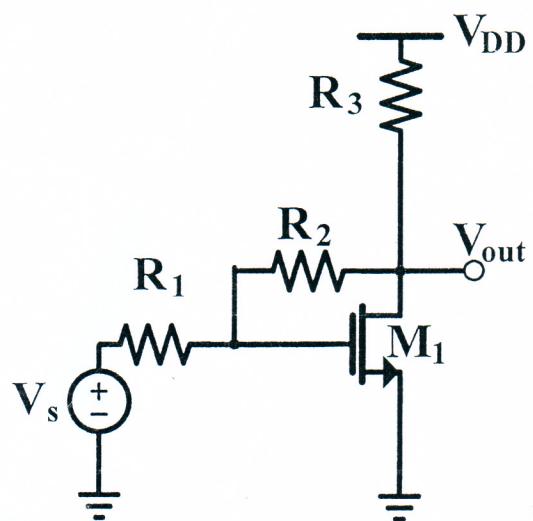
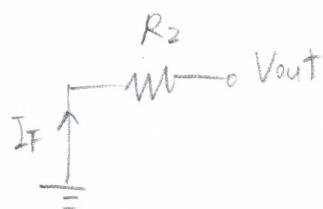


[1] Find the feedback factor  $K$  of each circuit. Assume that all the transistors are ideal (that is,  $\lambda=0$  and no parasitic capacitors).

A. [4 points]

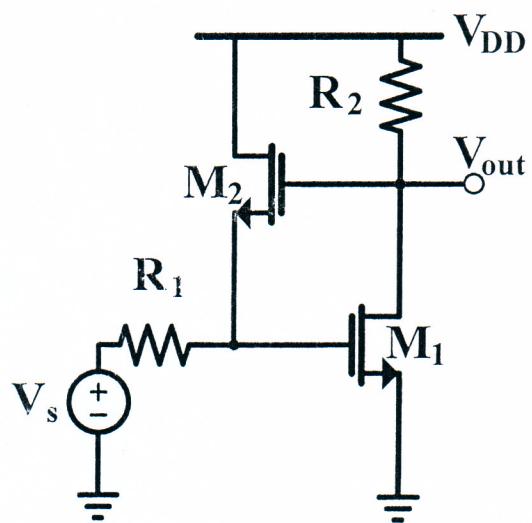


$V-I$  feedback

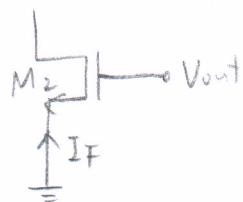


$$K = \frac{I_F}{V_{out}} = -\frac{1}{R_2}$$

B. [4 points]

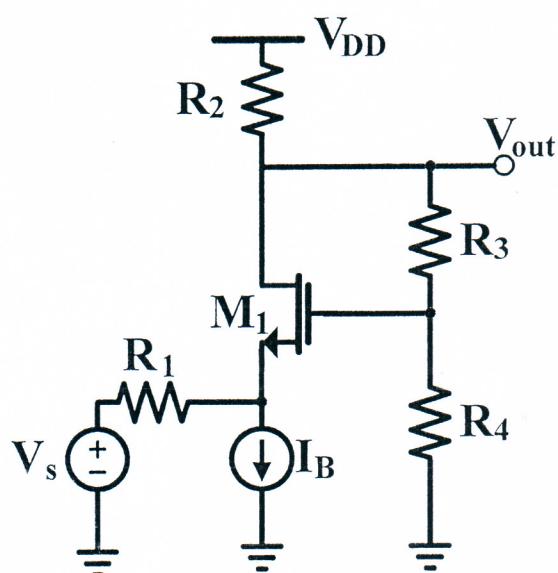


$V-I$  feedback

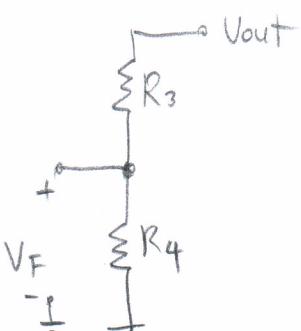


$$K = \frac{I_F}{V_{out}} = -g_m M_2$$

C. [4 points]



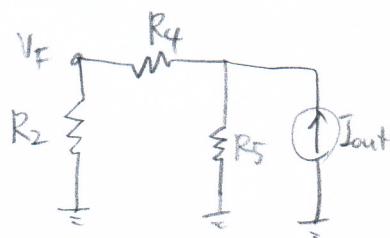
V-V feedback



$$k = \frac{V_F}{V_{out}} = \frac{R_4}{R_3 + R_4}$$

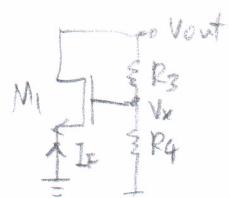
V-I feedback으로 볼 경우

D. I-V feedback 으로 볼 경우



$$\frac{V_F}{I_{out}} = \frac{R_2 \cdot R_5}{R_5 + (R_1 + R_4)}$$

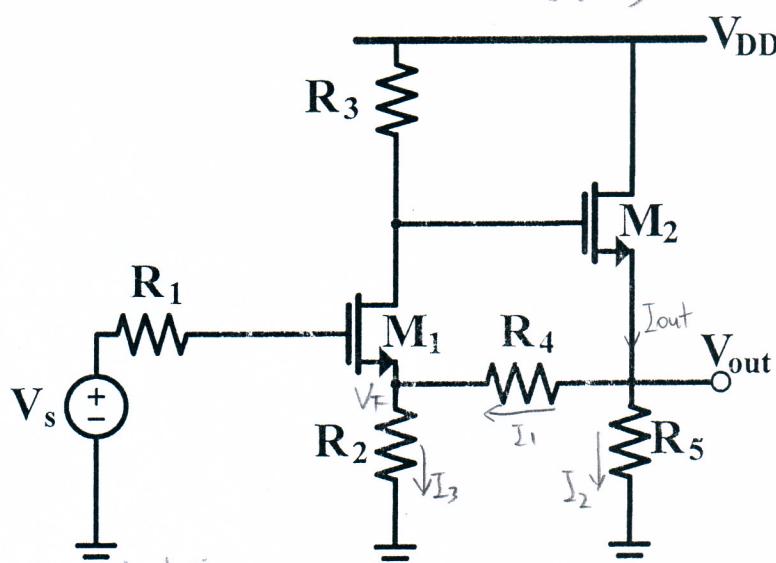
$$\frac{V_F}{I_{out}} = \frac{(R_2 \parallel \frac{1}{g_m}) \cdot R_5}{R_5 + (R_2 \parallel \frac{1}{g_m}) + R_4}$$



$$k = \frac{I_F}{V_{out}} = \frac{I_F \cdot V_x}{V_x \cdot V_{out}}$$

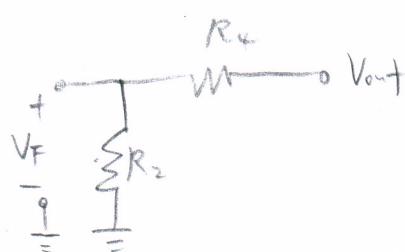
$$= -g_{mi} \cdot \frac{R_4}{R_3 + R_4}$$

D. [4 points]



방법 1.

V-V feedback



$$k = \frac{V_F}{V_{out}} = \frac{R_2}{R_2 + R_4}$$

방법 2. direct analysis

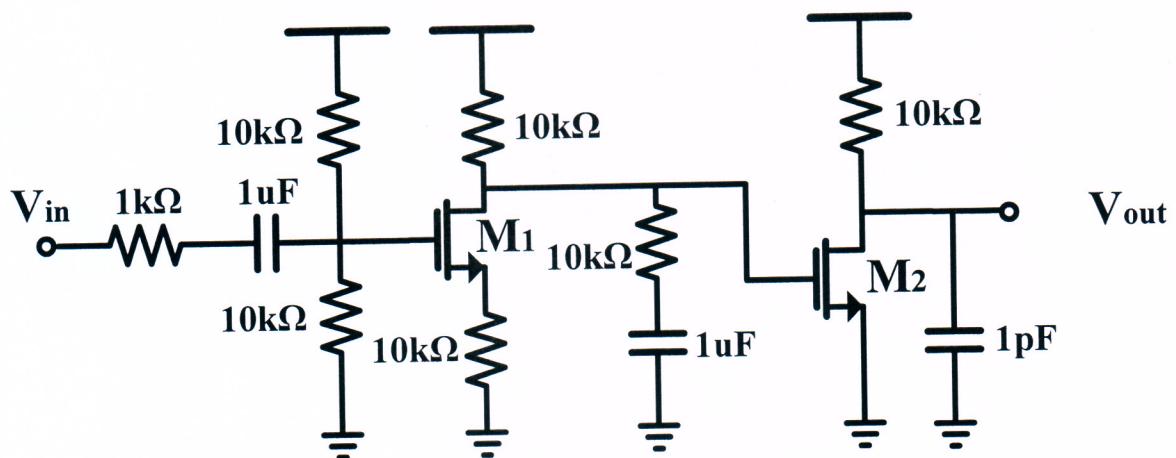
$$I_1 = \frac{R_5}{R_5 + (R_4 + R_2 \parallel \frac{1}{g_m})} \cdot I_{out}$$

$$V_{out} = I_2 R_5 = \frac{(R_4 + R_2 \parallel \frac{1}{g_m}) \cdot R_5}{R_5 + (R_4 + R_2 \parallel \frac{1}{g_m})} \cdot I_{out}$$

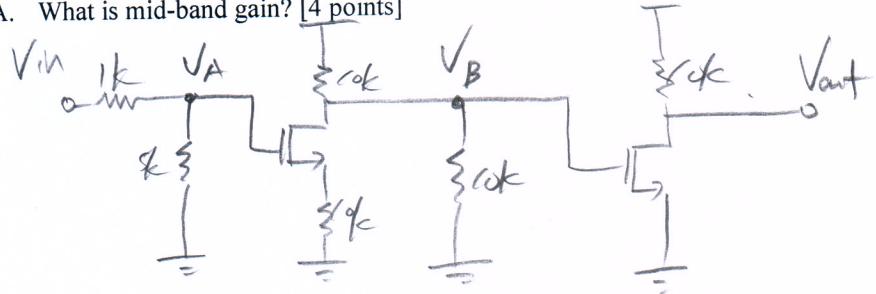
$$I_3 = I_1 \cdot \frac{\frac{1}{g_m}}{R_2 + \frac{1}{g_m}} \Rightarrow V_F = I_3 \cdot R_2 = \frac{R_5}{R_5 + (R_4 + R_2 \parallel \frac{1}{g_m})} \cdot \frac{\frac{1}{g_m}}{R_2 + \frac{1}{g_m}} \cdot R_2 \cdot I_{out}$$

$$\therefore k = \frac{V_F}{V_{out}} = \frac{R_2 \parallel \frac{1}{g_m}}{R_4 + R_2 \parallel \frac{1}{g_m}}$$

[2] There is a two-stage amplifier. Answer the following questions. Assume  $g_{m1}=g_{m2}=1\text{mS}$ . Neglect the channel length modulation.



A. What is mid-band gain? [4 points]



$$\frac{V_A}{V_{in}} = \frac{sk}{1k+sk} = \frac{5}{6} \quad \text{--- ①}$$

③ ④ ⑤ ⑥

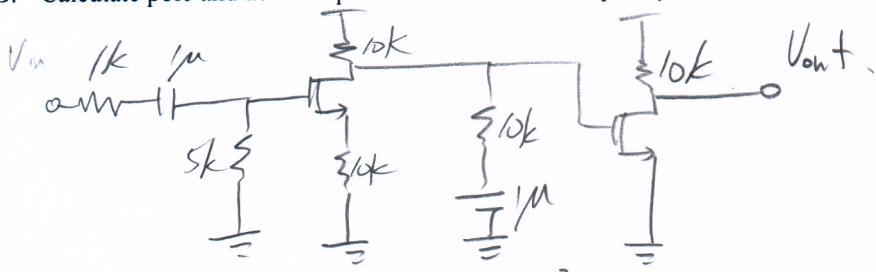
① - ④ 각 1점씩.

$$\frac{V_B}{V_A} = - \frac{10k || 10k}{g_{m1} + 10k} = - \frac{5}{11} \quad \text{--- ②}$$

$$\frac{V_{out}}{V_B} = -g_{m2} \cdot 10k = -10 \quad \text{--- ③}$$

$$\frac{V_{out}}{V_{in}} = \frac{125}{33} = 3.78 \quad \text{--- ④}$$

B. Calculate pole and zero frequencies in the lower frequency band. [4 points]



$$\frac{V_A}{V_{in}} = \frac{5k}{6k + \frac{1}{m_s}} = \frac{5 \times 10^{-3} s}{1 + 6 \times 10^{-3} s}$$

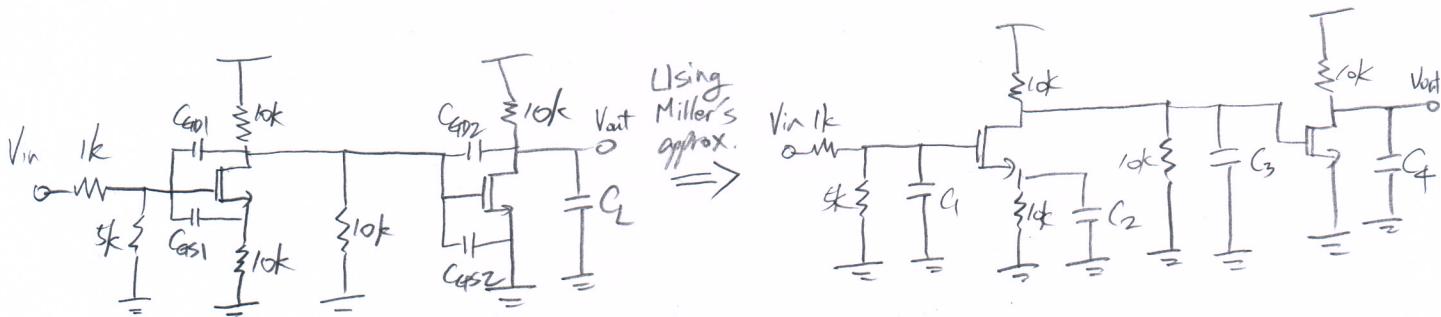
$$\frac{V_B}{V_A} = -\frac{10k \parallel (10k + \frac{1}{m_s})}{+\frac{1}{g_m} + 10k} = -\frac{\frac{10k(10k + \frac{1}{m_s})}{20k + \frac{1}{m_s}}}{11k} = -\frac{10}{11} \cdot \frac{1 + 10^{-2} s}{1 + 2 \times 10^{-2} s}$$

$$\frac{V_{out}}{V_B} = -g_m \cdot 10k = -10$$

$$\omega_{p1L} = \frac{1}{6 \times 10^{-3}} = 167 \text{ rad/s} \Rightarrow 26.5 \text{ Hz}$$

$$\omega_{p2L} = \frac{1}{2 \times 10^{-2}} = 50 \text{ rad/s} \Rightarrow 7.96 \text{ Hz}$$

C. Calculate pole frequencies in the high frequency band. Ignore any zero frequencies. Assume  $C_{GS}=1\text{pF}$ ,  $C_{GD}=1\text{pF}$ , and  $C_{DB}=C_{SB}=0\text{pF}$ . [8 points]



$$C_1 = C_{GD1} \left(1 + \frac{1}{11}\right) + C_{GS1} \left(1 - \frac{10}{11}\right) = \frac{17}{11} \text{ pF} = 1.55 \text{ pF}$$

$$|C_2| = |C_{GS1} \left(1 - \frac{10}{11}\right)| = 0.1 \text{ pF}$$

$$C_3 = C_{GD1} \left(1 + \frac{11}{5}\right) + C_{GD2} \left(1 + 10\right) + 1 = 15.2 \text{ pF}$$

$$C_4 = C_L + C_{GS2} \left(1 + \frac{1}{10}\right) = 2.1 \text{ pF}$$

$$\omega_{p1H} = \frac{1}{C_1 \cdot (1k \parallel 5k)} = 7.74 \times 10^8 \text{ rad/s} \Rightarrow 123 \text{ MHz}$$

$$\omega_{p2H} = \frac{1}{|C_2| \cdot (10k \parallel \frac{1}{g_m})} = 1.1 \times 10^{10} \text{ rad/s} \Rightarrow 1.75 \text{ GHz}$$

$$\omega_{p3H} = \frac{1}{C_3 \cdot (10k \parallel 10k)} = 1.32 \times 10^9 \text{ rad/s} \Rightarrow 2.10 \text{ MHz}$$

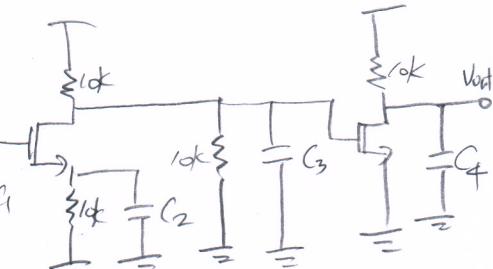
$$\omega_{p4H} = \frac{1}{C_4 \cdot 10k} = 4.76 \times 10^9 \text{ rad/s} \Rightarrow 7.58 \text{ MHz}$$

07/21 7/2.

pole, zero frequency 7/2  
1/2/23.

$$\boxed{\omega_{z1} = 0}$$

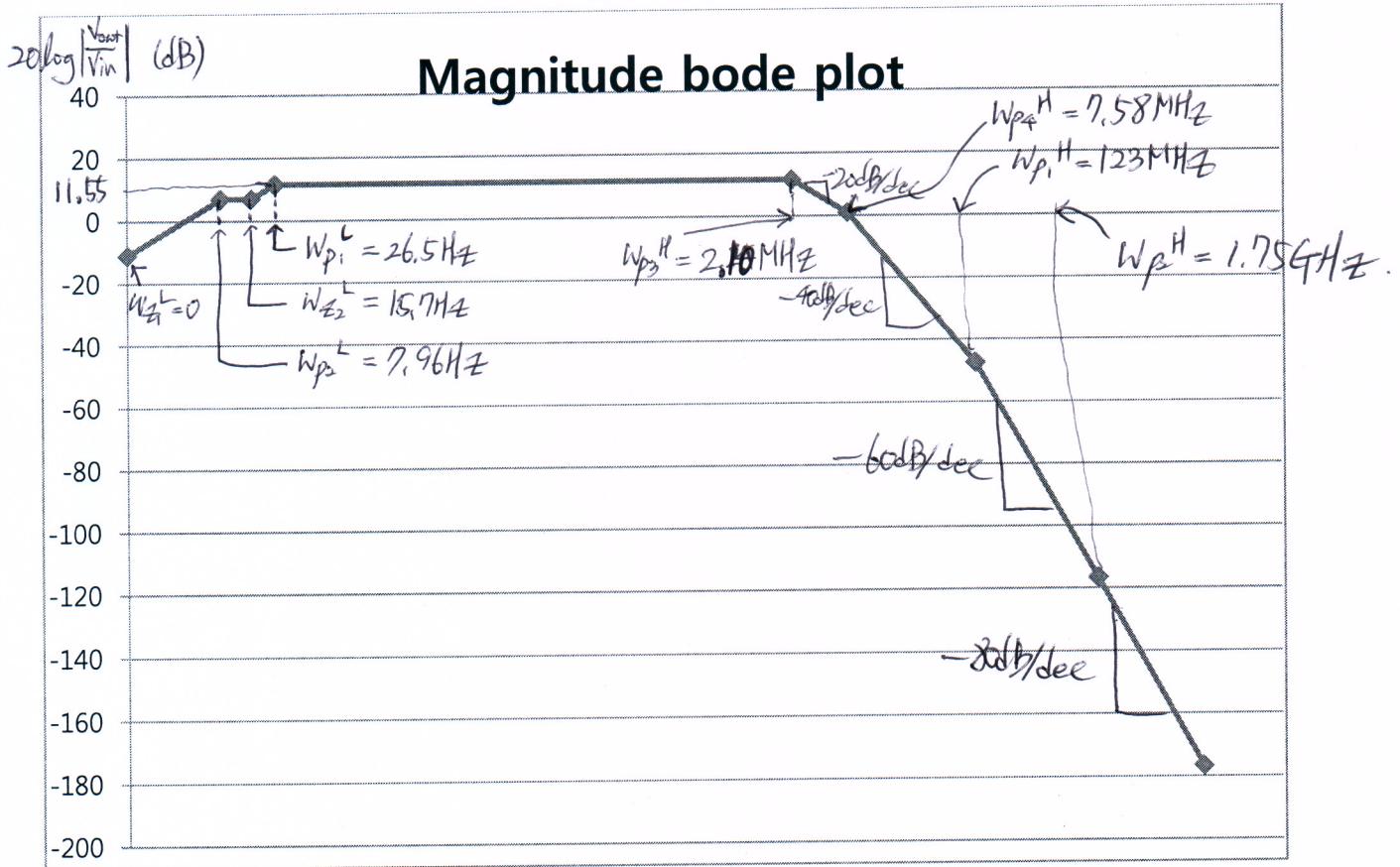
$$\boxed{\omega_{z2} = 100 \text{ rad/s} \Rightarrow 15.7 \text{ Hz}}$$



07/21 7/2

Cap 2k, frequency 2k 7/2 1/2.

- D. Draw a "magnitude" Bode Plot. Ignore the zeros in high frequency band. Indicate only the mid-band gain and the pole, zero frequencies at Bode Plot. [8 points]



○ 3/17 21주

Mid-band gain: 28.

graph 개정: 28.

pole, zero 위치를 예상치 -0.5 dB.

C.  $\text{df}_2$  쪽

source follower의 gain을 네이 1로 보고 대신 경우 ( $C_2$ 가 시리즈로 pole이 3이거나 되는)

$$C_1 = C_{GD1} \left(1 + \frac{5}{\pi}\right) = 1.45 \mu\text{F}$$

$$C_3 = C_{GD1} \left(1 + \frac{11}{5}\right) + C_{GD2} \left(1 + 10\right) + 1 = 15.2 \mu\text{F}$$

$$C_4 = C_L + C_{GD2} \left(1 + \frac{11}{10}\right) = 2.1 \mu\text{F}$$

$$\omega_{p1}^H = 8.28 \times 10^8 \text{ rad/s} \Rightarrow 132 \text{ MHz}$$

$$\omega_{p3}^H = 1.32 \times 10^7 \text{ rad/s} \Rightarrow 2.10 \text{ MHz}$$

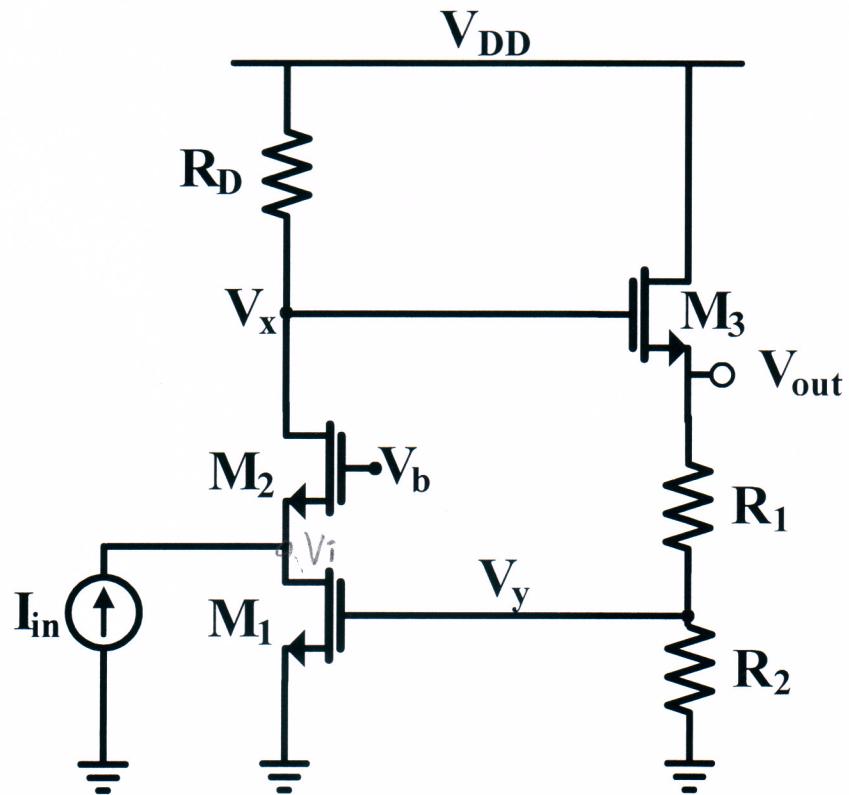
$$\omega_{p4}^H = 4.16 \times 10^7 \text{ rad/s} \Rightarrow 7.58 \text{ MHz}$$

○ 저주파 가군

$C_1, \omega_{p1}^H$  구하는 데 273  
4MHz 132MHz

D. 주파수 대비 하면 high frequency 쪽이 달라지고 초당 가중치  $-60 \text{ dB/dec}$ 가 된다.

[3] For the following circuit, answer the questions. Full credit will be not given without explanation.



A. Determine the polarity of feedback.

$$V_y \uparrow \rightarrow V_{out} \uparrow \rightarrow V_i \uparrow \rightarrow V_x \downarrow \frac{1}{2} : \text{negative feedback}$$

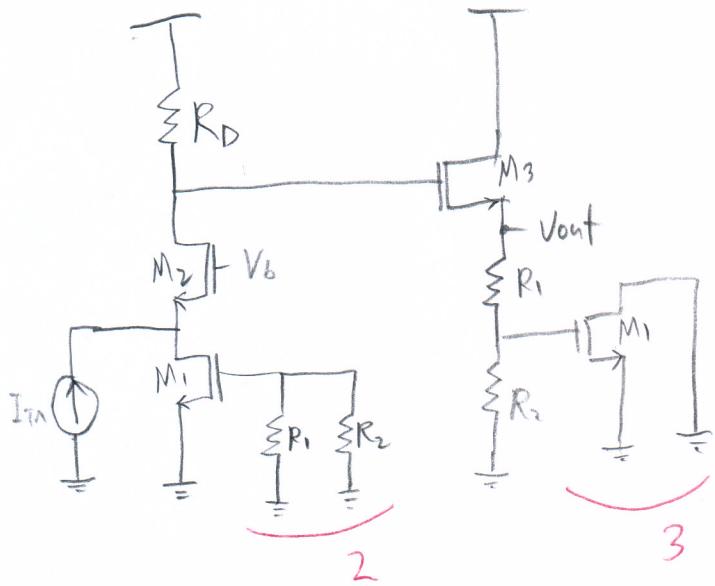
B. classify the type of feedback (e.g. voltage-voltage feedback, or voltage sense & voltage return)

Voltage sensing at the input의 전류를 shunt로 보내기므로

Voltage - current feedback. (or, voltage sense & current return)

- C. Draw the circuit with a broken feedback loop. Add sense and return duplicates to include loading effect.

voltage-current feedback 이므로 양쪽 모두 short으로 끊어야 한다.



- D. Find the feed-forward gain and feedback factor K. Denote the transconductance and output resistance of transistor  $M_x$  are  $g_{mx}$  and  $r_{ox}$ , respectively.

feed-forward gain:

$$R_o = \frac{V_{out}}{I_{in}} = \frac{V_x}{I_{in}} \cdot \frac{V_{out}}{V_x}$$

$$= R_D \cdot \frac{\frac{R_1 + R_2}{\frac{1}{g_m 3} + R_1 + R_2}}{1/3}$$

feedback factor:

$$K = \frac{I_F}{V_{out}} = \frac{R_2}{R_1 + R_2} \cdot g_m 1 / 3$$

E. Find the closed-loop gain, and input and output resistances ( $R_{in, closed}$  and  $R_{out, closed}$ ).

$$R_{in, open} = \frac{1}{g_m 2} \quad (1)$$

$$R_{out, open} = \frac{1}{g_m 3} \parallel (R_1 + R_2) \quad (1)$$

$$\left| \begin{array}{l} \frac{V_{out}}{I_{in}} \\ \text{closed} \end{array} \right. = \frac{R_o}{1 + kR_o} = \frac{R_o \cdot \frac{R_1 + R_2}{\frac{1}{g_m 3} + R_1 + R_2}}{1 + \frac{g_m 1 R_2 \cdot R_o}{\frac{1}{g_m 3} + R_1 + R_2}} \quad (2)$$

$$R_{in, closed} = \frac{R_{in, open}}{1 + KR_o} = \frac{\frac{1}{g_m 2}}{1 + \frac{g_m 1 R_2 R_o}{\frac{1}{g_m 3} + R_1 + R_2}} \quad (1)$$

$$R_{out, closed} = \frac{R_{out, open}}{1 + KR_o} = \frac{\frac{1}{g_m 3} \parallel (R_1 + R_2)}{1 + \frac{g_m 1 R_2 R_o}{\frac{1}{g_m 3} + R_1 + R_2}} \quad (1)$$

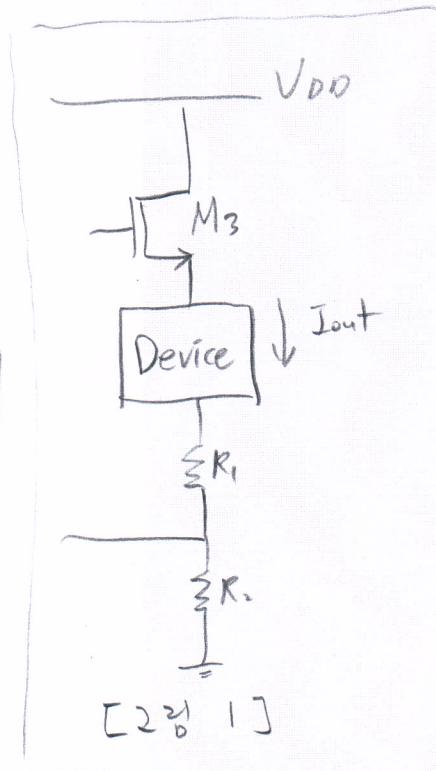
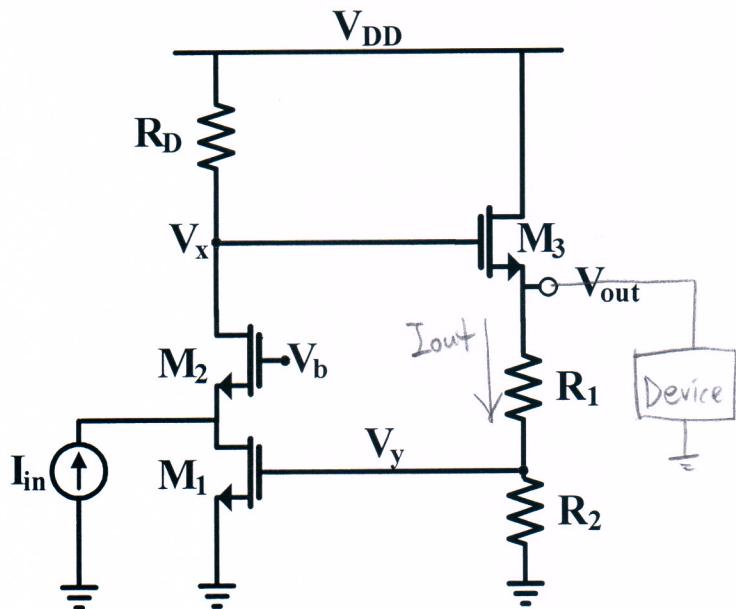
F. Determine the polarity of feedback if  $M_3$  is replaced by PMOS. (drain node and source node of the PMOS are connected to output node and  $V_{DD}$  node, respectively.)

$V_x \uparrow \rightarrow V_{out} \downarrow \rightarrow V_y \downarrow \rightarrow V_i \uparrow \rightarrow V_x \uparrow$  : positive feedback  
1/2      13

I-I feedback으로 풀 있을 경우

[3] For the following circuit, answer the questions. Full credit will not be given without explanation.

Assume that  $\lambda = 0$  for all transistors.



A. Determine the polarity of feedback. [4 points]

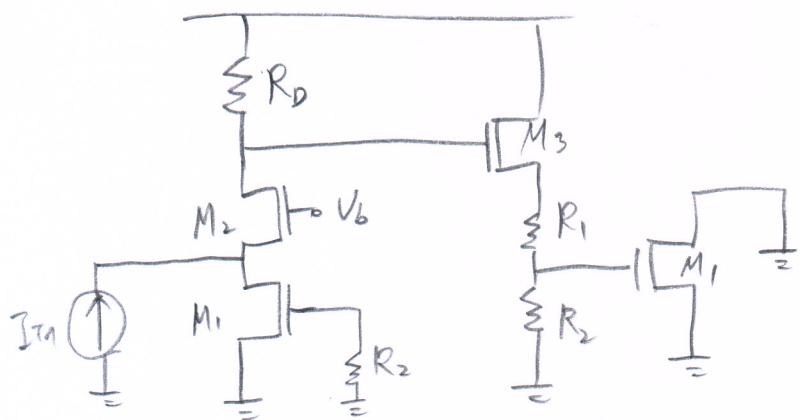
B. Classify the type of feedback. (e.g. voltage-voltage feedback, or voltage sense & voltage return) [4 points]

이 회로는 output node의 낮은 impedance를 통해 다음 stage로 Voltage  $\frac{2}{3}$  넘겨주기 위한 회로입니다. 만일 current를 sensing하는 회로였다면, 위의 [그림 1]과 같이 M<sub>3</sub>의 source node를 끊고 그 사이에 Device가 연결되어 있어야 할 것입니다. 따라서, I-I feedback으로 본 것은 회로의 역할 및 치도를 잘못 파악하였다고 간주하여 오답 처리 하도록 하겠습니다. 하지만, 뒤의 문제들은 J-I feedback 관점으로 맞게 풀었으면 정답처리 하겠습니다.

# I-I feedback 으로 풀었을 경우

C. Draw the circuit with a broken feedback loop. Add sense and return duplicates to include loading effect. [5 points]

I-I feedback의 관점이므로 input 단은 open, output 단은 short으로 끊어야 한다.



D. Find the feed-forward gain and feedback factor K. Denote the transconductance of transistor  $M_x$  are  $g_{m_x}$ . [6 points]

$$A_I = \frac{I_{out}}{I_{in}} = \frac{V_x}{I_{in}} \cdot \frac{V_{out}}{V_x} \cdot \frac{I_{out}}{V_{out}}$$

$$= R_D \cdot \frac{\frac{1}{g_{m3}} + R_1 + R_2}{\frac{1}{g_{m3}} + R_1 + R_2} \cdot \frac{1}{R_1 + R_2} = \frac{R_D}{\frac{1}{g_{m3}} + R_1 + R_2}$$

$$\begin{aligned} & \text{Circuit diagram showing the feed-forward path: } V_{out} \rightarrow M_1 \rightarrow R_1 \rightarrow I_F \rightarrow M_1 \rightarrow R_2 \rightarrow I_{out} \\ & k = \frac{I_F}{I_{out}} = \frac{I_F}{V_{out}} \cdot \frac{V_{out}}{I_{out}} \\ & = \left( \frac{R_2}{R_1 + R_2} \cdot g_{m1} \right) \cdot (R_1 + R_2) \end{aligned}$$

$$= g_{m1} \cdot R_2$$

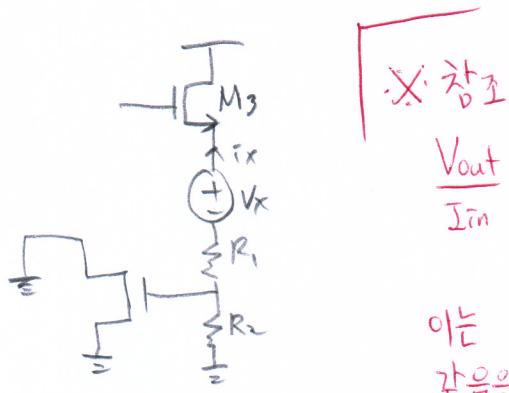
## I-I feedback 으로 풀었을 경우

E. Find the closed-loop gain, and input and output resistances ( $R_{in, closed}$  and  $R_{out, closed}$ ). [6 points]

$$A_{I, closed} = \frac{A_I}{1+KA_I} = \frac{\frac{R_D}{\frac{1}{g_m 3} + R_1 + R_2}}{1 + g_m 1 R_2 \frac{\frac{R_D}{\frac{1}{g_m 3} + R_1 + R_2}}{1 + g_m 1 R_2}}$$

$$R_{in, open} = \frac{1}{g_m 2} \Rightarrow R_{in, closed} = \frac{R_{in, open}}{1+KA_I}$$

$$R_{out, open} = \frac{V_r}{i_x} = R_1 + R_2 + \frac{1}{g_m 3} \Rightarrow R_{out, closed} = R_{out, open} \cdot (1+KA_I)$$

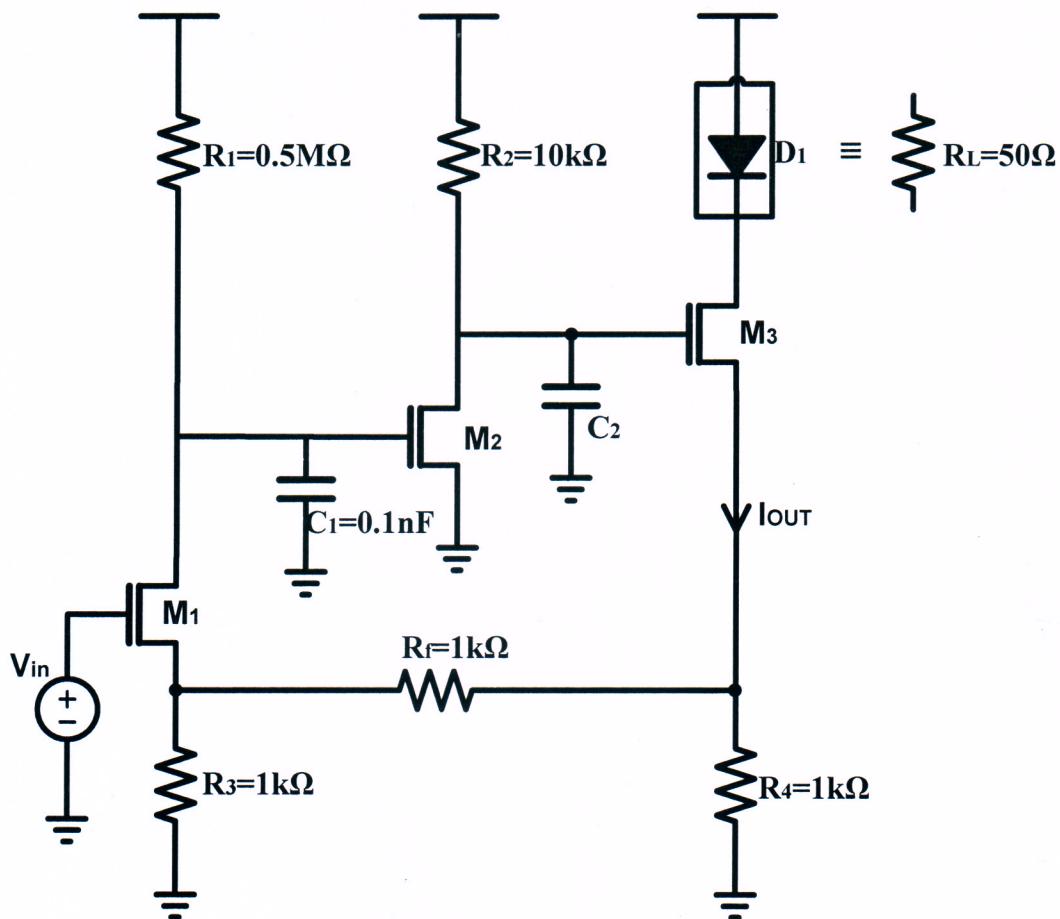


이는 V-I feedback 의 관점에서 풀었을 때의  $\frac{V_{out}}{I_{in}}$  과 같음을 알 수 있다.

$$\frac{V_{out}}{I_{in}} = A_{I, closed} \times \frac{V_{out}}{I_{out}} = (R_1 + R_2) \cdot \frac{\frac{R_D}{\frac{1}{g_m 3} + R_1 + R_2}}{1 + g_m 1 R_2 \frac{\frac{R_D}{\frac{1}{g_m 3} + R_1 + R_2}}{1 + g_m 1 R_2}}$$

F. Determine the polarity of feedback if  $M_3$  is replaced by PMOS. (drain node and source node of the PMOS are connected to the output node and  $V_{DD}$  node, respectively.) [5 points]

[4] For the following circuit, give your solutions. Note that  $g_{m1}=3\text{mS}$ ,  $g_{m2}=1\text{mS}$ ,  $g_{m3}=1\text{mS}$ ,  $R_1=0.5\text{M}\Omega$ ,  $R_2=10\text{k}\Omega$ ,  $R_3=R_4=R_f=1\text{k}\Omega$ ,  $R_L=50\Omega$ . Assume there is no channel length modulation.



A. Find the feedback factor K.[5points]

(I-V Feedback)

$$\left\{ \begin{array}{l} i_f = \frac{V_f}{R_3} + \frac{V_f}{R_3 + R_f} \\ V_f = V_i \cdot \frac{R_3}{R_3 + R_f} \end{array} \right.$$

$$\Rightarrow k = \frac{V_f}{V_i} = \boxed{\frac{1000}{3}} \left( \frac{R_4 \cdot R_3}{R_4 + R_3 + R_f} \right)$$

(V-V Feedback)

$$k = \frac{V_f}{V_i} = \frac{R_3}{R_f + R_3} = \boxed{\frac{1}{2}}$$

<자유기준>

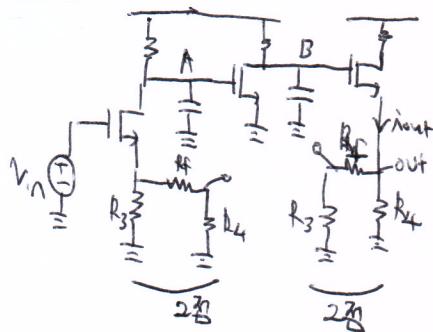
- Feedback Topology 혹은 구조도 찾으면  $\Rightarrow 3$ 점
- $1/g_m$  고려한 경우는 중립점
- Return 부분이 주어진 것은 미드백으로 설명 불가하므로 0점

$\frac{V_{out}}{V_{in}}$  (보정기) (- Transfer function 정의는  $\frac{\text{output}}{\text{input}}$ ) --- 1점

B. Find the transfer function of the open loop amplifier. Use the proper Break Rule. [10points]

$\frac{V_{out}}{V_{in}}$  Break)

Some Feedback



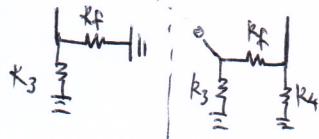
$$\frac{V_A}{V_{in}} = -\frac{R_3 \parallel \frac{1}{jC_1}}{g_m + R_3 \parallel (R_2 + R_4)} \quad \text{--- 1점}$$

$$\frac{V_B}{V_A} = -g_{m2}(R_2 \parallel \frac{1}{jC_2}) \quad \text{--- 1점}$$

$$\frac{V_{out}}{V_B} = \frac{g_{m3}}{\frac{1}{R_4 \parallel (R_3 + R_f)} + g_{m3}} \quad \text{--- 1점}$$

$$\frac{V_{out}}{V_{in}} = \frac{1}{(R_3 + R_f) \parallel R_4} = \frac{g_{m3}}{1 + g_{m3} R_f} = \frac{1}{g_{m3} + R_f} \quad \text{--- 1점}$$

$\frac{V_{out}}{V_{in}}$  Break)



$$G(s) = \frac{V_{out}(s)}{V_{in}(s)} = \boxed{3 \frac{1}{1+s \cdot 5 \cdot 10^{-5}} \frac{1}{1+sC_2 \cdot 10k}}$$

C. Assume that the pole made by  $C_1$  is the dominant pole. When the phase margin of this system is  $45^\circ$ , determine the value of  $C_2$ . [10points]

$$R_3 \parallel (R_f + R_4) = R_4 \parallel (R_3 + R_f) = \frac{2}{3} k$$

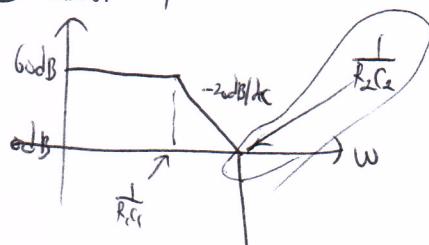
$$\text{DC gain of } k_f(s) = 10^3 \Leftrightarrow 60\text{dB}$$

3점

$\omega_d, g/(k_f R_f)$

3점 (unity Gain)

Pole  $\left\{ \begin{array}{l} \frac{1}{R_1 C_1} : \text{dominant } (\text{보정기}) \\ \frac{1}{R_2 C_2} \end{array} \right.$



$$\boxed{-\frac{1}{R_1 C_1} = -\frac{1}{1000} \cdot \frac{1}{R_2 C_2}} \quad \text{3점}$$

$$-\frac{1}{R_1 C_1} = \frac{1}{10^3} \frac{R_2 C_1}{R_1}$$

$$= 5 \cdot 10^{-12} = \boxed{5 \text{ pF}}$$

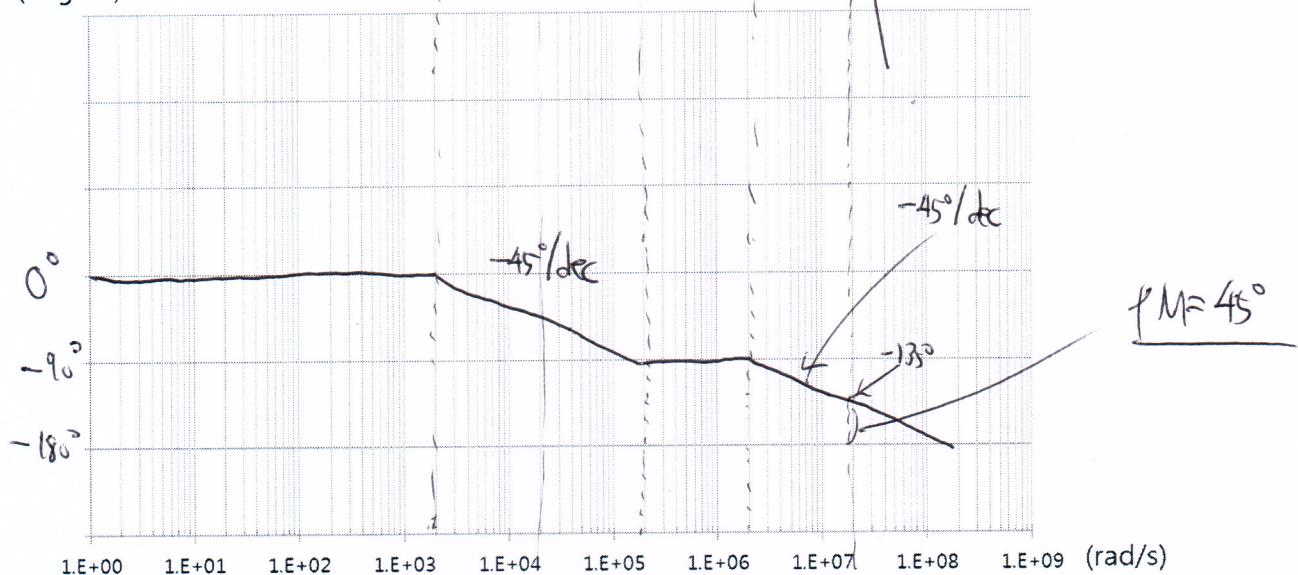
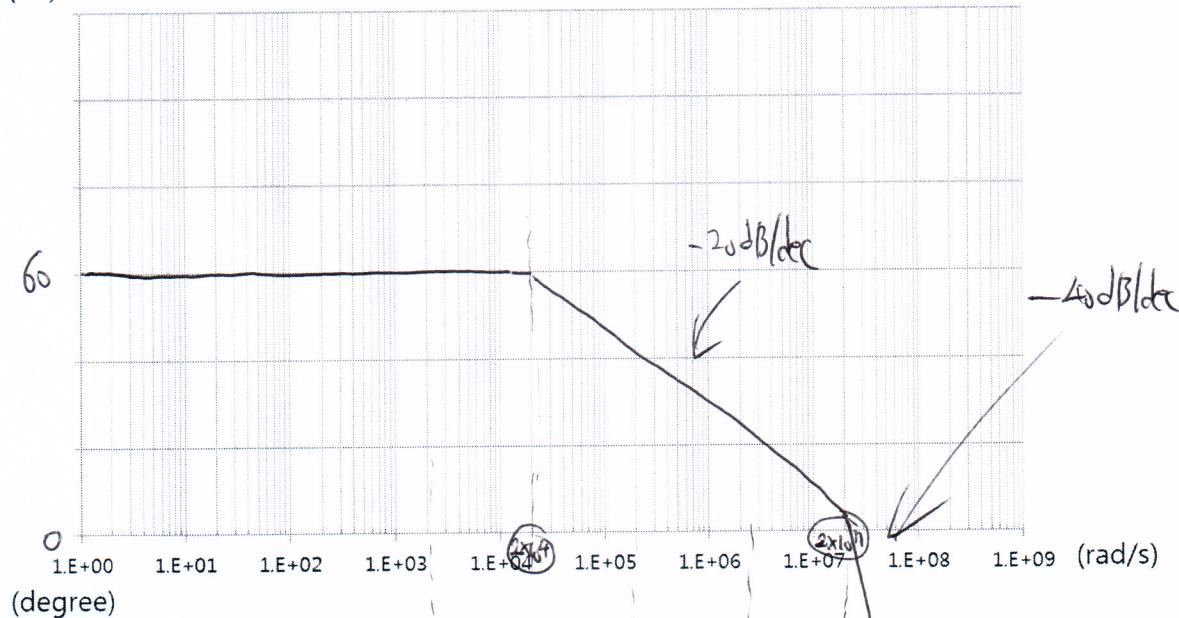
- D. Draw a Bode plot (both amplitude and phase) of the loop gain with the determined  $C_2$ . Indicate DC gain, slope, and pole(zero) frequencies.[5points]

$$\frac{f}{R_1 C_1} = 2 \cdot 10^4 \text{ (rad/s)}$$

$$\frac{f}{R_2 C_2} = (2 \cdot 10^4) \cdot 10^3 \text{ (rad/s)}$$

<제작기준>

- M1 Plot 7회 | 1점
  - Phase Plot 7회 | 1점
  - M1 Plot 7회 | 1점
  - Phase Plot 7회 | 1점
- (dB)



{End of Midterm 2}