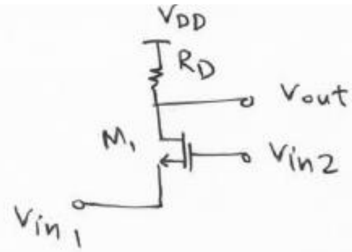
1.

10.30

(4 1)



$$I_{D1} = \frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)\left(V_{in2} - V_{in1} - V_{TH}\right)^2$$

(1) The current is not an odd function of $(V_{in2} - V_{in1})$. Therefore it is not symmetric around $V_{in1} = V_{in2}$ $[(V_{in1} - V_{in2}) = 0]$.

(2) The input impedance seen at V_{in1} and V_{in2} are different

(3) The circuit cannot suppress the supply noise. because there is no differential output available.

10.32

$$(V_{in1} - V_{in2})^2 = \frac{2}{\mu_n C_{ox} \frac{W}{L}} (I_{SS} - 2\sqrt{I_{D1} I_{D2}})$$

(a)

$I_{D1} = 0 \Rightarrow$

$$(V_{in1} - V_{in2})^2 = \frac{2 I_{SS}}{\mu_n C_{ox} \frac{W}{L}} \rightarrow V_{in1} - V_{in2} = -\sqrt{\frac{2 I_{SS}}{\mu_n C_{ox} \frac{W}{L}}}$$

This is the minimum differential input voltage to turn M_1 off.

(b) $I_{D1} = \frac{I_{SS}}{2} \Rightarrow I_{D2} = \frac{I_{SS}}{2}$

$$(V_{in1} - V_{in2})^2 = \frac{2}{\mu_n C_{ox} \frac{W}{L}} (I_{SS} - I_{SS}) = 0 \rightarrow V_{in1} - V_{in2} = 0$$

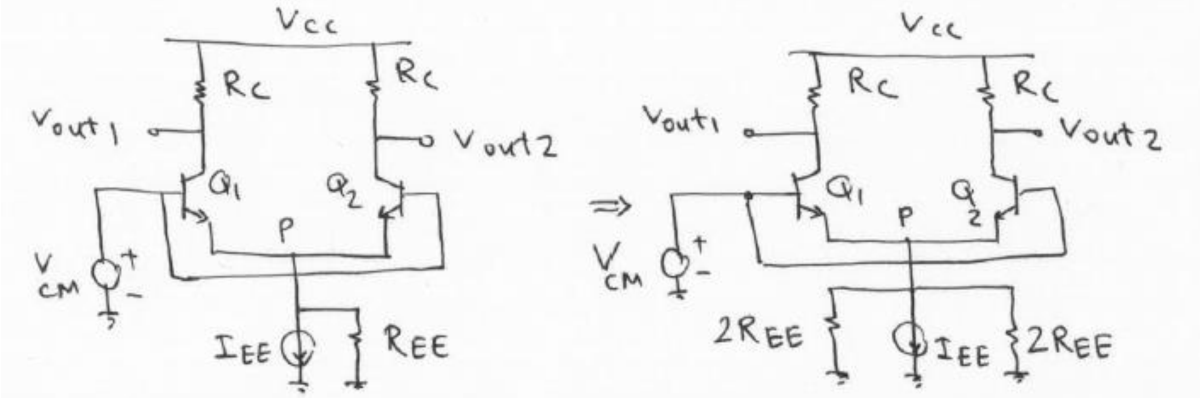
This is the equilibrium input case.

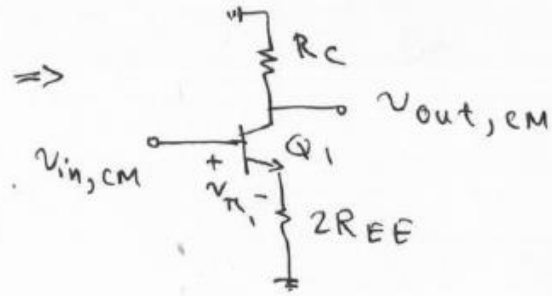
(c) $I_{D1} = I_{SS} \rightarrow I_{D2} = 0$

$$(V_{in1} - V_{in2})^2 = \frac{2 I_{SS}}{\mu_n C_{ox} \frac{W}{L}} \rightarrow V_{in1} - V_{in2} = +\sqrt{\frac{2 I_{SS}}{\mu_n C_{ox} \frac{W}{L}}}$$

This is the minimum input differential voltage to turn M_2 off.

10.53



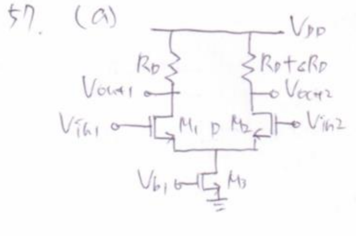


$$v_{out,CM} = -g_{m1} v_{\pi 1} R_C = -g_{m1} R_C \frac{\frac{1}{g_{m1}}}{\frac{1}{g_{m1}} + 2R_{EE}} v_{in,CM}$$

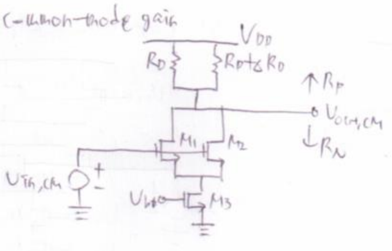
$$\Rightarrow \frac{v_{out,CM}}{v_{in,CM}} = -\frac{g_{m1} R_C}{1 + 2R_{EE} g_{m1}} = -\frac{\frac{R_C}{2}}{R_{EE} + \frac{1}{2g_{m1}}}$$

10.57
(a)

57. (a)



i) common-mode gain

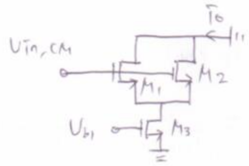


$$R_P = R_D \,||\, (R_D + \Delta R_D)$$

$$R_N = 2g_{m1}\frac{r_{O1}}{2} r_{O3} + \frac{r_{O1}}{2} + r_{O3} \approx g_{m1} r_{O1} r_{O3}$$

$$R_{out} = R_P \,||\, R_N$$

G_m 계산:

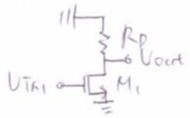


$$G_m = \frac{I_o}{V_{in,CM}} = \frac{2g_{m1} v_{gs1}}{V_{in,CM}}$$

$$= \frac{2g_{m1}}{V_{in,CM}} \cdot \frac{\frac{1}{2g_{m1}}}{\frac{1}{2g_{m1}} + r_{O3}} V_{in,CM} \approx \frac{1}{r_{O3}}$$

$$A_{CM} = -G_m R_{out}$$

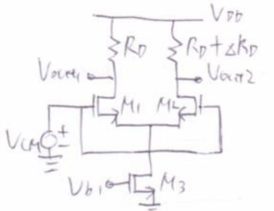
ii) A_{DM}을 계산하기 위해 half circuit을 사용하면,



$$A_{DM} = \frac{V_{out}}{V_{in1}} = -g_{m1} R_D$$

iii) A_{CM-DM} 계산

$$A_{CM-DM} = \frac{\Delta V_{out}}{\Delta V_{CM}}$$



$$\Delta V_{CM} = \Delta V_{GS} + 2\Delta I_D r_{O3}$$

$$= \Delta I_D \left(\frac{1}{g_{m1}} + 2r_{O3}\right)$$

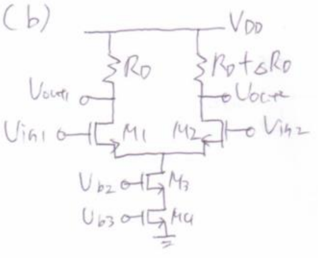
$$\Delta V_{out} = \Delta V_{out1} - \Delta V_{out2} = -\Delta R_D \Delta I_D$$

$$A_{CM-DM} = -\frac{\Delta R_D}{\frac{1}{g_{m1}} + 2r_{O3}}$$

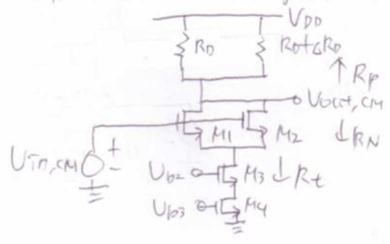
$$CMRR = \frac{A_{DM}}{A_{CM-DM}} = \frac{g_{m1} R_D}{\frac{\Delta R_D}{\frac{1}{g_{m1}} + 2r_{O3}}} = (1 + 2g_{m1} r_{O3}) \frac{R_D}{\Delta R_D}$$

(b)

57. (b)



i) common-mode gain

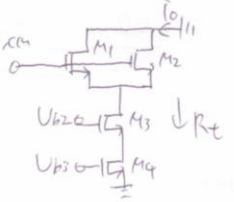


$$R_P = R_D \parallel (R_D + \Delta R_D)$$

$$R_N = \frac{r_{o1}}{2} + R_t + 2g_{m1}\frac{r_{o1}}{2}R_t \simeq g_{m1} r_{o1} R_t \approx g_{m1} r_{o1} g_{m3} r_{o3} r_{o4}$$

$$R_{out} = R_P \parallel R_N = R_D \parallel (R_D + \Delta R_D) \parallel (g_{m1} r_{o1} g_{m3} r_{o3} r_{o4})$$

G_m 계산 :



$$G_m = \frac{I_o}{V_{in,CM}} = \frac{2g_{m1}V_{gs1}}{V_{in,CM}}$$

$$= \frac{2g_{m1}}{V_{in,CM}} \frac{\frac{1}{2g_{m1}}}{\frac{1}{2g_{m1}} + R_t} V_{in,CM} \approx \frac{1}{R_t}$$

$$\underline{A_{CM} = -G_m R_{out} = -\frac{R_{out}}{R_t}}$$

ii) $A_{DM} = -g_{m1} R_D$ (57.(a)와 같음)

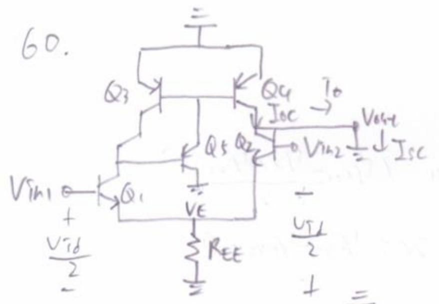
iii) $A_{CM-DM} = -\dfrac{\Delta R_D}{\frac{1}{g_{m1}} + 2[g_{m3} r_{o3} r_{o4} + r_{o3} + r_{o4}]}$

$$CMRR = \frac{A_{DM}}{A_{CM-DM}} = \frac{g_{m1}R_D}{\dfrac{\Delta R_D}{\frac{1}{g_{m1}} + 2[g_{m3} r_{o3} r_{o4} + r_{o3} + r_{o4}]}} = \boxed{[1 + 2g_{m1}(g_{m3} r_{o3} r_{o4} + r_{o3} + r_{o4})] \times \frac{R_D}{\Delta R_D}}$$

(b)의 CMRR이 (b)의 CMRR보다 훨씬 크다.

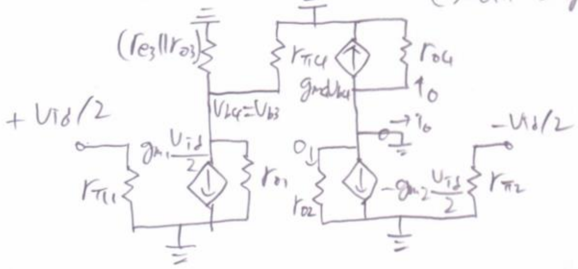
10.60

60.



Q5는 버퍼로 동작 → 생략가능

(small-signal)



$$v_{b3} = -g_{m1}\left(\frac{v_{id}}{2}\right)(r_{e3} \| r_{o3} \| r_{o1} \| r_{\pi 4})$$

$$\approx -g_{m1} r_{e3}\left(\frac{v_{id}}{2}\right)$$

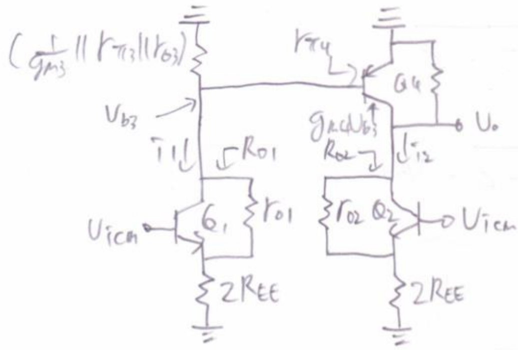
$$g_{m4} v_{b4} = -g_{m4} g_{m1} r_{e3}\left(\frac{v_{id}}{2}\right)$$

$$i_o = g_{m2}\left(\frac{v_{id}}{2}\right) - g_{m4} v_{b4}$$

$$= (g_{m2} + g_{m4} g_{m1} r_{e3})\left(\frac{v_{id}}{2}\right)$$

$$G_m = i_o / v_{id} = (g_{m2} + g_{m4} g_{m1} r_{e3})/2 \approx g_m.$$

(common-mode gain)



$$i_1 \approx i_2 \approx v_{icm} / 2R_{EE}$$

$$v_{b3} = -i_1\left(\frac{1}{g_{m3}} \| r_{\pi 3} \| r_{o3} \| r_{\pi 4}\right)$$

$$v_o = -r_{o4}(g_{m4} v_{b3} + i_2)$$

$$A_{cm} = \frac{v_o}{v_{icm}}$$

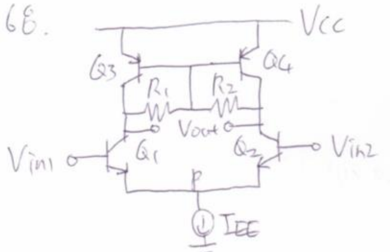
$$= \frac{r_{o4}}{2R_{EE}}\left[g_{m4}\left(\frac{1}{g_{m3}} \| r_{\pi 3} \| r_{o3} \| r_{\pi 4}\right) - 1\right]$$

$$\approx -\frac{r_{o4}}{2R_{EE}} \frac{\frac{2}{r_{\pi 3}}}{g_{m3} + \frac{2}{r_{\pi 3}}}$$

$$\approx -\frac{r_{o4}}{\beta_3 R_{EE}}$$

10.68

68.

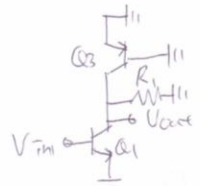


$A_v = 100$

$P = 1mW$

$V_{A,n}=10V,\ V_{A,p}=5V,\ V_{CC}=2.5V,\ R_1=R_2$

(Half Circuit)



$$A_V = -g_{m1}(R_1 \| r_{o1} \| r_{o3})$$

$$g_{m1} = \frac{I_{EE}}{2V_T},\quad r_{o1} = \frac{2V_{A,n}}{I_{EE}},\quad r_{o3} = \frac{2V_{A,p}}{I_{EE}}$$

$$100 = \frac{1}{2V_T}\left[(R_1 I_{EE}) \| \underbrace{(2V_{A,n})}_{20} \| \underbrace{(2V_{A,p})}_{10}\right]$$

$$\frac{6.67 R_1 I_{EE}}{R_1 I_{EE}+6.67} = 200\times 26m = 5.2$$

$$6.67 R_1 I_{EE} = 5.2 R_1 I_{EE} + 5.2\times 6.67$$

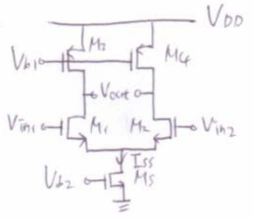
$$1.47 R_1 I_{EE} = 5.2\times 6.67,\quad R_1 I_{EE} = 2.359\times 10$$

$$P = 1mW = I_{EE}V_{CC} \Rightarrow I_{EE} = \frac{10^{-3}}{2.5} = 0.4mA$$

$$\Rightarrow R_1 = \frac{23.59}{I_{EE}} = 58.98\ k\Omega$$

10.70

70.



$A_v = 40$

$(V_{GS} - V_{TH})_{equil} = ?$

$\lambda_n = 0.1V^{-1}$, $\lambda_p = 0.2V^{-1}$

$\mu_n C_{ox} = 100\mu A/V^2$, $\mu_p C_{ox} = 100\mu A/V^2$

$V_{DD} = 1.8V$, $P = 2mW$

$$A_V = -g_{mN}(r_{op} \| r_{oN}) = -\frac{I_{SS}}{(V_{GS1} - V_{TH})_{equil}}\left(\frac{1}{\frac{I_{SS}}{2}\lambda_n} \| \frac{1}{\frac{I_{SS}}{2}\lambda_p}\right)$$

$$= -\frac{2}{(V_{GS1} - V_{TH})_{equil}}\left(\frac{1}{\lambda_n} \| \frac{1}{\lambda_p}\right)$$

$$= \frac{2}{(V_{GS1} - V_{TH})_{equil}}(10 \| 5) = 40 \Rightarrow (V_{GS1} - V_{TH})_{equil} = 166.67mV$$

$$P = 2\times10^{-3} = V_{DD} I_{SS} \Rightarrow I_{SS} = \frac{2\times10^{-3}}{1.8} = 1.11mA$$

$$\left(\frac{W}{L}\right)_{1,2} = \frac{I_{SS}}{\mu_n C_{ox}(V_{GS1} - V_{TH})_{equil}^2} = \frac{1.11\times10^{-3}}{10^{-4}\times0.16667^2} = 400$$

$$\left(\frac{W}{L}\right)_{3,4} = \frac{I_{SS}}{\mu_p C_{ox}(V_{GS} - V_{TH})_{equil}^2} = \frac{1.11\times10^{-3}}{10^{-4}\times0.16667^2} = 400$$

$$\left(\frac{W}{L}\right)_{5} = \frac{2I_{SS}}{\mu_n C_{ox}(V_{GS} - V_{TH})_{equil}} = \frac{2\times1.11\times10^{-3}}{10^{-4}\times0.16667^2} = 800$$

2.

(a) $V_{in1} = V_{in2} \Rightarrow V_{offset} = \Delta R \times \frac{1}{2} I_{SS}$.

(b) $V_{in1} = V_{in2}$

$$\Delta I_D = \frac{1}{2} \mu_n C_{ox} \, \Delta\left(\frac{W}{L}\right) (V_{in} - V_{SS} - V_{th})^2$$

$$I_{SS} = 2 \times \frac{1}{2} \mu_n C_{ox} \left(\frac{W}{L}\right) (V_{in} - V_{SS} - V_{th})^2$$

$$\Rightarrow \Delta I_D = I_{SS} \times \frac{\Delta\left(\frac{W}{L}\right)}{2\left(\frac{W}{L}\right)}$$

$$\therefore V_{offset} = R \cdot \Delta I_D = R I_{SS} \cdot \frac{\Delta\left(\frac{W}{L}\right)}{2\left(\frac{W}{L}\right)}$$

(c). $\Delta\left(\frac{W}{L}\right) \neq 0$, $\Delta R \neq 0$.

when $V_{in1} = V_{in2}$,

$$V_{out1} - V_{out2} = \Delta R \cdot \frac{1}{2} I_{SS} + R \cdot \Delta I_D \quad (\text{1차근사})$$

$$\doteq \Delta R \cdot \frac{1}{2} I_{SS} + R \cdot \frac{1}{2} I_{SS} \cdot \frac{\Delta(W/L)}{(W/L)}$$

$$= \frac{1}{2} I_{SS} \left(\Delta R + R \cdot \frac{\Delta(W/L)}{(W/L)}\right)$$

$$V_{in,offset} = \frac{V_{out,offset}}{A_v}$$

$$= \frac{1}{2} I_{SS}/g_m \cdot \left[\frac{\Delta R}{R} + \frac{\Delta(W/L)}{\left(\frac{W}{L}\right)}\right]$$