac{V_o}{V_i} = -\frac{307\mu \times 333K}{1+307\mu\times 333K} \times 725\mu \times 167K$$

$$= -128.1$$



$C_{sb4} + C_{db5} + C_{gd5}$

$$C_{sb4} = \frac{C_{sb0}}{\sqrt{1+\frac{V_{SB}}{\psi_0}}} = \frac{0.8f\,(7.83)}{\sqrt{1+\frac{0.958}{0.6}}} = 3.89fF$$

$$C_{db5} = \frac{0.8f(100)}{\sqrt{1+\frac{0.958}{0.6}}} = 49.6fF$$

$$C_{gd5} = 0.3\times 100\mu = 30fF = C_{gd7}$$

$$C_{gs7} = \frac{2}{3}WLC_{ox} + 30fF = 261fF$$

$$C_{db7} = \frac{C_{db0}}{\sqrt{1+\frac{V_{SB}}{\psi_0}}} = 35.2fF = C_{db6}$$

$$R_{o1}(C_{sb4} + C_{db5} + C_{gd5} + C_{gs7}) = 0.968nS$$

$$(r_{o7} // r_{o6})(C_{db7} + C_{db6} + C_{gd6}) = 16.8nS$$

6

$$C_{gd7}(R_{o1} + R_{o3} + g_{m2} R_{o1} R_{o3}) = 16\,ns.$$

$$\therefore f_{-3dB} = \frac{1}{2\pi} \cdot \frac{10^9}{0.968 + 16.8 + 16} = \underline{\underline{4.71\,MHz}}$$

3. For the circuit a there are two poles associated with input and output node.

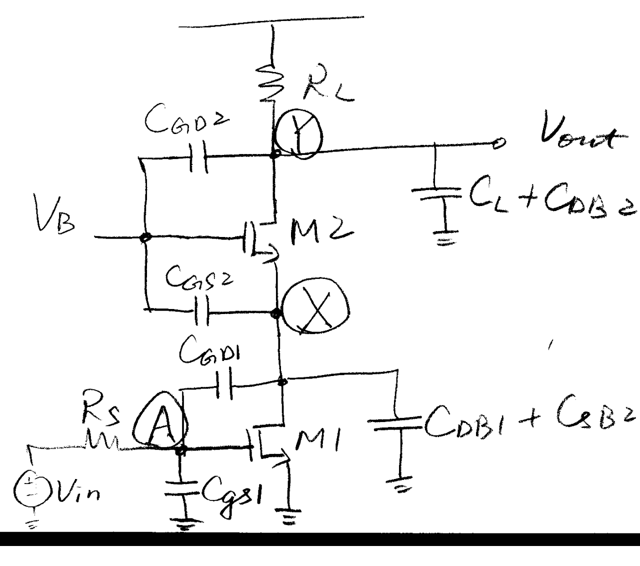
At input, since $R_L C_L << g_{m1} R_L R_S C_{gd}$, do the miller approximation

$$P_{input} = \frac{1}{g_{m1} R_L R_S C_{gd} + R_S \cdot C_{gS}} \leftarrow \text{dominant pole}$$

At output.

$$P_{output} = \frac{1}{R_L C_L} \leftarrow \text{second pole.}$$

For the circuit b. we can draw the equiv. model shown below:



The pole associated with node A is estimated as:

$$\omega_{p,A} = \frac{1}{R_S\left[C_{GS1} + \underbrace{\left(1+\frac{g_{m1}}{g_{m2}+g_{mb2}}\right)C_{GD1}}_{\text{miller approximation}}\right]} \leftarrow \text{dominant pole}$$

the pole associated with node X is:

$$\omega_{p,X} = \frac{g_{m2}+g_{mb2}}{2C_{GD1}+C_{DB1}+C_{SB2}+C_{GS2}}$$

Finally, there is a pole associated with output

$$\omega_{p,Y} = \frac{1}{R_L(C_{DB2}+C_L+C_{GD2})}$$

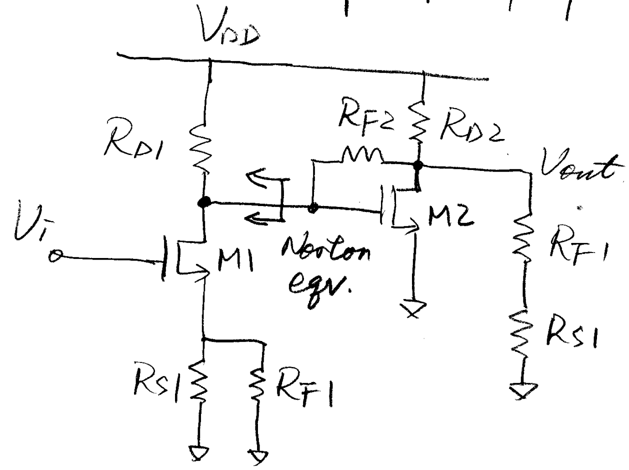
Compare the dominant pole of two circuits. We find out that by cascoding, circuit frequency response has been greatly improved.

4

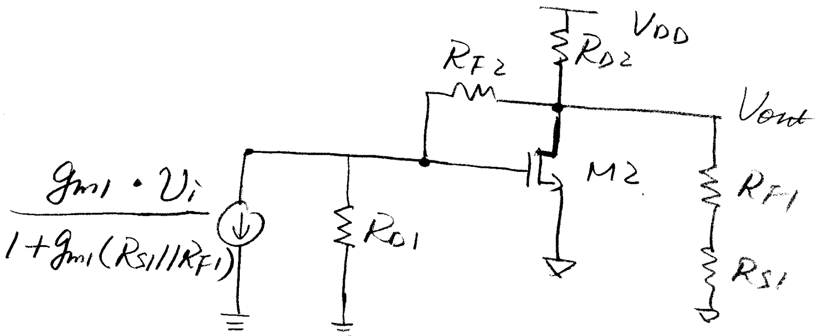
a) There are two feedback loops in this circuit The external feedback include M1, M2, R_{F1} & R_{S1} Internal feedback is M2 & R_F.

b) External feedback is series - shunt.
Internal feedback is shunt - shunt

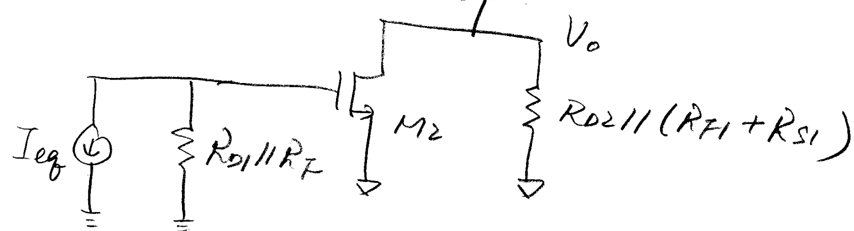
c) For the external feedback loop. open the feedback loop w/ proper loading.



Using Norton eqv. circuit to simplify ~~the~~ circuit we have:



Open the internal loop:



$$\therefore \left(\frac{V_o}{I_{eq}}\right)_{OL} = g_{m2} \cdot \Big(R_{D2}//(R_{F1}+R_{S1})\Big) \cdot \big(R_{D1}//R_F\big)$$

$$f = \frac{1}{R_{F2}}$$

$$\therefore \left(\frac{V_o}{I_{eq}}\right)_{CL} = \frac{\left(\frac{V_o}{I_{eq}}\right)_{OL}}{1+f \cdot \left(\frac{V_o}{I_{eq}}\right)_{OL}} \simeq \frac{g_{m2} \cdot \big(R_{D2}//(R_{F1}+R_{S1})\big) \cdot R_{D1}}{1+\frac{1}{R_{F2}} \cdot g_{m2} \cdot \big(R_{D2}//(R_{F1}+R_{S1})\big) \cdot (R_{D1}//R}$$

$$\left(\frac{V_o}{I_{eq}}\right)_{CL} = \frac{V_o}{\dfrac{g_{m1} \cdot V_i}{1 + g_{m1}(R_{S1} // R_{F1})}}$$

$$\therefore \left(\frac{V_o}{V_i}\right)_{OL} = A = \frac{g_{m1}}{1 + g_{m1}(R_{S1}//R_{F1})} \cdot \left(\frac{V_o}{I_{eq}}\right)_{CL}$$

$$= \frac{\frac{1}{200}}{1 + \frac{1}{200} \times 1K\Omega} \times \frac{\frac{1}{200} \times (1K // 2K) \times 0.5K}{1 + \frac{1}{2K} \times \frac{1}{200} \times (1K // 2K) \times 0.5K}$$

$$= \frac{1}{1.2K} \times \frac{\frac{5}{3}K}{1 + \frac{5}{6}} = \underline{\underline{757.6}}$$

$$f = \frac{R_{S1}}{R_{S1} + R_{F1}} = \underline{\underline{\frac{1}{2}}}$$

$$T = A \cdot f = \underline{\underline{378.8}}$$

d) $$\left(\frac{V_o}{V_i}\right)_{CL} = \frac{A}{1 + A \cdot f} = \frac{757.6}{388.8} = 1.949$$

$$R_{in} = \infty$$

$$R_{out} = \frac{R_{out}(OL)}{1 + T_{external}} = \frac{\dfrac{R_{F2} // R_{D2} // (R_{F1} + R_{S1})}{1 + T_{internal}}}{1 + T_{external}}$$

$$= \frac{1K\Omega // 1K\Omega // 2K\Omega}{(1 + 378.8)\left(1 + \frac{1}{2K} \times \frac{1}{200} \times (1K//2K) \times 0.5K\right)}$$

$$= \frac{0.41 k\Omega}{\frac{11}{6} \times 388.8} = 0.56\,\Omega$$