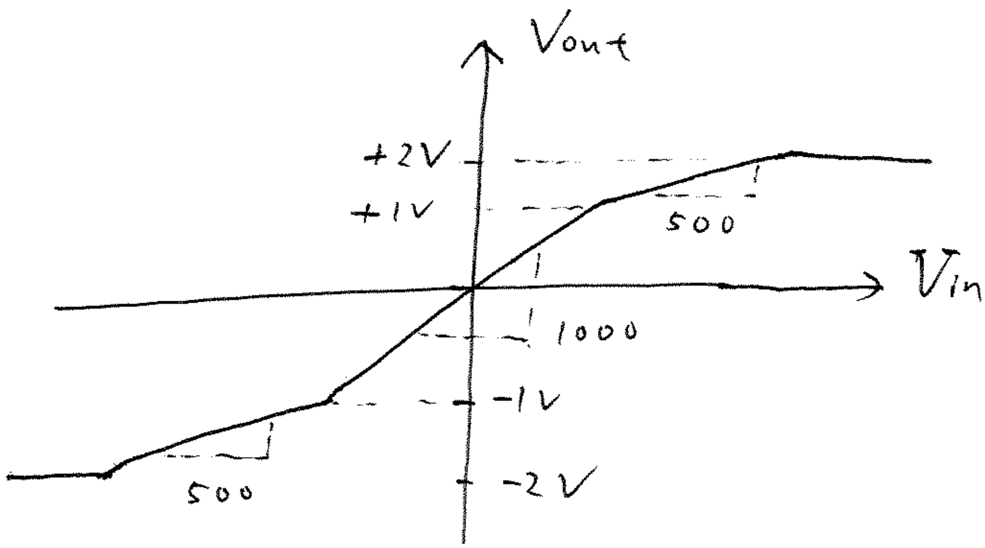
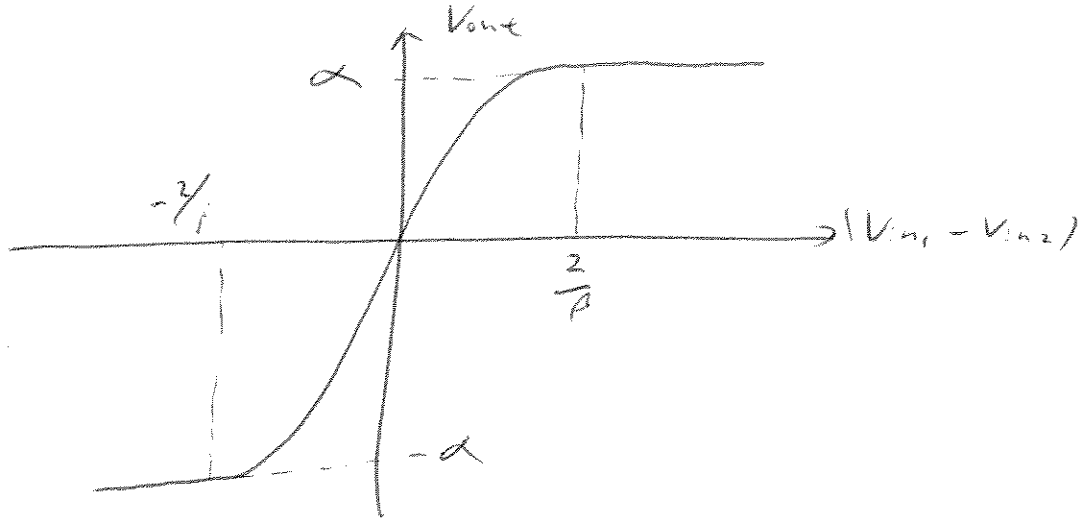
① a)



b) The largest input swing is $\pm$ 1mV, because gain is constant at 1000 over this range of input.

(2) $V_{out} = \alpha \tanh[\beta(V_{in1} - V_{in2})]$



To find small-signal gain,

$\because \tanh z = z - \frac{1}{3}z^3 + \frac{2}{15}z^5 + \cdots$

$\therefore$ for $\beta(V_{in1} - V_{in2}) \simeq 0$,

$$\frac{d V_{out}}{d(V_{in1} - V_{in2})} \simeq \frac{d}{d(V_{in1} - V_{in2})} \alpha\beta(V_{in1} - V_{in2})$$

$$= \underline{\underline{\alpha\beta}}$$

(3) Closed-loop gain $= \left(1 + \frac{R_1}{R_2}\right)$

$$= 8$$

Gain error $= \left(1 + \frac{R_1}{R_2}\right)(A_0)^{-1}$

$$= \frac{8}{2000}$$

$$= \underline{\underline{0.4\%}}$$

4 Closed loop gain $= \left(1+\frac{R_1}{R_2}\right)$

$= 4$

Gain error $= \left(1+\frac{R_1}{R_2}\right)\left(\frac{1}{A_0}\right)$

$= 0.1\%$

$\therefore \quad 4/A_0 = 0.1\%$

$A_0 = \underline{\underline{4000}}$

⑤ Let $G_0 = \left(1 + \frac{R_1}{R_2}\right)$

Desired gain $= \alpha_1$

$$= \frac{A_0}{1 + \frac{R_2}{R_1 + R_2} A_0}$$

$$\therefore \quad \alpha_1 = \frac{A_0}{1 + \frac{A_0}{G_0}}$$

$$1 + \frac{A_0}{G_0} = \frac{A_0}{\alpha_1}$$

$$\frac{1}{G_0} = \frac{1}{\alpha_1} - \frac{1}{A_0}$$

$$G_0 = \frac{A_0 \alpha_1}{A_0 - \alpha_1}$$

$$\therefore \quad \frac{R_2}{R_1 + R_2} = \frac{1}{G_0} = \frac{1}{\alpha_1} - \frac{1}{A_0}$$

b) if A_0 drops to $0.6 A_0$,

$$\text{Actual gain} = \frac{0.6 A_0}{1 + \left(\frac{1}{\alpha_1} - \frac{1}{A_0}\right) 0.6 A_0}$$

$$= \frac{0.6 A_0}{0.4 + \frac{0.6 A_0}{\alpha_1}}$$

(5) b) (cont'd)

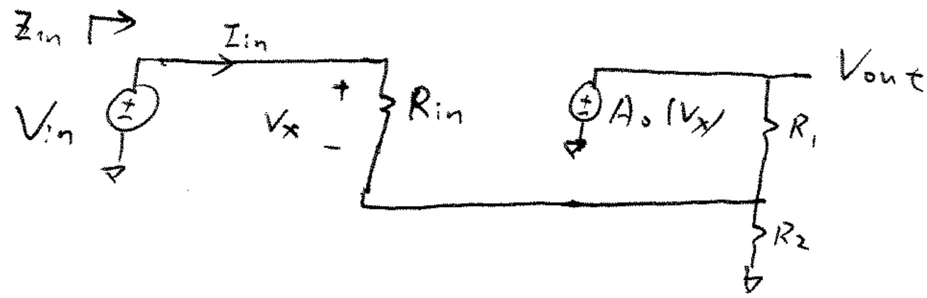
$$\text{Actual gain} = \frac{\alpha_1}{1 + \frac{0.4}{0.6}\frac{\alpha_1}{A_o}}$$

$$\simeq \alpha_1\left(1 - \frac{0.4}{0.6}\frac{\alpha_1}{A_o}\right)$$

$\therefore$ the gain error $\simeq \dfrac{0.4}{0.6}\dfrac{\alpha_1^2}{A_o}$

$$= \frac{2}{3}\frac{\alpha_1^2}{A_o}$$

⑥ Using the model in Fig. 8.44,



$$V_x = V_{in} - V_{out}\frac{R_1}{R_1+R_2}$$

$$V_{out} = A_0 V_x$$

$$= A_0\left(V_{in} - V_{out}\frac{R_1}{R_1+R_2}\right)$$

$$A_0 V_{in} = V_{out}\left(1 + A_0\frac{R_1}{R_1+R_2}\right)$$

$$\frac{V_{out}}{V_{in}} = \frac{A_0}{1 + A_0\frac{R_1}{R_1+R_2}} \quad \text{—— (1)}$$

To find input impedance (Z_{in}),

$$I_{in} = \frac{V_x}{R_{in}}$$

$$= \frac{1}{R_{in}}\left(V_{in} - V_{out}\frac{R_1}{R_1+R_2}\right)$$

$$= \frac{V_{in}}{R_{in}}\left(1 - \frac{V_{out}}{V_{in}}\frac{R_1}{R_1+R_2}\right)$$

6 (cont'd)

$$I_{in} = \frac{V_{in}}{R_{in}}\left(1 - \frac{A_0}{1 + A_0 \frac{R_1}{R_1+R_2}} \frac{R_1}{R_1+R_2}\right)$$

$$= \frac{V_{in}}{R_{in}}\left(1 - \frac{1}{\frac{R_1+R_2}{A_0 R_1} + 1}\right)$$

$$= \frac{V_{in}}{R_{in}}\left(\frac{\frac{R_1+R_2}{A_0 R_1}}{\frac{R_1+R_2}{A_0 R_1} + 1}\right)$$

$$\therefore Z_{in} = \frac{V_{in}}{I_{in}} = R_{in}\left[\frac{1 + \frac{R_1+R_2}{A_0 R_1}}{\frac{R_1+R_2}{A_0 R_1}}\right] \quad (2)$$

As $A_0 \to \infty$,

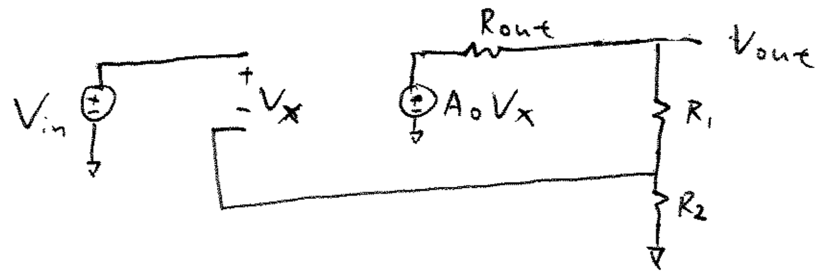
$$\text{gain} = \left.\frac{V_{out}}{V_{in}}\right|_{A_0\to\infty} \quad [\text{From } (1)]$$

$$= 1 + \frac{R_2}{R_1}$$

$$Z_{in} = \left.\frac{V_{in}}{I_{in}}\right|_{A_0\to\infty} \quad [\text{From } (2)]$$

$$= \infty$$

(7)



Similar to Prob. (6),

$$\text{gain} = \frac{V_{out}}{V_{in}}$$

$$V_x = V_{in} - V_{out} \frac{R_2}{R_1 + R_2}$$

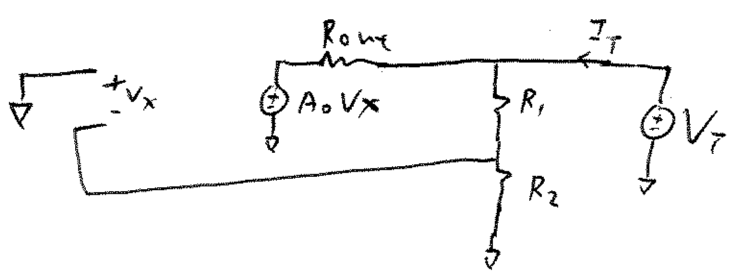
$$V_{out} = A_0 V_x \frac{R_1 + R_2}{R_{out} + R_1 + R_2}$$

$$= A_0 \left(V_{in} - V_{out} \frac{R_2}{R_1 + R_2} \right) \frac{R_1 + R_2}{R_{out} + R_1 + R_2}$$

$$V_{in} A_0 \frac{R_1 + R_2}{R_{out} + R_1 + R_2} = V_{out} \left(1 + \frac{A_0 R_2}{R_{out} + R_1 + R_2} \right)$$

$$\frac{V_{out}}{V_{in}} = \frac{A_0 \frac{R_1 + R_2}{R_{out} + R_1 + R_2}}{1 + \frac{A_0 R_2}{R_{out} + R_1 + R_2}}$$

To find output impedance (Z_{out})



(7) (cont'd) $V_x = \frac{R_2}{R_1 + R_2} V_T$

$$I_T = \frac{V_T}{R_1 + R_2} + \frac{V_T - A_0 V_x}{R_{out}}$$

$$= V_T \left[\frac{R_{out} + R_1 + R_2 - A_0 R_2}{(R_{out})(R_1 + R_2)} \right]$$

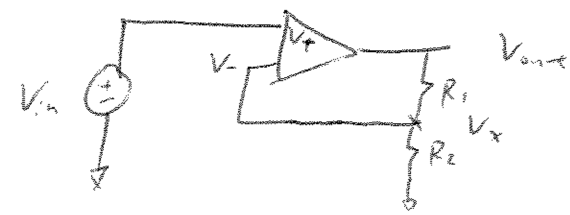
$$Z_{out} = \frac{V_T}{I_T} = \frac{(R_{out})(R_1 + R_2)}{R_{out} + R_1 + R_2 - A_0 R_2}$$

As $A_0 \to \infty$,

$$\text{gain} = 1 + \frac{R_1}{R_2}$$

$$Z_{out} = 0$$

(8)



ΔR for now.

$$V_{out} = A_0 (V_x)$$

$$V_x = V_{in} - \frac{R_2}{R_1+R_2} V_{out}$$

$$\therefore \frac{-V_{out}}{A_0} = V_{in} - \frac{R_1}{R_1+R_2} V_{out}$$

$$\frac{V_{out}}{V_{in}} = \frac{A_0(R_1+R_2)}{A_0 R_1 - 1} = \text{nominal gain}$$

if $R_2' = \Delta R + R_2$

$$\left(\frac{V_{out}}{V_{in}}\right)' = \frac{A_0(R_1+\Delta R+R_2)}{A_0 R_1 - 1}$$

$$\therefore \text{gain error} = \frac{\left(\frac{V_{out}}{V_{in}}\right)' - \left(\frac{V_{out}}{V_{in}}\right)}{\frac{V_{out}}{V_{in}}}$$

$$= \frac{\Delta R}{A_0 R_1 - 1} \times \frac{A_0 R_1 - 1}{A_0(R_1+R_2)}$$

$$= \frac{\Delta R}{A_0(R_1+R_2)} \quad //$$

(9) Closed-loop gain $\approx \left(1+\frac{R_1}{R_2}\right)\left[1-\left(1+\frac{R_1}{R_2}\right)\frac{1}{A_0}\right]$

$$= 5\left[1-\frac{5}{A_0}\right]$$

$\therefore$ As A_0 decreases to $0.8A_0$, closed-loop gain decreases along (deviating more from the norminal

A_0 drops to $0.8A_0$ when $|V_{in1} - V_{in2}| = 2mV$.

$$\because \quad V_{in2} = V_{out}\left(\frac{R_2}{R_1+R_2}\right)$$

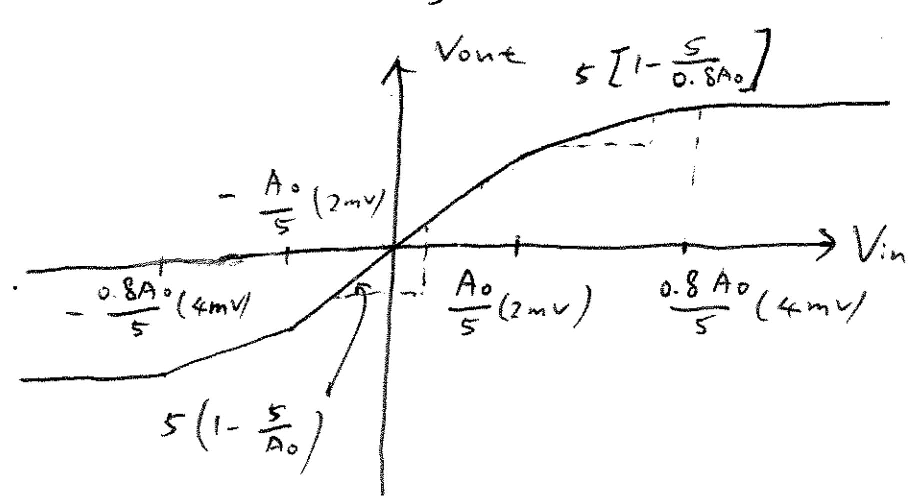
and $V_{out} = 5\left(1-\frac{5}{A_0}\right)V_{in1}$

$$\therefore \quad V_{in2} = 5\left(1-\frac{5}{A_0}\right)\left(\frac{1}{5}\right)V_{in1}$$

$$V_{in1} - V_{in2} = \frac{5}{A_0}V_{in1}$$

At $V_{in1} - V_{in2} = 2mV$,

$$V_{in1} = \frac{A_0}{5}(2mV)$$



(10) $$\frac{V_{out}}{V_{in}} = 1 + \frac{R_1}{R_s}$$

$\because V_{in} = 1V,$ $$V_{out} = 1 + \frac{R_1}{R_0 + \alpha W}$$

$$\frac{dV_{out}}{dW} = -R_1 \alpha \left(R_0 + \alpha W \right)^{-2}.$$

$$= \frac{-R_1 \alpha}{(R_0 + \alpha W)^2}.$$

11 if $A_o = \infty$,

$$V_+ = V_- = V_{in}$$

$$V_- = \left(\frac{R_2}{R_2 + R_3}\right)\left[\frac{R_4 \,//\, (R_2 + R_3)}{R_1 + R_4 \,//\, (R_2 + R_3)}\right] V_{out}$$

$\therefore$ closed-loop gain $\dfrac{V_{out}}{V_{in}}$

$$= \frac{(R_2 + R_3)\,[R_1 + R_4 \,//\, (R_2 + R_3)]}{R_2\,[R_4 \,//\, (R_2 + R_3)]}$$

if $R_1 = 0$,

$$G\big|_{R_1 = 0} = 1 + \frac{R_3}{R_2}$$

if $R_3 = 0$,

$$G\big|_{R_3 = 0} = \frac{R_2\,[R_1 + R_4 \,//\, R_2]}{R_2\,[R_4 \,//\, R_2]}$$

$$= 1 + \frac{R_1}{R_4 \,//\, R_2}$$

(12) Gain Error $= \frac{1}{A_0}\left(1+\frac{R_1}{R_2}\right)$

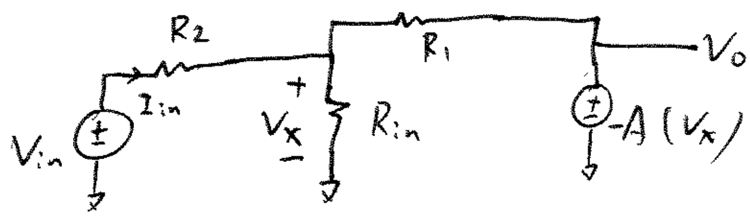
$$= \frac{1}{A_0}(1+8)$$

$$= 0.2\%$$

$$\therefore \quad \frac{1}{A_0}(9) = 0.2\%$$

$$A_0 = 4500$$

(13)



$$V_o = -A V_x \qquad \text{--- (1)}$$

$$\frac{V_{in} - V_x}{R_2} + \frac{V_o - V_x}{R_1} = \frac{V_x}{R_{in}} \qquad \text{--- (2)}$$

Combining (1) and (2),

$$\frac{V_{in}}{R_2} = -\frac{V_o}{R_1} + \frac{V_o}{(-A)}\left(\frac{1}{R_{in}} + \frac{1}{R_1} + \frac{1}{R_2}\right)$$

$$\frac{V_{in}}{R_2} = V_o \left[\frac{A R_{in} R_2 + R_1 R_2 + R_{in} R_2 + R_{in} R_1}{(-A) R_{in} R_1 R_2} \right]$$

$$\frac{V_o}{V_{in}} = -\frac{A R_{in} R_1}{R_1 R_2 + R_{in} R_2 + R_{in} R_1 + A R_{in} R_2}$$

Input impedance $(Z_{in}) = \dfrac{V_{in}}{I_{in}}$

$$I_{in} - \frac{V_x}{R_{in}} + \frac{(-A) V_x - V_x}{R_1} = 0$$

$$I_{in} = V_x \left[\frac{1}{R_{in}} + \frac{A+1}{R_1} \right]$$

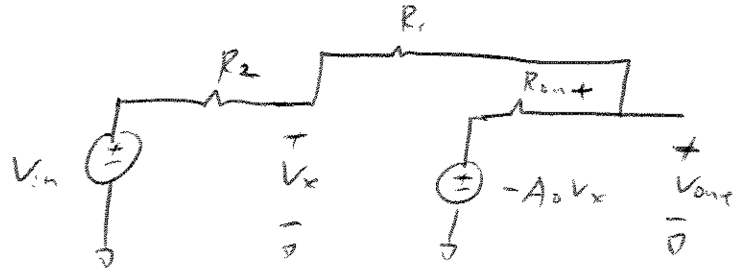
$$\because \quad V_x = V_{in} - I_{in} R_2$$

$$I_{in} = \left[V_{in} - I_{in} R_2 \right] \left[\frac{1}{R_{in}} + \frac{A+1}{R_1} \right]$$

$$I_{in} \left[1 + \frac{R_2}{R_{in}} + \frac{R_2}{R_1}(A+1) \right] = V_{in} \left(\frac{1}{R_{in}} + \frac{A+1}{R_1} \right)$$

$$Z_{in} = \frac{V_{in}}{I_{in}} = \frac{1 + \frac{R_2}{R_{in}} + \frac{R_2}{R_1}(A+1)}{\frac{1}{R_{in}} + \frac{A+1}{R_1}}$$

(14)



By KCL,

$$\frac{V_{in} - V_x}{R_2} = - \frac{-A_0 V_x - V_x}{R_1 + R_{out}}$$

$$\because \quad V_x = - \frac{V_{out}}{A_0}$$

$$\frac{V_{in}}{R_2} = - \frac{V_{out}}{A_0 R_2} - \frac{A_0 + 1}{A_0} \frac{V_{out}}{R_1 + R_{out}}$$

$$\because \quad \frac{A_0 + 1}{A_0} \approx 1$$

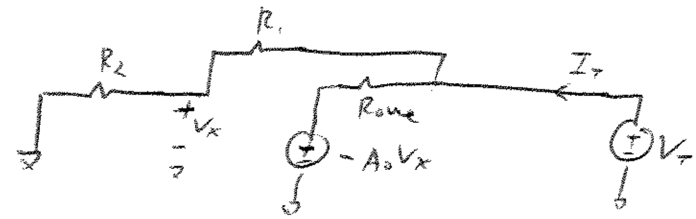
$$\therefore \quad \frac{V_{in}}{R_2} \approx - \frac{V_{out}}{A_0 R_2} - \frac{V_{out}}{R_1 + R_{out}}$$

$$\frac{V_{in}}{R_2} \approx - V_{out} \left(\frac{R_1 + R_{out} + A_0 R_2}{A_0 R_2 (R_1 + R_{out})} \right)$$

$$\therefore \quad \frac{V_{out}}{V_{in}} \approx - \frac{A_0 (R_1 + R_{out})}{R_1 + R_{out} + A_0 R_2}$$

(14) cont'd :

To find output impedance (Z_{out})



$$Z_{out} = \frac{V_T}{I_T}$$

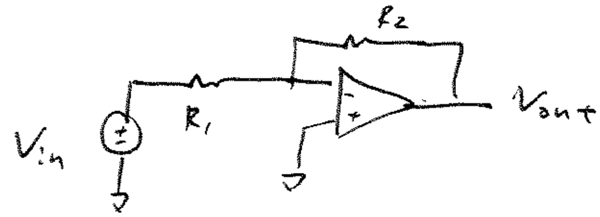
$$V_x = \frac{R_2}{R_1 + R_2} V_T \quad \text{———} \quad (1)$$

$$I_T = \frac{V_T}{R_1 + R_2} + \frac{V_T + A_o V_x}{R_{out}} \quad \text{———} \quad (2)$$

$$I_T = V_T \left[\frac{1}{R_1 + R_2} + \frac{1 + \frac{A_o R_2}{R_1 + R_2}}{R_{out}} \right]$$

$$\frac{V_T}{I_T} = \frac{R_{out}(R_1 + R_2)}{R_{out} + R_1 + (A_o + 1) R_2}$$

(15)



$$\left|\frac{V_{out}}{V_{in}}\right| = \frac{R_2}{R_1} = 4 \quad \text{——— (1)}$$

$$\therefore \; R_2 = 4R_1$$

$$Z_{in} \approx R_1 = 10\,k\Omega \quad \text{—— (2)}$$

$$\therefore \; R_2 = 40\,k\Omega$$

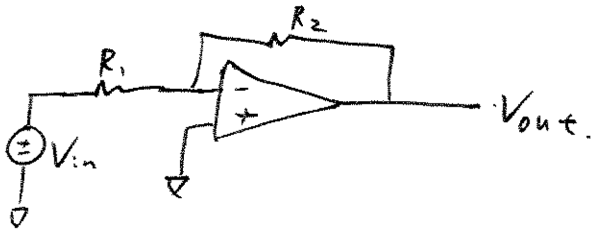
$$A_0 = 1000 \quad \text{——— (3)}$$

$$\text{gain error} = \frac{1}{A_0}\left(1 + \frac{R_2}{R_1}\right)$$

$$= \frac{1}{1000}(1+4)$$

$$= 0.5\,\%$$

(16)



$$\text{Nominal gain} = \frac{R_2}{R_1} = 8 \text{ ——— ①}$$

$$R_2 = 8R_1$$

$$\text{Input impedance} \approx R_1 = 1000\ \Omega \text{ ——— ②}$$

$$\therefore R_2 = 8000\ \Omega.$$

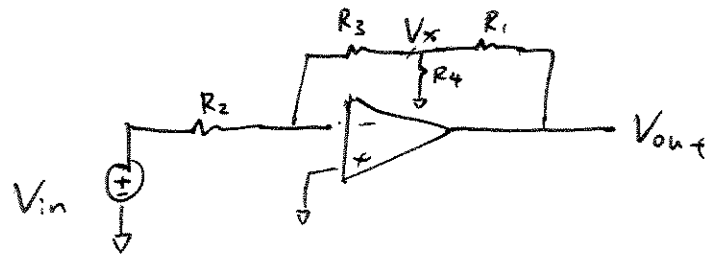
$$\text{gain error} = 0.1\% \text{ ——— ③}$$

$$\therefore \frac{1}{A_0}\left(1+\frac{R_2}{R_1}\right) = 0.1\%$$

$$\frac{1}{A_0}(9) = \frac{0.1}{100}$$

$$\therefore A_0 = 9000$$

(17)



$$V_- = V_+ = 0 \quad (\because A = \infty)$$

$$\frac{V_{in}}{R_2} = -\frac{V_x}{R_3} \longrightarrow ①$$

$$V_x = \frac{R_3 // R_4}{R_1 + R_3 // R_4} V_{out} \longrightarrow ②$$

Combining ① and ②,

$$\frac{V_{in}}{R_2} = -\frac{R_3 // R_4}{R_3 (R_1 + R_3 // R_4)} V_{out}$$

$$\frac{V_{out}}{V_{in}} = -\frac{R_3}{R_2} \frac{(R_1 + R_3 // R_4)}{R_3 // R_4}$$

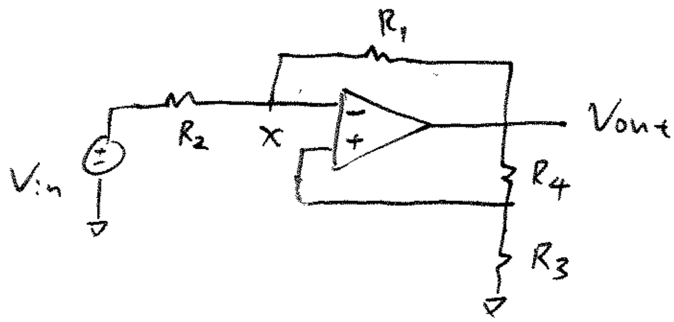
if $R_1 \longrightarrow 0$,

$$\frac{V_{out}}{V_{in}} = -\frac{R_3}{R_2} \quad \text{(typical inverting amplifier)}$$

if $R_3 \longrightarrow 0$,

$$\frac{V_{out}}{V_{in}} = -\frac{R_1}{R_2} \quad \text{(typical inverting amplifier)}$$

(18)



$\because A = \infty,$

$$V_- = V_+$$

$$\therefore \quad V_x = \frac{R_3}{R_3 + R_4} V_{out}$$

$$\frac{V_{in} - V_x}{R_2} = - \frac{V_{out} - V_x}{R_1}$$

$$\frac{V_{in}}{R_2} = V_x \left(\frac{1}{R_1} + \frac{1}{R_2} \right) - \frac{V_{out}}{R_1}$$

$$= \left[\left(\frac{R_3}{R_3 + R_4} \right) \left(\frac{1}{R_1} + \frac{1}{R_2} \right) - \frac{1}{R_1} \right] V_{out}$$

$$\therefore \quad \frac{V_{out}}{V_{in}} = \frac{\frac{1}{R_2}}{\left(\frac{R_3}{R_3 + R_4} \right) \left(\frac{1}{R_1} + \frac{1}{R_2} \right) - \frac{1}{R_1}}$$

(19) From eq. (8.31),

$$V_{out} = -\frac{1}{R_1 C_1}\int V_{in}\,dt$$

$$= -\frac{1}{R_1 C_1}\int V_0 \sin \omega t \; dt$$

$$= \frac{V_0}{R_1 C_1 \omega}\cos \omega t$$

$\therefore$ Amplitude of output $= \dfrac{V_0}{R_1 C_1 \omega}$ //

(20) From prob. (19)

Amplification of the integrator $= \dfrac{1}{R_1 C_1 \omega}$

$$\therefore \quad \frac{1}{R_1 C_1 \omega} = 10$$

$$\frac{1}{\omega} = 10 \times 10ns$$

$$\therefore \omega = 10 MHz.$$

$\therefore$ The frequency of the sinusoid is 10MHz.

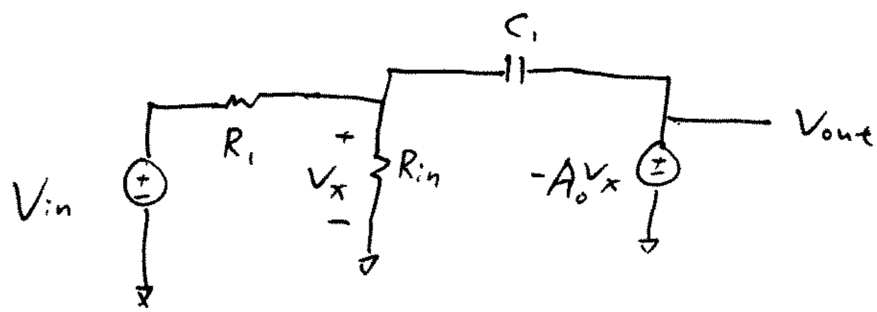
(21) From Eq. (8.37)

$$S_p = \frac{-1}{2\pi (A_0 + 1) R_1 C_1} \leq -1 \text{ Hz}.$$

$$\therefore \quad 2\pi (A_0 + 1)(10\text{ k}\Omega)(1\text{ nF}) \geq 1$$

$$A_0 \geq 15915$$

(22)



$$\frac{V_{in}-V_x}{R_1} + \frac{V_{out} - V_x}{\frac{1}{sC_1}} = \frac{V_x}{R_{in}},$$

where $s = jw$

$\because$ $V_{out} = -A_o V_x$

$$\therefore \frac{V_{in}}{R_1} = (sC_1)\left[-\frac{V_{out}}{A_o} - V_{out} \right] - \frac{V_{out}}{A_o}\left(\frac{1}{R_{in}}+\frac{1}{R_1}\right)$$

$$= -V_{out}\left[\frac{sC_1}{A_o} + sC_1 + \frac{1}{A_o R_{in}} + \frac{1}{A_o R_1} \right]$$

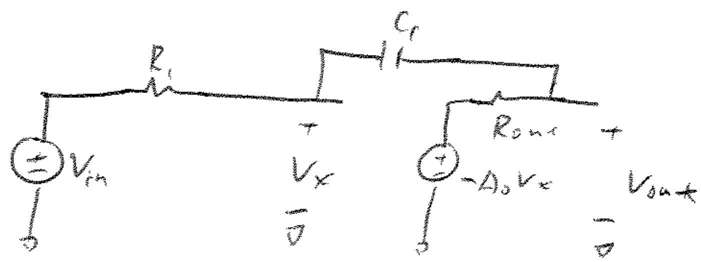
$$\frac{V_{out}}{V_{in}} = \frac{-1}{\left(\frac{1}{A_o}+\frac{R_1}{A_o R_{in}}\right) + \left(1+\frac{1}{A_o}\right) s R_1 C_1}$$

To find the pole, equate denominator to zero,

$$S_p = \frac{-1}{(A_o+1) R_1 C_1}\left(1 + \frac{R_1}{R_{in}}\right)$$

[$\therefore$ pole shifted out by $\left(1+\frac{R_1}{R_{in}}\right)$]

(23)



By KCL,

$$\frac{V_{in} - V_x}{R_1} = -\frac{-A_0 V_x - V_x}{R_{out} + \frac{1}{sC_1}}$$

$$\because \quad V_x = -\frac{V_{out}}{A_0}$$

$$\frac{V_{in}}{R_1} = -\frac{V_{out}}{A_0 R_1} - \frac{(A_0+1)}{A_0} \frac{V_{out}}{R_{out} + \frac{1}{sC_1}}$$

$$\simeq -V_{out} \left[\frac{1}{A_0 R_1} + \frac{1}{R_{out} + \frac{1}{sC_1}} \right]$$

$$\left(\because \frac{A_0+1}{A_0} \simeq 1 \right)$$

$$\therefore \frac{V_{out}}{V_{in}} = -\frac{A_0 \times \left(R_{out} + \frac{1}{sC_1}\right)}{\left(A_0 R_1 + R_{out} + \frac{1}{sC_1}\right)}$$

$$\text{pole} = -\frac{1}{C_1 \left(R_{out} + A_0 R_1\right)}$$

24 $\because A_o = \infty$

$$|A_v| = \frac{R_1}{\frac{1}{\omega C_1}}$$

$$= \omega R_1 C_1$$

$$= 5$$

$$\therefore R_1 C_1 = \frac{5}{\omega}$$

$$= \frac{5}{2\pi \times 10^6}$$

$$= 7.958 \times 10^{-7}$$

(25) From eqn (8.55)

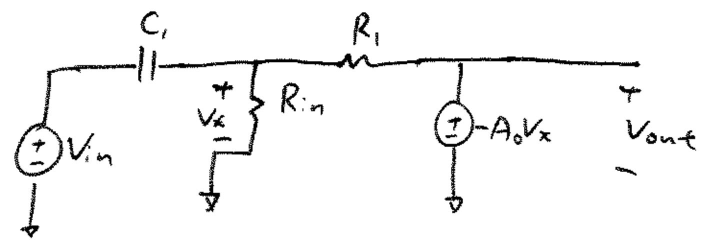
$$S_p = -\frac{A_o+1}{R_1 C_1}$$

$$2\pi \times 100 \times 10^6 = \frac{A_o+1}{1000 \times 10^{-9}}$$

(ie. R_1 and C_1 are chosen at minimum)

$$A_o \approx 627$$

(26)



By KCL,

$$(V_{in} - V_x) sC_1 = \frac{V_x}{R_{in}} + \frac{(V_x + A_0 V_x)}{R_1}$$

$$(V_{in}) sC_1 = V_x \left[sC_1 + \frac{1}{R_{in}} + (A_0 + 1)\frac{1}{R_1} \right]$$

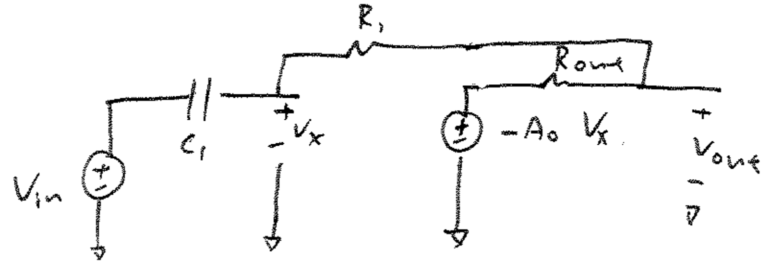
$$\frac{sC_1}{sC_1 + \frac{1}{R_{in}} + (A_0 + 1)\frac{1}{R_1}} = \frac{V_x}{V_{in}}$$

$\because \quad V_{out} = -A_0 V_x,$

$$\therefore \quad \frac{V_{out}}{V_{in}} = -\frac{A_0 \, sC_1}{sC_1 + \frac{1}{R_{in}} + (A_0 + 1)\frac{1}{R_1}}$$

As $A_0 \to \infty$, $\quad \frac{V_{out}}{V_{in}} \to -R_1 C_1 s. \quad$ [8.42]

27.



By KCL,

$$(V_{in} - V_x) S C_1 = (V_x + A_0 V_x) \frac{1}{R_1 + R_{out}}$$

$$(V_{in}) S C_1 = V_x \left[S C_1 + (A_0 + 1) \frac{1}{R_1 + R_{out}} \right]$$

$$\frac{V_x}{V_{in}} = \frac{S C_1}{S C_1 + (A_0 + 1) \frac{1}{R_1 + R_{out}}}$$

$$V_{out} = (-A_0 V_x - V_x) \frac{R_1}{R_1 + R_{out}}$$

(resistive divider)

$$= -V_x \frac{(A_0 + 1) R_1}{R_1 + R_{out}}$$

$$\therefore \frac{V_{out}}{V_{in}} = - \frac{\frac{(A_0 + 1) R_1 S C_1}{R_1 + R_{out}}}{S C_1 + (A_0 + 1) \frac{1}{R_1 + R_{out}}}$$

$$\frac{V_{out}}{V_{in}} = - R_1 S C_1 \quad (\text{as } A_0 \to \infty)$$

[8.42]

(28) $\because A_o = \infty$,

$V_+ = V_- = 0$

By KCL,

$$\frac{V_{in}}{R_1 \parallel \frac{1}{sC_1}} = -\frac{V_{out}}{R_2 \parallel \frac{1}{sC_2}}.$$

$$\therefore \frac{V_{out}}{V_{in}} = -\frac{R_2 \parallel \frac{1}{sC_2}}{R_1 \parallel \frac{1}{sC_1}}$$

$$= -\frac{R_2}{R_1} \times \frac{1+R_1C_1s}{1+R_2C_2s}.$$

For $\left|\frac{V_{out}}{V_{in}}\right| = 1$,

$$R_2 \parallel \frac{1}{sC_2} = R_1 \parallel \frac{1}{sC_1}$$

That is, choose the components such that the impedance of $R_2 \parallel \frac{1}{sC_2}$ is equal to $R_1 \parallel \frac{1}{sC_1}$ at the specific frequency.

(29) if $A_0 < \infty$,

Let V_- be the voltage at the negative input terminal of the opamp.

By KCL,

$$\frac{V_{in} - V_-}{R_1 // \frac{1}{sC_1}} = - \frac{V_{out} - V_-}{R_2 // \frac{1}{sC_2}}$$

$$V_{out} = -A_0 V_-,$$

$$\frac{V_{in} + \frac{V_{out}}{A_0}}{R_1 // \frac{1}{sC_1}} = - \frac{V_{out} + \frac{V_{out}}{A_0}}{R_2 // \frac{1}{sC_2}}$$

$$V_{in} = -\left[R_1 // \frac{1}{sC_1}\right] \left[\frac{\left(R_2 // \frac{1}{sC_2}\right) \frac{V_{out}}{A_0} + V_{out} + \frac{V_{out}}{A_0}}{R_2 // \frac{1}{sC_2}}\right.$$

$$\therefore \frac{V_{out}}{V_{in}} = - \frac{R_2 // \frac{1}{sC_2}}{R_1 // \frac{1}{sC_1}} \left[\frac{A_0}{(A_0+1) + \left(R_2 // \frac{1}{sC_2}\right)} \right]$$

To set $\left| \frac{V_{out}}{V_{in}} \right| = 1$,

Let $x = R_1 // \frac{1}{sC_1}$ and $y = R_2 // \frac{1}{sC_2}$.

$\therefore$ For $\left| \frac{V_{out}}{V_{in}} \right| = 1$, $\quad y A_0 = x \left[(A_0+1) + y \right]$

$$y (A_0 - 1) = x (A_0 + 1)$$

(29) Cont'd

$$\therefore \quad \frac{X}{Y} = \frac{A_0+1}{A_0-1},$$

ie. we need to set $\dfrac{R_1 // \frac{1}{sC_1}}{R_2 // \frac{1}{sC_1}} = \dfrac{A_0+1}{A_0-1}$.

Since A_0 is generally rather large,

$\dfrac{A_0+1}{A_0-1}$ is a rational fraction,

in which the numerator and the

denominator are large, and differ

by a small amount.

(e.g. if $A_0 = 1000$, $\dfrac{A_0+1}{A_0-1} = \dfrac{1001}{999}$)

Hence, setting $\left|\dfrac{V_{out}}{V_{in}}\right|$ to unity is possible

in principle, although it would be rather

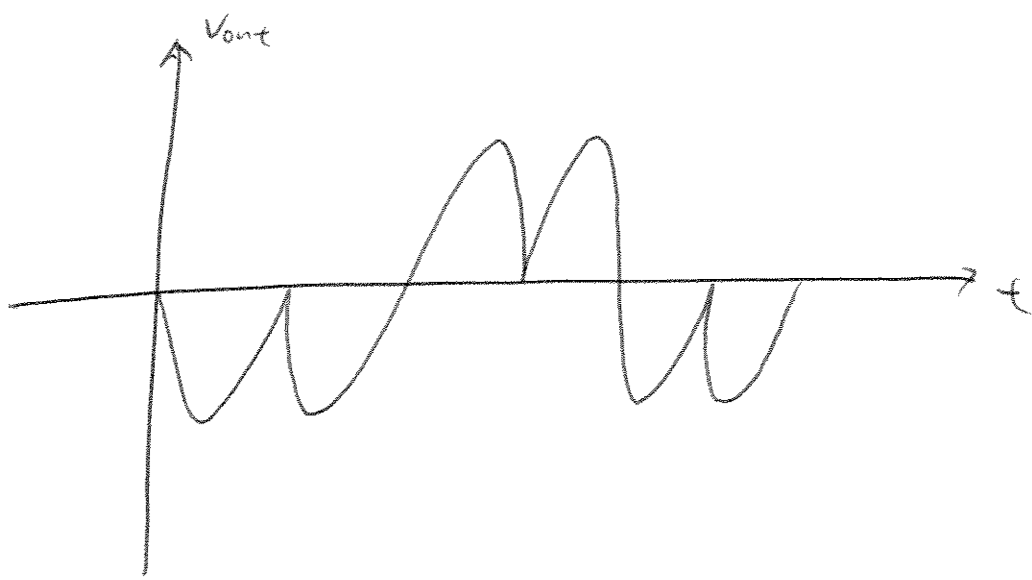
difficult to precisely control A_0.

(30) From eqn (8.63),

$$V_{out} = -R_F\left(\frac{V_1}{R_1} + \frac{V_2}{R_2}\right)$$

$\because R_1 = R_2$,

$$V_{out} = -\frac{R_F}{R_1}(V_1 + V_2)$$



(31) By KCL,

$$\frac{V_1 - V_x}{R_1} + \frac{V_2 - V_x}{R_2} = - \frac{V_{out} - V_x}{R_F}$$

$$\because \quad V_{out} = - A_0 V_x$$

$$V_x = - \frac{V_{out}}{A_0},$$

$$\left(\frac{V_1}{R_1} + \frac{V_2}{R_2}\right) + \frac{V_{out}}{A_0}\left(\frac{1}{R_2} + \frac{1}{R_1} + \frac{1}{R_F}\right) = - \frac{V_{out}}{R_F}$$

$$-\left(\frac{V_1}{R_1} + \frac{V_2}{R_2}\right) = V_{out}\left[\frac{1}{R_F} + \frac{1}{A_0}\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_F}\right)\right]$$

$$\therefore \quad V_{out} = -\left(\frac{1}{R_F} + \frac{1}{A_0}\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_F}\right)\right)^{-1} \times \left(\frac{V_1}{R_1} + \frac{V_2}{R_2}\right)$$

(32) For $A_o = \infty$,

$V_+ = V_- = 0$,

$\therefore$ No current flows through R_P,

i.e. No effect due to R_P

$$V_{out} = -R_F \left(\frac{V_1}{R_1} + \frac{V_2}{R_2} \right)$$

For $A_o \neq \infty$,

By KCL

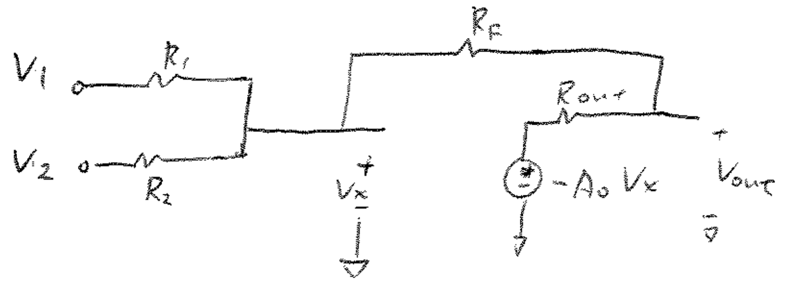
$$\frac{V_1 - V_x}{R_1} + \frac{V_2 - V_x}{R_2} - \frac{V_x}{R_P} = -\frac{V_{out} - V_x}{R_F}$$

$$\because \quad V_x = -\frac{V_{out}}{A_o},$$

$$\left(\frac{V_1}{R_1} + \frac{V_2}{R_2} \right) + \frac{V_{out}}{A_o} \left[\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_P} + \frac{1}{R_F} \right] = -\frac{V_{out}}{R_F}$$

$$V_{out} = -\left[\frac{1}{R_F} + \frac{1}{A_o} \left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_P} + \frac{1}{R_F} \right) \right]^{-1} \times \left(\frac{V_1}{R_1} + \frac{V_2}{R_2} \right)$$

(33)



By KCL,

$$\frac{V_1 - V_x}{R_1} + \frac{V_2 - V_x}{R_2} = \frac{V_x (A_0 + 1)}{R_F + R_{out}}$$

$$\left(\frac{V_1}{R_1} + \frac{V_2}{R_2} \right) = V_x \left[\frac{1}{R_1} + \frac{1}{R_2} + \frac{A_0 + 1}{R_F + R_{out}} \right]$$

$$\therefore V_{out} = (-A_0 V_x - V_x) \frac{R_F}{R_F + R_{out}}$$

$$= -V_x (1 + A_0) \frac{R_F}{R_F + R_{out}}$$

$$\therefore \frac{V_1}{R_1} + \frac{V_2}{R_2} = -\frac{R_F + R_{out}}{R_F (A_0 + 1)} \left[\frac{1}{R_1} + \frac{1}{R_2} + \frac{A_0 + 1}{R_F + R_{out}} \right] V_{out}$$

$$V_{out} = -\frac{R_F (A_0 + 1)}{R_F + R_{out}} \left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{A_0 + 1}{R_F + R_{out}} \right)^{-1}$$

$$\times \left(\frac{V_1}{R_1} + \frac{V_2}{R_2} \right)$$

//

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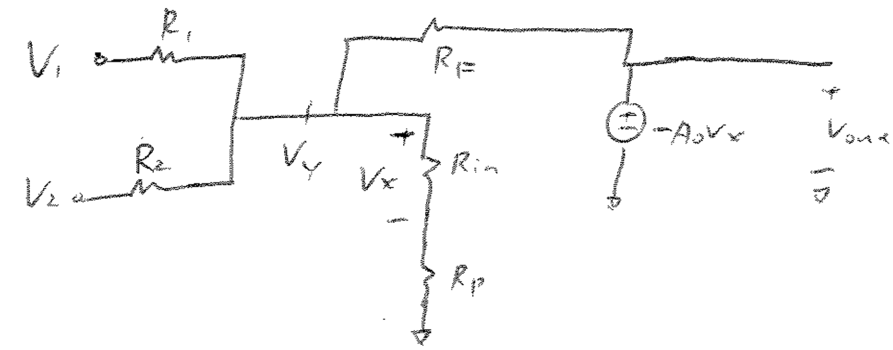


By KCL,

$$\frac{V_1 - V_Y}{R_1} + \frac{V_2 - V_Y}{R_2} = \frac{V_Y + A_0 V_x}{R_F} + \frac{V_Y}{R_{in} + R_p}$$

Using voltage divider,

$$V_x = V_Y \frac{R_{in}}{R_{in} + R_p}$$

$$V_Y = \frac{R_{in} + R_p}{R_p} V_x$$

$$\therefore \left(\frac{V_1}{R_1} + \frac{V_2}{R_2}\right) = V_Y\left(\frac{1}{R_F} + \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_{in}+R_p}\right) + \frac{A_0 V_x}{R_F}$$

$$= \left[\left(\frac{R_{in} + R_p}{R_p}\right)\left(\frac{1}{R_F} + \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_{in}+R_p}\right) + \frac{A_0}{R_F}\right] \times V_x$$

$$\because V_{out} = -A_0 V_x$$

$$\therefore \frac{V_1}{R_1} + \frac{V_2}{R_2} = -\left(\frac{V_{out}}{A_0}\right)\left[\left(\frac{R_{in}+R_p}{R_p}\right)\left(\frac{1}{R_F} + \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_{in}+R_p}\right) + \frac{A_0}{R_F}\right]$$

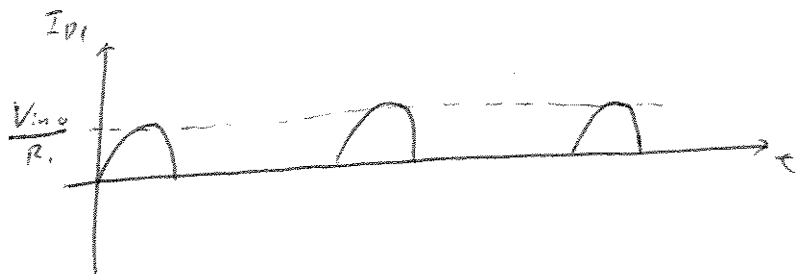
$$V_{out} = -A_0\left(\frac{V_1}{R_1} + \frac{V_2}{R_2}\right) \times \left[\left(\frac{R_{in}+R_p}{R_p}\right)\left(\frac{1}{R_F} + \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_{in}+R_p} + \frac{A_0}{R_F}\right)\right]^{-1}$$

(35) When D_1 is on, (i.e. when $V_{in} > 0$)

$$V_{out} = V_{in} = I_{D_1} R_1$$

$$\therefore I_{D_1} = \frac{V_{in}}{R_1}$$

when D_1 is off, $I_{D_1} = 0$.

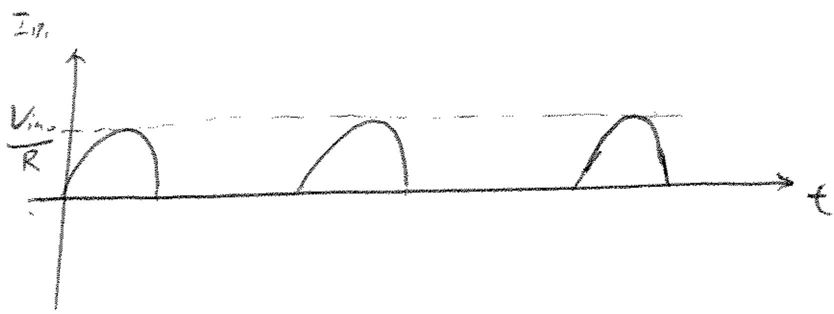


36 D_1 is on when $V_{in} > 0$,

$$V_X = 0$$

By KCL:

$$I_{D1} = \frac{V_{in}}{R_1}$$



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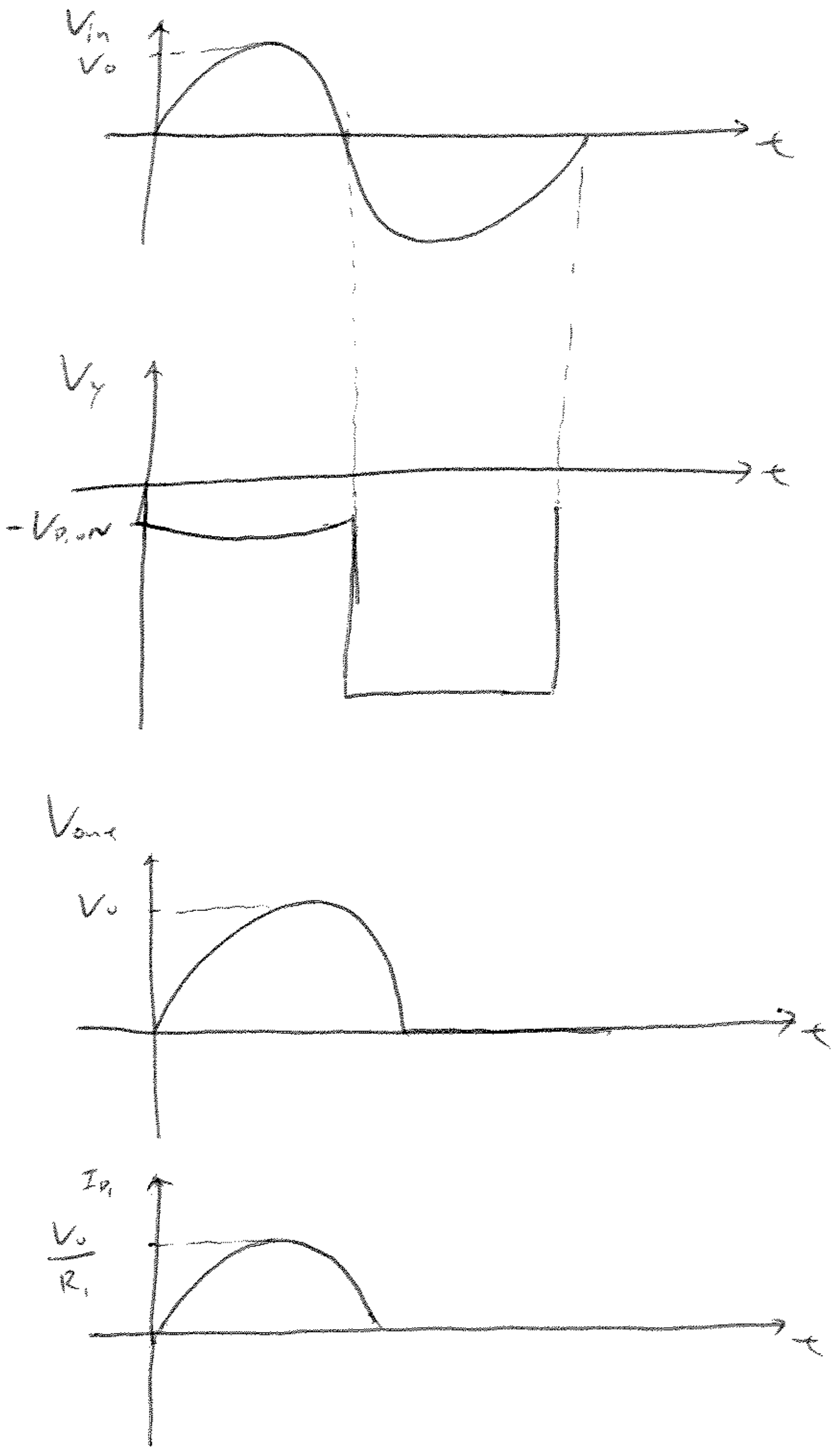


(38) $\because R_{D_1,on} \ll R_{P}$,

$\therefore$ when diode is on, R_P has no effect.

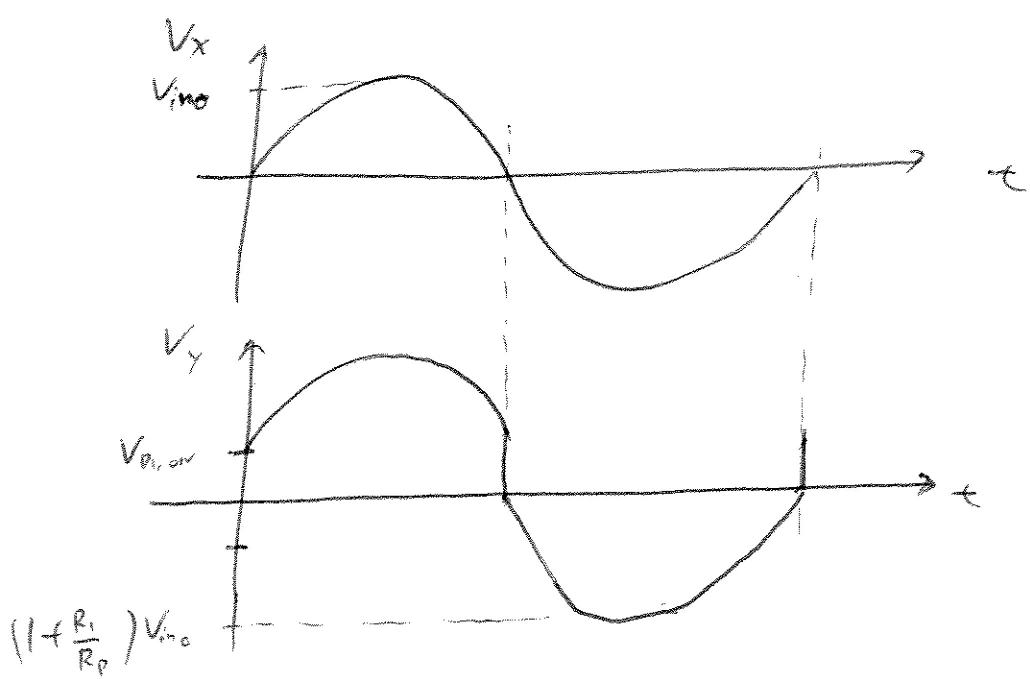
(diode "shorts" nodes X and Y)

when diode is off, R_P functions as a feedback resistor,

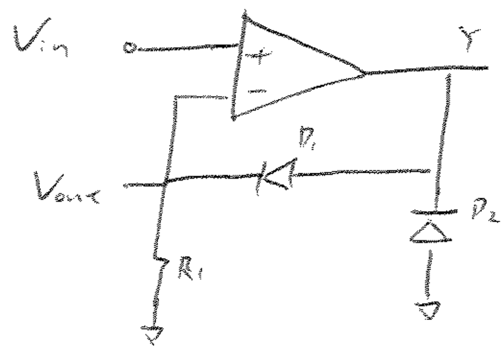
$$\therefore \frac{V_Y}{V_{in}} = 1 + \frac{R_1}{R_P}$$

and $V_{in} = V_{out}$.

$\therefore V_X = V_{in}$ for both D_1 is on and off.

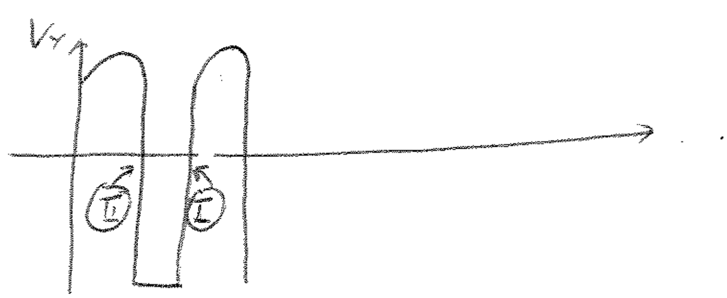


(39) Connecting a diode as below:



D_2 allows the parasitic capacitance to charge up faster, right before D_1 conducts.

This corresponds to sharpening the transition (I) of V_Y, as shown below



But it will not speed up transition (II).

(which is not critical)

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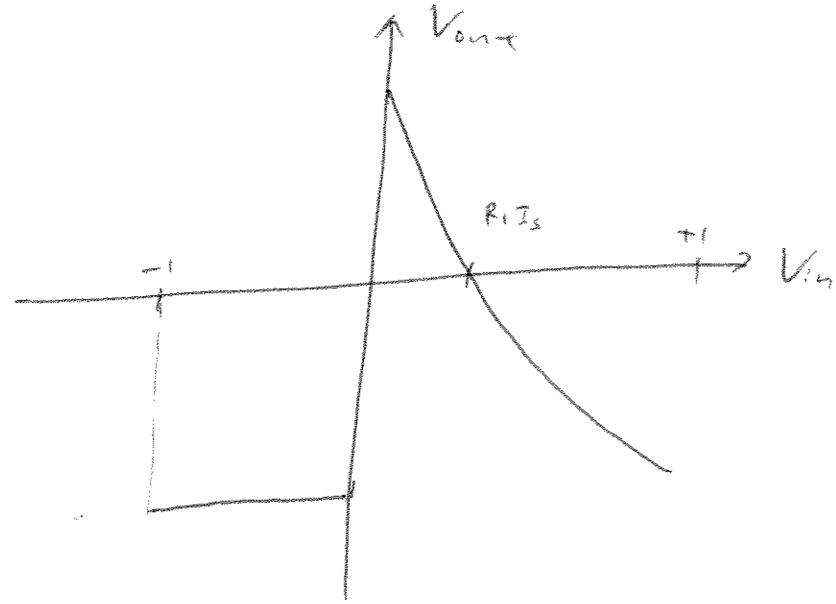


(41) By KCL,

$$\frac{V_{in} - V_x}{R_1} = I_{R_1}$$

$$\therefore \quad V_{BE} = V_T \ln \frac{\frac{V_{in} - V_x}{R_1}}{I_s}$$

$$= -V_{out}$$

$$\because -A_0 V_x = V_{out}$$

$$V_x = -\frac{V_{out}}{A_0}$$

$$\therefore \quad V_{out} = -V_T \ln \frac{V_{in} + \frac{V_{out}}{A_0}}{R_1 I_s}$$

(42). This circuit will not function as a noninverting opamp:

assuming $A_o = \infty$,

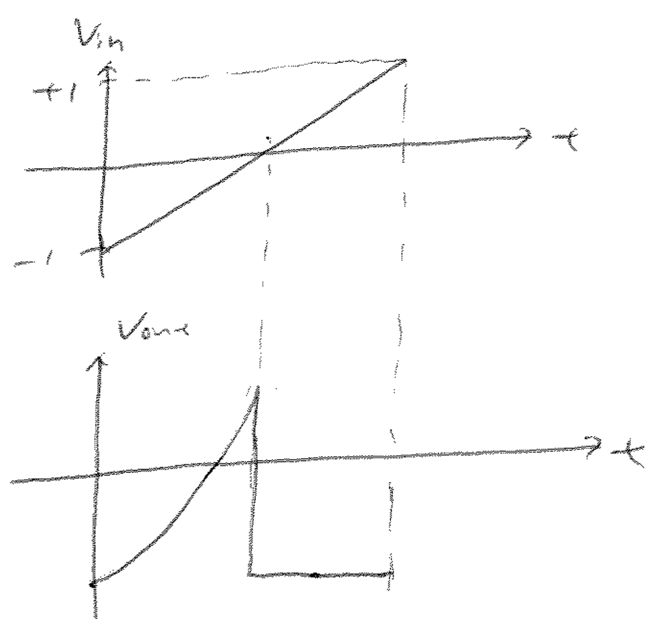
$$V_+ = V_- = V_{in}.$$

$$\therefore V_{BE} = V_T \ln \frac{\frac{-V_{in}}{R_1}}{I_s}$$

$$\therefore V_{out} = -V_{BE}.$$

$$V_{out} = -V_T \ln \frac{-V_{in}}{R_1 I_s}$$

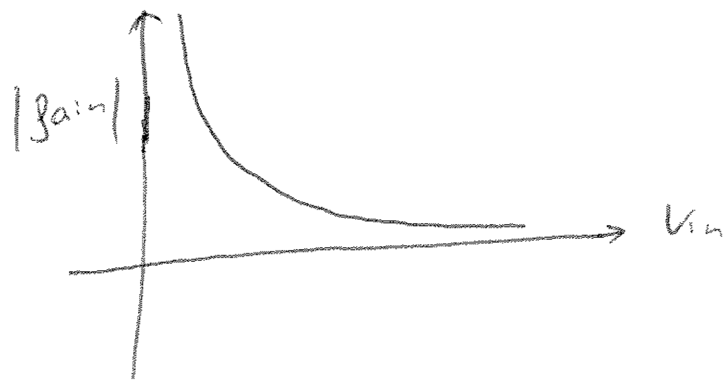
For example, as V_{in} varies from -1V to +1V:



(43)

$$V_{out} = -V_T \ln \frac{V_{in}}{R_1 I_s}$$

$$\frac{dV_{out}}{dV_{in}} = -\frac{V_T}{V_{in}}$$



the gain is compressive, because as V_{in} increases the magnitude of the gain decreases.

(44) Set $V_{out} = -0.5V$ when $V_{in} = 1V$

$$-0.5 = -V_T \ln \frac{1}{R_1 I_s}$$

$$\therefore R_1 I_s = 2.0612 \times 10^{-9}$$

when $V_{in} = 10V$,

$$V_{out} = -V_T \ln \frac{10}{2.0612 \times 10^{-9}}$$

$$= -0.558V \quad > -1V.$$

$\therefore$ setting $R_1 I_s = 2.0612 \times 10^{-9}$ meets the specification.

choose $I_s = 1 \times 10^{-16} A$.

$R_1 = 20.61 M\Omega$ //

(45) Assume $A_o = \infty$,

$$I_{R_1} = \frac{V_{in} - V_{TH}}{R_1}$$

$$= \frac{1}{2} k' \left(V_{GS} - V_{TH} \right)^2,$$

where $k' = \frac{W}{L} C_{ox}' \mu_n$

$\because V_{GS} = - V_{out}$,

$$\therefore \frac{1}{2} k' \left(-V_{out} - V_{TH} \right)^2 = \frac{V_{in} - V_{TH}}{R_1}$$

$$\left(-V_{out} - V_{TH} \right)^2 = \frac{2 (V_{in} - V_{TH})}{k' R_1}$$

$$\left(-V_{out} - V_{TH} \right) = \sqrt{\frac{2 (V_{in} - V_{TH})}{k' R_1}}$$

$$V_{out} = - \sqrt{\frac{2 (V_{in} - V_{TH})}{k' R_1}} - V_{TH}$$

$$\text{small signal gain} = - \frac{d}{dV_{in}} \sqrt{\frac{2 (V_{in} - V_{TH})}{k' R_1}}$$

$$= \frac{1}{k' R} \sqrt{\frac{k' R}{2 (V_{in} - V_{TH})}}$$

$$= \sqrt{\frac{1}{2 k' R (V_{in} - V_{TH})}}$$

(46) By KCL,

$$\frac{V_x - V_{in}}{R_1} = I_{SD,M_1}$$

Assume $A_0 = \infty$, $\therefore V_x = V_+ = 0V$.

$$\therefore -\frac{V_{in}}{R_1} = \frac{1}{2} k' (V_{GS} - |V_{TH}|)^2,$$

where $K' = \mu_p \frac{W}{L} C_{ox}'$.

$$\therefore V = -V_{out}$$

$$\therefore -\frac{V_{in}}{R_1} = \frac{1}{2} K' (-V_{out} - |V_{TH}|)^2$$

$$-\frac{2V_{in}}{R_1 k'} = (V_{out} + |V_{TH}|)^2$$

$$\therefore V_{out} = \sqrt{-\frac{2V_{in}}{R_1 k'}} - |V_{TH}|$$

(47) Assume $A_0 = \infty$,

$\therefore V_+ = V_- = V_{in}$

Using voltage divider:

$$V_{in} + V_{os} = V_{out} \frac{R_1}{R_1 + R_2}$$

$$V_{out} = \left(1 + \frac{R_2}{R_1}\right)(V_{in} + V_{os})$$

(48) In Fig. (8.25),

Assuming input is zero,

$$V_x = 10 \times V_{os,A_1}$$
$$= 30mV$$

$$\therefore V_{out} = 10 \times (V_{os,A_2} + V_x)$$
$$= 330mV$$

Thus, the maximum offset error is 330mV.

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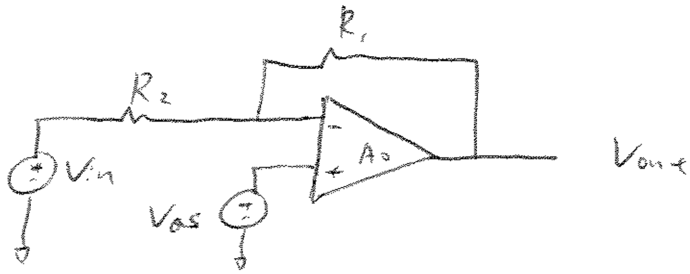


By KCL,

$$\frac{V_{in} - V_{os}}{R_2} = - \frac{V_{out} - V_{os}}{R_1}$$

$$V_{out} = - \frac{R_1}{R_2} (V_{in} - V_{os}) + V_{os}$$

50 By eqn (8.72)

$$V_{out} = V_{os}\left(1 + \frac{R_2}{R_1}\right)$$

$$\therefore\ 20\,mV = 3\,mV\left(1 + \frac{R_2}{R_1}\right)$$

$$\frac{17}{3} = \frac{R_2}{R_1} \quad \text{—— (1)}$$

$$\because\ \frac{1}{R_2 C_1} \ll 2\pi(1000)$$

and setting $C_1 = 100\,pF$,

$$\frac{1}{R_2 \times 100 \times 10^{-12}} \ll 2\pi(1000)$$

$$\frac{1}{R_2} \ll 6.283 \times 10^{-7}$$

$$\therefore\ R_2 \gg 1.59\,M\Omega$$

choose $R_2 = 17\,M\Omega$.

$R_1 = 3\,M\Omega$. (From (1))

(51) From eq$^{\underline{n}}$ (8.44),

$$V_{out} \propto \frac{d\,V_{in}}{dt}$$

(proportional)

Since offset is static (invariant with time)

i.e. $\frac{d\,V_{os}}{dt} = 0$.

$\therefore$ offset has no effect to V_{out}.

(5-2) From eqn (8.6),

with the presence of offset (V_{os}),

$$V_{out} = -V_T \ln \frac{V_{in} + V_{os}}{R_1 I_s}$$

The effect of offset to Vout is very small, because Vout is proportional to the log. of ($V_{in} + V_{os}$)

Thus, Vout is very insensitive to the magnitude of the offset.

(53). From eq$^{\underline{n}}$ (8.76).

$V_{out} = R_1 I_{B2}$

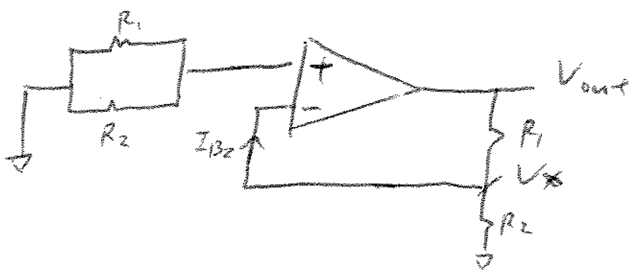
$\therefore$ V_{out} is independent of I_{B1}

Also I_{B1} will not affect $\frac{V_{out}}{V_{in}}$.

Thus, the small offset (ΔI) in the input bias currents has no effect on V_{out}.

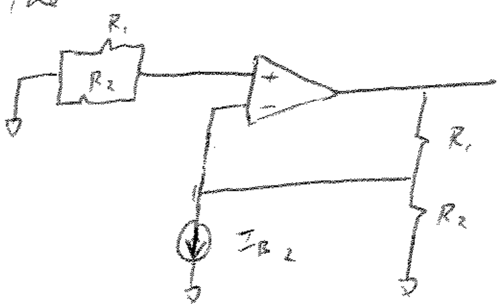
(54) Using superposition:

(I) turn off I_{B1}:



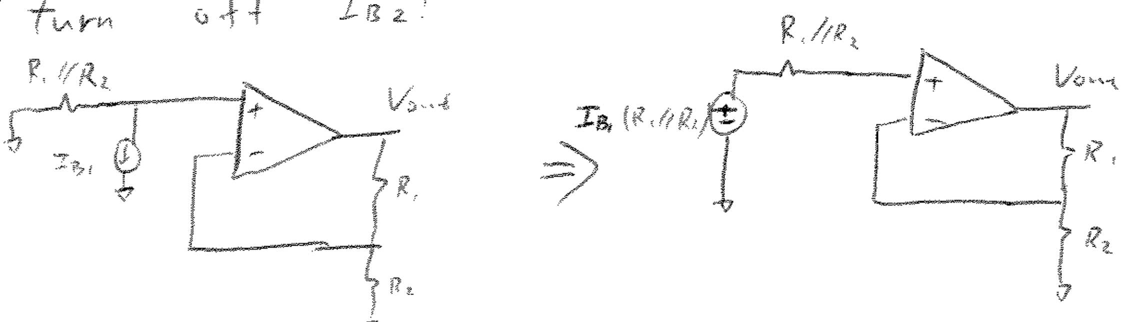
$\because V_+ = V_- = 0$, $\therefore V_x = 0$.

The circuit becomes:



$\therefore$ From eqn (8.76), $V_{out,2} = -R_1 I_{B2}$

(II) turn off I_{B2}:



$$\therefore V_{out,I_{B1}} = I_{B1}\left(\frac{R_1 R_2}{R_1 + R_2}\right) \times \left(1 + \frac{R_1}{R_2}\right)$$

$$= I_{B1} R_1$$

(54) Cont'd

$\therefore$ given $I_{B1} - I_{B2} = \Delta I$, and V_{out}, $I_{B1} + I_{B2}$,

$$I_{B1} R_1 - I_{B2} R_1 < \Delta V$$

$$\Delta I \; R_1 < \Delta V$$

$$\therefore R_1 < \frac{\Delta V}{\Delta I}$$

There is no dependence of output error on R_2.

(55) Using eqn. (8.84)

$$\text{Gain} = \frac{A_0}{1 + \frac{s}{\omega_1}}$$

For opamp (a): At 100 MHz:

$$\text{Gain}_{(a)} = \frac{1000}{1 + \frac{2\pi \times 100 \times 10^6}{2\pi \times 50}}$$

$$\approx 5 \times 10^{-4}$$

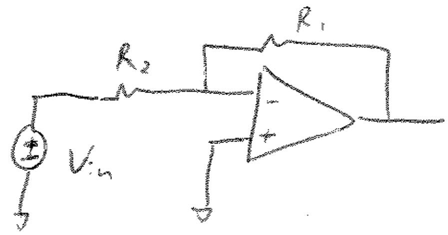
For opamp (b) at 100 MHz,

$$\text{Gain}_{(b)} = \frac{500}{1 + \frac{2\pi \times 100 \times 10^6}{2\pi \times 10}}$$

$$\approx 4.95 \quad > 4$$

$\therefore$ opamp (b) is a possible candidate

5-6



Using eqn (8.20).

$$\frac{V_{out}}{V_{in}} = - \frac{1}{\frac{R_2}{R_1} + \frac{1}{A_0}\left(1 + \frac{R_2}{R_1}\right)}$$

Here, A_0 becomes $\frac{A_0}{1 + \frac{s}{\omega_1}}$.

$$\therefore \frac{V_{out}}{V_{in}} = \frac{-1}{\frac{R_2}{R_1} + \frac{A_0}{1+\frac{s}{\omega_1}}\left(1 + \frac{R_2}{R_1}\right)}$$

$$= \frac{-\left(1 + \frac{s}{\omega_1}\right)}{\left(1 + \frac{s}{\omega_1}\right)\frac{R_2}{R_1} + A_0\left(1 + \frac{R_2}{R_1}\right)}$$

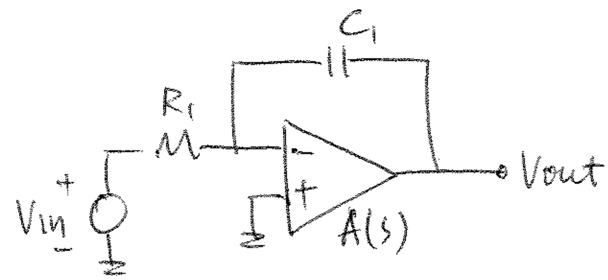
To find the pole, equate denominator to 0.

i.e. $\left(1 + \frac{s}{\omega_1}\right)\frac{R_2}{R_1} + A_0\left(1 + \frac{R_2}{R_1}\right) = 0$

$$\left(1 + \frac{s}{\omega_1}\right) = -\frac{R_1}{R_2} A_0 \left(1 + \frac{R_2}{R_1}\right)$$

$$\therefore |\omega_{p,closed}| = \left(1 + \frac{R_1}{R_2} A_0 \left(1 + \frac{R_2}{R_1}\right)\right)\omega_1$$

57.



$$A(s) = \frac{A_0}{1 + \frac{s}{\omega_0}}$$

$$\omega_0 \gg \frac{1}{R_1 C_1}$$

$$\frac{V_{in} - V_{(-)}}{R_1} = \left(V_{(-)} - V_{out}\right) s C_1$$

$$-V_{(-)} \times A(s) = V_{out}$$

Substitute ② into ①:

$$\frac{V_{out}}{V_{in}}(s) = -\left[\frac{sC_1R_1 + 1}{A(s)} + sC_1R_1\right]^{-1}$$

$$= -\left[\frac{(sC_1R_1 + 1)(1 + s/\omega_0)}{A_0} + sC_1R_1\right]^{-1}$$

$$\simeq -\left\{\frac{1}{A_0\omega_0}\left[s\omega_0 C_1R_1 + s^2C_1R_1 + s\right] + sCR\right\}^{-1}$$

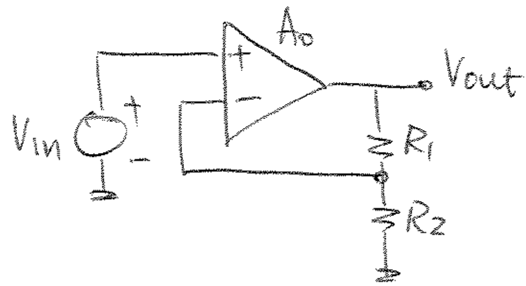
$$\simeq -\left[s\left(C_1R_1 + \frac{1}{A_0\omega_0}\right) + s^2\left(\frac{C_1R_1}{A_0\omega_0}\right)\right]^{-1}$$

$$\approx -\left[sC_1R_1 + s^2\frac{C_1R_1}{A_0\omega_0}\right]^{-1}$$

$$= \frac{-1}{\left(1 + \frac{s}{A_0\omega_0}\right)\frac{s}{\left(\frac{1}{R_1C_1}\right)}}$$

58.

Nominal gain $= 4$
Slew Rate $= 1V/ns$
$V_p = 0.5\ V$



$$V_{in}(t) = 0.5 \sin \omega t \Rightarrow V_{out} = 0.5 \times \underbrace{\left(1 + \frac{R_1}{R_2}\right)}_{=4} \sin \omega t.$$

$$\frac{dV_{out}}{dt} = 0.5 \left(1 + \frac{R_1}{R_2}\right) \omega \cdot \cos \omega t.$$

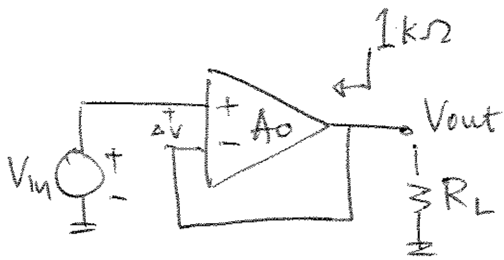
$= $ maximum when $\cos \omega t = 1$

$$\Rightarrow \left.\frac{dV_{out}}{dt}\right|_{max} = 0.5\omega \left(1 + \frac{R_1}{R_2}\right) = 2\omega$$

$\therefore$ Highest frequency $\Rightarrow 2\omega = 1\ V/ns$

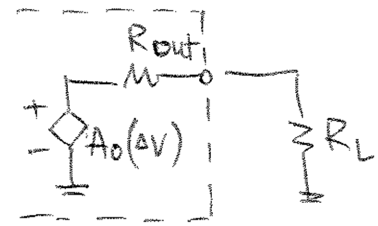
$\Rightarrow \omega = 0.5\ rad/ns \Rightarrow f_{MAX} \simeq 79.6\ MHz$

59.



$R_L = 100\,\Omega$

Gain Error $= 0.5\%$



$$(V_{in} - V_{out}) A_o \times \frac{R_L}{R_{out} + R_L} = V_{out}$$

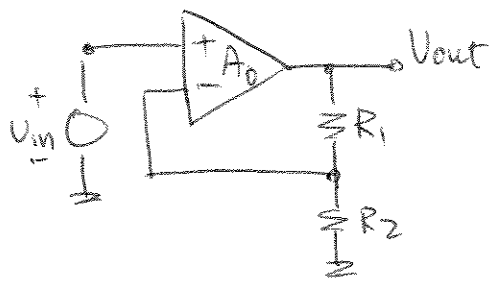
$$\Rightarrow \frac{V_{out}}{V_{in}} = \frac{1}{1 + \frac{R_{out} + R_L}{A_o R_L}} \simeq 1 - \underbrace{\frac{R_{out} + R_L}{A_o R_L}}_{=\epsilon}$$

$$\therefore \epsilon = \frac{R_{out} + R_L}{A_o R_L} \Rightarrow A_o = \frac{R_{out} + R_L}{\epsilon R_L} = \frac{1000 + 100}{0.5\% \times 100}$$

$$\approx 2200.$$

60.

Nominal Gain $=4$
Gain Error $=0.2\%$
$R_1+R_2 = 20\,k\Omega$



$$\left[V_{in} - \frac{R_2}{R_1+R_2}\times V_{out}\right]A_0 = V_{out}$$

$$\Rightarrow \frac{V_{out}}{V_{in}} = \frac{A_0}{1+\frac{R_2}{R_1+R_2}A_0} \simeq \left(1+\frac{R_1}{R_2}\right)\left[1-\left(1+\frac{R_1}{R_2}\right)\frac{1}{A_0}\right]$$

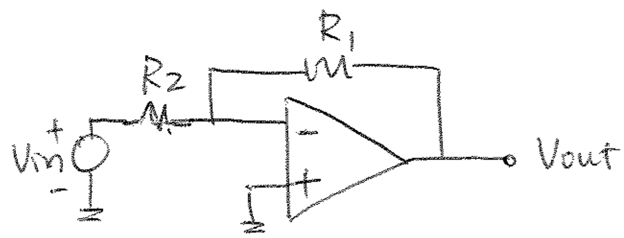
$(1+R_1/R_2) = 4$ & $(R_1+R_2) = 20\,k\Omega$

$\Rightarrow R_1 = 15\,k\Omega$, $R_2 = 5\,k\Omega$.

$$0.2\% = \left(1+\frac{R_1}{R_2}\right)\frac{1}{A_0} \Rightarrow A_0 = \left(1+\frac{R_1}{R_2}\right)\times\frac{1}{0.2\%}$$

$$= 2000$$

61.



Nominal Gain = 8
Gain Error = 0.1%
Rout = 0.1%

$$V_x = V_{in} + (V_{out} - V_{in}) \frac{R_2}{R_1 + R_2} \quad \text{— ①}$$

$$\frac{V_{out} - V_{in}}{R_1 + R_2} = \frac{-A_0 V_x - V_{out}}{R_{out}} \quad \text{— ②}$$

Substitute ② into ① gives:

$$\frac{V_{out}}{V_{in}} = \left(-\frac{R_1}{R_2}\right) \underbrace{\frac{A_0 - R_{out}/R_1}{1 + \frac{R_{out}}{R_2} + A_0 + \frac{R_1}{R_2}}}_{(1-\varepsilon)}$$

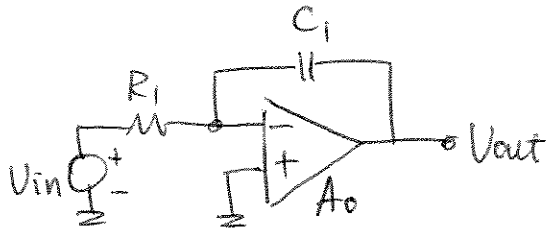
$$\Rightarrow \quad 8 = R_1/R_2$$

$$0.1\% = 1 - \frac{A_0 - 100/R_1}{1 + \frac{100}{R_2} + A_0 + (8)}$$

$\Rightarrow$ Choose $R_1 = 8\,K\Omega$, $R_2 = 1\,K\Omega$

$\Rightarrow$ $A_0 \approx 9100$

62.



$= 100\ kHz$

pole $= 100\ Hz$

$C_{MAX} = 50\ pF$.

$$\frac{V_{in} - V_{(-)}}{R_1} = (V_{(-)} - V_{out})\, s C_1 \quad \text{—— ①}$$

$$V_{(-)} \cdot (-A_0) = V_{out} \quad \text{—— ②}$$

Substitute ② into ①:

$$\frac{V_{out}}{V_{in}} = \frac{-1}{\frac{1}{A_0} + \left(1 + \frac{1}{A_0}\right) R_1 C_1 s}$$

$$\Rightarrow S_p = \frac{-1}{(A_0 + 1) R_1 C_1} = -100\ Hz \quad \text{—— ①}$$

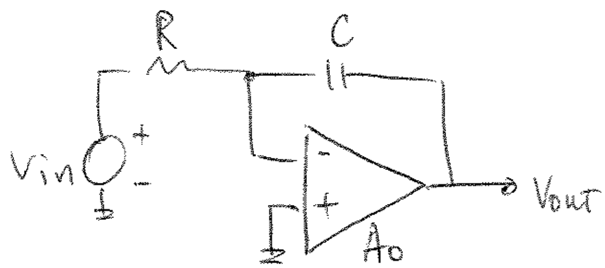
Attenuation above 100 kHz $\Rightarrow \left|\frac{V_{out}}{V_{in}}\right|_{100KHz} = 1$

$$\Rightarrow \left.\frac{A_0}{\sqrt{1 + \left[(A_0+1) R_1 C_1 \omega_z\right]^2}}\right|_{100KHz} = 1 \quad \text{—— ②}$$

Substitute ① into ②:

$\Rightarrow A_0 \simeq 1000$. Choose $C = 50pF \Rightarrow R \simeq 200\ k\Omega$.

63.



$V(t) = \alpha t$

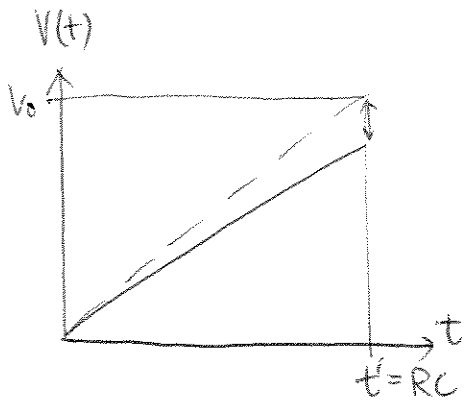
$0 < V(t) < V_o$

where $\alpha = 10 V/\mu s$

$V_o = 1 V$

$C_{max} = 20 pF$

Error $< 0.1\%$



$V_{out}(t) = -\frac{V_o}{RC} t \quad , \quad t \in [0, RC]$

$V(t) = -\alpha t$

At $t = RC$, $\frac{\Delta V}{V_o} = \left. \frac{V_{out}(t) - V(t)}{V_o} \right|_{t=RC} < 0.1\%$

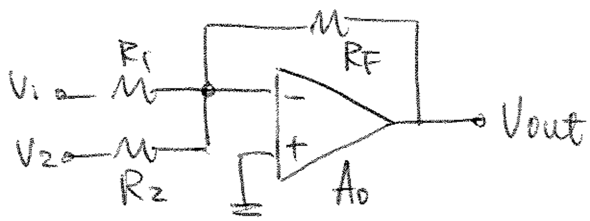
$\Rightarrow \Delta V = V_o \times 0.1\% = 0.001 V$

$\Rightarrow \left. -\frac{V_o}{RC} \times t + \alpha t \right|_{t=RC} = 0.00 \quad V \quad (= \Delta V)$

Choose $C = 20 pF$

$\therefore R = \frac{V_o - \Delta V}{\alpha C} = \frac{1V - 0.001 V}{10 V/\mu s \times 20 pF} = 4995 \Omega$

64.



$$V_{out} = \underset{\substack{\uparrow \\ 0.5}}{\alpha_1} V_1 + \underset{\substack{\uparrow \\ 1.5}}{\alpha_2} V_2$$

Error of $\alpha \le 0.5\%$

$r_{in} \ge 10\,k\Omega$.

$$\frac{V_1 - V_{(-)}}{R_1} + \frac{V_2 - V_{(-)}}{R_2} = \frac{V_{(-)} - V_{out}}{R_F} \quad \text{— ①}$$

$$V(-A_0) = V_{out} \quad \text{— ②}$$

Substitute ② into ① & solve for V_{out}:

$$V_{out} = -\left(\frac{R_F}{R_1}V_1 + \frac{R_F}{R_2}V_2\right)\cdot\left[\frac{1}{A_0}\left(\frac{R_F}{R_1} + \frac{R_F}{R_2} + 1\right) + 1\right]^{-1}$$

$$\simeq -\left(\frac{R_F}{R_1}V_1 + \frac{R_F}{R_2}V_2\right)\cdot\left[1 - \frac{1}{A_0}\left(\frac{R_F}{R_1} + \frac{R_F}{R_2} + 1\right)\right]$$

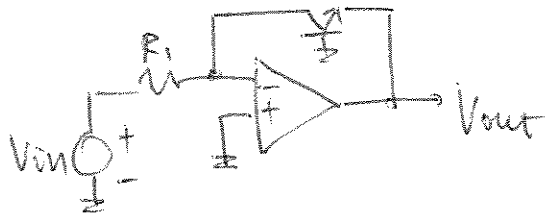
Choose $R_{in,v_2}\ (\simeq R_2) = 10\,k\Omega \Rightarrow R_F = \alpha_2 \times R_2 = 15\,k\Omega$

$\Rightarrow R_1 = R_F/\alpha_1 = 30\,k\Omega \simeq R_{in,v_1}$

$$\Rightarrow \epsilon = 0.5\% = \frac{1}{A_0}\left(\frac{R_F}{R_1} + \frac{R_F}{R_2} + 1\right)$$

$$\Rightarrow A_0 = \frac{1}{0.5\%}\left(0.5 + 1.5 + 1\right) = 600 \quad \text{(or larger)}$$

65.



$[0.1, 2]V \longmapsto [-0.5, -1]V$

$$V_{out} = -V_T \ln \frac{V_{in}}{I_s R_1}$$

$$-0.5V = -V_T \ln\left[\frac{(0.1)}{I_s R_1}\right] \Rightarrow I_s R_1 = 4.45 \cdot 10^{-10} V \quad \text{—①}$$

$$\Rightarrow -V_T \ln \frac{(2)}{I_s R_1} = -0.026V \ln\left(\frac{2}{4.45 \cdot 10^{-10}}\right) \approx -0.58V$$

∴ input range of $0.1 \leftrightarrow 2$ V corresponds to output range of $-0.5 \leftrightarrow -0.58$ V

Choose $I_s = 1 \times 10^{-16} A \Rightarrow R_1 = 4.45\ M\Omega$.

66. No, this is not possible to ... requirements.

$$\frac{dV_{out}}{dV_{in}} = \frac{V_T}{V_{in}}$$

Assuming temperature is fixed, V_T is a fixed quantity that is both process and design independent.

At 25°C, $V_T \approx 25\text{mV}$.

$$\therefore \left.\frac{dV_{out}}{dV_{in}}\right|_{V_{in}=1V} = 25\text{ mV/V}$$

$$\left.\frac{dV_{out}}{dV_{in}}\right|_{V_{in}=2V} = 12.5\text{ mV/V}$$