1 -1)

I_{Q}[redacted] $= 100\mu A$

$I_{Q2} = 100\mu A$

$I_{Q3} = 100\mu A$

$I_{Q4} = 300\mu A$

$I_{Q5} = 1mA$

$V_{ov1} = 0.316V$

$V_{ov2} = 0.316V$

$V_{ov3} = -0.316V$

$V_{ov4} = -0.316V$

$V_{ov5} = 1V$

2) $g_{m1} = 0.632 mA/V$

$g_{m2} = 0.632 mA/V$

$g_{m3} = 0.632 mA/V$

$g_{m4} = 1.9 mA/V$

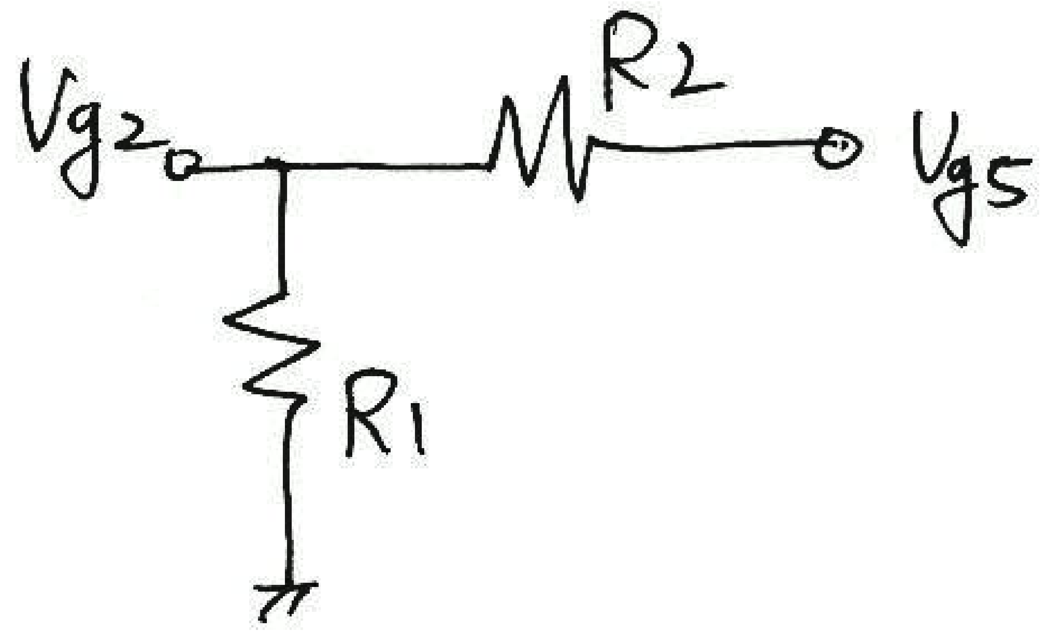
$g_{m5} = 2 mA/V$

$r_{o1} = \frac{V_A}{I_D} = 300k\Omega.$

$r_{o2} = r_{o1} = r_{o3}$

$r_{o4} = 100k\Omega.$

$r_{o5} = 30k\Omega.$

∴ 

은 Q_2. Q_5 사이에

붙인다 $\frac{R_1}{R_1+R_2} = 0.145.$

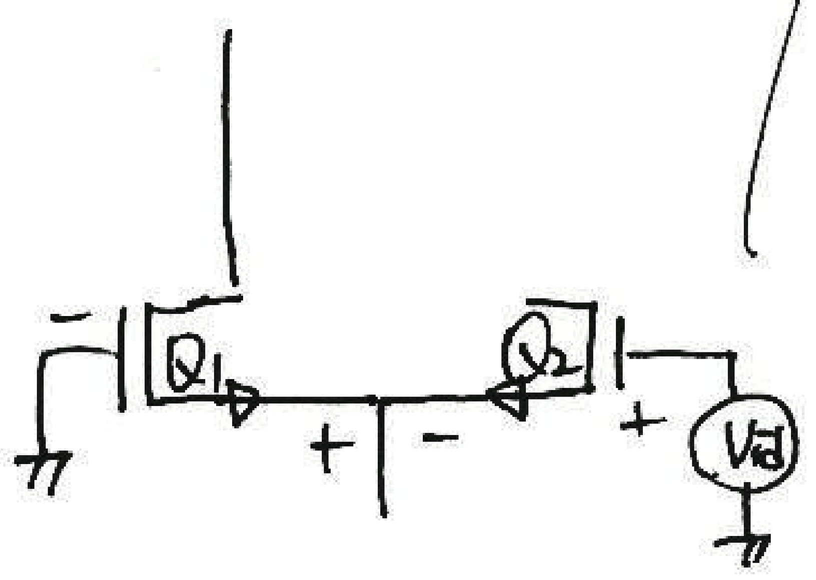
⇒ loading effect 가 최소가 되게 하려면

$R_1 = 145k\Omega$ $R_2 = 855k\Omega$. 으로 해준다.

$$R_{out} = R_{of} = \frac{r_{o5} \,\|\, \frac{1}{g_{m5}} \,\|\, R_1+R_2}{1+A\beta} = \frac{490}{1+47\times 0.145} = 62.7\Omega$$

3) $Q_3 \cdot Q_4$는 current mirror 이므로 gain stage가 아님.

Differential 이므로 input에 $V_{id} \times \frac{1}{2}$씩 나눠서 걸린다.



$$\therefore V_o = -\frac{1}{2}V_{id} \times (-g_{m1}(r_{o1} \| r_{o3}))$$

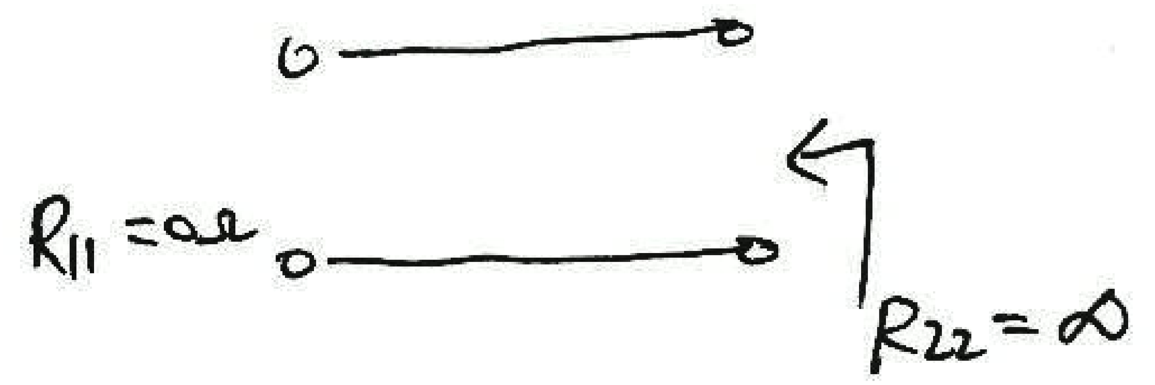
$$\therefore A = \frac{V_o}{V_{id}} = \frac{1}{2}g_m(r_{o1} \| r_{o3})$$

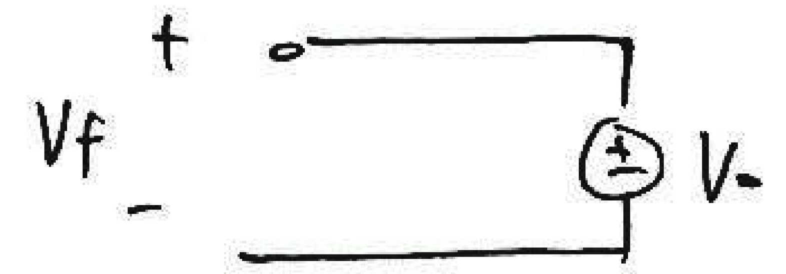
$$= 47 V/V$$

output resistance: $R_o = r_{o5} \| \frac{1}{g_{m5}} = 30k\Omega \| \frac{1}{2m} = 491\Omega$

$R_o = r_{o1} \| r_{o3} = 150k\Omega$

4) feedback loop





$\beta = 1.$

$$A_f = \frac{47}{1+47 \cdot 1} = 0.98 V/V$$

$R_o = 491$

$$R_{of} = \frac{R_o}{1+A\beta} = \frac{491}{1+47} = 12.3\Omega.$$

5) closed loop gain 6V/V

$$A_f = \frac{47}{1+47 \cdot \beta} = 6V/V \qquad \beta = 0.145.$$

2.

1

1). $I_{C17} = \underline{550\mu A}$

$I_{E17} \doteq \underline{550\mu A}$. $\left(\frac{\beta+1}{\beta} = \frac{201}{200} \simeq 1\right)$

$V_{B17} = V_{E17} + V_{BE17} = 0.055 + 0.62 = \underline{0.67V}$

$\therefore \underline{I_{E16}} = \frac{V_{E16}}{R_9} = 13.4mA = I_{C16}$.

$V_{BE16} = \underline{0.53V}$

$V_{B16} = V_{E16} + V_{BE16} = \underline{1.2V}$

$r_{e16} = \frac{V_T}{I_{E16}} = \frac{25mV}{13.4mA} = 1.87k\Omega$.

$r_{e17} = \frac{V_T}{I_{E17}} = \underline{45\,\Omega}$

$r_{\pi16} = (\beta+1)\, r_{e16} = \underline{376k\Omega}$

$r_{\pi17} = \underline{9k\Omega}$.

$g_{m16} = \frac{I_{C16}}{V_T} = \frac{13.4mA}{25mV} = \underline{\overset{0.535}{\cancel{5.35}}\ mA/V}$

$g_{m17} = \frac{I_{E17}}{V_T} = \frac{550\mu A}{25mV} = \underline{22mA/V}$

$r_{o16} = \frac{V_A}{I_{C16}} = \frac{125V}{13.4mA} = \underline{9.3M\Omega}$

$r_{o17} = \frac{V_A}{I_{C17}} = \frac{125V}{550\mu A} = \underline{0.2M\Omega}$.

1×6.

13dB — 118kHz.

$A_{vo} = -\underline{g_m \cdot R_o}$.

$A_{vo} = -\frac{g_m}{1+g_m R_E} \cdot (1+g_m R_o) V_a$.

2-2) i) Voltage gain $A_V = -\frac{R_{in}}{R_{sig}+R_{in}} G_{m2} \cdot R_{o1n}$

$$G_{m2} = \frac{i_{c1n}\ (Q_{1n}\ C\ \text{short})}{V_{i2}}$$

$$i_{c1n} = \frac{\alpha V_{b1n}}{r_{e1n} + R_8}$$

$$V_{b1n} = V_{i2} \frac{\overset{50k\quad 145k}{(R_9 \parallel R_{i1n})}\ {}^{\swarrow 37k\Omega}}{(R_9 \parallel R_{i1n}) + \underbrace{r_{e16}}_{2k\Omega}} \simeq V_{i2}$$

$$R_{i1n} = (\underset{45}{\beta_{1n}} + 1)(r_{e1n} + \underset{100}{R_8}) = 145$$

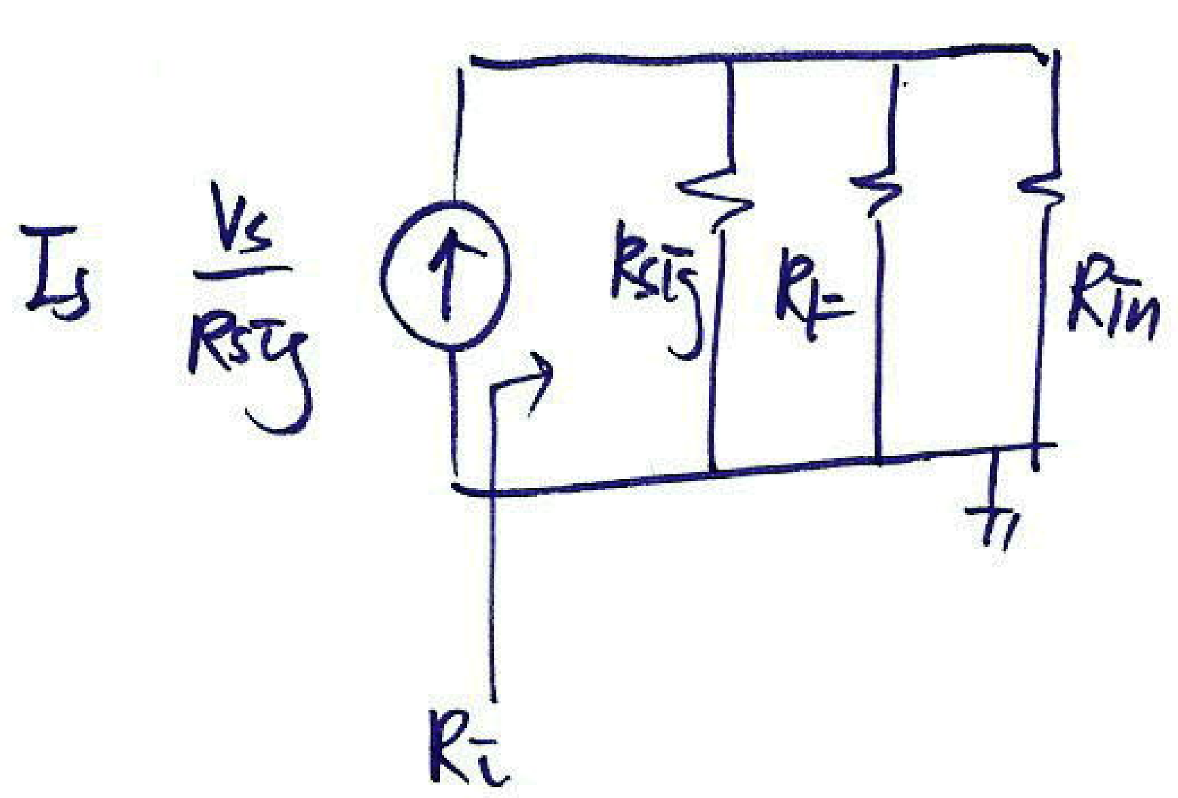
$$\therefore\ G_{m2} \simeq \frac{i_{c1n}}{V_{i2}} \simeq \frac{i_{c1n}}{V_{b1n}} = \frac{\alpha \nearrow 1}{r_{e1n} + R_8} \simeq 7\,mA/V$$

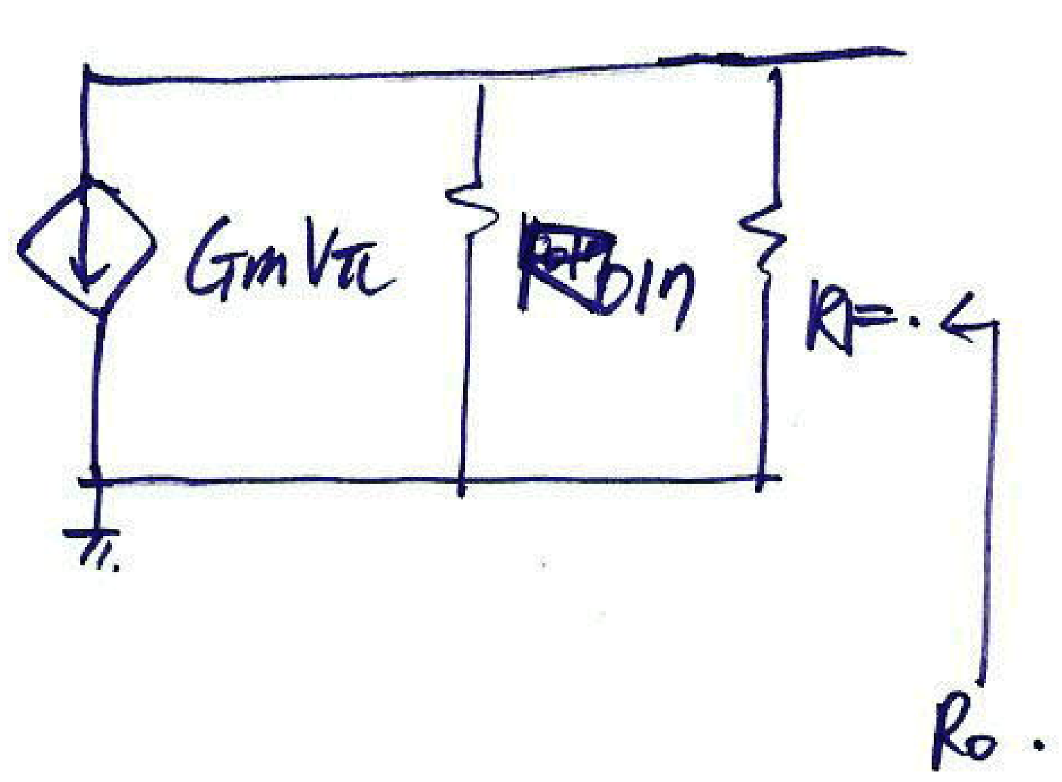
$$\therefore A_V = \frac{-R_{in1}}{R_{sig} + \underset{\uparrow\ 4M\Omega}{R_{in1}}} \cdot \underset{\downarrow\ 7mA/V}{G_{m2}} \cdot \underset{\downarrow\ \underline{640k\Omega}}{R_{o1n}}$$

where $R_{o1n} = r_{o1n}(1 + g_{m2}(R_8 \parallel r_{\pi 1n}))$
$= 200k\,(1 + 22mA/V \cdot 100\Omega)$
$= 640k\Omega$.

$= -4480\,V/V$.

2-3) 수정된 회로. shunt – shunt





$A_f = \frac{A}{1+A\beta}$ ∘ $A = \frac{V_o}{I_s} = -G_m \underset{\downarrow\ I_s(R_{sig} \parallel R_F \parallel R_{in})}{V_\pi} \cdot \underbrace{(R_{o1n} \parallel R_F)}_{46k}$ $= -8.3k\Omega \cdot 7mA/V \cdot 46k\Omega = 2673\ V/I$.

∘ $\beta = -2 \times 10^{-5}$

$\therefore A\beta = 0.055$ $\therefore A_f = -2530\ V/A$.

2-3) $R_{if} = \frac{R_i}{1+A\beta} = \frac{8.3k}{1.055} \simeq 7.87\,k\Omega.$

$R_{of} = \frac{R_o}{1+A\beta} = \frac{46k}{1.055} = 46.7\,k\Omega.$

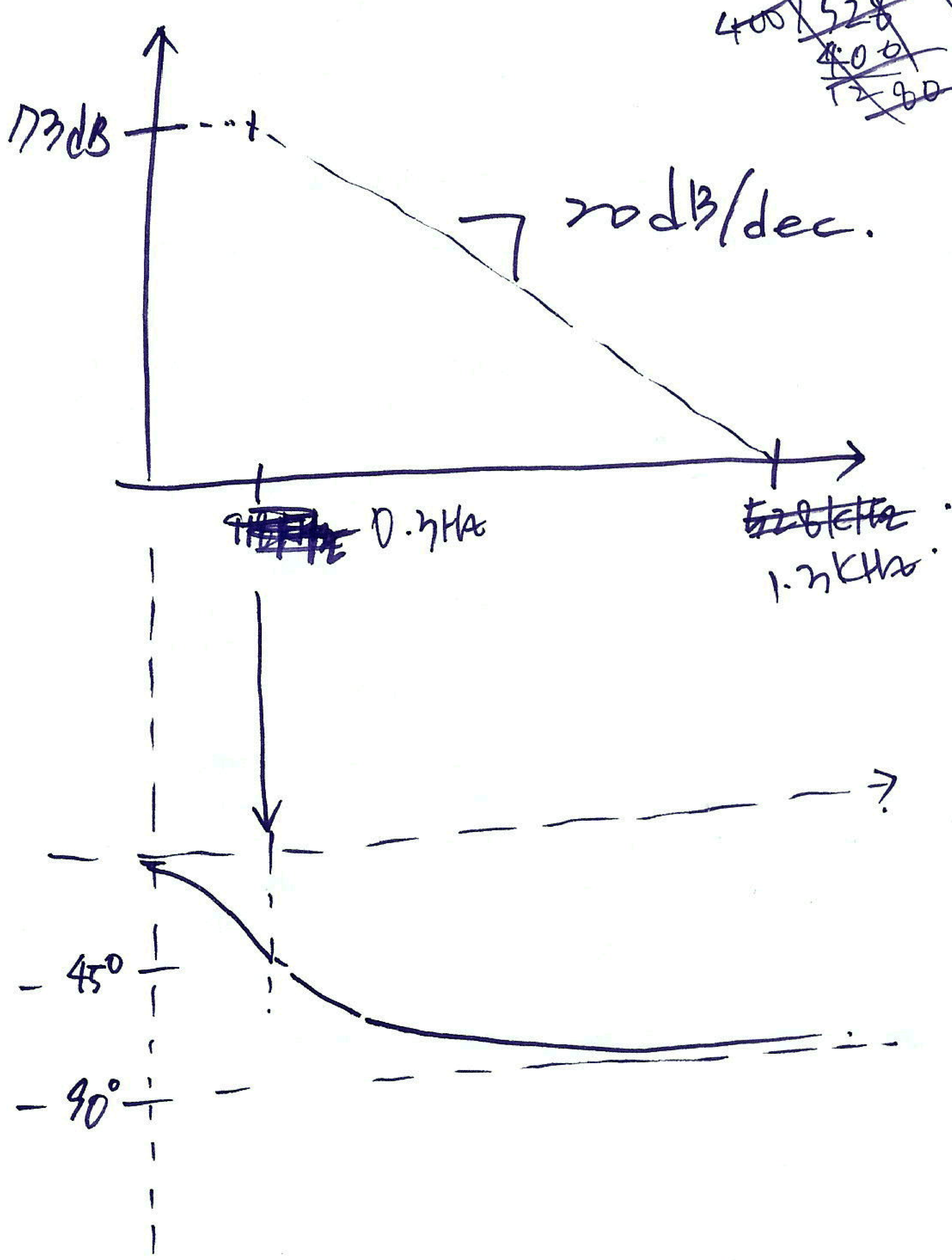
2-4) → miller effect..

$$f_{3dB} = \frac{1}{2\pi \cdot C_f(1+|A_v|)\cancel{(R_{sig}\| R_{in})}\,R_{in}}$$

$$\frac{1}{2\pi\cdot 30\cdot 10^{-12}(1+4480)\cdot 4\cdot 10^{6}} = \overset{1.18}{\cancel{118\,Hz}}\ 0.3\,Hz.$$

$$f_T = |A_M|\cdot \cancel{f_H}\ f_{3dB}.$$

$$= \cancel{528.6\,kHz}.\quad \underline{1.3\,kHz}.$$



2-5) pole . zero 가 더 크게 split 된다.

$$Zero = \frac{1}{\left(\frac{1}{g_m} - R_f\right) C_f}$$

⇒ R_f이 커지면 high frequency 에서 positive phase shift 를 얻어서 phase margin 을 더 증가시킨다.

<Solution>

P3. 17)

5

$$i_C = I_S e^{V_{BE}/V_T}$$

· $V_{BE19} + V_{BE18} = 1$

계산 틀리면 -1 감점

수식은 맞는데 계산오류경우 2점

$$\Rightarrow \begin{cases} V_T \ln \dfrac{I_{C19}}{I_S} + V_T \ln \dfrac{I_{C18}}{I_S} = 1V \quad \cdots ① \\ I_{C18} + I_{C19} = 180\mu A \quad \cdots ② \end{cases}$$

2식에

$$I_{C18} = I_S e^{V_{BE18}/V_T} \quad \cdots ②\text{-}1$$

$$I_{C19} = I_S e^{V_{BE19}/V_T} \quad \cdots ②\text{-}2$$

②-1 × ②-2 해주면

$$I_{C18} \cdot I_{C19} = I_S^2 e^{\overset{\text{"1"}}{(V_{BE18}+V_{BE19})}/V_T} = I_S^2 e^{\frac{1}{V_T}} \cdots ③$$

③과 ①에서 I_{C18}을 구하면

$$I_{C18} \fallingdotseq 179.87\mu A \text{ or } 0.133\mu A$$

보통 $I_{C18} > I_{C19}$ 이므로

$I_{C18} \fallingdotseq 179.87\mu A \rightarrow V_{BE18} \fallingdotseq 0.59V$

$\frac{0.59}{R_{10}} = 0.133\mu A \rightarrow R_{10} \fallingdotseq 4.53M\Omega$

※ Q_{18}에 180μA가 흐른다고 가정

$$V_{BE18} = 0.025 \ln \left(\frac{180\mu A}{10^{-14}}\right) = 0.59V$$

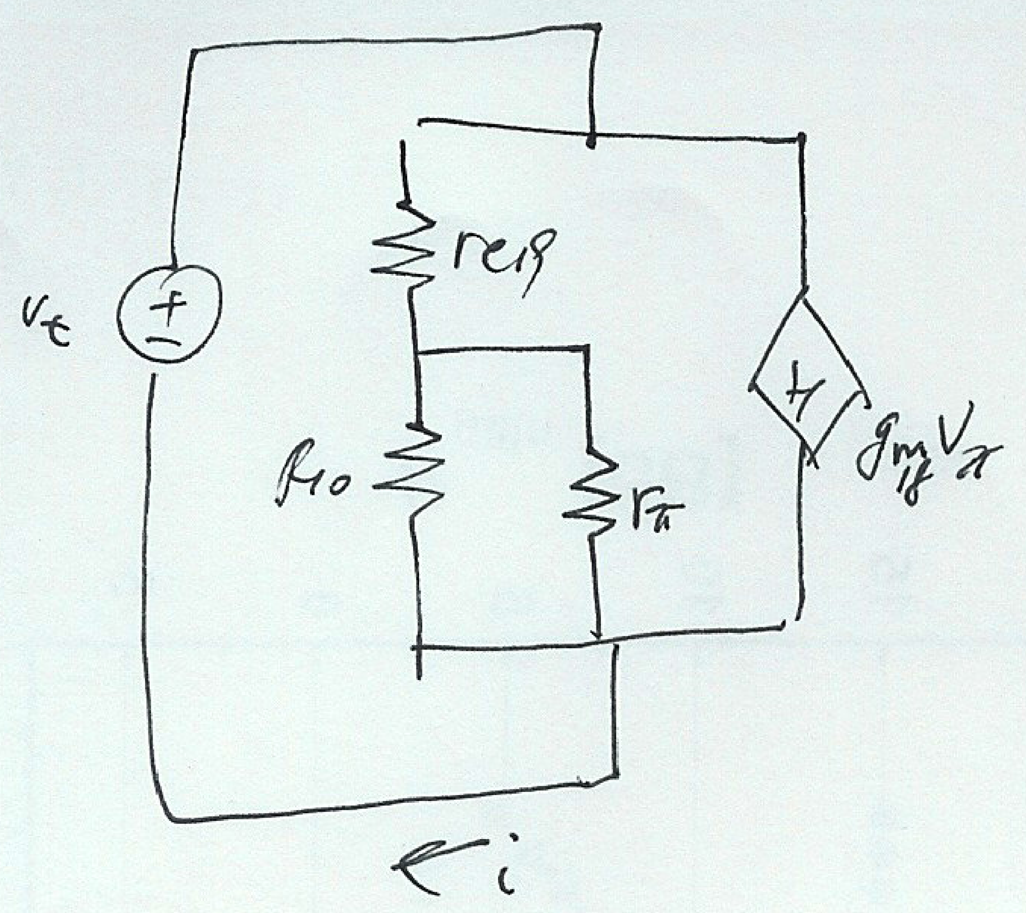
$\therefore V_{BE19} = 1 - 0.59V = 0.41V$

$I_{C19} = 0.13\mu A \rightarrow R_{10} = \frac{0.59}{I_{C19}} \fallingdotseq 4.53M\Omega$

2)

2)

5



$r_{e19} = \frac{V_T}{I_C} = \frac{25\times10^{-3}}{0.133\times10^{-6}} \doteqdot 187.97\,k\Omega$

$r_{\pi18} = \beta\left(\frac{V_T}{I_C}\right) = 200\times\frac{25\times10^{-3}}{179.87\times10^{-6}} \doteqdot 27.8\,k\Omega$

$V_\pi = V_t \frac{(R_{10} \parallel r_{\pi18})}{r_{e19} + (R_{10}\parallel r_{\pi18})} = V_t\frac{27.629}{187.97+27.629} \doteqdot 0.128V_t$

$R_{10}\parallel r_{\pi18} = \frac{R_{10}\cdot r_{\pi18}}{R_{10}+r_{\pi18}} \doteqdot \frac{4.5\times10^{6}\times27.8\times10^{3}}{4.5\times10^{6}+27.8\times10^{3}}$

$\doteqdot 27.629\,k\Omega$

$i = \frac{V_t}{r_{e19} + (R_{10}\parallel r_{\pi18})} + g_{m18}V_\pi$

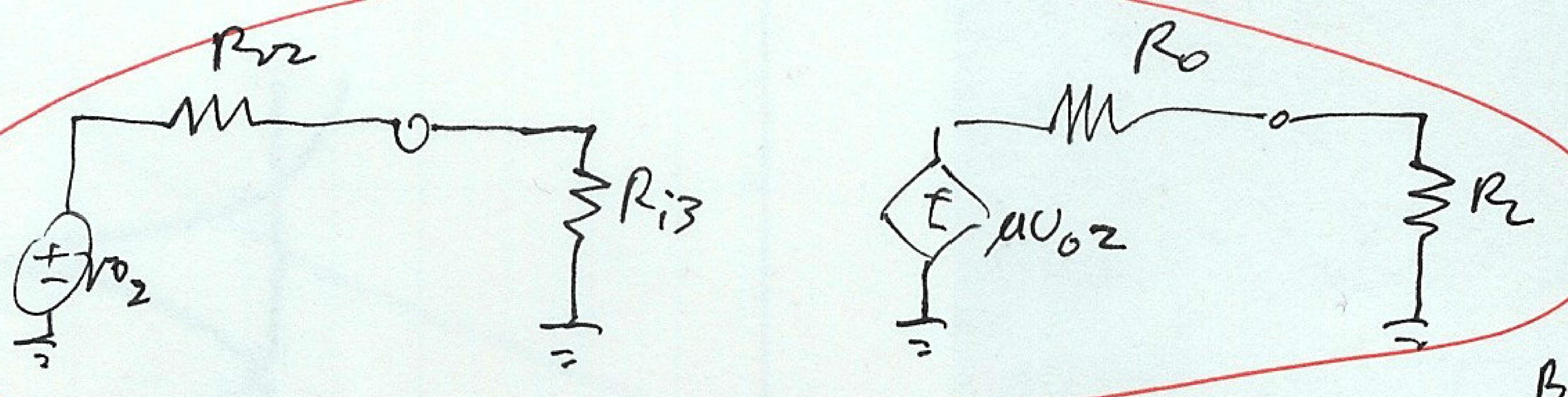
$= \frac{V_t}{(187.97+27.629)\times10^{3}} + g_{m18}\cdot 0.128V_t$

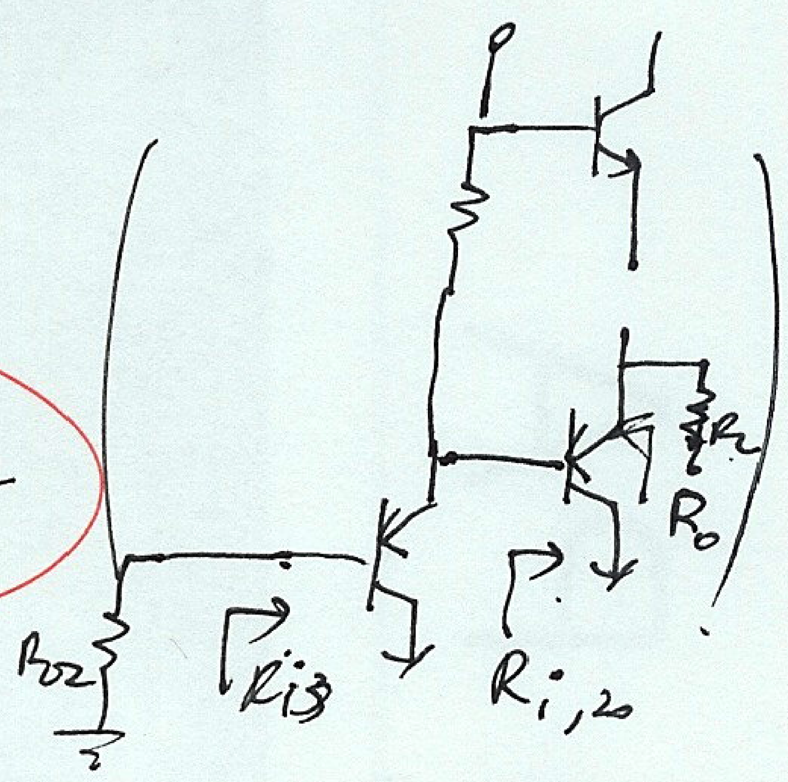
$= 4.63\times10^{-6}V_t + \frac{I_{C18}}{V_T}\cdot0.128V_t = 4.63\times10^{-6}V_t + \frac{179.87\times10^{-6}}{25\times10^{-3}}\cdot0.128V_t \doteqdot (4.63\times10^{-6}+0.92\times10^{-3})V_t$

$R = \frac{V_t}{i} \simeq \frac{1}{4.63\times10^{-6}+0.92\times10^{-3}} \doteqdot 1081.5\,\Omega$ //

저항 안구했으면 −2점

i) r_o가 negative 일때





+3 (positive, negative 한쪽만 해도 됨)

2번 일반적으로 구하려고 그런경우

+2

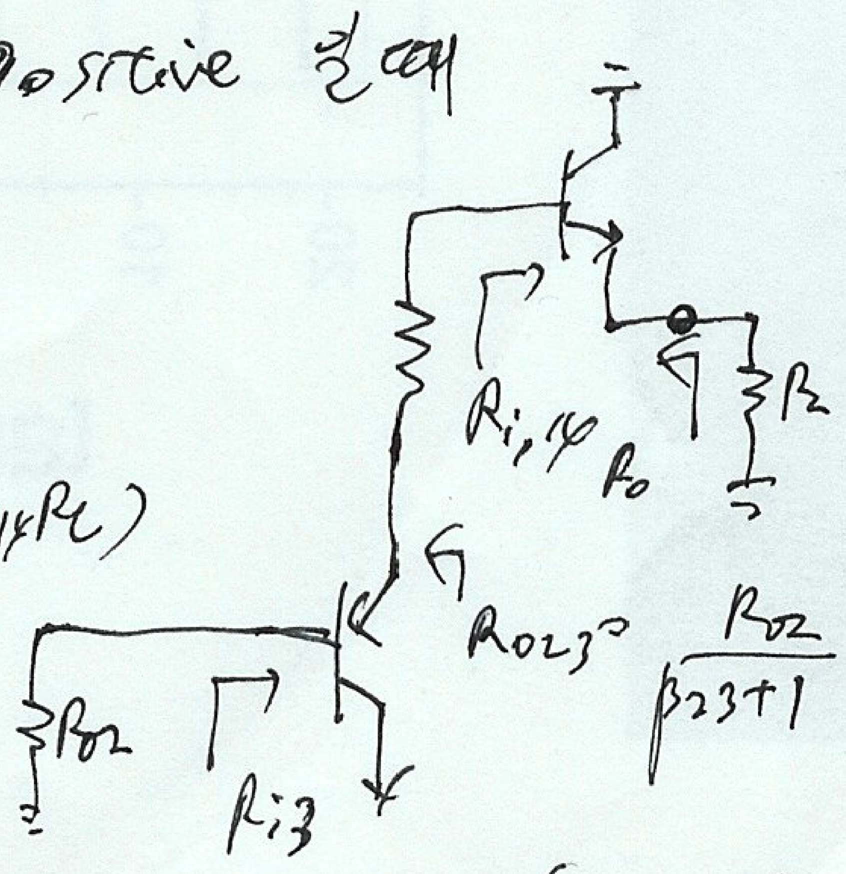
$R_{i,20} \doteqdot \beta_{20}R_L$, $R_{i3} \doteqdot \beta_{23}(\beta_{20}R_L)$

$R_o = r_{e20} + \frac{R_{o23}}{\beta_{20}+1}$

ii) r_o가 positive 일때

$R_{i,14} = \beta_{14}R_L$

$R_{i3} \doteqdot \beta_{23}(R+\beta_{14}R_L)$



$R_{o23} = \frac{R_{o2}}{\beta_{23}+1}$

$R_o \simeq \frac{(R_{o23}+R)}{\beta_{14}+1} + r_{e14}$

(계산생략)

(3)

5

(2)에서 v_O가 negative 일때와 positive 일때 input resistance가 감소하는데 각각 $\beta_{23}(\beta_{20}R_L)$, $\beta_{23}(R+\beta_{19}R_L)$ 이어서 이런 내용 있으면 +5

$\beta_{20}R_L < R+\beta_{19}R_L$ 이므로 ($R\approx1k\Omega$, $\beta_{19}=4\beta_{20}$) input resistance가 (하나만 있으면 +2)

차이가 난다. 따라서 symmetric한 voltage swing을 할 수 없다

(4) 위에서 두 input resistance가 같아지려면?

10 or 30

문제에서 R_L에 대해 주어진 값이 없으므로 Q_{23}에서 바라본 Q_{19}, Q_{20}의 input resistance가 같아야 한다는 내용이 있으면 맞게 해줌.

P4. (1)

series - series feedback

or.

Voltage mixing, Current Sampling (Sensing)

(2) $I = 100mA$, $V_A = 100V$, $\beta = 100$

$R_e = 75\Omega$, $R_{sig} = 5k\Omega$, $V_T = 25mV$

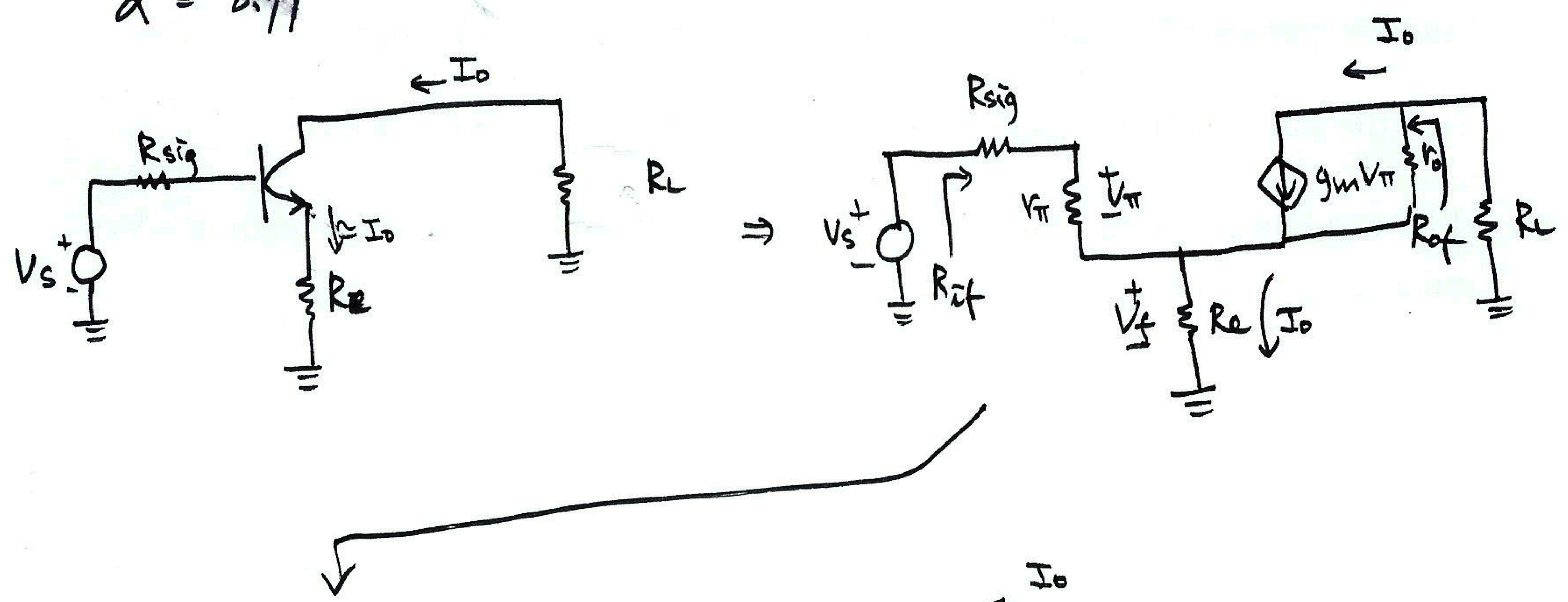
$\therefore$ $g_m = 4\,A/V$

$r_e \cong 0.25\,\Omega$

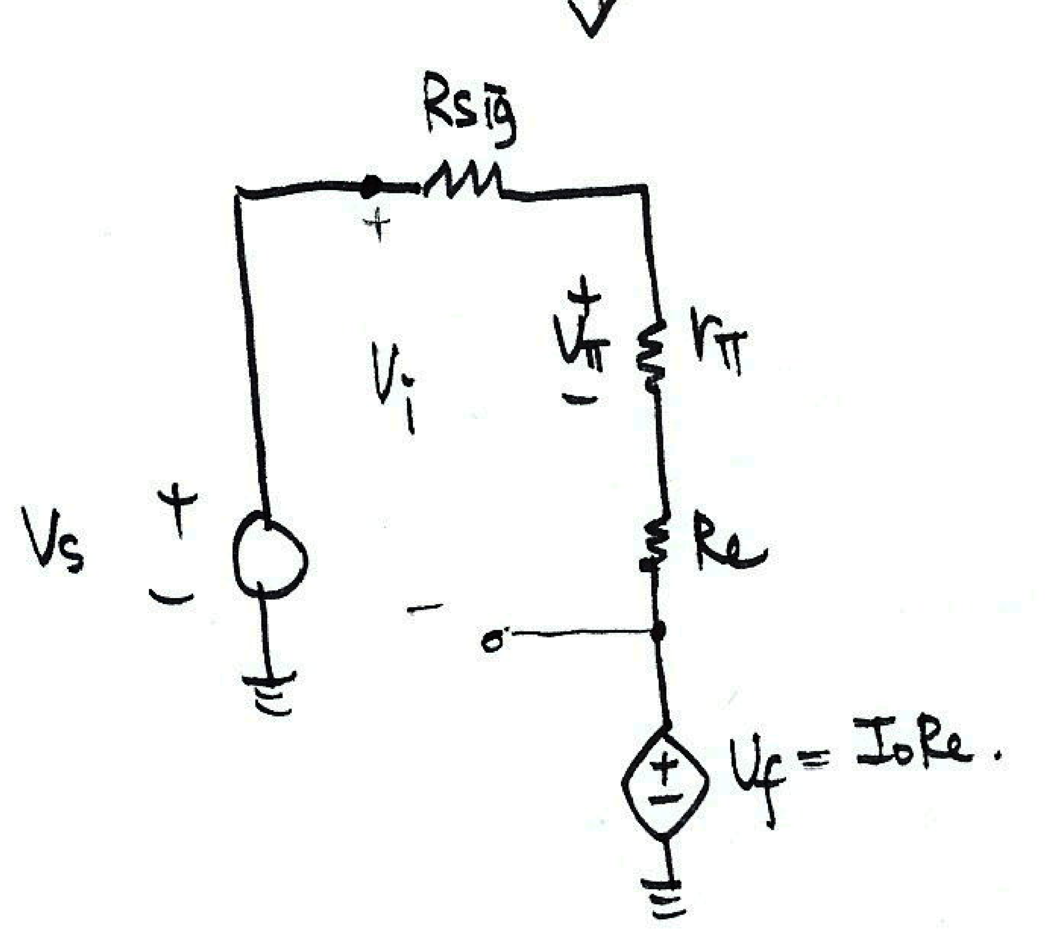
$r_\pi = 25\,\Omega$

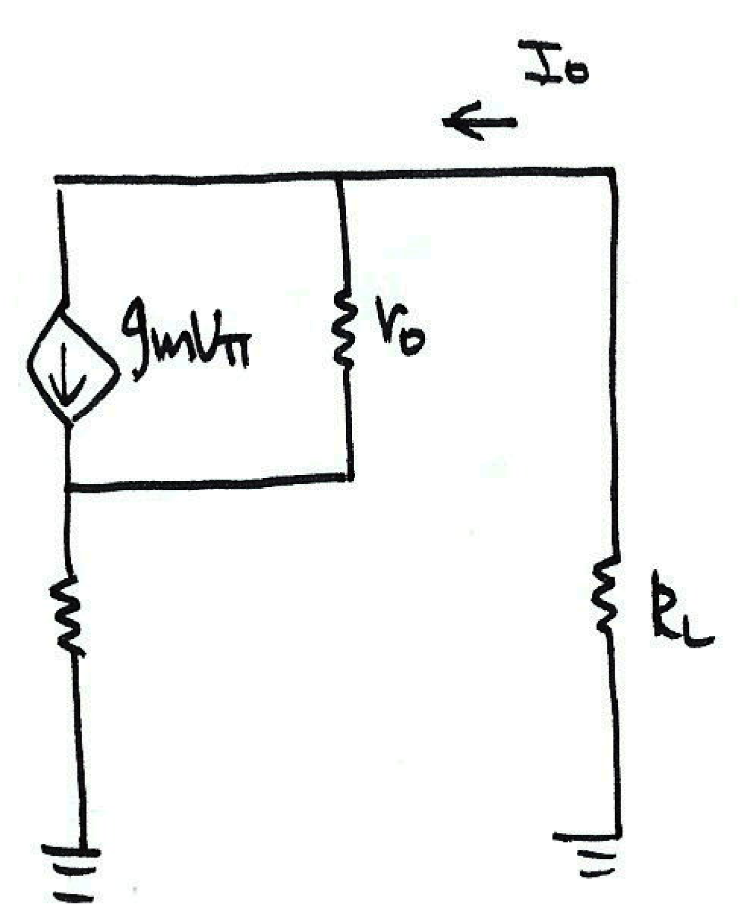
$r_o = 1k\Omega$

$\alpha \cong 0.99$



i)





$$V_\pi = \frac{r_\pi}{R_{sig} + r_\pi + R_e}(V_s - V_f)$$

$$I_o = \frac{g_m r_\pi}{r_\pi + R_{sig} + R_e}(V_s - V_f) = \frac{g_m r_\pi}{R_{sig} + R_e + r_\pi} V_i \quad (\because r_o \text{ 는 무시} \Rightarrow I_o \simeq g_m V_\pi)$$

$$\therefore A = \underline{\frac{g_m r_\pi}{R_{sig} + r_\pi + R_e}}, \qquad \text{Feedback Factor } \beta' = \frac{V_f}{I_o} = R_e.$$

$\rightarrow$ Loop Gain

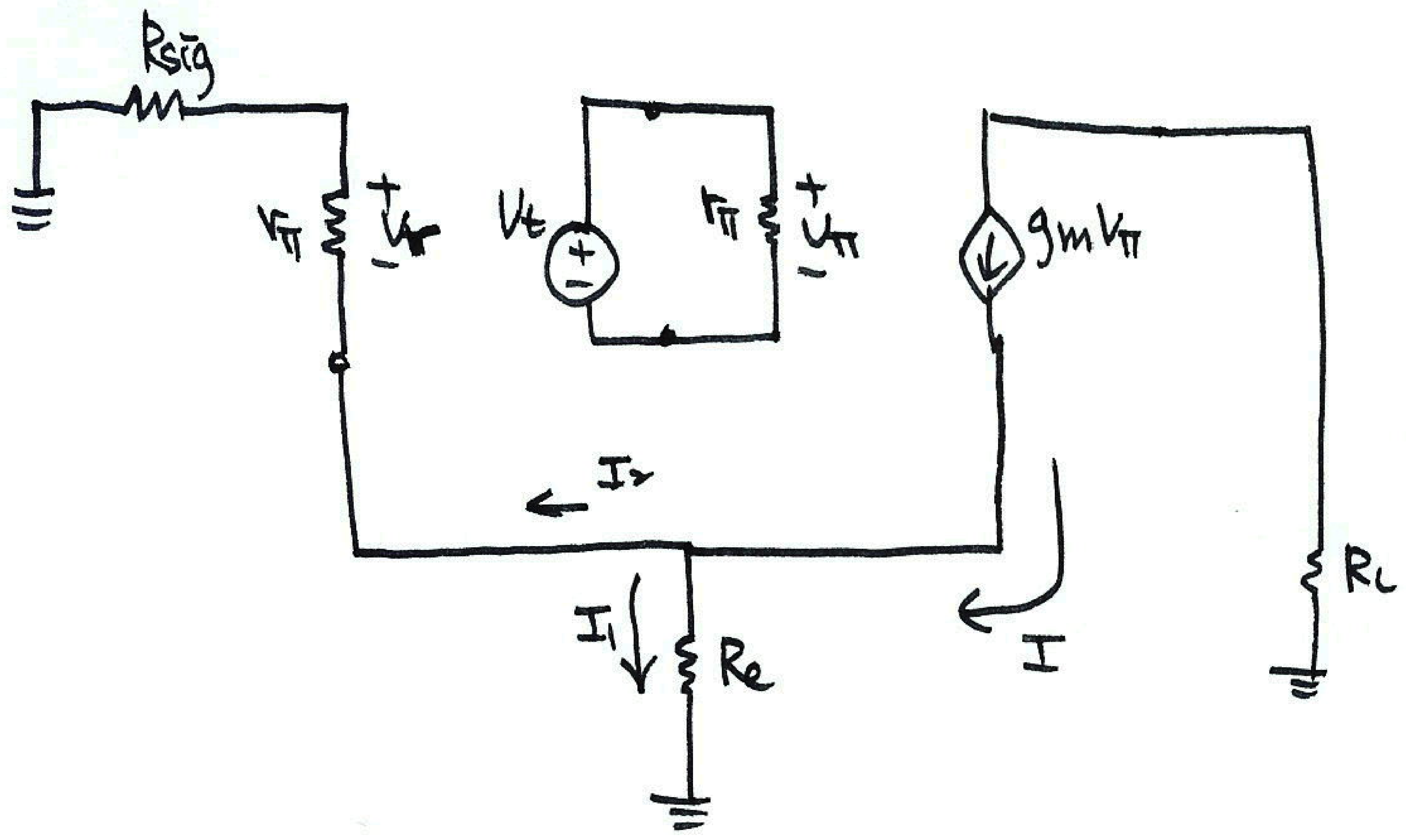
$$\therefore A\beta' = \frac{g_m r_\pi R_e}{R_{sig} + r_\pi + R_e}$$

$$\therefore A_f = \frac{A}{1+A\beta'} = \frac{g_m r_\pi}{R_{sig}+r_\pi+R_e+g_m r_\pi R_e} = \frac{\beta}{R_{sig}+(1+\beta)[r_e+R_e]} = 0.00793635$$

$(\because g_m r_\pi = \beta)$

$$\simeq 0.008\ A/V$$

ii) Loop Gain 구하기 방법.



$$A\beta' = -\frac{V_r}{V_t}$$

$$V_t = V_\pi, \quad V_r = -\frac{g_m r_\pi R_e}{R_e+(r_\pi+R_{sig})} V_t$$

$$\therefore A\beta' = \frac{g_m r_\pi R_e}{R_{sig}+r_\pi+R_e}$$

$\beta' = R_e$ 이므로. $\Rightarrow A = \dfrac{g_m r_\pi}{R_{sig}+r_\pi+R_e}$

$$\therefore A_f = \frac{\beta}{R_{sig}+(1+\beta)(r_e+R_e)}$$ $\Rightarrow$ 위 결과와 동일.

iii) $R_i = R_{sig}+r_\pi+R_e$

$$\therefore R_{if} = R_i(1+A\beta') = (R_{sig}+r_\pi+R_e)\left(1+\frac{g_m r_\pi R_e}{R_{sig}+r_\pi+R_e}\right) = R_{sig}+(1+\beta)(r_e+R_e)$$

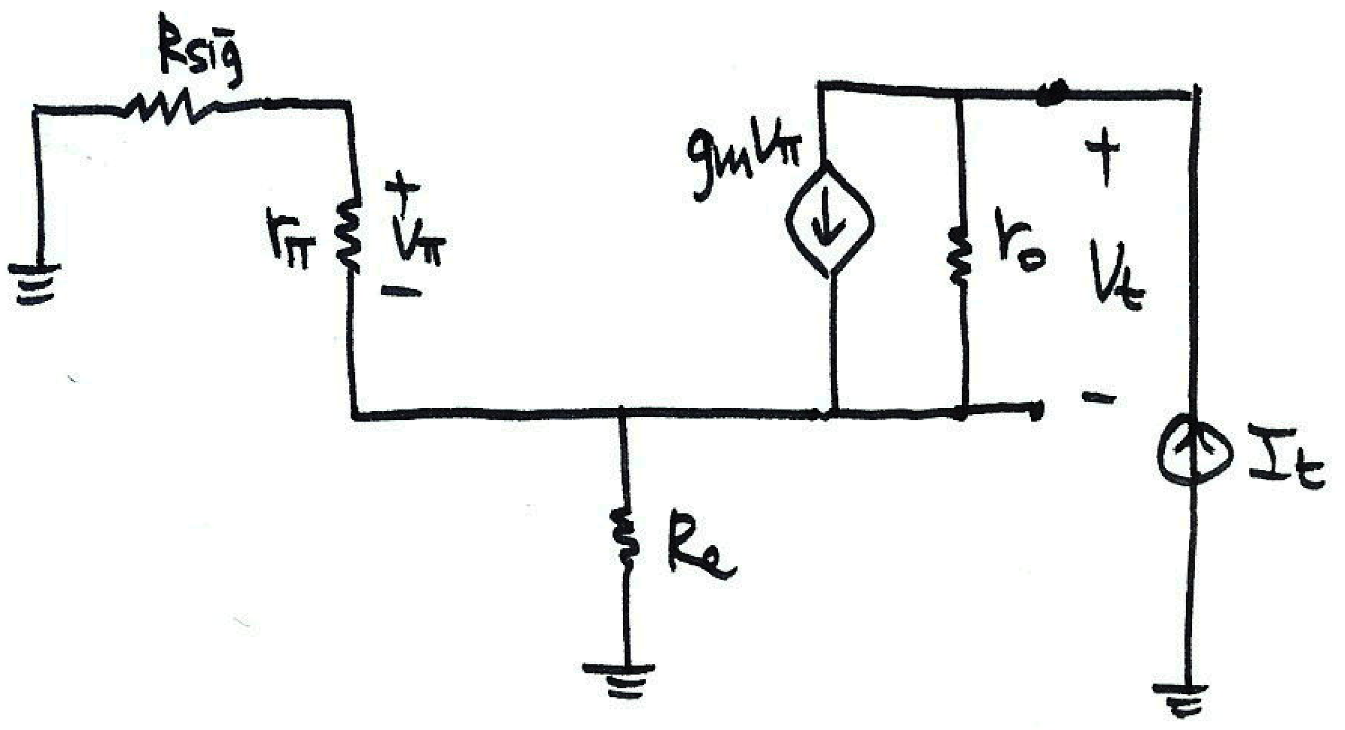
$\Rightarrow$ r_o를 고려했을시: $R_{sig}+(1+\beta)[r_e+R_e /\!/ r_o] \simeq 12.7k\Omega \longleftrightarrow = 12.6k\Omega$

↳ 너무커서 무시가능   비슷한 값.

iv) $R_o \cong r_o$ ($\because r_o$를 무시하면 $R_o = \infty$)

$$\therefore R_{of} = R_o(1+A\beta') = r_o\left(1+\frac{g_m r_\pi R_e}{R_{sig}+r_\pi+R_e}\right) = 2.47k\Omega$$

IV-i) R_{of} 구하는 다른 방법



$$I_t = g_m V_\pi + \frac{V_t}{r_o}$$

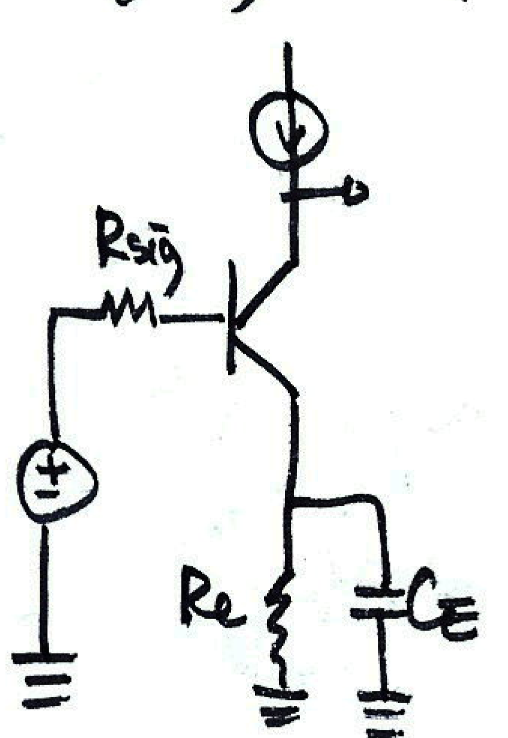
$$V_\pi = -I_t \cdot \frac{r_\pi R_e}{R_{sig} + r_\pi + R_e}$$

$$\therefore \frac{V_t}{I_t} = r_o \left(1 + \frac{g_m r_\pi R_e}{R_{sig} + r_\pi + R_e}\right)$$ ⇒ 위 결과와 동일

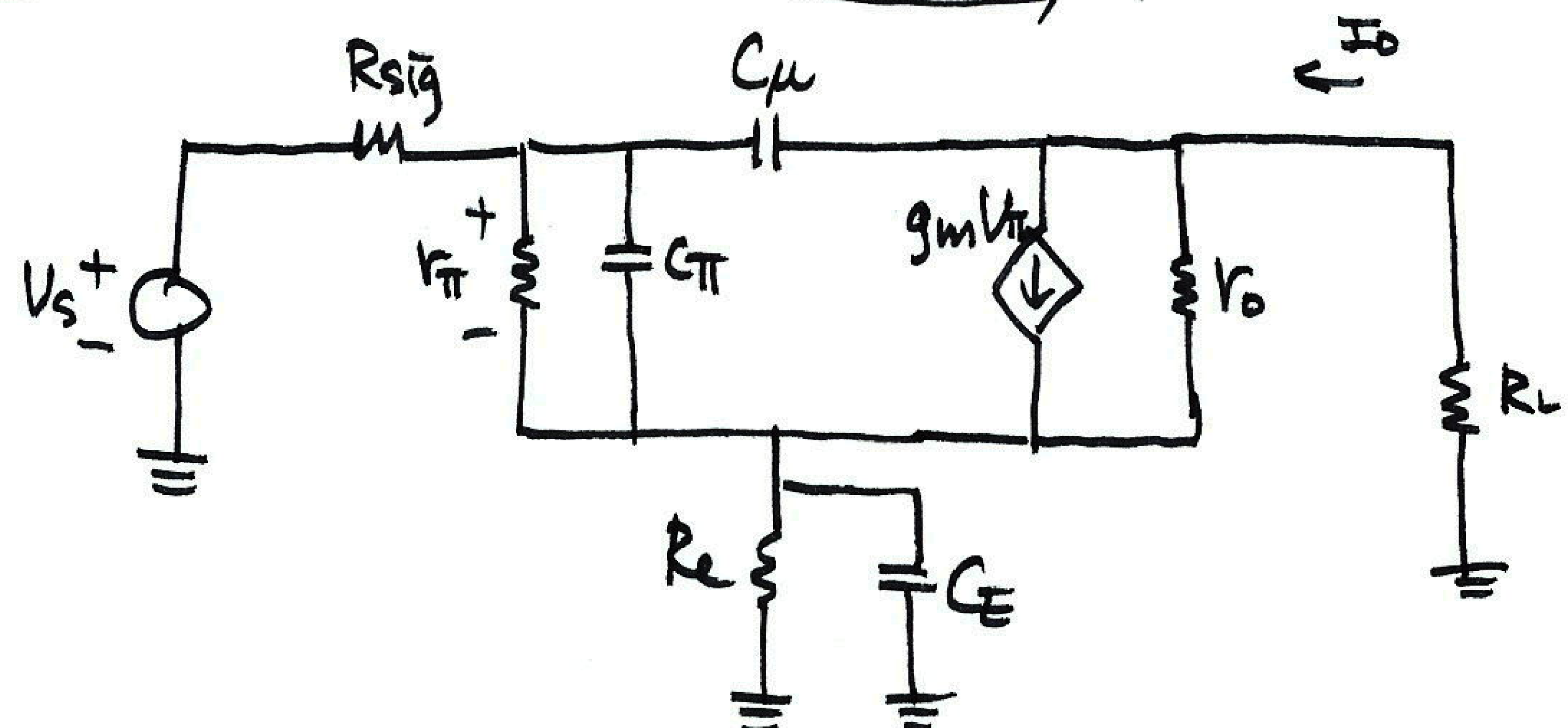
→ R_{sig} 효과로 인해 $R_{of} = r_o(1+g_m R_e)$로 근사되지 않습니다.

$R_{sig} \sim 5k\Omega \gg r_\pi = 25\Omega$

(3) 주어진 회로를 parasitic 성분을 고려하여 다시 그리면



⇒



이에 대한 언급없이 CE만으로 문제를 풀면 single pole response이므로 항상 stable. → 원하는 답 X.

즉 3-pole response의 회로를 얻을 수 있다.

C_μ, C_π는 BJT internal parameter이므로

C_E를 적당히 조절하면 unstable, stable 사이에서 design이 가능해진다.

i) Total Transfer function을 구하여 얻기.

$$T(s) = \frac{I_o}{V_s} = \frac{\alpha\left(s + j\frac{f}{f_z}\right)\cdots}{\left(s+j\frac{f}{f_{p1}}\right)\left(s+j\frac{f}{f_{p2}}\right)\left(s+j\frac{f}{f_{p3}}\right)}$$ → 굉장히 복잡합니다.

ω_{180}를 f_z보다 작은 주파수에서 발생하도록 C_E값을 결정.

ii) $|A\beta| \geq 1$을 이용해서 ωC_E를 구함.

여기서 $A(j\omega)$, $\beta(j\omega)$로 모두 주파수의 함수.

β만을 주파수의 함수로 놓고 $|A\beta| \geq 1$을 이용하여 풀면 엉뚱한 결과를 보입니다.

논리에 맞고 위의 의미를 전달하는 답을 작성하셨으면 점수를 드렸습니다.