# TUTORIAL 5

1.

$I = 0.75 mA$

$W/L = 60$

$\mu_n C_{ox} = 300 \mu A/V^2$

$V_A = 15V$

$R_D = 4.7K$

$$g_m = \sqrt{2 \times I \times k_n' W/L}$$

$$= \sqrt{2 \times 0.75 \times 10^{-3} \times 300 \times 10^{-6} \times 60}$$

$$= 5.196 mA/V$$

$$R_o = \frac{V_A}{I_D} = \frac{15}{0.75 mA} = 20K\Omega$$

$$V_{ov} = \sqrt{\frac{2I}{k_n' W/L}}$$

$$= \sqrt{\frac{2 \times 0.75 mA}{300 \times 10^{-6} \times 60}}$$

$$V_{ov} = 0.288 V$$

$$A_d = g_m \frac{R_D}{2}$$

$$= 5.196 \times 10^{-3} \times \frac{4.7 \times 10^3}{2}$$

$$= 12.2106$$

$I = 0.375 mA$

3.67 mA/V

47K

0.2V

~~Rt~~

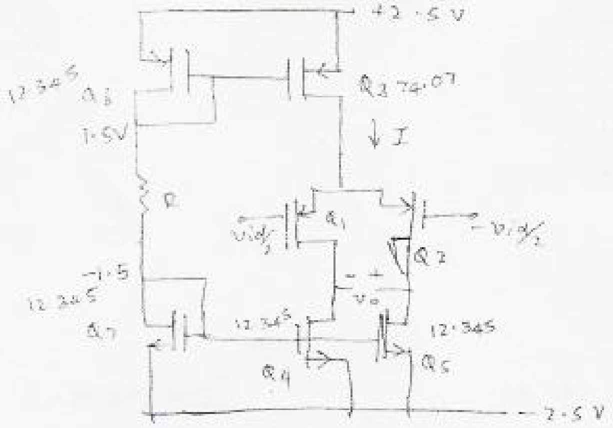
$= 3.67 \times 10^{-3}$

$\times (4.7K \| 40K)$

$= 15.435$

2.

a) $A_d = 80$




$A_d = 80$

$I = 0.1mA$

$V_{G3} = 1.5V$

$V_{G5} = -1.5V$

$\mu_n C_{ox} = 90\mu A/V^2$

$\mu_p C_{ox} = 30\mu A/V^2$

$|V_t| = 0.7V$

$|V_A| = 20V$

$I = 0.1mA$

$0.1mA = \frac{1}{2} \times 30 \times 10^{-6} \times \left(\frac{W}{L}\right)_3 \times (1.5 - 2.5 - (-0.7))^2$

$0.1mA = \frac{1}{2} \times 30 \times 10^{-6} \times \left(\frac{W}{L}\right)_3 \times (-1 + 0.7)^2$

$0.1mA = \frac{1}{2} \times 30 \times 10^{-6} \times \left(\frac{W}{L}\right)_3 \times (-0.3)^2$

$\boxed{\left(\frac{W}{L}\right)_3 = 74.07} = \left(\frac{W}{L}\right)_6$

Current thru $Q_5 = \frac{0.1}{2} = 0.05mA$

$0.05mA = \frac{1}{2} \times 90 \times 10^{-6} \times \left(\frac{W}{L}\right)_5 \times (-1.5 + 2.5 - 0.7)^2$

$\boxed{\left(\frac{W}{L}\right)_5 = 12.345} = \left(\frac{W}{L}\right)_4 = \left(\frac{W}{L}\right)_7$ $\quad \left(\frac{W}{L}\right)_2 = 2\left(\frac{W}{L}\right)_5 = 24.7$

$\frac{g_m R_d}{} = 80$

$g_m \times 200K = 80$

$g_m = 0.4 mA/V$

$r_{o4} = \frac{20}{0.05mA} = 400k\Omega$

$r_{o1} = r_{o2} = 400k\Omega$

$$\sqrt{2 I k_p' (W/L)_1} = 0.4\ mA/V$$

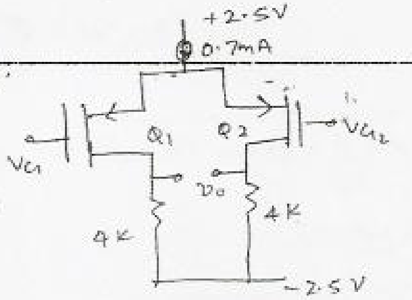
$$2 I k_p' (W/L) = 0.16 \times 10^{-6}$$

$$(W/L)_1 = (W/L)_2 = \frac{0.16 \times 10^{-6}}{2 \times 0.05 \times 10^{-3} \times 30 \times 10^{-6}}$$

$$\boxed{(W/L)_1 = (W/L)_2 = \sout{53.33}} \quad 53.33$$

$$R = \frac{1.5 - (-1.5)}{0.1\ mA} = 30\ k\Omega$$

4.




$\mu_p C_{ox} \cdot W/L = 4\ mA/V^2$

$R_{SS} = 25\ k\Omega$

$V_{ov}$ $g_m$ $A_d$ $A_{cm}$

CMRR mismatch ±5%

$$V_{ov} = \sqrt{\frac{2I}{k_p W/L}}$$

$$= \sqrt{\frac{2 \times 0.7/2}{4 \times 10^{-3}}} = 0.418\ V$$

$$g_m = \sqrt{2 I k_p W/L}$$

$$= \sqrt{0.7 \times 10^{-3} \times 4 \times 10^{-3}}$$

$$= 1.673\ mA/V$$

$$A_d = g_m R_d$$

$$= 1.673 \times 10^{-3} \times 4 \times 10^{3}$$

$$= 6.692$$

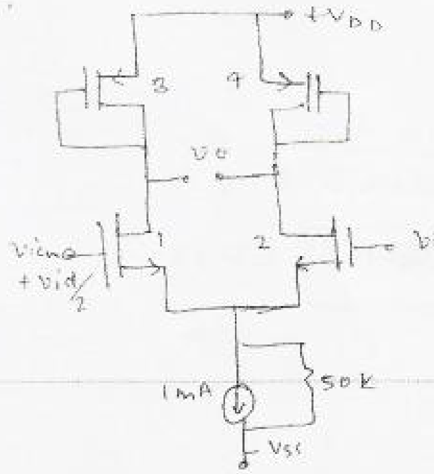
$$A_{cm} = \frac{\Delta R_d}{2 R_{SS}}$$

$$A_{cm} = \frac{1.5 \times 4K}{100 \times 2 \times 25K}$$

$$= 0.0012$$

CMRR = 6.692 —

5.




$\left(\frac{W}{L}\right)_1 = \left(\frac{W}{L}\right)_2 = 200$

$\left(\frac{W}{L}\right)_3 = 100 \quad \left(\frac{W}{L}\right)_4 = 120$

$K_n' = 100\mu A/V^2$

$K_p' = 75\mu A/V^2$

$V_{An} = 5V, \; V_{Ap} = 6V$

0.5mA.

$g_{m3} = \sqrt{2\times 0.5\times 10^{-3}\times 75\times 10^{-6}\times 100}$

$= 2.7386\, mA/V$

$r_{o3} = \frac{6}{0.5mA} = 12K$

$r_{o4} = \frac{6}{0.5mA} = 12K$

$g_{m4} = \sqrt{2\times 0.5\times 10^{-3}\times 75\times 10^{-6}\times 120}$

$= 3\, mA/V$

$\left(\frac{1}{g_{m3}} \,||\, r_{o3}\right) = \left(\frac{1}{2.7386\, mA/V} \,||\, 12K\right)$

$= (0.365K \,||\, 12K)$

$= 0.354K$

$\left(\frac{1}{g_{m4}} \,||\, r_{o4}\right) = (0.333K \,||\, 12K)$

$= 0.324K$

$A_d = g_m \frac{R_{d1}}{2} - \left(-g_m \frac{R_{d2}}{2}\right)$

$= g_m\left(\frac{R_{d1}}{2} + \frac{R_{d2}}{2}\right)$

$g_m = \sqrt{2\times 0.5\times 10^{-3}\times 100\times 10^{-6}\times 200}$

$= 4.47\times 10^{-3} A/V$

$= 4.47\times 10^{-3}\times\left(\frac{0.354}{2} + \frac{0.324}{2}\right)$

$= 1.51533$

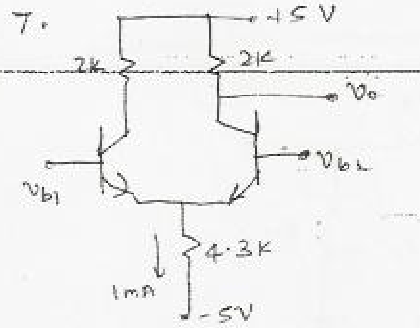
$$A_{cm} = \frac{\Delta R_d}{2R_u}$$

$$= \frac{0.030K}{2 \times 50K}$$

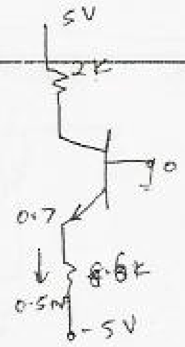
$$= 3 \times 10^{-4}$$

$$CMRR = \frac{1.5153}{3 \times 10^{-4}} = 74.067\,dB$$

7.




a)




~~$A_d$~~ $r_e = \frac{26}{0.5} = 52\Omega$

$$v_{1d} - v_{2d} = \frac{v_{id}}{2} \times \left(-\frac{R_c}{r_e}\right) - \left[-\frac{v_{id}}{2}\left(-\frac{R_c}{r_e}\right)\right]$$

$$v_{id} - v_{id} = \frac{v_{id}}{2}\left[-\frac{R_c}{r_e} - \frac{R_c}{r_e}\right] \quad A_d = \frac{R_c}{r_e} \text{ (single ended)}$$

$$= \frac{2K}{102\Omega} = 19.60$$

b) $A_{cm} = \frac{R_c}{2R_E}$

$$= \frac{2K}{2 \times 4.6K}$$

$$= 0.2326$$

c) $CMRR = \frac{19.60}{0.2326} =$ ~~44.26~~ $dB$ 38.513

d) $v_{cm} = 0.2326\,(0.1 \sin 2\pi 60t)$

$= 0.02326 \sin 2\pi 60t$

$v_{od} = 19.6 \times 2 \times 0.005 \sin 2\pi 1000t$

$= 0.196 \sin 2\pi 1000t$

$v_o = 0.02326 \sin 2\pi 60t + 0.196 \sin 2\pi 1000t$

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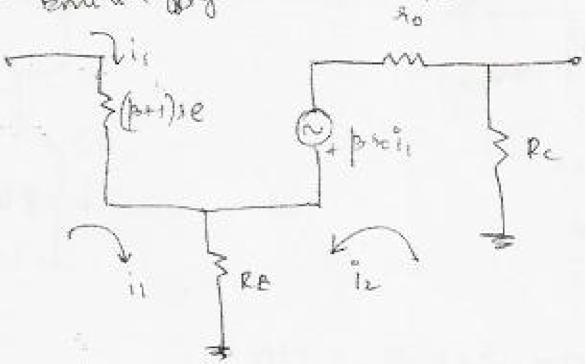
Tut 3) Emitter degen




$$i_2(R_C + R_E + r_o) = \beta r_o i_1$$

$$i_2 = \frac{\beta r_o}{R_C + R_E + r_o} i_1$$

$$= \frac{\beta}{1 + \frac{R_E + R_C}{r_o}} i_1$$

$$i_2 = \beta' i_1$$

$$v_o = -i_2 R_C$$

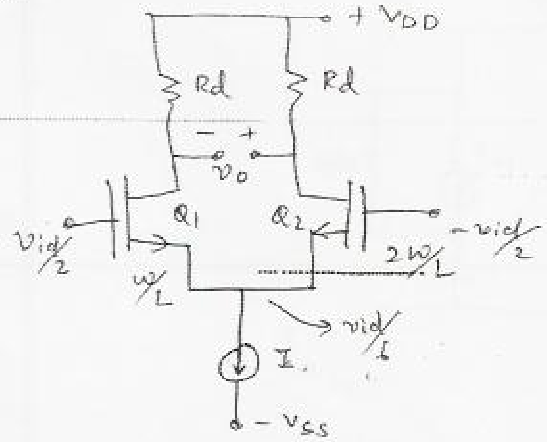
$$= -\beta' i_1 R_C$$

$$v_o = -\beta' R_C \frac{v_{in}}{R_{in}}$$

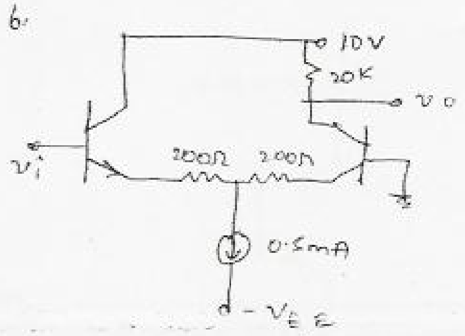
$$\frac{v_o}{v_{in}} = \frac{-\beta' R_C}{(\beta+1)r_e + R_E + \beta' R_E}$$

$$\frac{v_o}{v_{in}} = -\frac{R_C}{R_E}$$

3.




6.




$R_C = 20K$

$r_e = 100\Omega$

$R_E = 200 + 200 + 200$

$= 600$

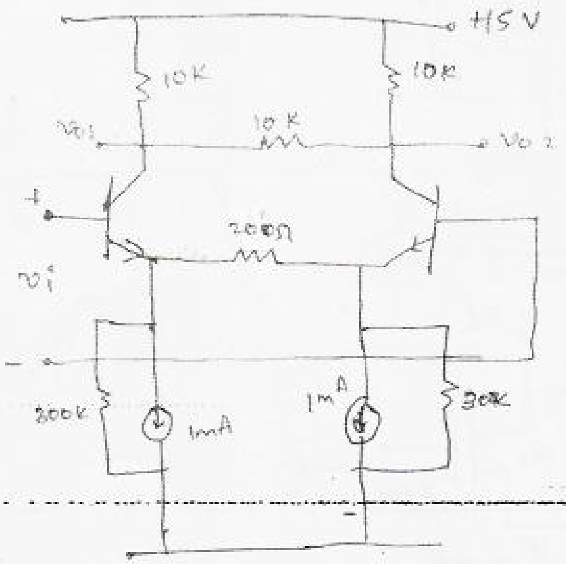
$A_d = \frac{R_C}{R_E} = 33.33$

$R_{in} = (\beta+1)(r_e + 200 + 200 + r_e)$

$= 101\,(600)$

$= 60.6\,K\Omega$

8)




Ad , Rid, Acm & Ricm

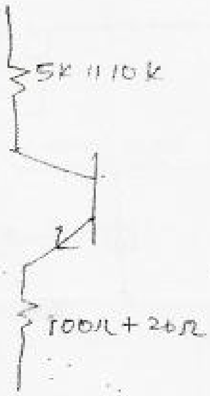
$Ad = 3.33K$

~~RE~~ = 126 Ω

= 26.428

$Ad = \frac{\text{Total } R_C}{\text{Total } R_E} = \frac{6.667}{200+52}$

= 26.458



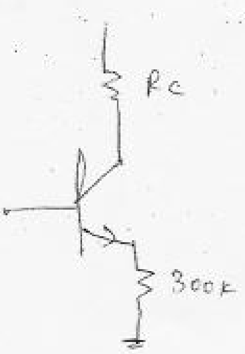

(10K is redundant)

~~Rid~~ $A_{cm} = \frac{10K}{300K} = 0.0333$

$R_{icm} = (\beta+1)r_e + R_E + R_E\beta'$

$\simeq R_E\beta'$

$\simeq R_E \times \frac{\beta}{1+\frac{R_E}{r_o}}$



$V_A = 100\,V \qquad \beta = 100$

$$R_{icm} = \frac{\beta (R_E \| r_o)}{2}$$

$r_o = \frac{100V}{1mA}$

$= 50 \times (300k \| r_o)$

$= 50 \times (300k \| 100k\Omega)$

~~$= 11838.44k\Omega$~~

$= \underline{\underline{3.75\,M\Omega}}$

$R_{id} = 2(\beta+1)(200\Omega + 52\Omega)$

$(r_e + 200 + r_e) \times (\beta+1)$

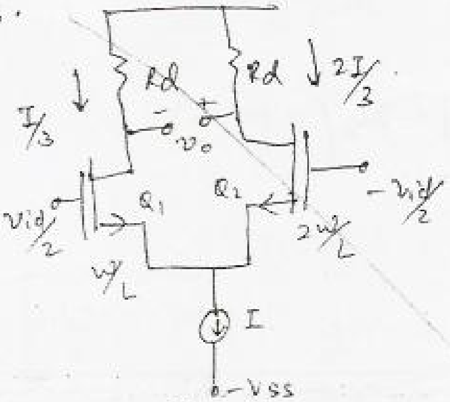
~~$= 2 \times 101 \times 252\Omega$~~

~~$= 50.9k\Omega$~~

$= 101 \times (200 + 52)$

$= \underline{25.452\,k\Omega}$

3.




$I_2 = 2I_1$

$I_1 + 2I_1 = I$

$I_1 = I/3$

$I_{d1} = I/3 \qquad I_{d2} = 2I/3$

b) $V_{ov} = \sqrt{\frac{2I}{k_n' W/L}}$

$= \sqrt{\frac{2I}{3 k_n' W/L}}$

c) $A_d$ :

$$v_o = -\frac{v_{id}}{2}(-g_{m2} R_d) - \frac{v_{id}}{2}(-g_{m1} R_d)$$

$$v_o = v_{id}\left[\frac{g_{m2} R_d}{2} + \frac{g_{m1} R_d}{2}\right] \qquad g_{m2} = 2g_{m1}$$

$\frac{v_o}{v_{id}} = \frac{R_d}{}(g_{m1} + g \quad )$

$$g_{m1} = \frac{2 I_{d1}}{V_{ov}}$$

$$A_d = \frac{3}{2} R_d \times \frac{2 I_{d1}}{V_{ov}} \qquad I_{d1} = I/3$$

$$= \frac{3}{2} \frac{R_d \times 2 I}{3 V_{ov}} = \boxed{\frac{I R_d}{V_{ov}}}$$

$$i_1 = g_{m1}\left(\frac{v_{id}}{2} - v_s\right)$$

$$i_2 = -g_{m2}\left(-\frac{v_{id}}{2} - v_s\right)$$

$$g_{m2}\left(\frac{v_{id}}{2} + v_s\right) = g_{m1}\left(\frac{v_{id}}{2} - v_s\right)$$

$$2 g_{m1}\left(\frac{v_{id}}{2} + v_s\right) = g_{m1}\left(\frac{v_{id}}{2} - v_s\right)$$

$$v_{id} + 2v_s = \frac{v_{id}}{2} - v_s$$

$$3v_s = -\frac{v_{id}}{2} \qquad \boxed{v_s = -\frac{v_{id}}{6}}$$

9\.

NMOS

$V_{ov} = 0.25\ V$

$V_{AN} = 8V$

$C_{gm} = 0.075\ pF$

$C_L = 0.15\ pF$

$I = 0.4mA$

$$g_n = \frac{2I}{V_{ov}} = \frac{2 \times 0.4mA}{0.25} = 3.2mA/V$$

PMOS

$V_{ov} = 0.4V$

$V_{Ap} = 8V$

$$g_p = \frac{2I}{V_{ov}} = \frac{2 \times 0.4mA}{0.4} = 2mA/V$$

$R_o = r_{o4} \| r_{o2}$

$= 10k\Omega$

$A_d = \frac{A_o}{2} = g_n \times R_o$

$= 3.2\times10^{-3} \times 10\times10^{3}$

$= 32$

$A_{cm} = \frac{1}{2 g_{m3} R_4}$ $R_4$ assume 100K

$= \frac{1}{2\times 2\times10^{-3}\times100\times10^{3}}$

$= 2.5\times10^{-3}$

$CMRR = \frac{32}{2.5\times10^{-3}} = 82.144dB$

$f_{P1} = \frac{g_m}{2\pi C_m} = \frac{g_{mp}}{2\pi C_m}$

$= \frac{2\times10^{-3}}{2\times\pi\times0.075pF}$

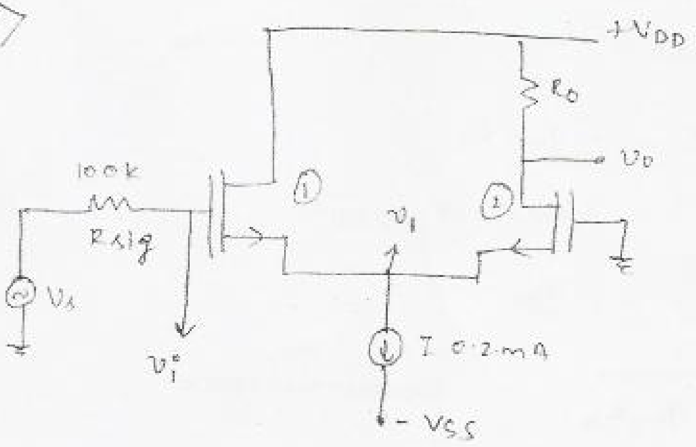
$= 4.244GHz$

$f_z = 2f_{P1} = 8.488\ GHz$

$f_{P2} = \frac{1}{2\pi R_o C_L} = \frac{1}{2\pi\times10k\times0.15\times10^{-12}}$

$= 106.103\ MHz$

10)




Stg ① is CD config

$$\text{Gain} = \frac{R_s}{R_s + 1/g_m}$$

$R_s$ is impedance looking into source of ②

$$\text{Gain} = \frac{1/g_{m_2}}{1/g_{m_2} + 1/g_{m_1}}$$

Given: $V_{OV} = 0.25V$ $\quad I = 0.2mA$

$$\therefore g_m = \frac{2 \times 0.1}{0.25} = 0.8 mA/V$$

$$g_{m_1} = g_{m_2}$$

$$\therefore \text{Gain} = 1/2 \Rightarrow \frac{v_1}{v_i} = 1/2$$

$$\boxed{v_1 = v_i/2}$$

Now going ②. CG config

$$\text{Gain} = g_m R_d$$

$$\frac{v_o}{v_1} = g_m R_d$$

$$\frac{v_o}{v_i} 2 = g_m R_d$$

$$\boxed{\frac{v_o}{v_i} = g_m R_d = 12}$$

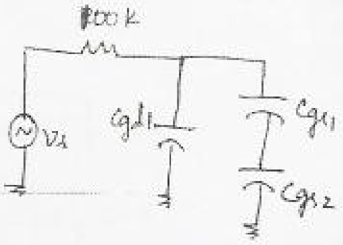
Since $Z_{in}$ of MOSFET = $\infty$

$$\frac{v_o}{v_i} = \frac{V_o}{V_1} = 12$$

At high frequency:

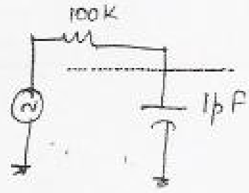
Eqt:

Input:




$C_{gs} = 1pF$

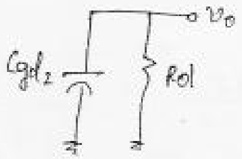
$C_{gd} = 0.5pF$




$$f_{P1} = \frac{1}{2\pi \times 100K \times 1 \times 10^{-12}}$$

$$= \underline{1.59 \text{ MHz}}$$

Output:



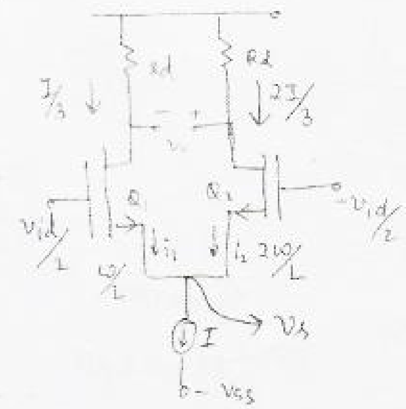

$$f_{P2} = \frac{1}{2\pi \times 30K \times 0.5 \times 10^{-12}}$$

$$= \underline{10.6 \text{ MHz}}$$

No zeroes exist only poles

$$\boxed{f_H \simeq 1.6 \text{ MHz}}$$

3)




$I_1 + I_2 = I$

$I_1 + 2I_1 = I$

$3I_1 = I$

$I_1 = I/3$

$g_m = \sqrt{2 I_D k_n' W/L}$

$g_{m1} = \sqrt{2 \times I/3 \times k_n' \times W/L}$

$g_{m2} = \sqrt{2 \times 2I/3 \times k_n' \times 2W/L}$

$\Rightarrow \boxed{g_{m2} = 2g_{m1}}$

$$A_d = \frac{\text{Total resistance in drain loop}}{\text{Total resistance in source loop}}$$

$$= \frac{2R_d}{1/g_{m1} + 1/g_{m2}} = \frac{2R_d}{1/g_{m1} + 1/2g_{m1}}$$

$$= \frac{4R_d}{\frac{1}{g_{m1}} \times 3} = \boxed{\frac{4}{3} g_{m1} R_d}$$

$V_{ov1} = \sqrt{\frac{2I_D}{k_n' W/L}} = \sqrt{\frac{2I}{3k_n' W/L}}$

$V_{ov2} = \sqrt{\frac{2 \times 2I}{3 \times k_n' \times 2W/L}} = \sqrt{\frac{2I}{3k_n' W/L}} \Rightarrow \boxed{V_{ov2} = V_{ov1}}$

$A_d = \frac{4}{3} g_{m1} R_d \qquad g_{m1} = \frac{2 \times I}{3 \times V_{ov}}$

$$\boxed{A_d = \frac{4}{3} \times \frac{2I}{3V_{ov}} R_d = \frac{8}{9} \frac{I R_d}{V_{ov}}}$$

To prove $v_s = v_{id}/6$

$$i_1 = g_{m1}\left(\frac{v_{id}}{2} - v_s\right) \quad \text{(AC current)}$$

$$i_2 = -g_{m2}\left(-\frac{v_{id}}{2} - v_s\right)$$

$$i_1 = i_2$$

$$g_{m}\left(\frac{v_{id}}{2} - v_s\right) = -2g_{m}\left(-\frac{v_{id}}{2} - v_s\right)$$

$$\frac{v_{id}}{2} - v_s = v_{id} + 2v_s$$

$$-3v_s = \frac{v_{id}}{2} \qquad \boxed{v_s = -\frac{v_{id}}{6}}$$