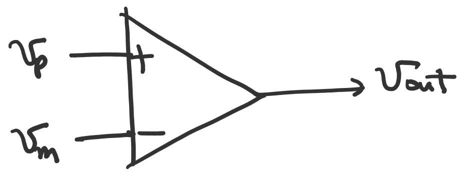
ECE 310- Lecture 35

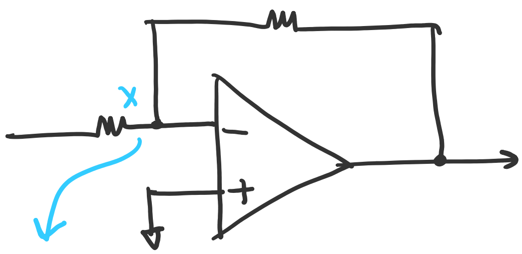
Monday, April 23, 2018 2:08 AM



$$v_{out} = A_o (v_p - v_m)$$

finite ∞ $v_p \simeq v_m$

Also, $v_p - v_m = \frac{v_{out}}{A_o} \to 0$ as $A_o \to \infty$

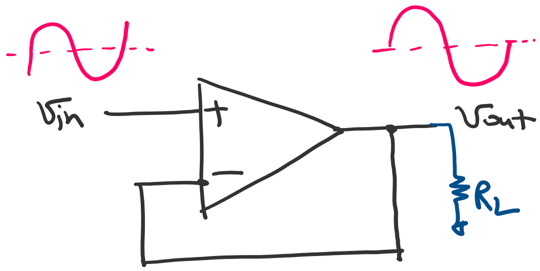


$v_x \simeq 0$

"Virtual ground"

Monday, April 23, 2018 5:14 AM

Unity Gain Buffer



from Taylor series expansion : $(1+x)^{-1} \simeq 1-x$ for $|x| \ll 1$

$$V_{out} = A_o(V_{in} - V_{out})$$

$$\Rightarrow \frac{V_{out}}{V_{in}} = \frac{A_o}{1+A_o} = \frac{1}{1+\frac{1}{A_o}}$$

$$= \left(1+\frac{1}{A_o}\right)^{-1} \simeq 1-\frac{1}{A_o} \longrightarrow 1 \text{ as } A_o \to \infty$$

Unity gain as $A_o \to \infty$

Voltage Buffer using an opamp.

Let $A_o = 1000$

$\hookrightarrow 20\log_{10}(1000) = 20 \times \log_{10}(10^3)$

$= 20 \times 3 = \underline{60\text{ dB}}$.

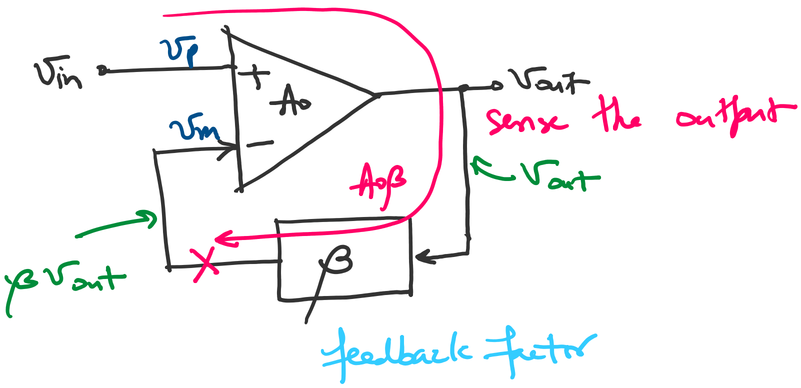
If $V_{in} = 1V$

$$V_{out} = \frac{1}{1+\frac{1}{1000}} = 0.999V$$

error $\Rightarrow$ 0.001 V

$\Rightarrow$ larger the opamp gain $\Rightarrow$ smaller is the error

Negative feedback Amplifier:



Typically $0 \le \beta \le 1$
↳ precise

$$\Rightarrow v_{out} = A_o(v_p - v_m)$$
$$= A_o(v_{in} - \beta v_{out})$$

$$\Rightarrow \frac{v_{out}}{v_{in}} = \frac{A_o}{1 + A_o\beta} = \frac{1}{\beta} \cdot \frac{1}{1 + \frac{1}{A_o\beta}}$$

$$= \frac{1}{\beta} \cdot \left(1 + \frac{1}{A_o\beta}\right)^{-1}$$

$$\simeq \frac{1}{\beta} \left(1 - \frac{1}{A_o\beta}\right)$$

Here:

$A_o\beta$ ← open loop gain

$\frac{A_o}{1 + A_o\beta}$ ← closed loop gain

$\simeq \frac{1}{\beta}$ ← independent of A_o for $A_o\beta \gg 1$

Very precise gain set by β for loop gain $\underbrace{A_o\beta \gg 1}$

$$\frac{v_{out}}{v_{in}} \simeq \frac{1}{\beta}\left(1 - \frac{1}{A_o\beta}\right) = \frac{1}{\beta}(1 - \epsilon)$$

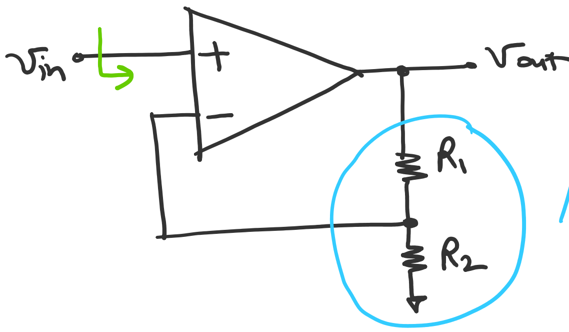
precision

$$\frac{V_{out}}{V_{in}} \simeq \underbrace{\frac{1}{\beta}} \underbrace{\left(1 - \frac{1}{A_0\beta}\right)} = \frac{1}{\beta}(1-\epsilon)$$

$\hookrightarrow$ $\epsilon \Rightarrow$ error due to finite gain

precision

Non-inverting amplifier:



$$\beta = \frac{R_2}{R_1+R_2} \Rightarrow \frac{1}{\beta} = \frac{R_1+R_2}{R_1} = \boxed{1+\frac{R_2}{R_1}}$$

closed loop gain

$$\frac{V_{out}}{v_{in}} = \frac{1}{\beta}\cdot\left(1-\frac{1}{A_0\beta}\right)$$

$$= \underbrace{\left(1+\frac{R_2}{R_1}\right)}_{\text{ideal closed-loop gain}} \cdot \left[1-\underbrace{\left(1+\frac{R_2}{R_1}\right)\cdot\frac{1}{A_0}}_{\epsilon \Rightarrow \text{gain error}}\right]$$

If $A_0\beta \gg 1$ then

$$\boxed{\frac{V_{out}}{v_{in}} \simeq 1+\frac{R_2}{R_1}}$$

non-inverting amplifier

$R_1 = 1k\Omega$, $R_2 = 9k\Omega$

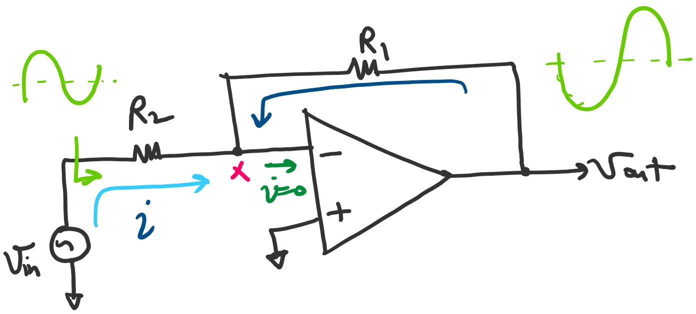
$\Rightarrow$ gain $= 10$

$\Rightarrow$ This gain is precise as it only depends upon the resistor ratio

↳ very precise

Input impedance $= \infty$ for an ideal opamp.

Inverting Amplifier:



$$i = \frac{v_{in} - v_x}{R_2} = \frac{v_x - v_{out}}{R_1} \longrightarrow (1)$$

$$v_{out} = A_0 (v_p - v_m)$$
$$= A_0 (0 - v_x)$$

$$\Rightarrow \quad v_x = -\frac{v_{out}}{A_0} \longrightarrow (2)$$

from (1) & (2)

$$\frac{v_{out}}{R_1} = -\frac{v_{in}}{R_2} + \frac{v_x}{R_2} + \frac{v_x}{R_1}$$

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

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

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

$$\Rightarrow \quad \frac{v_{out}}{v_{in}} = -\frac{R_1}{R_2} \cdot \frac{1}{1 + A_0\left(1 + \frac{R_1}{R_2}\right)}$$

$$= -\frac{R_1}{R_2} \cdot \frac{1}{1 + A_0 \beta}$$ for $A_0 \beta \to \infty$

$$\boxed{\frac{v_{out}}{v_{in}} \simeq -\frac{R_1}{R_2}}$$

$V_x \simeq 0$ for $A_0 \to \infty$

Node X is the virtual ground

& inverting gain is $-\frac{R_1}{R_2}$

* Input impedance is R_2

↳ lower impedance than ∞

Q. What happens if we have finite opamp gain

$$\frac{V_{out}}{V_{in}} \simeq \frac{1}{\beta} \cdot \Big(1 - \underbrace{\frac{1}{A_0\beta}}_{\epsilon}\Big)$$

for loop-gain $A_0\beta \to \infty$

$\epsilon \to 0$

for large closed-loop gain $= \frac{1}{\beta}$

$\Rightarrow \beta$ is small

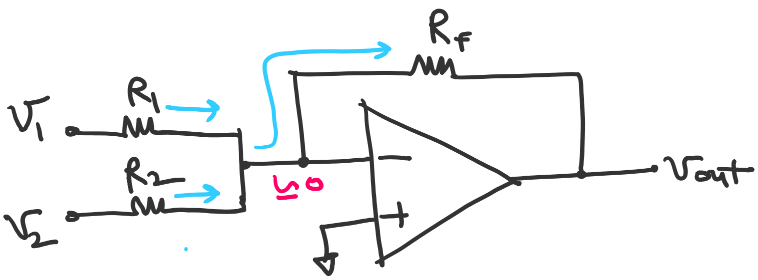
$\Rightarrow A_0\beta$ is smaller than A_0

$\Rightarrow$ higher closed-loop error $\left(\epsilon = \frac{1}{A_0\beta}\right)$ for a higher closed loop gain $\frac{1}{\beta}$.

higher closed-loop gain $\Rightarrow$ higher error.

* higher precision $\Rightarrow$ high $A_0\beta \Rightarrow$ higher $A_0 \Rightarrow$ more power in the opamp.

Voltage Adder :



KCL at x

$$\Rightarrow \quad \frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_{out}}{R_F} = 0$$

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

$$= -G_1 \cdot V_1 - G_2 V_2$$

$$g_1 = \frac{R_F}{R_1} \qquad g_2 = \frac{R_F}{R_2}$$

If $g_1 = g_2 = 1$

$$V_{out} = -(V_1 + V_2)$$