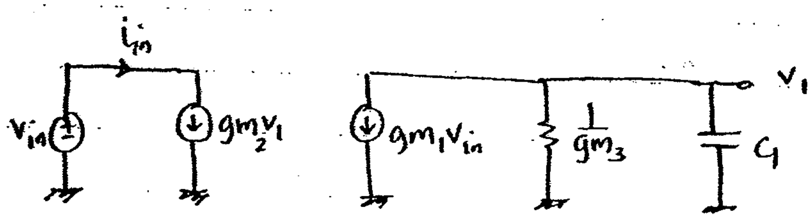
5.19 small signal model.



$$Z_{in} = \frac{v_{in}}{i_{in}} = \frac{v_{in}}{g_{m2}v_1} \qquad v_1 = -g_{m1}\left(\frac{1}{C_1 s + g_{m3}}\right)v_{in}$$

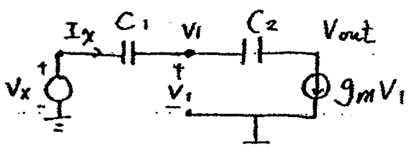
$$= -\frac{C_1 s + g_{m3}}{g_{m2}g_{m1}}$$

if all transistors are equal $g_{m1} = g_{m2} = g_{m3}$.

$$Z_{in} = -\frac{C_1 s}{g_m^2} - \frac{1}{g_m}$$

negative $C = -\frac{C_1}{g_m^2}$ and negative $R = \frac{1}{g_m}$.

6. 6(a)



g_m : transconductance of M_1

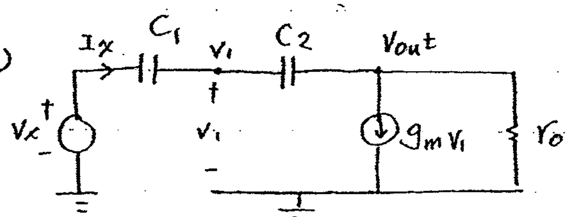
$$I_x = sC_1(V_x - V_1) = sC_2(V_1 - V_{out}) = g_m V_1$$

$$\therefore \quad sC_1 V_x = (g_m + sC_1)V_1 \Rightarrow V_1 = \left[\frac{sC_1}{g_m + sC_1}\right] V_x$$

$$\Rightarrow I_x = g_m V_1 = \left[g_m sC_1 / g_m + sC_1 \right] V_x$$

$$\Rightarrow Z_{in} = \frac{V_x}{I_x} = \frac{g_m + sC_1}{g_m s C_1} \quad ※$$

(b)



$g_m = g_{m1} + g_{m2}$
$r_o = r_{o1} // r_{o2}$

g_{m1}, g_{m2} : transconductance for M_1, M_2
r_{o1}, r_{o2} : output resistance for M_1, M_2

$$\therefore I_x = \overbrace{sC_1(V_x - V_1) = sC_2(V_1 - V_{out})}^{②} = \underbrace{sC_2(V_1 - V_{out}) = g_m V_1 + \frac{V_{out}}{r_o}}_{①}$$

from ① :

$$\frac{V_{out}}{V_1} = \frac{sC_2 - g_m}{sC_2 + \frac{1}{r_o}}$$

from ② :

$$(sC_1 + sC_2)V_1 = sC_1 V_x + sC_2 V_{out}$$

$$= sC_1 V_x + \frac{s^2 C_2^2 - g_m s C_2}{sC_2 + \frac{1}{r_o}} V_1$$

$$\Rightarrow \left[sC_1 + sC_2 - \frac{s^2 C_2^2 - g_m sC_2}{sC_2 + \frac{1}{r_o}} \right] V_1 = sC_1 V_x$$

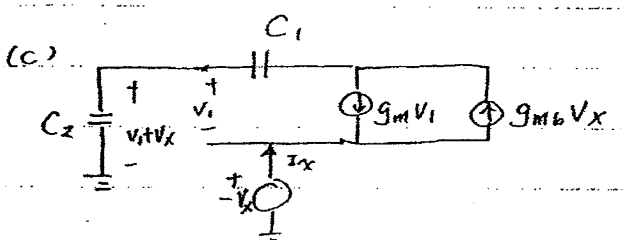
$$\Rightarrow \left[\frac{s^2C_1C_2 + \frac{sC_1}{r_o} + \frac{sC_2}{r_o} + g_m s C_2}{sC_2 + \frac{1}{r_o}} \right] V_1 = sC_1 V_X$$

$$\therefore V_1 = \left[\frac{sC_1C_2 + \frac{C_1}{r_o}}{sC_1C_2 + \frac{C_1}{r_o} + \frac{C_2}{r_o} + g_m C_2} \right] V_x$$

$$I_X = sC_1(V_X - V_1) = sC_1 \cdot \left[\frac{\frac{C_2}{r_o} + g_m C_2}{sC_1C_2 + \frac{C_1}{r_o} + \frac{C_2}{r_o} + g_m C_2} \right] V_X$$

$$Z_{in} = \frac{V_X}{I_X} = \frac{sC_1C_2 + \frac{C_1}{r_o} + \frac{C_2}{r_o} + g_m C_2}{sC_1C_2\left(\frac{1}{r_o} + g_m\right)} \quad \star$$

(c)



$$sC_2(V_1 + V_X) + g_m V_1 = g_{mb} V_X$$

$$\Rightarrow (sC_2 + g_m)V_1 = (g_{mb} - sC_2)V_X$$

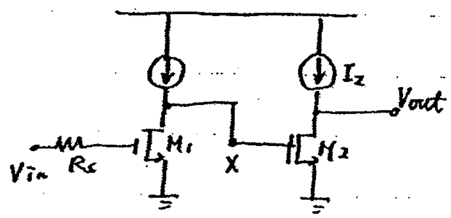
$$\frac{V_X}{V_1} = \frac{sC_2 + g_m}{g_{mb} - sC_2}$$

$$I_X = -g_m V_1 + g_{mb} V_X$$

$$= \left[-g_m \cdot \frac{g_{mb} - sC_2}{sC_2 + g_m} + g_{mb} \right] V_X = \left[\frac{(g_m + g_{mb})sC_2}{sC_2 + g_m} \right] V_X$$

$$Z_{in} = \frac{V_X}{I_X} = \frac{sC_2 + g_m}{sC_2(g_m + g_{mb})} \quad \star$$

6.7 (a)



There are three poles associated with this circuit.

The first pole @ Vout

$$\omega_{p,out} = \frac{1}{r_{o2}\cdot(C_{gd2}+C_{dB2})}$$

The pole @ the input

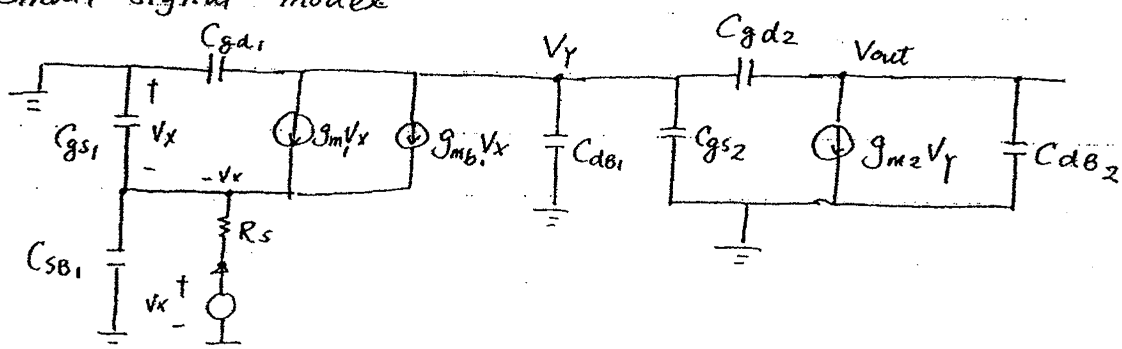
$$\omega_{p,in} = \frac{1}{R_S\cdot[(1+g_{m1}r_{o1})C_{gd1}+C_{gs1}]}$$

The pole @ node X

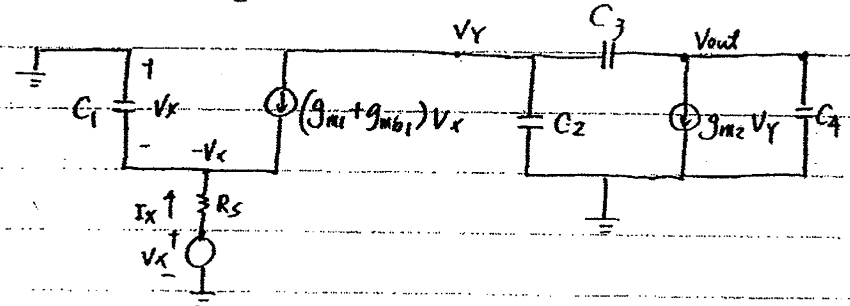
$$\omega_{p,X} = \frac{1}{r_{o1}\cdot[(C_{gd1}+C_{dB1}+C_{gs2})+(1+g_{m2}r_{o2})\cdot C_{gd2}]}$$

Please note that the above approximation is based on Miller effect. In order to get more accuracy approximation, transfer function has to be derived.

(b) Small signal model



Redraw small signal model



where,

$C_1 = C_{gs1} + C_{SB1}$

$C_2 = C_{gs2} + C_{dB1} + C_{gd1}$

$C_3 = C_{gd2}$

$C_4 = C_{dB2}$

KCL @ V_{out} : $sC_3(V_Y - V_{out}) = g_{m2}V_Y + sC_4V_{out}$

$$\Rightarrow \frac{V_{out}}{V_Y} = \frac{-g_{m2}+sC_3}{s(C_3+C_4)}$$

KCL @ V_Y : $(g_{m1}+g_{mb1})V_X + sC_2V_Y + sC_3(V_Y - V_{out}) = 0$

$$(g_{m1}+g_{mb1})V_X = -V_Y\left(sC_2 + \frac{s^2C_3C_4 + sC_3\cdot g_{m2}}{s(C_3+C_4)}\right)$$

$$\frac{V_Y}{V_X} = -\frac{g_{m1}+g_{mb1}}{[s(C_2C_3+C_2C_4+C_3C_4)+C_3g_{m2}]/(C_3+C_4)}$$

KCL @ V_X : $\frac{V_{in}+V_X}{R_S} + sC_1V_X + (g_{m1}+g_{mb1})V_X = 0$

$$\frac{V_X}{V_{in}} = -\frac{1}{sC_1R_S + (1+(g_{m1}+g_{mb1})\cdot R_S)}$$

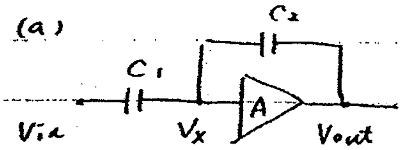
Thus, there are three poles

$\omega_{P0} = 0$

$$\omega_{P1} = \frac{-C_3g_{m2}}{C_2C_3+C_2C_4+C_3C_4} \quad \text{*}$$

$$\omega_{P2} = \frac{-(1+(g_{m1}+g_{mb1})\cdot R_S)}{C_1R_S} \quad \text{*}$$

6.9 (a)



$A = -\infty$

(i) At low frequency, V_x is like virtual ground

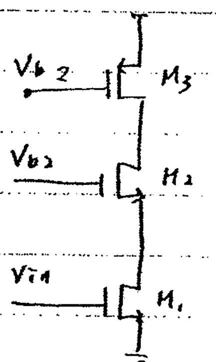
$sC_1 V_{in} = -sC_2 V_{out}$

$$\frac{V_{out}}{V_{in}} = -\frac{C_1}{C_2}$$

(ii) At high frequency, C_1, C_2 is like a short circuit

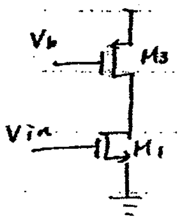
$$\frac{V_{out}}{V_{in}} = 1$$

(b) At low frequency, the equivalent circuit is shown as



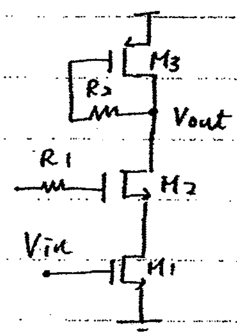
$A_v \cong -g_{m1} r_{o3} \to \infty$, if $\lambda = 0$

(ii) At high frequency, the equivalent circuit

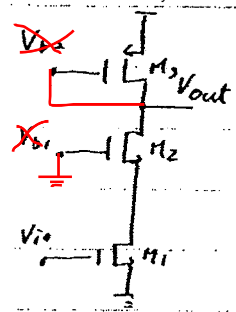


$Av = -g_{m1}(r_{o1} // r_{o3}) \rightarrow \infty$ if $\lambda = 0$

(c) (i) At low frequency, the equivalent circuit



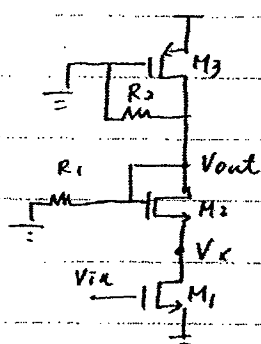
R_1, R_2 can be ignored $\Rightarrow$



The impedance @ Vout $= \frac{1}{g_{m3}}$

$$Av \cong -g_{m1} \cdot 1/g_{m3} = -\frac{g_{m1}}{g_{m3}}$$

(ii) At high frequency.



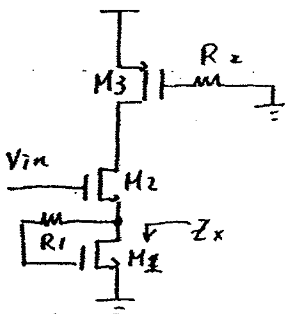
$$\frac{V_X}{V_{in}} = -g_{m1} \cdot \underbrace{\frac{1}{g_{m2}}}$$

↳ the impedance looking into V_x

The impedance @ Vout = $R_1 // R_2$

$$\therefore Av = \left(-g_{m1} \cdot \frac{1}{g_{m2}}\right) \cdot g_{m2} \cdot (R_1 // R_2) = -g_{m1}(R_1 // R_2)$$

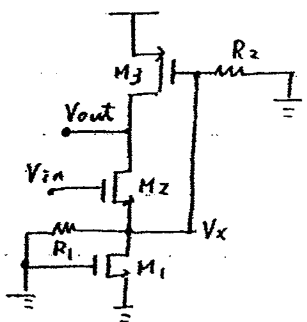
(d) (i) At low frequency, the equivalent circuit is



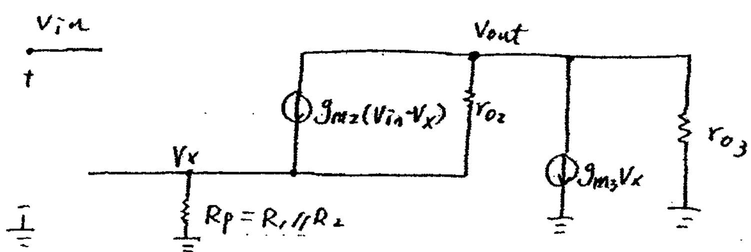
$$\frac{V_{out}}{V_{in}} = \frac{g_{m2}\left(r_{o3} /\!/ (1+g_{m2}r_{o2})Z_x\right]}{1+g_{m2}Z_x} \simeq \frac{g_{m2}(r_{o3}/\!/r_{o2})}{1+\frac{g_{m2}}{g_{m1}}} \to \infty \quad \text{if } \lambda = 0$$

$$Z_x = \frac{1}{g_m}$$

(ii) At high frequency



Small-signal model



$$\text{KCL @ } V_x, V_{out}: \quad \frac{V_x}{R_p} = g_{m2}(V_{in} - V_x) + \frac{V_{out} - V_x}{r_{o2}} = -\left(g_{m3}V_x + \frac{V_{out}}{r_{o3}}\right)$$

$$\frac{V_x}{R_p} = -\left(g_{m3}V_x + \frac{V_{out}}{r_{o3}}\right) \Rightarrow \frac{V_{out}}{V_x} = -r_{o3}\left(g_{m3} + \frac{1}{R_p}\right)$$

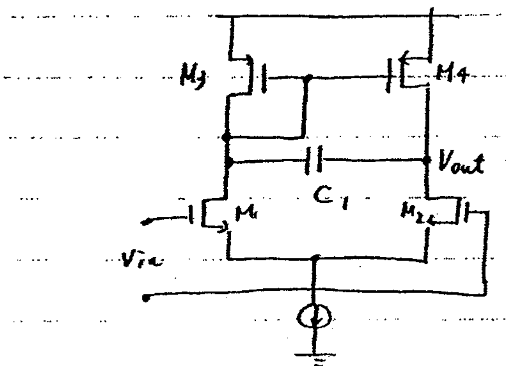
$$g_{m2}(V_{in} - V_x) + \frac{V_{out} - V_x}{r_{o2}} = \frac{V_x}{R_p} \Rightarrow g_{m2}V_{in} = \left(\frac{1}{R_p} + \frac{1}{r_{o2}} + g_{m2}\right)V_x + \frac{V_{out}}{r_{o2}}$$

$$\Rightarrow g_{m2}V_{in} = \left[-\left(\frac{1}{R_p} + \frac{1}{r_{o2}} + g_{m2}\right)\frac{1}{r_{o3}\left(g_{m3} + \frac{1}{R_p}\right)} + \frac{1}{r_{o2}}\right]V_{out}$$

$$\Rightarrow \frac{V_{out}}{V_{in}} = \frac{-g_{m2}r_{o3}\left(g_{m3} + \frac{1}{R_p}\right)}{\left(\frac{1}{R_p} + \frac{1}{r_{o2}} + g_{m2}\right) - \frac{r_{o3}}{r_{o2}}\left(g_{m3} + \frac{1}{R_p}\right)} \to \infty \quad \text{if } \lambda = 0$$

#

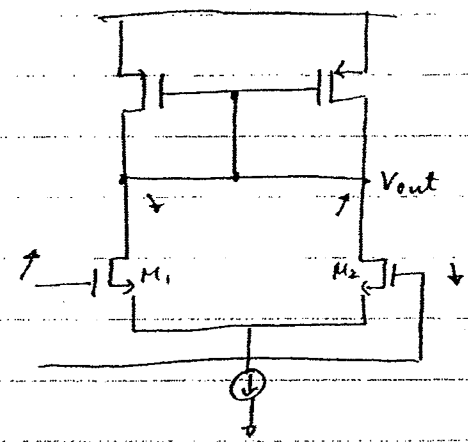
6.10(a) (i) At low frequency



C_1 is like an open circuit @ very low frequency

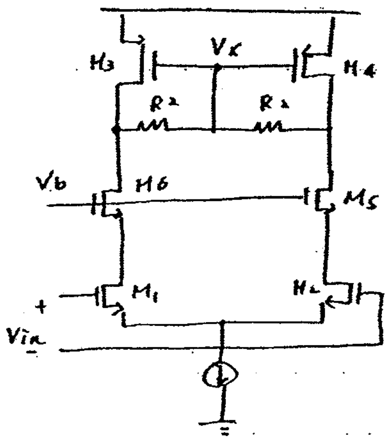
$$\Rightarrow \frac{V_{out}}{V_{in}} = -g_{m_1}(r_{o2} \parallel r_{o4}) \to \infty \text{ if } \lambda = 0$$

(ii) At very high frequency, C_1 is like a short circuit



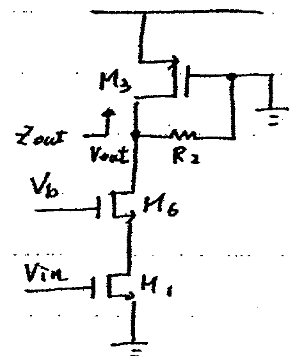
Gain = 0

6.10 (b) (i) At low frequency, the equivalent circuit is



half circuit →

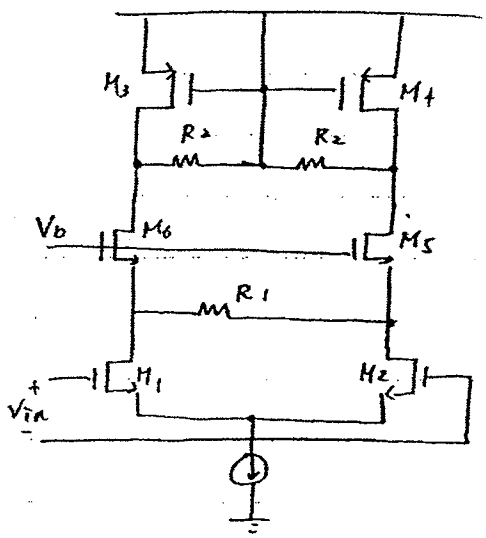
Vx is virtual ground



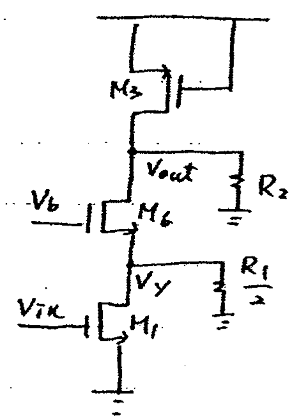
$Z_{out} \cong r_{o3} // R_2 \cong R_2$

$A_V = -g_{m1} \cdot (R_2 // r_{o3}) \cong -g_{m1} R_2$ ※

(ii) At high frequency



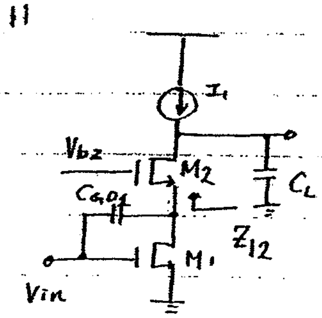
half circuit →



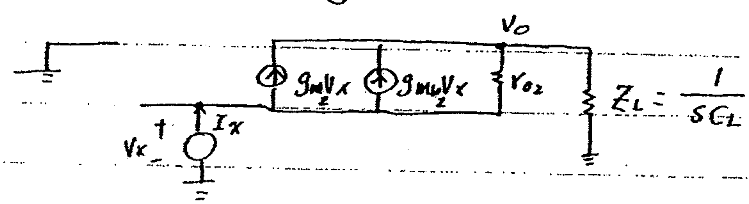
$$\frac{V_y}{V_{in}} = -g_{m1}\left(\frac{1}{g_{m6}} // \frac{R_1}{2}\right), \quad \frac{V_{out}}{V_y} \cong +g_{m6} \cdot R_2$$

$$\frac{V_{out}}{V_{in}} = -\frac{g_{m1} g_{m6} R_1 R_2}{(2 + g_{m6} \cdot R_1)}$$ ※

6.11



The impedance Z_{12} can be derived from the following small signal model



KCL @ V_o : $\dfrac{V_o}{Z_L} + \dfrac{V_o - V_x}{r_{o_2}} = (g_{m_2} + g_{mb_2})V_x \Rightarrow \left(\dfrac{1}{Z_L} + \dfrac{1}{r_{o_2}}\right)V_o = \left(g_{m_2} + g_{mb_2} + \dfrac{1}{r_{o_2}}\right)V_x$

$$\Rightarrow V_o = \left(\frac{g_{m_2} + g_{mb2} + \frac{1}{r_{o2}}}{1 + \frac{Z_L}{r_{o2}}}\right)V_x$$

$$\Rightarrow I_x = \frac{V_o}{Z_L} = \left[\frac{g_{m_2} + g_{mb_2} + \frac{1}{r_{o2}}}{1 + \frac{Z_L}{r_{o2}}}\right]V_x \Rightarrow \frac{V_x}{I_x} = Z_{12} = \frac{1 + \frac{Z_L}{r_{o2}}}{g_{m_2} + g_{mb_2} + \frac{1}{r_{o2}}}$$

$$\Rightarrow Z_{12} = \frac{r_{o2} + Z_L}{1 + (g_{m_2} + g_{mb2})r_{o2}}$$

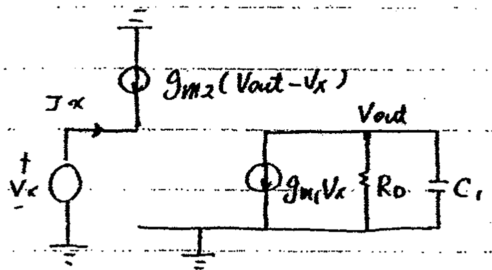
The miller multiplication for C_{GD_1} $= 1 + g_{m1} Z_{12}$

$$= 1 + \frac{g_{m1}(r_{o2} + Z_L)}{1 + (g_{m2} + g_{mb2})r_{o2}} \quad \text{—— ①}$$

If C_L is relatively large $\Rightarrow \left|\dfrac{1}{sC_L}\right| \ll r_{o2}$

eq ① can be approximated as $\cong 1 + \dfrac{g_{m1} r_{o2}}{1 + (g_{m2} + g_{mb2})r_{o2}} \cong 1 + \dfrac{g_{m1}}{g_{m2} + g_{mb2}}$

6.12 (a)



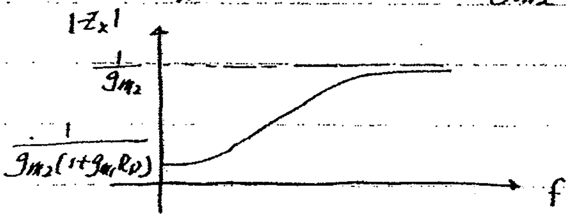
$$V_{out} = -g_{m1}V_X\left(R_D // \frac{1}{sC_1}\right)$$

$$I_X = -g_{m2}(V_{out}-V_x) = -g_{m2}V_{out} + g_{m2}V_X = \left[g_{m2}g_{m1}\left(R_D // \frac{1}{sC_1}\right) + g_{m2}\right]V_x$$

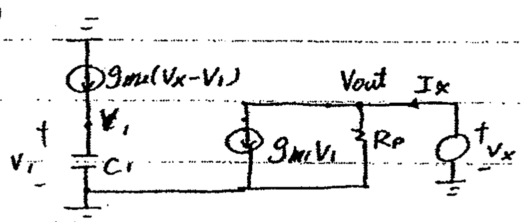
$$Z_X = \frac{V_x}{I_X} = \frac{1}{g_{m2}g_{m1}\frac{R_D/sC_1}{R_D+1/sC_1}+g_{m2}} = \frac{1}{g_{m2}\left[\left(\frac{g_{m1}R_D}{1+sR_DC_1}\right)+1\right]}$$

Thus, $Z_X(s\to 0) = 1/g_{m2}(1+g_{m1}R_D)$

$Z_X(s\to \infty) = 1/g_{m2}$



(b)



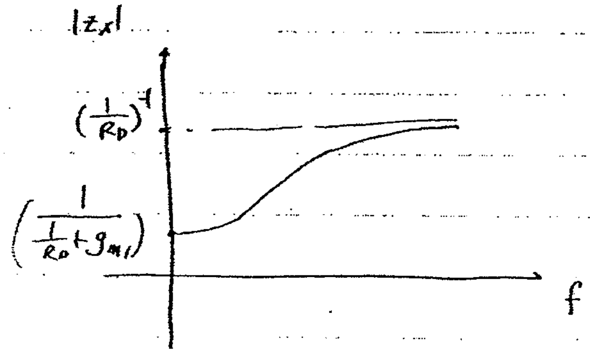
KCL @ V_1: $g_{m2}(V_X-V_1) = sC_1V_1$

$$\Rightarrow V_1 = \left(\frac{g_{m2}}{sC_1+g_{m2}}\right)V_X$$

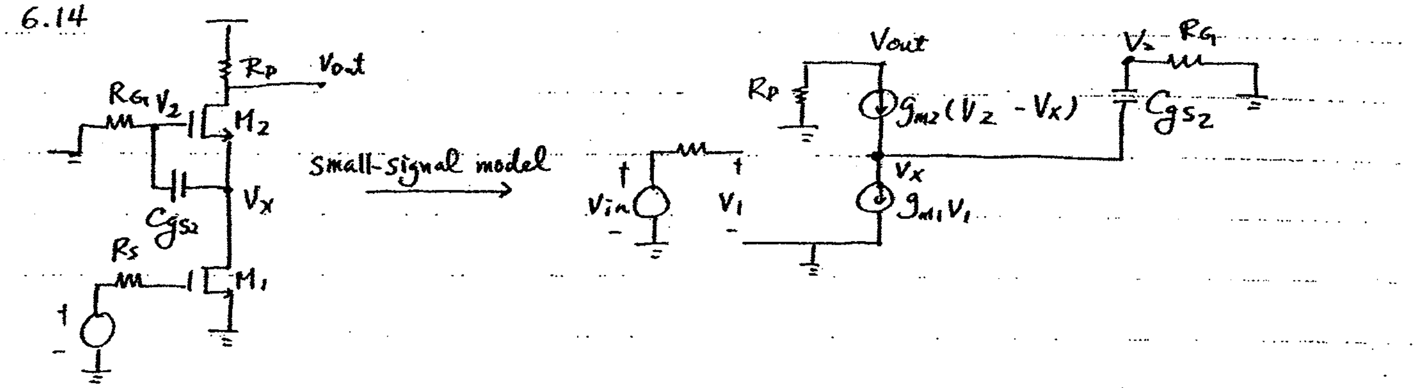
KCL @ V_{out}: $I_X = \frac{V_x}{R_D} + g_{m1}V_1$

$$= \frac{V_x}{R_D} + \frac{g_{m1}g_{m2}}{sC_1+g_{m2}}V_X$$

$$\Rightarrow Z_X = \frac{1}{\frac{1}{R_D}+\frac{g_{m1}g_{m2}}{sC_1+g_{m2}}}$$



6.14



KCL @ V_2 : $\frac{V_2}{R_G} = sC_{gs2}(V_x - V_2)$

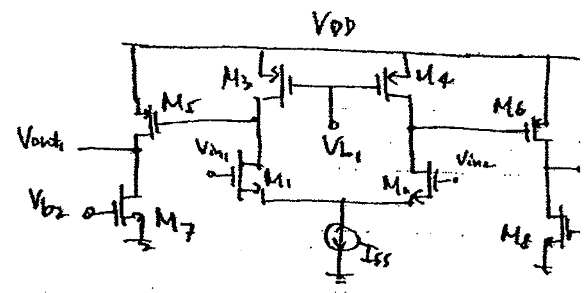
$$\Rightarrow \frac{V_2}{V_x} = \frac{sC_{gs2}}{\frac{1}{R_G} + sC_{gs2}} = \frac{sR_G C_{gs2}}{1 + sR_G C_{gs2}} \quad \text{— ①}$$

KCL @ V_{out} : $V_{out} = -g_{m2}(V_2 - V_x)R_D = \left[\frac{g_{m2}R_D}{1 + sR_G C_{gs2}}\right] V_x$ — ②

KCL @ V_x : $g_{m1}V_1 = g_{m1}V_{in} = (g_{m2} + sC_{gs2})(V_2 - V_x)$

$$= \frac{-(g_{m2} + sC_{gs2})}{1 + sR_G C_{gs2}} V_x \quad \text{— ③}$$

from ②, ③, $\frac{V_{out}}{V_{in}} = \frac{-g_{m1}g_{m2}R_D}{g_{m2} + sC_{gs2}}$ *



Problem 9.7

Design the op amp of fig. 9.21

Max diff. swing = 4V

total Power = 6mW $I_{SS} = 0.5mA$

Total current driven by $V_{DD} = \frac{6mW}{3V} = 2mA$

$I_{D5} + I_{D6} = 2mA - I_{SS} = 1.5mA \Rightarrow I_{D5} = I_{D6} = 0.75mA$

Max diff swing $= 2[V_{DD} - |V_{OD5}| - V_{OD7}] = 4V$

$\Rightarrow |V_{OD5}| + |V_{OD7}| = 1$ choose $V_{OD5} = 0.6V$, $V_{OD7} = 0.4V$

$I_D = \frac{1}{2}\mu C_{ox}(\frac{W}{L_{eff}})(V_{GS} - V_{TH})^2(1+\lambda V_{DS})$

$(\frac{W}{L_{eff}})_5 = \frac{2I_D}{\mu_p C_{ox}(V_{GS} - V_{TH})^2(1+\lambda V_{DS})} = \frac{2(0.75mA)}{(100)(383.6\times10^{-9})(0.6)^2(1+0.2\times0.6)}$

$(\frac{W}{L_{eff}})_5 = 97 \Rightarrow W_{5,6} = 97\times0.32\mu = 31\mu m$

$(\frac{W}{L_{eff}})_7 = \frac{2(0.75m)}{(350)(383.6\times10^{-9})(0.4)^2(1+0.1(0.4))}$

$= 67 \Rightarrow W_{7,8} = 67\times0.34\mu m = 23\mu m$

We are generally not worried about the swing of 1st stage,

assume $|V_{OD3}| = 1V$, $V_{OD1} = 1V$.

$(\frac{W}{L_{eff}})_3 = \frac{2(0.25m)}{(100)(383.6\times10^{-9})(1)^2(1+0.2(1))} = 10.86$

$W_{3,4} = 3.5\mu m$

$(\frac{W}{L_{eff}})_1 = \frac{2(0.25m)}{(350)(383.6\times10^{-9})(1)^2(1+0.1)} = 3.4$

$W_{1,2} = 1.2\mu m$

$V_{b1} = V_{DD} - |V_{OD3}| - V_{TH3} = 3 - 1 - 0.8 = 1.2V.$

$V_{in,CM} = V_{ISS} + V_{TH1} + V_{OD1} = 0.3 + 0.7 + \cancel{0.}\ 1.0 = 2V.$

$V_{b2} = V_{TH7} + V_{OD7} = 0.7 + 0.4 = 1.1V.$

Summary $L = 0.5\mu m$	
$W_1 = W_2 = 1.2\mu m$	$V_{b1} = 1.2V$
$W_{3,4} = 3.5\mu m$	$V_{b2} = 1.1V$
$W_{5,6} = 31\mu m$	$V_{in,CM} = 2V$
$W_{7,8} = 23\mu m$	

Problem 9.18

$P = 6mW$, output Swing = 2.5V

$L_{eff} = 0.5\mu m$

a) $I_{D5,6} = 1mA$. $V_{OD5} \simeq V_{OD6} = \frac{V_{DD} - \text{Output Swing}}{2} = \frac{3-2.5}{2} = 0.25V$

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

$(\frac{W}{L_{eff}}) = \frac{2I_D}{\mu C_{ox} (V_{GS}-V_{TH})^2 (1+\lambda V_{DS})}$

$(\frac{W}{L})_5 = \frac{2(1mA)}{(350)(383.6n)(0.25)^2(1+(0.1)(0.25))}$ $I_{D5} = I_{D6} = 1mA$

$= 233$

$(\frac{W}{L})_6 = \frac{2(1mA)}{(100)(383.6n)(0.25)^2(1+0.2(0.25))}$

$= 795$

$\boxed{(\frac{W}{L})_5 = 233 \qquad (\frac{W}{L})_6 = 795}$

b, A_v of 1st stage $= g_{m1}(r_{o2} \| r_{o4})$

A_v of 2nd stage $= g_{m5}(r_{o5} \| r_{o6})$

$g_{m5} = \frac{2I_D}{V_{GS} - V_{TH}} = \frac{2(1mA)}{0.25} = 8m\Omega^{-1}$

$r_{o5} = \frac{1}{\lambda I_D} = \frac{1}{(0.1)(1mA)} = 10k\Omega$

$r_{o6} = \frac{1}{\lambda I_D} = \frac{1}{(0.2)(1mA)} = 5k\Omega$

$\boxed{\begin{aligned} A_v \text{ of output stage} &= (8m)(10k \| 5k) \\ &= 26.67 \end{aligned}}$

c) $I_{D7} = 1mA \Rightarrow I_{D3} = I_{D4} = 0.5mA$

$V_{GS5} - V_{TH} = 0.25V \Rightarrow V_{GS5} = 0.25 + V_{TH} = 0.95V$

$V_{GS3} - V_{TH} = 0.25$

$(\frac{W}{L})_{3,4} = \frac{2(0.5mA)}{(350)(383.6n)(0.25)^2(1+0.1\times0.25)}$

$\boxed{(\frac{W}{L})_{3,4} = 116}$

9.18

d) $A_{v\,tot} = g_{m1}(r_{o2} \| r_{o4})\, g_{m5}(r_{o5} \| r_{o6})$

$r_{o2} = \dfrac{1}{\lambda I_D} = \dfrac{1}{(0.2)(0.5m)} = 10k\Omega.$

$r_{o4} = \dfrac{1}{(0.1)(0.5m)} = 20k\Omega.$

$r_{o2} \| r_{o4} = 6.67k\Omega$

$A_{v\,tot} = g_{m1}(6.67k)(26.7) = 500$

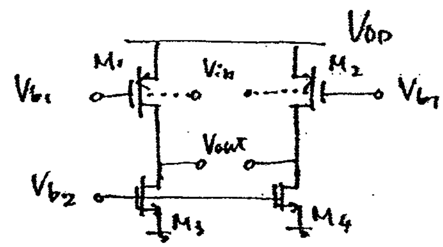
$g_{m1} = 2.81\ m\Omega^{-1}$

$g_{m1} = \sqrt{2\mu_p C_{ox} \left(\frac{W}{L}\right) I_D} \Rightarrow \left(\frac{W}{L}\right) = \dfrac{g_{m1}^2}{2\mu_p C_{ox} I_D}$

$\left(\frac{W}{L}\right)_{1,2} = \dfrac{(2.81\ m)^2}{2(100)(383.6n)(0.5m)}$

$\boxed{\left(\frac{W}{L}\right)_{1,2} = 206}$

9.22.



(a) $A_V = g_{mb1,2}\,(r_{o1} \,//\, r_{o3})$

b) $V_{in} > V_{DD} - V_{D1}$ where V_{D1} is the diode junction voltage of the diode between source and body.

(c) $$g_{mb} = g_m \frac{\gamma}{2\sqrt{|2\phi_F| + |V_{SB}|}}$$

As $V_{in,CM}$ decreases, $|V_{SB}| \uparrow$, g_{mb} decreases.

. More accurately, $g_{mb} \propto \dfrac{1}{\sqrt{|2\phi_F| + |V_{SB}|}}$

As a result, A_V decreases.

(d)

$$\overline{V_{n,out}^2} = \left[4kT\gamma\,(g_{m1} + g_{m3})\,R_{out}^2\right] \times 2$$

$$\overline{V_{n,in}^2} = \frac{4kT\gamma\,(g_{m1} + g_{m3})\,R_{out}^2 \times 2}{\left[g_{mb1,2}\,(R_{out})\right]^2}$$

$$= \left[4kT\gamma\,\frac{g_{m1} + g_{m3}}{(g_{mb1,2})^2}\right] \times 2$$

Problem 9.23

a. A_v of 1st stage $= g_{m1,2}(r_{o1} \| r_{o3})$

A_v of 2nd stage $= [g_{m5,9}(r_{o7} \| r_{o5})] \times 2$

$A_{v\text{-tot}} = g_{m1,2}(r_{o1} \| r_{o3})\, g_{m5,9}(r_{o5} \| r_{o7}) \times 2$

b. 1st major pole:

$$\omega_1 = \frac{1}{(r_{o9} \| r_{o11})[C_{DG9} + C_{DB9} + C_{GS11} + C_{DB11} + C_{GS7} + C_{GD7}(1 + g_{m7}(r_{o5} \| r_{o7}))]}$$

2nd major pole: node X, Y

$$\omega_X = \frac{1}{(r_{o1} \| r_{o3})\left[C_{DG1} + C_{DB1} + C_{DG3} + C_{DB3} + C_{GS10} + C_{GD10}\left(1 + \frac{g_{m10}}{g_{m12}}\right) + C_{GS5} + C_{GD5}(1 + g_{m5}(r_{o5} \| r_{o7})\right]}$$

3rd major pole: node output

$$\omega_{out} = \frac{1}{(r_{o5} \| r_{o7})(C_{GD5} + C_{DB5} + C_{GD7} + C_{DB7})}$$

Prob. 9.24.

A_v of fast path: $g_{m1}'(r_{o5} \| r_{o7})$

A_v of slow path: $g_{m1}(r_{o1} \| r_{o3})\, g_{m5}(r_{o5} \| r_{o7})$.

Overall gain $A_{v\text{-tot}} = \left[\dfrac{g_{m1}' + g_{m1} g_{m5}(r_{o1} \| r_{o3})}{2}\right](r_{o5} \| r_{o7})$

The output swing is usually limited by M_{5-8}, i.e. $V_{DD} - |V_{OD7}| - V_{OD5}$.