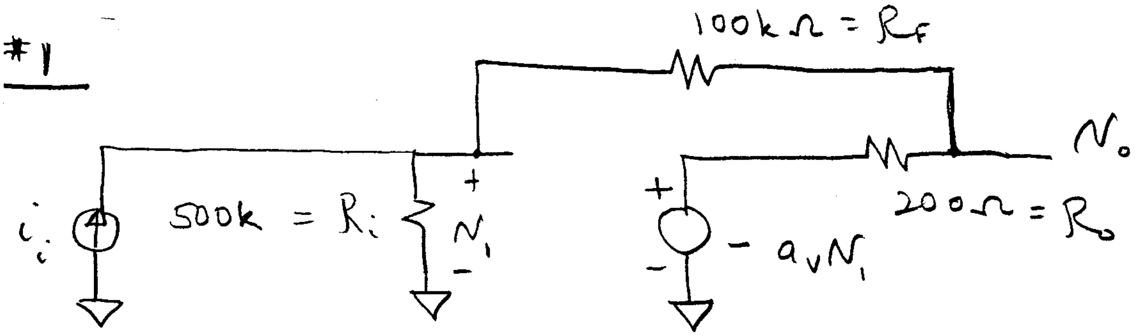
#1



- if $a_v \to \infty$ (causing $RR \to \infty$); then $N_i \to 0$ (ideal op amp) and $N_o = -100k\Omega \cdot i_i$

$$\Rightarrow A_\infty = -100k\Omega$$

- $$d = \left.\frac{N_o}{i_i}\right|_{a_v=0} = \frac{R_i}{R_i + R_F + R_o} \cdot R_o = \underline{167\Omega}$$

- $$RR = a_v \cdot \frac{R_i}{R_i + R_o + R_F} = \underline{\underline{62.5k}}$$

$$A_{CL} = A_\infty \frac{RR}{1+RR} + \frac{d}{1+RR} \cong A_\infty = \underline{\underline{-100k\Omega}}$$

$$R_{in}\,(C.L.) = R_{in}(a=0) \cdot \frac{1 + RR(\text{in shorted})}{1 + RR(\text{in open})}$$

$$R_{in}(a=0) = R_i \parallel (R_F + R_o) = 83.5k\Omega$$

$RR(\text{in shorted}) = 0 \qquad (\because N_1 = 0)$

$RR(\text{in open}) = RR \text{ above} = 62.5k$

$$\Rightarrow R_{IN}(C.L.) = 83.5k\Omega \; \frac{1+0}{1+62.5k} = \underline{\underline{1.3\Omega}}$$

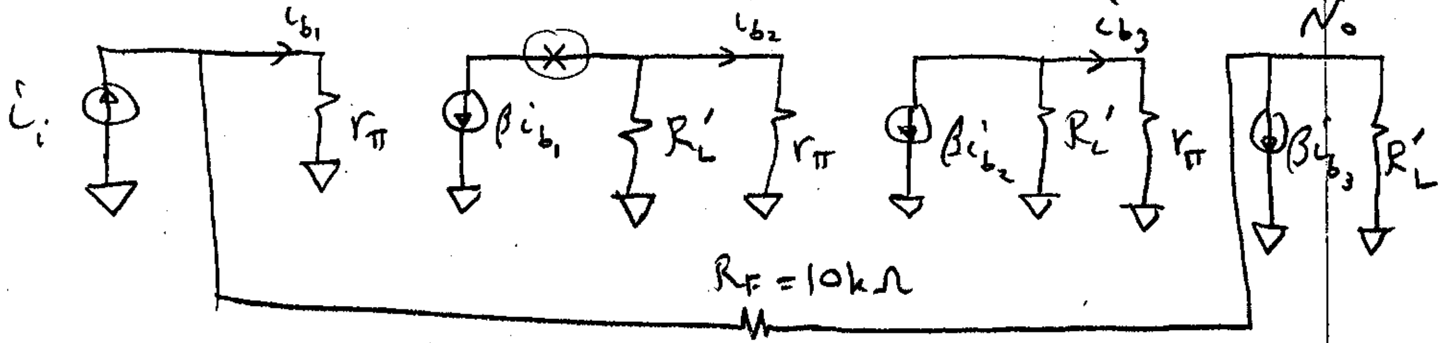
(quite a drop!)

$$R_{OUT}(C.L.) = R_{OUT}(a=0) \cdot \frac{1 + RR(\text{out shorted})}{1 + RR(\text{out open})}$$

$$= (200\Omega \,\|\, 600k\Omega) \cdot \frac{1+0}{1+62.5k} = \underline{\underline{3.2m\Omega}}$$

#2 Each Xtr has $r_o = \frac{50V}{1mA} = 50k\Omega$, $r_\pi = 5.2k\Omega$

$R_L' = 5k \| 50k\Omega = 4.55k\Omega$



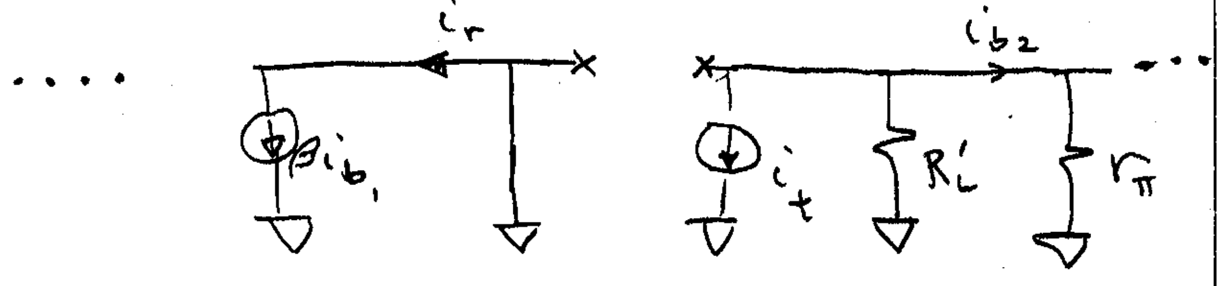
- if $\beta \to \infty$, $RR \to \infty$. $\beta \to \infty \Rightarrow i_{b_1} = 0$

So all i_i flows thru R_F giving $N_o = -R_F i_i$

$\therefore A_\infty = -R_F = -10k\Omega$

- RR (any βi_b source) = $RR(\beta i_{b_1})$ = ?

break at x, inject i_t to right of break, measure $i_r \Rightarrow RR = -\left.\frac{i_r}{i_t}\right|_{i_i=0}$



$$i_{b_2} = -\frac{R_L'}{r_\pi + R_L'} \cdot i_t$$

$$i_{b_3} = -\beta\, i_{b_2} \cdot \frac{R_L'}{r_\pi + R_L'}$$

$$i_{b_1} = -\beta\, i_{b_3} \cdot \frac{R_L'}{r_\pi + R_F + R_L'}$$

$$i_r = +\beta\, i_{b_1} = -\beta^3 \cdot \left(\frac{R_L'}{r_\pi + R_L'}\right)^2 \cdot \frac{R_L'}{r_\pi + R_F + R_L'}\; i_t$$

$$\Rightarrow RR = -\frac{i_r}{i_t} = \underline{\underline{401k}}$$

$$\cdot\; d = \left.\frac{v_o}{i_i}\right|_{\beta=0} = \frac{r_\pi}{r_\pi + R_F + R_L'} \cdot R_L' = 1.2k\Omega$$

$$A_{CL} = A_\infty \cdot \frac{RR}{1+RR} + \frac{d}{1+RR} \simeq -10k\Omega$$

$$R_{IN}(C.L.) \simeq R_{IN}(\beta=0) \cdot \frac{1 + RR\,(\text{in shorted})}{1 + RR\,(\text{in open})}$$

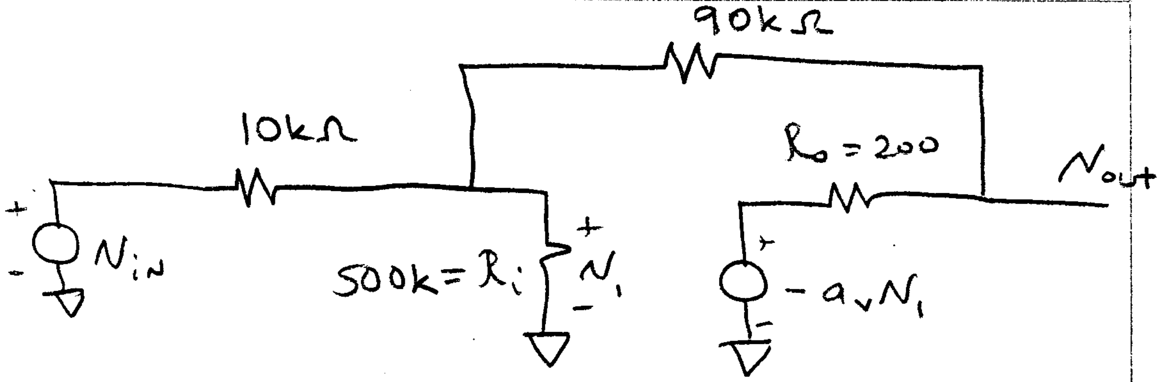
$$= r_\pi \| (R_F + R_L') \cdot \frac{1+0}{1+401k} = 9.5m\Omega$$

$$R_{OUT}(C.L.) = R_{OUT}(\beta=0) \cdot \frac{1+RR(\text{out shorted})}{1+RR(\text{out open})}$$

$$= \underbrace{R_L' \| (R_F + r_\pi)}_{3.5k\Omega} \cdot \frac{1+0}{1+401k}$$

$$= \underline{\underline{8.7m\Omega}}$$

#3.



if $a_v \to \infty$, (ideal op amp) $\Rightarrow A_\infty = -\frac{90k}{10k} = -9$

$$d = \left.\frac{v_o}{v_{in}}\right|_{a=0} = \frac{R_i \| (90k + R_o)}{10k + R_i \| (90k + R_o)} \cdot \frac{R_o}{90k + R_o} = 2\times 10^{-3}$$

$$RR = a_v \cdot \frac{10k \| 500k}{10k \| 500k + 90k + 200} = \underline{\underline{7350}}$$

$$A_u = -9 \cdot \frac{RR}{1+RR} + \frac{2\times 10^{-3}}{1+RR} \cong \underline{\underline{-9}}$$

$$R_{in} = R_{in}(a=0) \cdot \frac{1 + RR\ (\text{in short})}{1 + RR\ (\text{in open})}$$

$$R_{in}(a=0) = 10k\Omega + R_i \| (90k\Omega + R_o) = 86.4k\Omega$$

$$RR\ (\text{in short}) = a_v \cdot \frac{10k \| R_i}{10k \| R_i + 90k + R_o} = 7350$$

$$RR\ (\text{in open}) = a_v \cdot \frac{R_i}{R_i + 90k + R_o} \cong 63{,}500$$

$$\therefore R_{IN}(CL) = 86.4k\Omega \cdot \frac{1+7350}{1+63500} = \underline{\underline{10.0k\Omega}}$$

[not surprising, since the virtual ground forces $v_1 \simeq 0V \Rightarrow R_{IN} \simeq 10k\Omega$]

- To find Rout, set indep. source $v_{in} = 0$.

$$R_{out}(a_v=0) = 200 \| [90k + 10k \| 500k]\,\Omega \simeq 200\,\Omega$$

$RR(\text{out shorted}) = 0$ (if $v_{out}=0$; $v_1 = 0 \Rightarrow RR=0$)

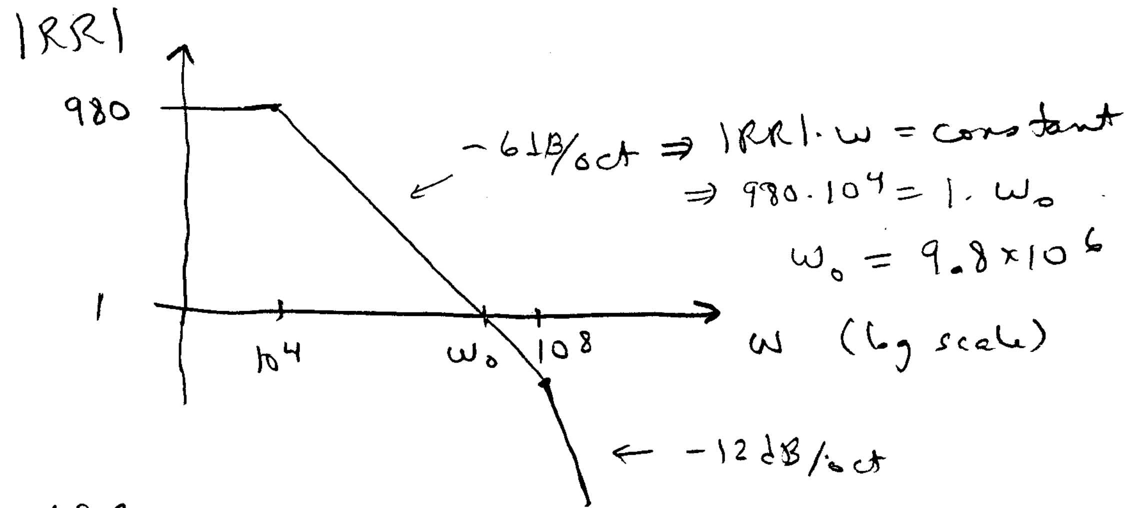
$RR(\text{out open}) = RR(\text{in shorted}) = 7350$ (see last page)

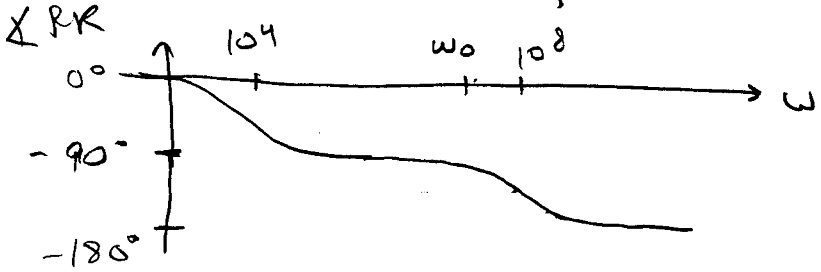
$$\therefore R_{out}(CL) = 200 \cdot \frac{1+0}{1+7350} \simeq 0.027\,\Omega$$

4. a) RR is same as in #3 w/ new $a_v(s)$:

$$RR = a_v(s) \cdot \frac{10k \| 500k}{10k \| 500k + 90k + 200}$$

$$= \frac{980}{\left(1+\frac{s}{10^4}\right)\left(1+\frac{s}{10^8}\right)}$$





$|RR(\omega_o)| = 1$

$$\measuredangle RR(\omega_o) = \measuredangle 980 - \measuredangle\left(1+\frac{j\omega_o}{10^4}\right) - \measuredangle\left(1+\frac{j\omega_o}{10^8}\right)$$

$$\cong 0 - 90° - \tan^{-1}\left(\frac{9.8\times10^6}{10^8}\right)$$

$$= -95.6°$$

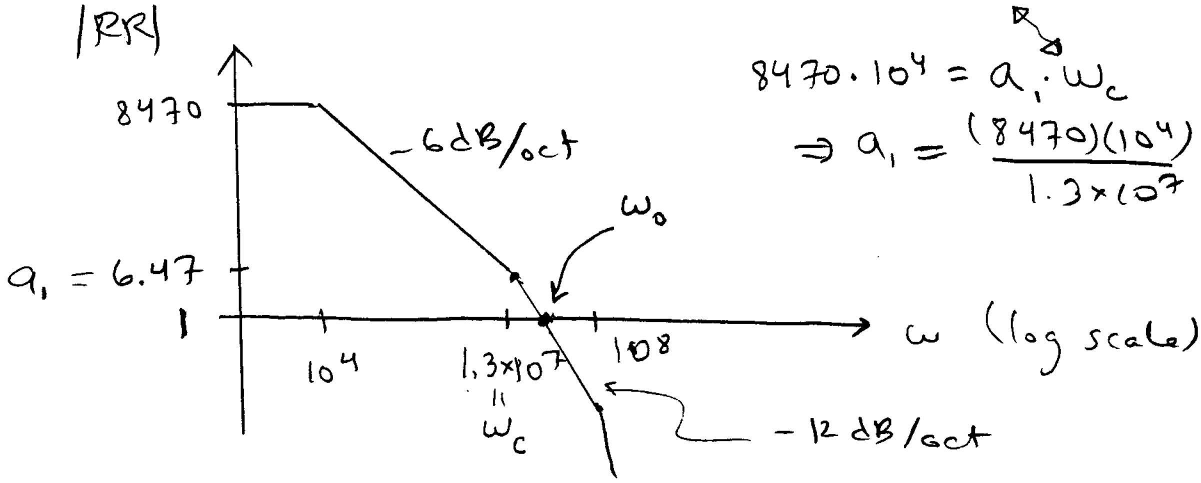
$PM = 180° + (-95.6°) = 84.4°$ ← circuit is stable w/ large PM.

4 b) now $RR = a_v(s) \cdot \dfrac{\frac{1}{sC} \parallel 500k}{\frac{1}{sC} \parallel 500k + 90k + 200}$

$$= a_v(s) \cdot \frac{500k\Omega}{590.2k\Omega + (90.2k\Omega)Cs(500k\Omega)}$$

$$= a_v(s) \cdot \frac{0.847}{1 + (76.4k\Omega)(C)s} \qquad C = 1pF$$

$$= \frac{8.47 \times 10^3}{\left(1 + \frac{s}{10^4}\right)\left(1 + \frac{s}{10^8}\right)\left(1 + \frac{s}{1.3 \times 10^7}\right)}$$



$8470 \cdot 10^4 = a_1 \cdot \omega_c$

$\Rightarrow a_1 = \dfrac{(8470)(10^4)}{1.3 \times 10^7} = 6.47$

-12 dB/oct $\Rightarrow |RR| \cdot \omega^2 = \text{constant}$

$$\Rightarrow a_1 \cdot \omega_c^2 = 1 \cdot \omega_o^2 \Rightarrow \omega_o = \sqrt{(6.47)(1.3 \times 10^7)^2} = 3.31 \times 10^7$$

$|RR(\omega_o)| = 1$

$$\measuredangle RR(\omega_o) = \measuredangle 8.47 \times 10^3 - \measuredangle\left(1 + \frac{j\omega_o}{10^4}\right) - \measuredangle\left(1 + \frac{j\omega_o}{10^8}\right) - \measuredangle\left(1 + \frac{j\omega_o}{1.3 \times 10^7}\right)$$

$$= 0 - 90° - 18.3° - 68.6° = -176.9°$$

$PM = 180 + \measuredangle RR(\omega_o) = 3.1°$ barely stable (PM is unacceptable!)

5. a) $\omega_{-3dB} \simeq \omega_o$ $\quad \omega_o =$ freq where $|RR(\omega_o)| = 1$

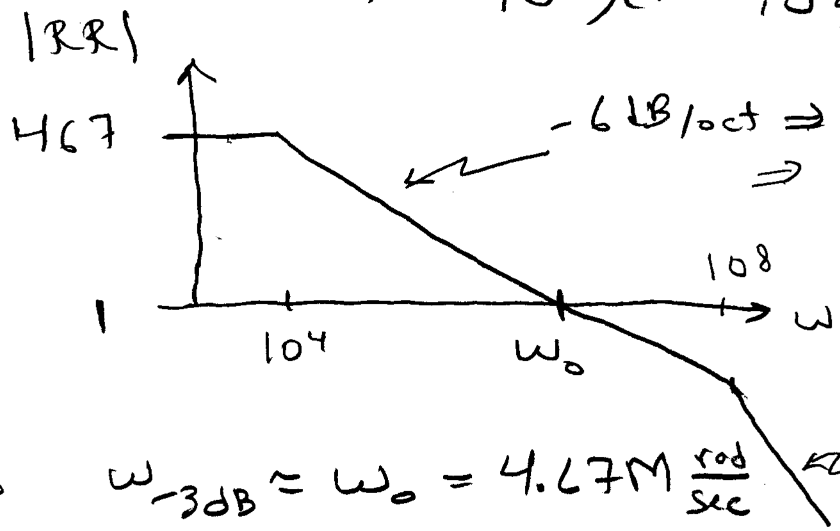
On plot of $|RR|$ for #4a):

$$\omega_o = 9.8 \times 10^6 \frac{rad}{s}$$

So $\omega_{-3dB} \simeq 9.8M \frac{rad}{s}$

b) now $RR = a_v(s) \cdot \dfrac{10k \parallel 500k}{10k \parallel 500k + 200k + 200}$

$$= \frac{467}{\left(1 + \frac{s}{10^4}\right)\left(1 + \frac{s}{10^8}\right)}$$



$-6\,dB/oct \Rightarrow |RR|\omega = \text{constant}$

$\Rightarrow 467 \cdot 10^4 = 1 \cdot \omega_o$

$\omega_o = 4.67M \frac{rad}{s}$

so $\omega_{-3dB} \simeq \omega_o = 4.67M \frac{rad}{sec}$

c) a) $|DC\ gain| = 9$ $\quad BW = 9.8M \frac{rad}{sec}$

b) $|DC\ gain| = 20$ $\quad BW = 4.67 \frac{rad}{sec}$

as $|gain| \uparrow$, $BW \downarrow$

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