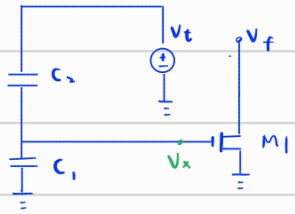
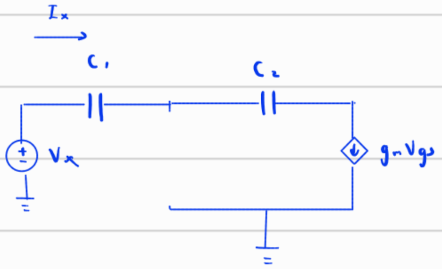
6.1

(a)





$$V_x = \frac{C_2}{C_1+C_2} V_t$$

$$V_f = -g_m r_o V_x$$

$$r_o = \infty$$

$$\frac{V_f}{V_t} = -\frac{C_2}{C_1+C_2} g_m r_o$$

$$AB = \frac{C_2}{C_1+C_2} g_m r_o$$

Open-loop $R_{out} = r_{o1}$

$\downarrow$

Closed-loop R_{out}

$$= \frac{r_{o1}}{1+AB} = \frac{\cancel{r_{o1}}}{1 + \frac{C_2}{C_1+C_2} g_{m1} \cancel{r_{o1}}}$$

$$= \frac{C_1+C_2}{g_{m1} C_1} \quad \#$$

$$I_x = g_{m1} V_{gs}$$

$$V_{gs} = V_x - \frac{g_{m1} V_{gs}}{s C_1}$$

$$\left(1 + \frac{g_m}{sC_1}\right) V_{gs} = V_x$$

$$V_{gs} = \frac{V_x}{1 + \frac{g_{m1}}{sC_1}}$$

$$I_x = g_{m1} \cdot \frac{V_x}{1 + \frac{g_{m1}}{sC_1}}$$

$$\frac{V_x}{I_x} = \frac{\cancel{V_x}}{\frac{g_{m1}}{1+\frac{g_{m1}}{sC_1}} \cancel{V_x}}$$

$$= \frac{1 + \frac{g_{m1}}{sC_1}}{g_{m1}}$$

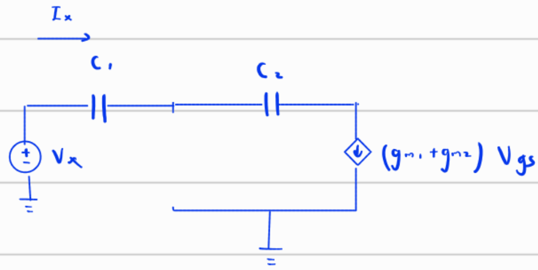
$$R_{in} = \frac{1}{g_{m1}} + \frac{1}{sC_1} \quad \#$$

(b) Complementary CS

PMOS & NMOS can be combined into

a compound device with $g_m' = g_{m1} + g_{m2}$

$r_o' = r_{o1} \parallel r_{o2}$



AB has the same form as (b)

$$AB = \frac{C_2}{C_1+C_2} (g_{m1}+g_{m2})(r_{o1} \parallel r_{o2})$$

Open-loop $R_{out} = r_{o1} \parallel r_{o2}$

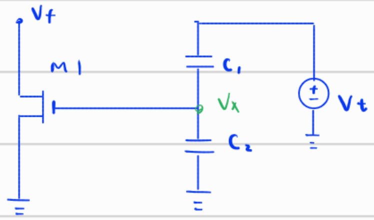
$$R_{in} = \frac{1}{g_{m1}+g_{m2}} + \frac{1}{sC_1} \quad \#$$

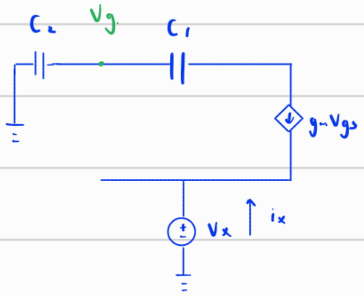
Closed-loop R_{out}

$$= \frac{(r_{o1} \parallel r_{o2})}{1+AB} = \frac{\cancel{r_{o1} \parallel r_{o2}}}{1 + \frac{C_2}{C_1+C_2}(g_{m1}+g_{m2})(\cancel{r_{o1} \parallel r_{o2}})}$$

$$= \frac{C_1+C_2}{(g_{m1}+g_{m2}) C_2} \quad \#$$

(c)





$$V_x = V_t \cdot \frac{C_1}{C_1+C_2}$$

$$V_f = -g_m r_o V_x$$

$$\frac{V_f}{V_t} = -\frac{C_1}{C_1+C_2} g_m r_o$$

$$AB = \frac{C_1}{C_1+C_2} g_m r_o$$

Open-loop $R_{out} = r_{o1}$

Closed-loop R_{out}

$$= \frac{r_{o1}}{1+AB}$$

$$= \frac{\cancel{r_{o1}}}{1+\frac{C_1}{C_1+C_2} g_{m1} \cancel{r_{o1}}}$$

$$= \frac{C_1+C_2}{g_{m1} C_1} \quad \#$$

$$V_g = -g_m (V_g - V_x) \frac{1}{sC_2}$$

$$V_g = -\frac{g_m}{sC_2} V_g + \frac{g_m}{sC_2} V_x$$

$$\left(1+\frac{g_m}{sC_2}\right) V_g = \frac{g_m}{sC_2} V_x$$

$$V_g = \frac{\frac{g_m}{sC_2}}{1+\frac{g_m}{sC_2}} V_x$$

$$V_{gs} = \left(\frac{\frac{g_m}{sC_2}}{1+\frac{g_m}{sC_2}} - 1\right) V_x$$

$$= \left(\frac{\frac{g_m}{sC_2} - 1 - \frac{g_m}{sC_2}}{1+\frac{g_m}{sC_2}}\right) V_x$$

$$I_x = -g_m V_{gs}$$

$$= -g_m \frac{-1}{1+\frac{g_m}{sC_2}} V_x$$

$$= \frac{g_m}{1+\frac{g_m}{sC_2}} V_x$$

$$\frac{V_x}{I_x} = \frac{\cancel{V_x}}{\frac{g_m}{1+\frac{g_m}{sC_2}} \cancel{V_x}}$$

$$= \frac{1+\frac{g_m}{sC_2}}{g_m}$$

$$= \frac{1}{g_{m1}} + \frac{1}{sC_2}$$

$$R_{in} = \frac{1}{g_{m1}} + \frac{1}{sC_2}$$

\#

6.2

(a) $k_{n,1} = 0.13428m \times 100 = 13.428\,mA/V^2$

$k_{p,2,3} = 0.03837m \times 100 = 3.837\,mA/V^2$

$I_{D1} = 0.5\,mA = \frac{1}{2} \cdot 13.428m \cdot V_{ov1}^2$

$V_{ov1} = 0.27289\,V$

$V_{gs1} = 0.97289V$

$V_{s1} = 0.5m \cdot R_{s1} = 1V$

$V_{g1} = 1V + 0.97289V = 1.97289V$

$V_{in} = 1.973\,V$ \#

$V_{DD} = 3V$

$C_{ox} = 3.9 \frac{\varepsilon_0}{t_{ox}} = 3.83673 \times 10^{-7}\,F/cm^2 = 3.83673 \times 10^{-15}\,F/\mu m^2$

$\mu_n = 350\,cm^2/V/s$ $\quad V_{t_n} = 0.7$

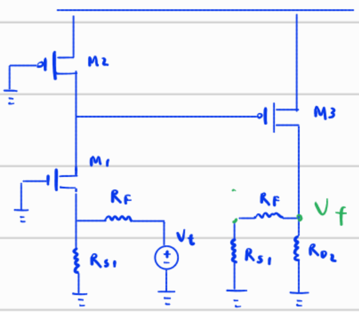
$\mu_p = 100\,cm^2/V/s$ $\quad V_{t_p} = -0.8$

$k_n' = 0.13428\,mA/V^2$ $\quad k_p' = 0.03837\,mA/V^2$

$\lambda_n = 0.1$

$\lambda_p = 0.2$

(b)



$g_{m1} = \sqrt{2k\ 0.5m} = 3.6644m \qquad g_{m3} = 1.9588m \qquad r_{o2} = 10k = r_{o3}$

(No r_{o1} because $\lambda_1 = 0$)

$$A_v \text{ (Open-loop gain)} = + \frac{g_{m1}}{1 + g_{m1}(R_{S1} \| R_F)} \cdot r_{o2} \cdot (+g_{m3}) \left[r_{o3} \| R_{o2} \| (R_F + R_{S1}) \right]$$

$$= \frac{3.6644m}{1 + 3.6644m \cdot 1k} \cdot 10k \cdot 1.9588m \cdot 1.17647k$$

$$= 18.1041 \text{ V/V}$$

$$V_f = \frac{V_t}{R_F} \times (R_F \| R_{S1}) \times \frac{g_{m1}}{1 + g_{m1}(R_{S1} \| R_F)} \cdot r_{o2} \times (-g_{m3}) \left[r_{o3} \| R_{o2} \| (R_F + R_{S1}) \right] \cdot \frac{R_{S1}}{\frac{1}{g_{m1}} + R_{S1}} \cdot r_{o2}$$

$A\beta = 7.346$

$$\frac{A}{1 + A\beta} = \frac{18.1041}{1 + A\beta} = 2.170 \text{ V/V} \quad \#$$

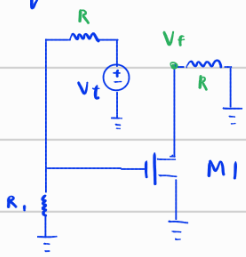
$$\text{Open-loop } R_{out} = R_{o2} \| (R_{S1} + R_F) \| r_{o3}$$

$$= 1.17647k$$

$$\text{Closed-loop } R_{out} = \frac{1.17647k}{1 + A\beta} = 140.962\ \Omega \quad \#$$

6.3 Let $R = R_2 + R_3 = 6k\Omega$ p.312

Low Freq:



$$V_f = V_t \cdot \frac{R_1}{R_1 + R} \cdot (-g_{m1}) R$$

$$= V_t \frac{R_1}{R_1 + R_2 + R_3} \cdot (-g_{m1})(R_2 + R_3)$$

$$A\beta = \frac{3}{9} g_{m1} \cdot 6k$$

$$= \frac{1}{3} \cdot 10m \cdot 6k = 20$$

Feedback resistors sense Vout and convert it to current

$$A_v(\text{open}) = \frac{1}{R_1} \left[R_1 \| (R_2 + R_3) \right] - g_{m1}(R_2 + R_3)$$

convert V source to I source

$$= \frac{1}{3k} (3k \| 6k) - 10m \cdot 6k$$

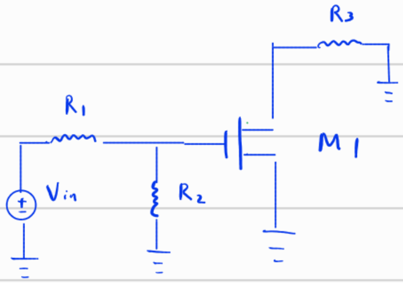
$$= \frac{2}{3} \cdot -60$$

$$= -40$$

$$\frac{A}{1 + A\beta} = \frac{-40}{1 + 20}$$

$$= -1.9048 \text{ V/V} \quad \#$$

High Freq:



$$A_v = \frac{R_2}{R_1 + R_2} \quad -g_{m1} R_3$$

$$= \frac{3}{6} \quad -10m \cdot 3k$$

$$= -15 \quad V/V$$

#