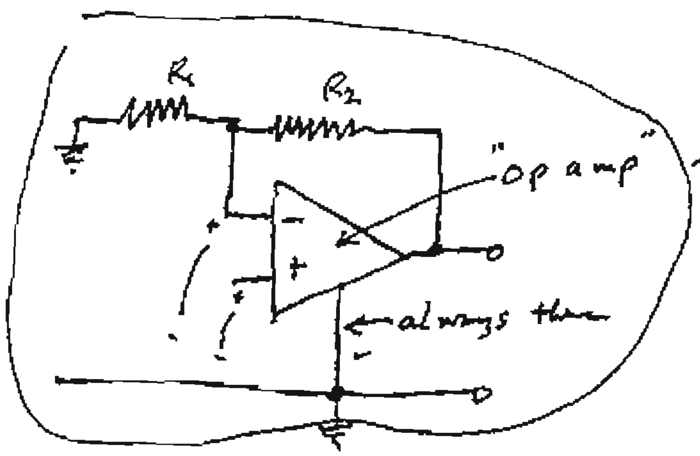
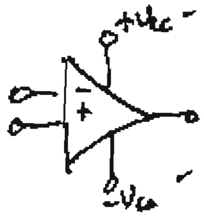
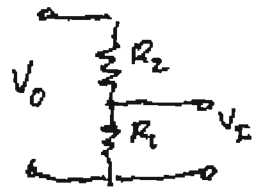


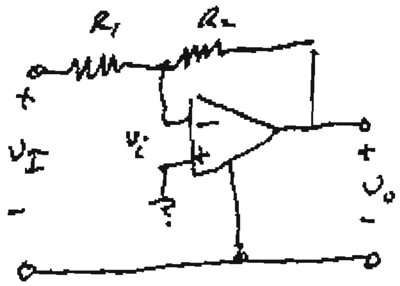

amplifier circuit

power supplies = "rails"




+ additional



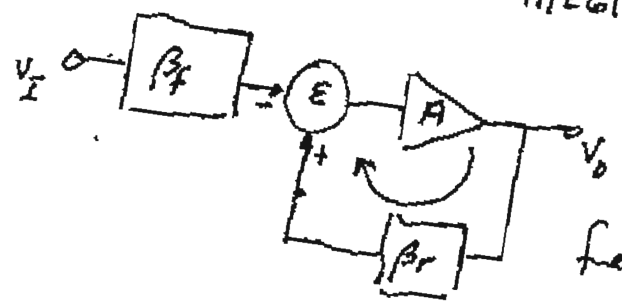




$$-\left[\left(\frac{R_2}{R_1+R_2}\right)v_I + \left(\frac{R_1}{R_1+R_2}\right)v_O\right]A = v_O$$

$$\Rightarrow \frac{v_O}{v_I} = -\frac{\left(\frac{R_2}{R_1+R_2}\right)A}{1+\left(\frac{R_1}{R_1+R_2}\right)A} = \frac{\text{feedforward const} \cdot A_{OL}}{1+\underbrace{\text{feedback const} \cdot A_{OL}}_{\text{loop gain}}}$$

closed loop gain

$A_{OL}$ = open-loop gain




feedback loop

$\beta_f$ = feedforward constant

$\beta_r$ = feedback constant

$A_{OL}$ = open-loop gain (op amp) "A"

$-\beta_f A$ = open-loop gain (circuit)

$\beta_r A$ = loop gain

$$\frac{V_o}{V_I} = \frac{-\beta_f A}{1+\beta_r A} = \text{closed loop gain}$$

$$\text{Closed loop gain} = \frac{\text{open loop gain}}{1 + \text{loop gain}}$$

Non-inverting gain by inspection (no diagram)

$$\Rightarrow \frac{V_o}{V_I} = \frac{A}{1+\left(\frac{R_1}{R_1+R_2}\right)A}$$

$$\lim_{A\to\infty} = \frac{R_1+R_2}{R_1} = 1+\frac{R_2}{R_1}$$

Finite gain

inverting $\lim A \to 0$ $\frac{V_o}{V_I} \to 0$

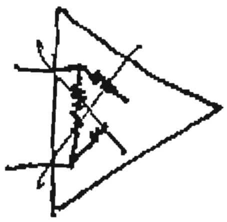
non-inverting $\lim A \to 0$ $\frac{V_o}{V_I} \to 0$

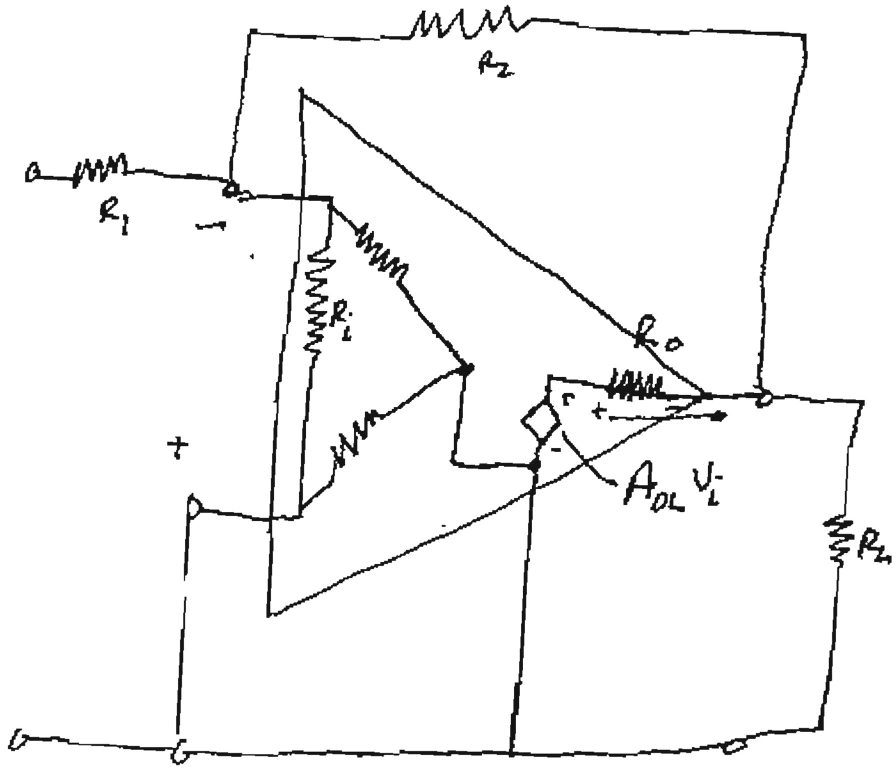
$\beta_r A \gg 1$, then $A \to \infty$

$\beta_r A \approx 1$, $<1$, then use formula

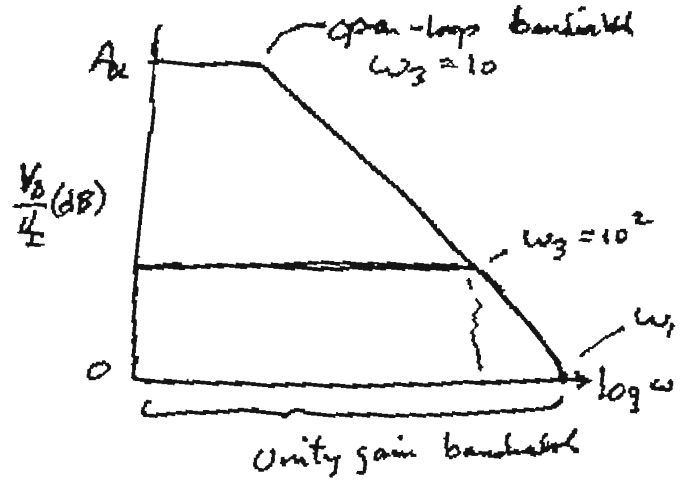
Other deviations

1. finite input resistance ✓
2. non-zero output resistance ✓
3. finite bandwidth
4. finite gain ✓
5. other bias considerations





gain-bandwidth product = constant



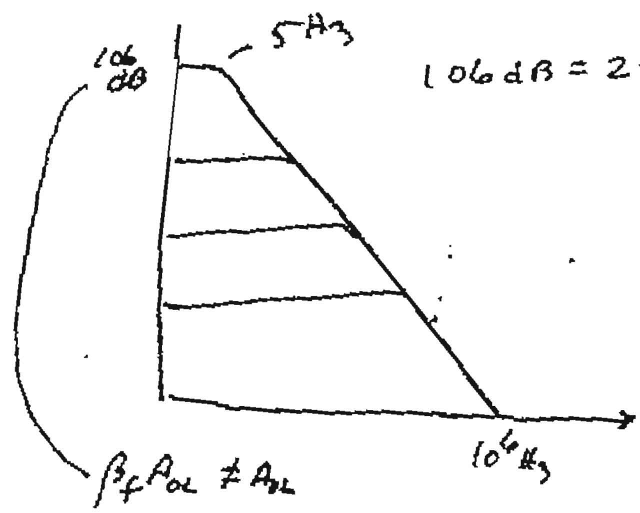

$A_{OL} = 10^3$

$\omega_1 = 10^5 > 10^4$

$\omega_3 = 10$

closed loop gain = $100 = 10^2$

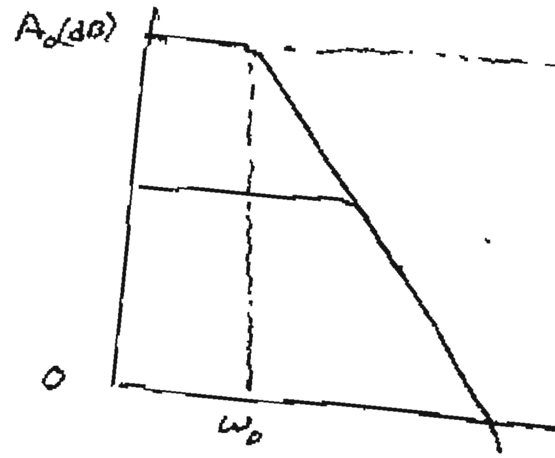
$\omega_3 = 100$




106 dB = $2 \times 10^5$ = 200 000

open loop gain = $A(s) = \frac{A_0}{1 + s/\omega_0} = \frac{A_0 \omega_0}{s + \omega_0}$

"dc gain" = low freq limit gain = $A_0$




$$\frac{V_O}{V_I} = \frac{A(s)}{1+\left(\frac{R_1}{R_1+R_2}\right)A(s)} = \frac{\frac{A_o\omega_o}{s+\omega_o}}{1+\beta_r\frac{A_o\omega_o}{s+\omega_o}}$$

$$= \frac{A_o\omega_o}{(s+\omega_o)+\beta_r A_o\omega_o} = \frac{A_o\omega_o}{s+(1+\beta_r A_o)\omega_o}$$

$$= \frac{A_o\omega_o}{s+\underbrace{(1+\beta_r A_o)\omega_o}_{\text{new BW}}}$$

new band width = old bandwidth $(1+\beta_r A_o)$

new dc gain = old dc gain $= \frac{A_o}{1+\beta_r A_o}$

dc went down by $1+\beta_r A_o$
bandwidth up by $1+\beta_r A_o$
gain-bandwidth product = constant

inverting gain $R_i' = R_i/1+\beta_r A$
$R_o' = R_o/1+\beta_r A$

non-inverting gain $R_i' = R_i(1+\beta_r A)$
$R_o' = R_o/1+\beta_r A$

unprimed = without feedback
primed = with feedback

$R_o = 200\,\Omega$

$A_{OL} = 200{,}000$

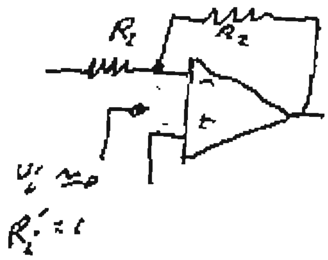
$A_{CL} = 10$

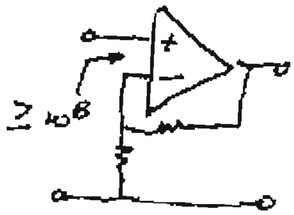
loop gain $\simeq 20{,}000$

$R_o' = \frac{200}{20{,}000} = 0.01\,\Omega$

$R_i' = 20{,}000$

$R' = \frac{20{,}000}{20{,}000} = 1\,\Omega$



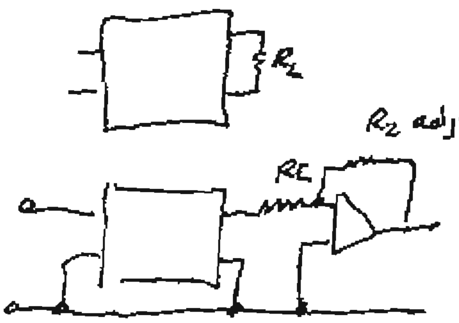




$R_i' = R_i(1+\beta_1 A)$

$= (20{,}000)(20{,}000)$

$R_{in}$(circuit) $= R_1 +$ op amp $R_i'$

$\simeq R_1$



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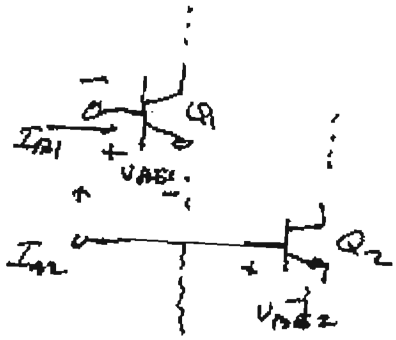
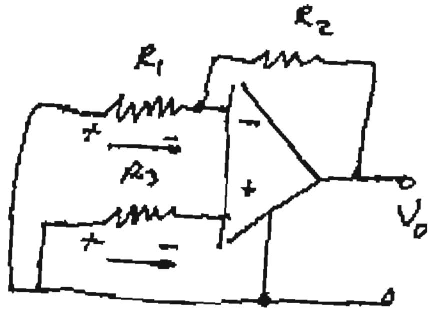



$I_{B1} \neq I_{B2}$

$V_{BE1} \neq V_{BE2}$

∴ $I_{C1} \neq I_{C2}$




Adjust $R_1$-V-$R_3$ to give $V_o = 0$

Drop $R_1 \geq R_3$ or $R_1 \leq R_3$  $V_o$ goes + or −

equivalent input offset (includes both V, I)

$V_{os} = \frac{V_o}{A_{OL}}$ with no input

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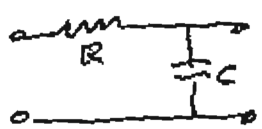
Integrator

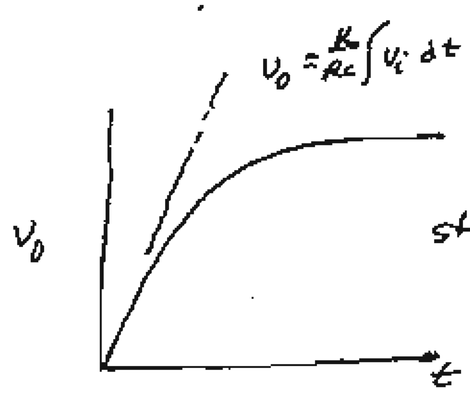
operation in Operational Amplifier

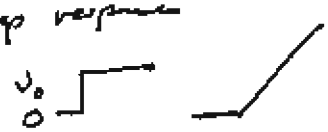
Circuit

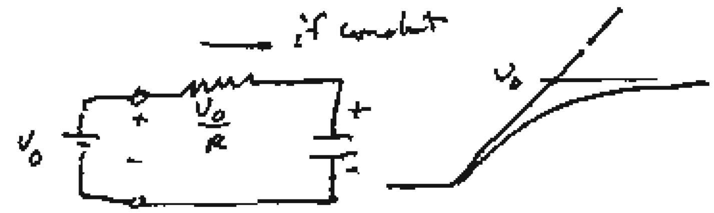


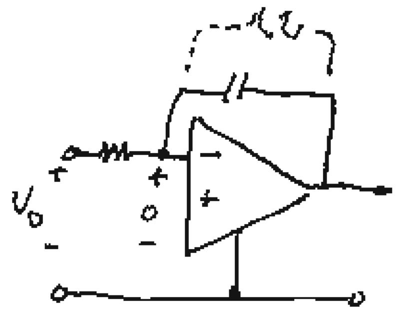

$V_i = Ri + \underbrace{\frac{1}{C}\int i\,dt}_{V_o}$   $i = I_o e^{-t/RC}$

Circuit

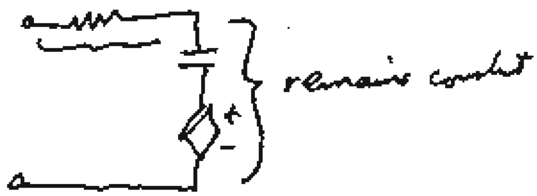



$$V_0 = \frac{1}{RC}\int V_I\,dt$$




Analog Computer