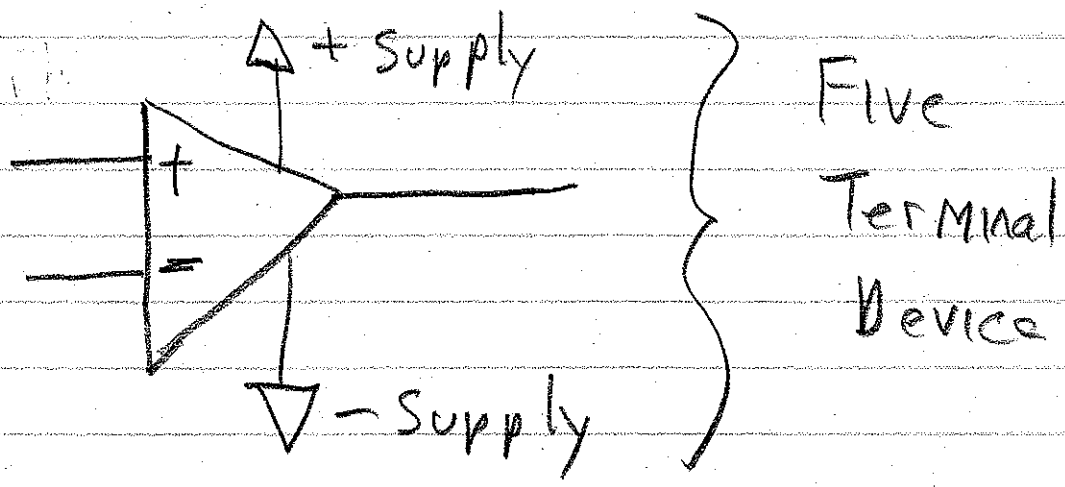
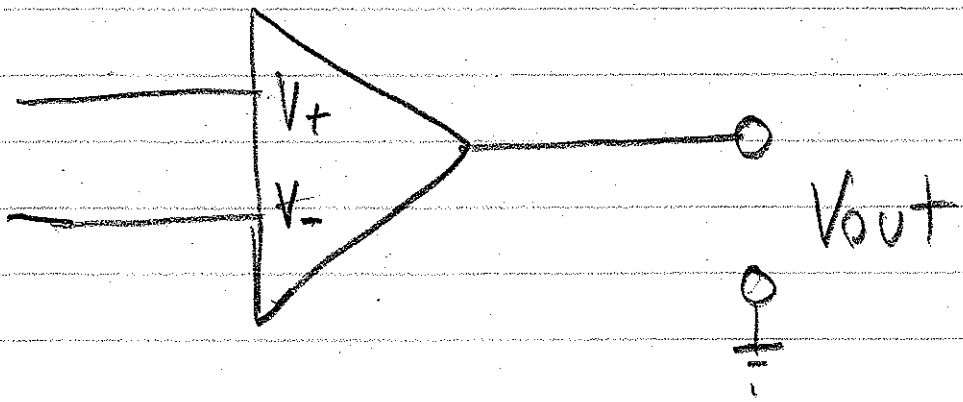
11/07/2006 6.081

Op. Amp



Our Usual View

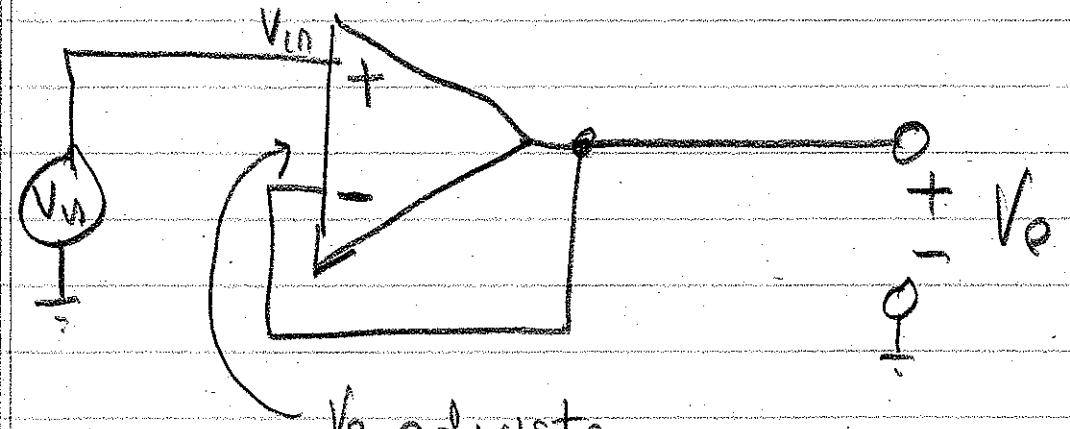


Simple Model

The output of the op-amp adjusts so as to make the V+ input and the V- input nearly equal

* And no current flows into the V+ and V- terminals

Simple Circuit Follower

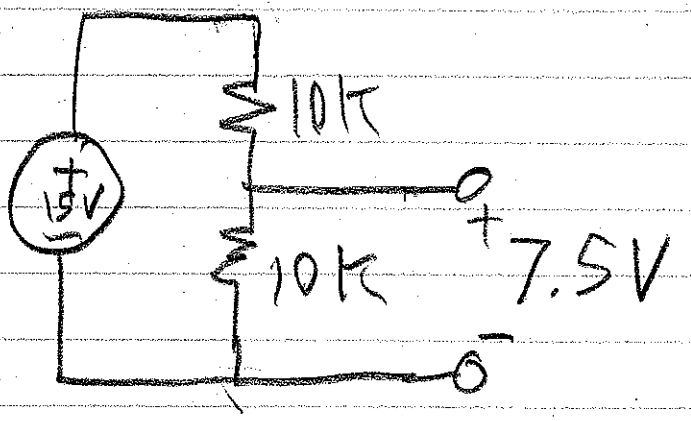


V_o adjusts to make $V_- = V_{in}$

$\Rightarrow V_o = V_{in}$

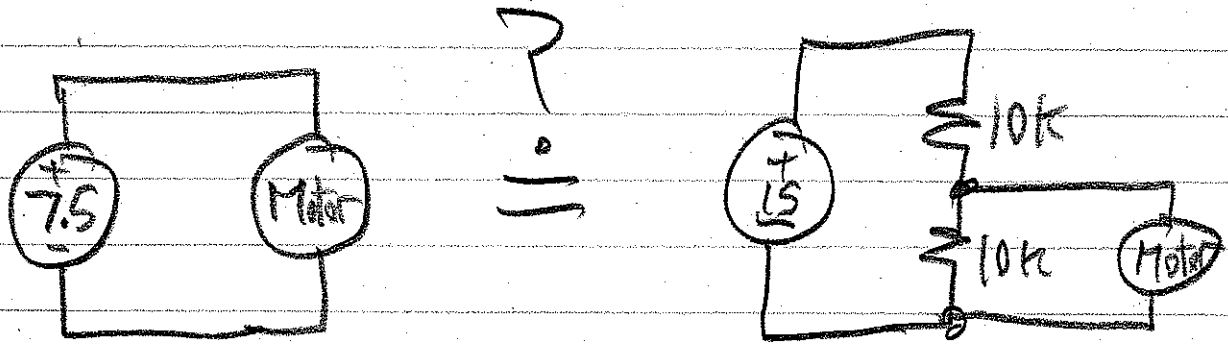
An Aside on Motors

Suppose one has a 15V supply can one create 7.5V using a resistor divider?

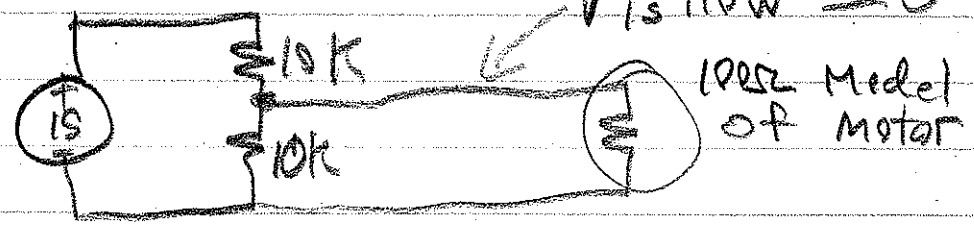


Yes!

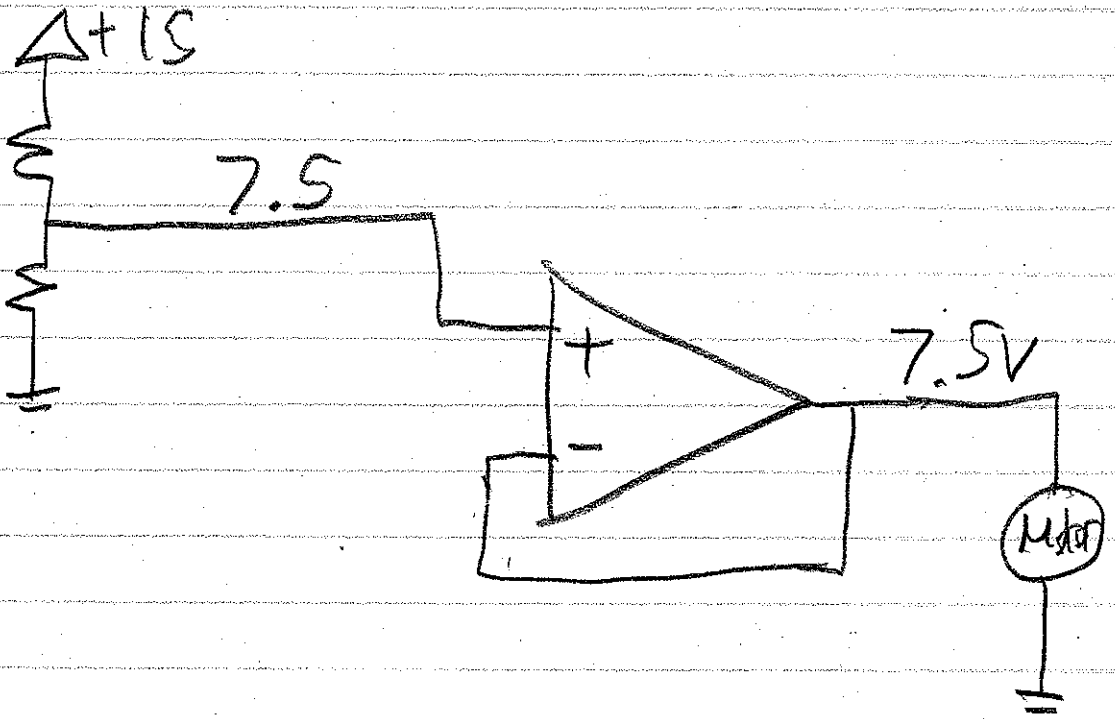
When driving a motor does



No the motor "loads" the divide



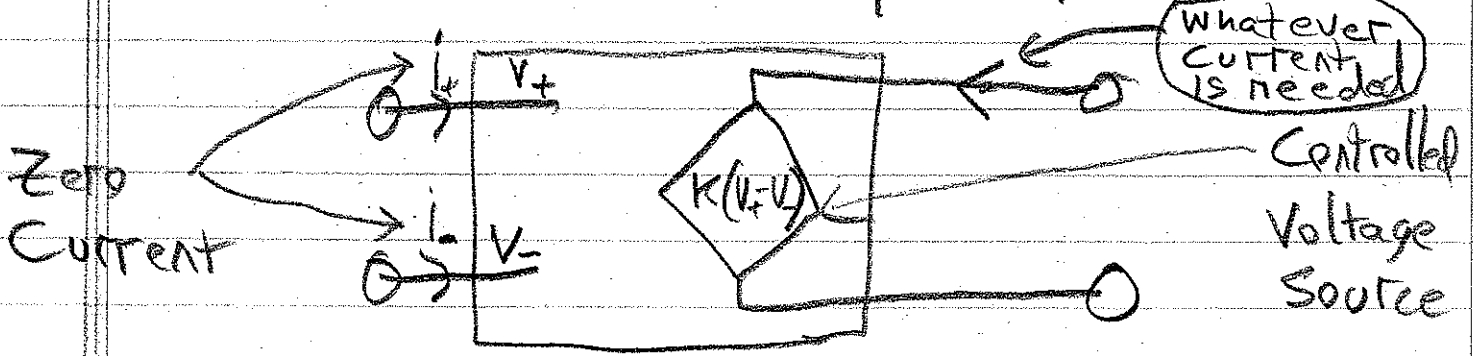
Use a op-amp Follower



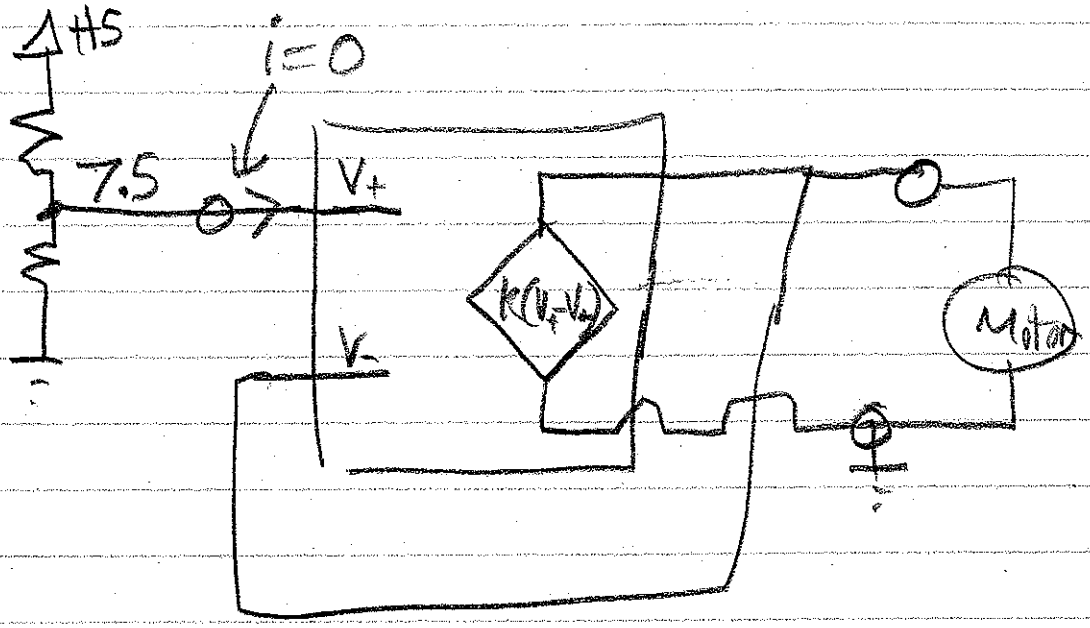
Why does follower help?

Need a better Model of op-amp!

More Detailed Op-amp Model



Follower

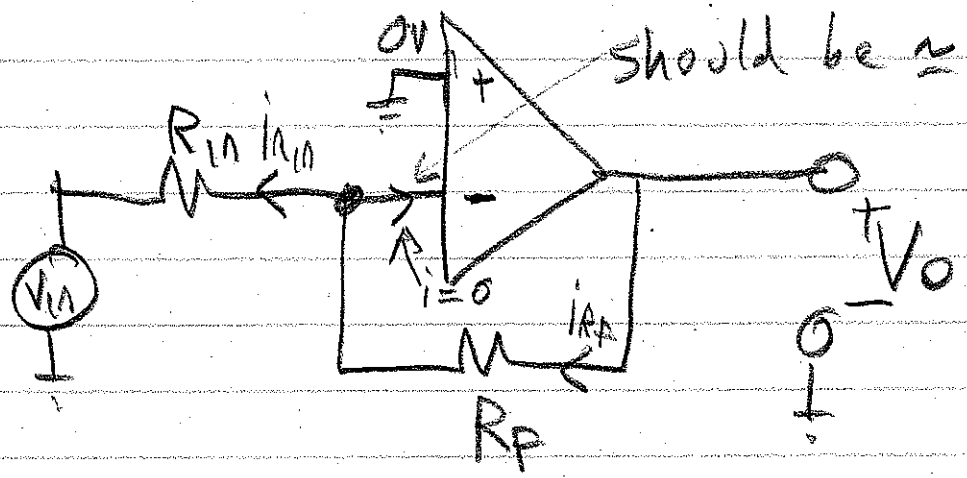


$$V_o = K(\underbrace{V_+}_{=7.5} - \underbrace{V_-}_{=V_o})$$

$$V_o = K(7.5 - V_o) \Rightarrow V_o = \frac{K}{K+1}7.5$$

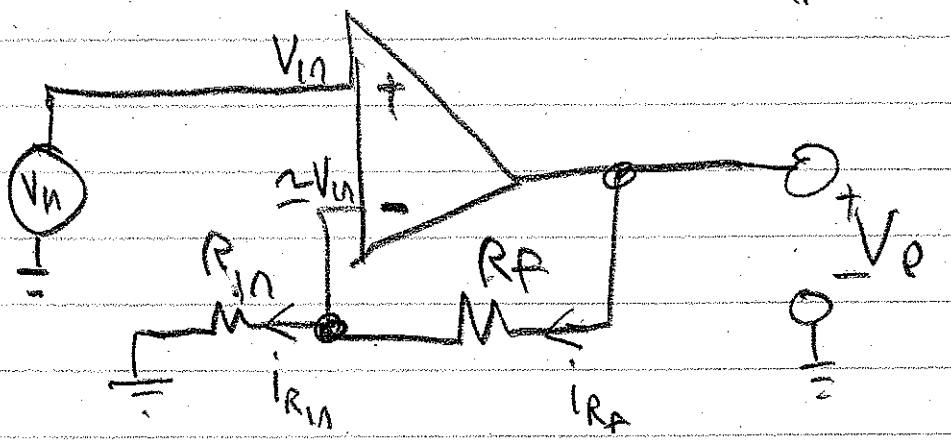
$\frac{K}{K+1} \simeq 1$ for large K

Simple Model is great for Design



$$\frac{V_o - 0}{R_f} = i_{R_f} = i_{R_{in}} = \frac{0 - V_{in}}{R_{in}}$$

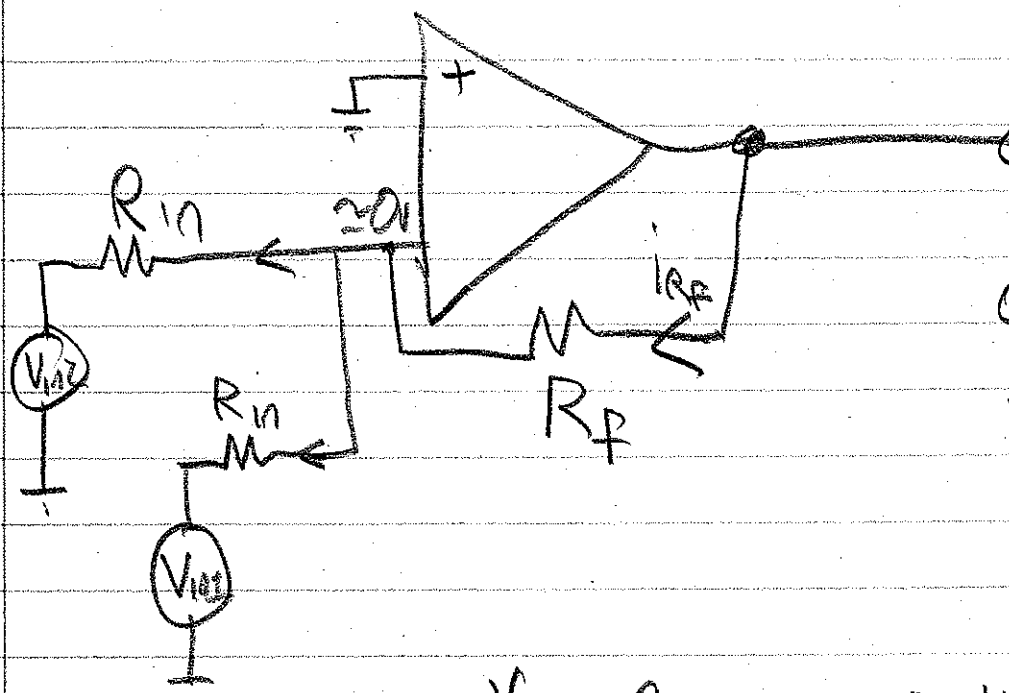
$$\Rightarrow V_o = -\frac{R_f}{R_{in}} V_{in}$$



$$\frac{V_o - V_{in}}{R_f} = \frac{V_{in} - 0}{R_{in}} \Rightarrow V_o = \left(1 + \frac{R_f}{R_{in}}\right) V_{in}$$

More Complicated Circuits

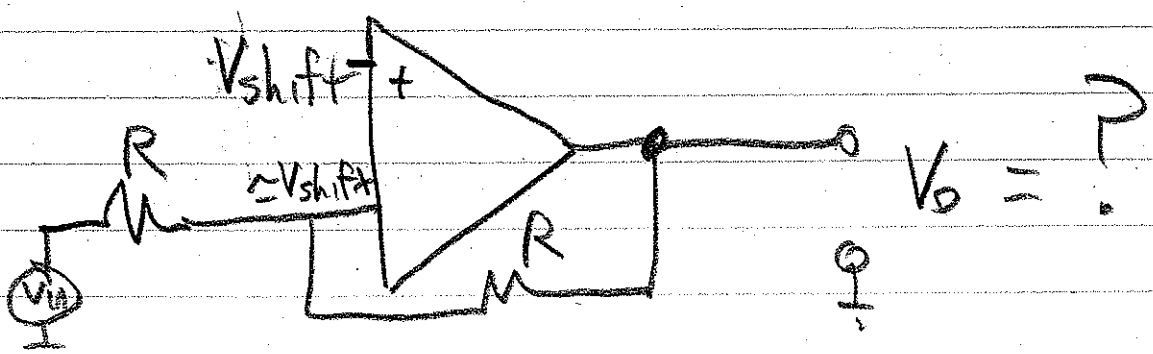
Summer (Inverting)



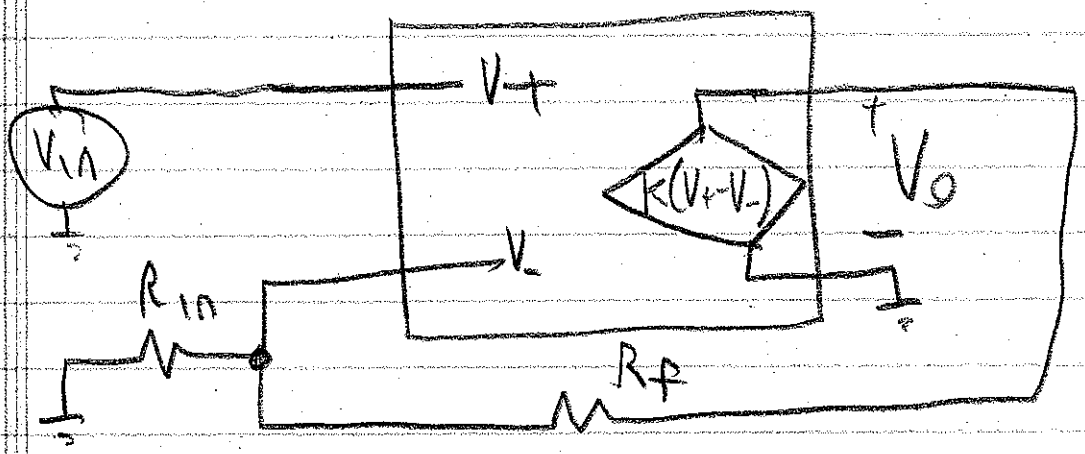
$$\frac{V_o - 0}{R_F} = \frac{0 - V_{in2}}{R_{in}} + \frac{0 - V_{in1}}{R_{in}}$$

$$V_o = -\frac{R_F}{R_{in}}\left(V_{in1} + V_{in2}\right)$$

Level Shifter



Non-inverting Amp Using Detailed Model



$$V_o = K(V_+ - V_-) \qquad V_+ = V_{in}$$

$$V_- = V_o \frac{R_{in}}{R_{in}+R_f}$$

$$V_o = K\left(V_{in} - \left(\frac{R_{in}}{R_{in}+R_f}\right) V_o\right)$$

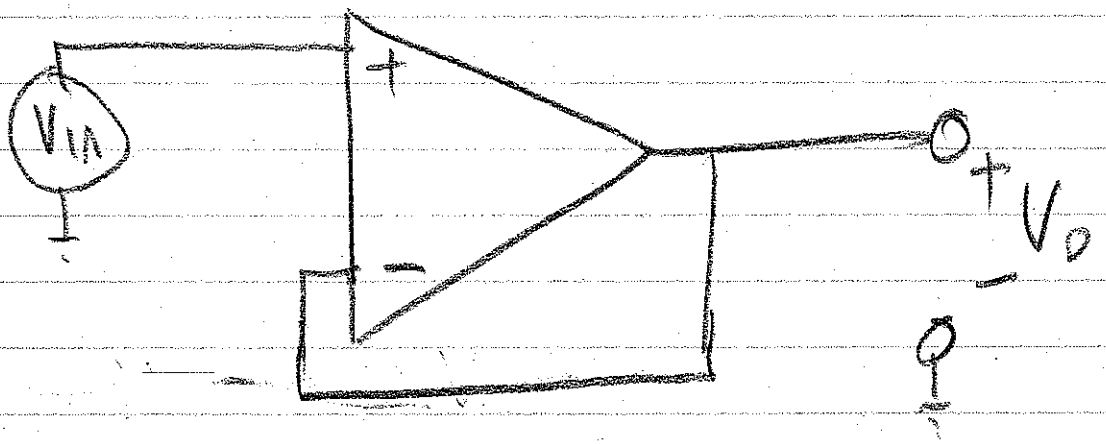
$$\left(1 + K\frac{R_{in}}{R_{in}+R_f}\right) V_o = K V_{in}$$

$$V_o = \frac{K}{1 + K\frac{R_{in}}{R_{in}+R_f}} V_{in}$$

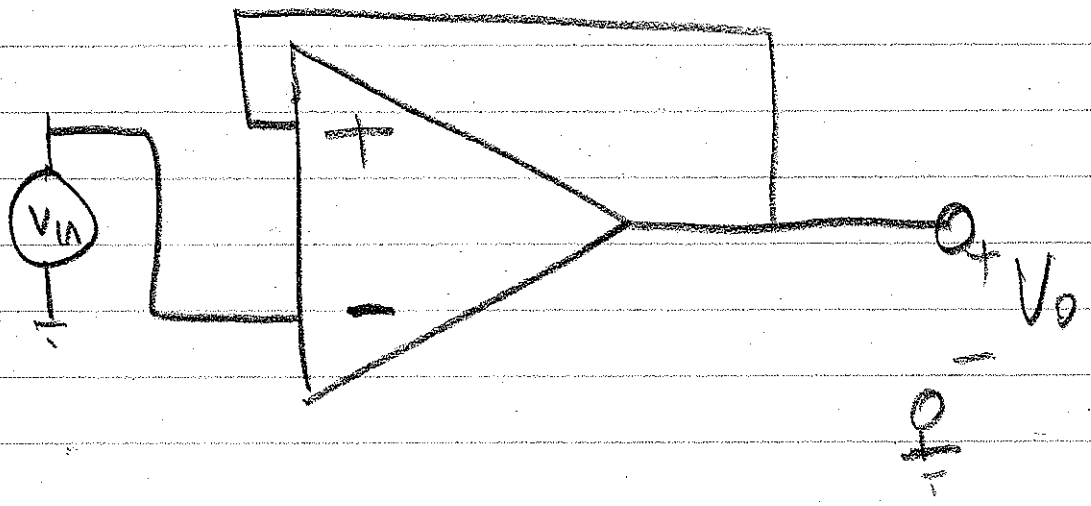
$$= 1 + \frac{R_f}{R_{in}} \quad \text{if } K \text{ large}$$

Questions About Followers

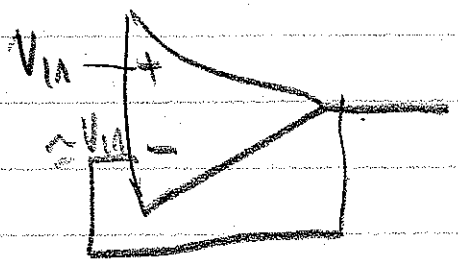
"Good" Follower



"Bad" Follower

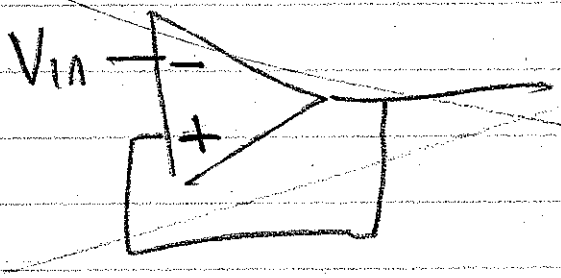


Simple Model



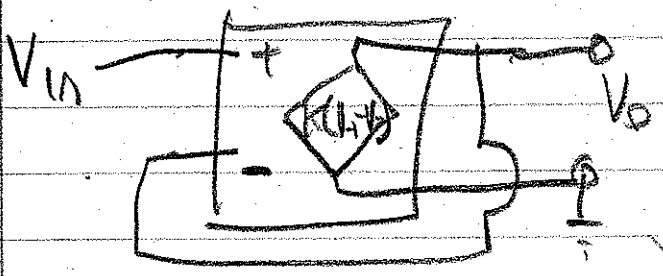
$$V_o \cong V_{in}$$

Wrong



$$V_o \simeq V_{in}$$

More Detailed Model

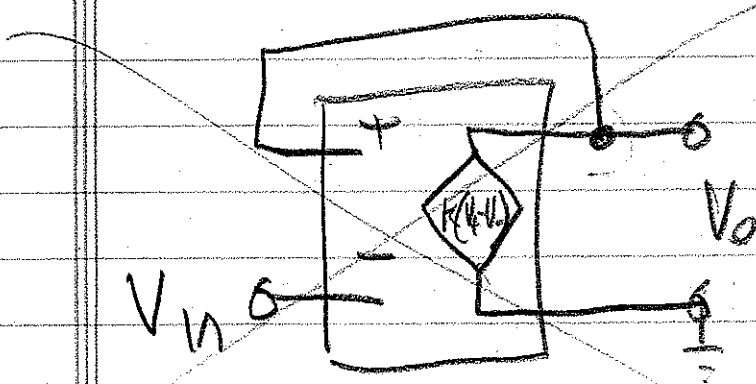


$$V_o = K(V_+ - V_-)$$

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

Wrong

$$V_o = \frac{K}{K+1} V_{in} \cong V_{in} \quad (K \text{ large})$$



$$V_o = K(V_+ - V_-)$$

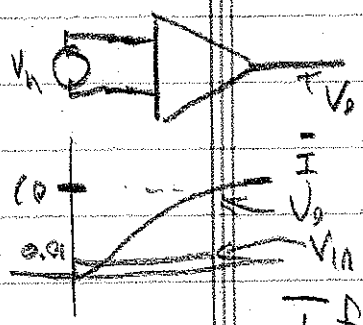
$V_- = V_o$, $V_+ = V_{in}$

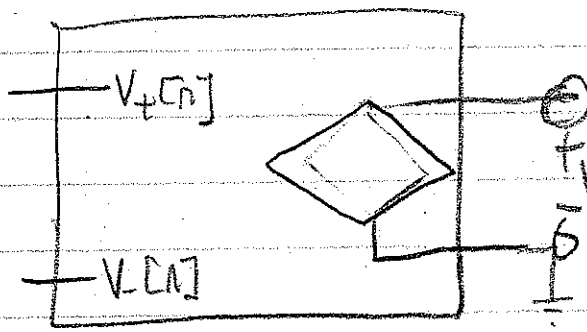
$$(1+K)V_o = K V_{in}$$

$$V_o = \frac{K}{K+1} V_{in} \cong V_{in}$$

More Detailed Op amp model

What to Model





$$V_o[n+1] = \frac{k-1}{k} V_o[n] + \left(V_+[n] - V_-[n]\right)$$

If $k = 1000$

$$V_o[n+1] = \frac{999}{1000} V_o[n] + \left(V_+[n] - V_-[n]\right)$$

What if $V_+[n] - V_-[n] = 0.01 \quad \forall n$

If $V_o[0] = 0$

$$V_o[n] = \sum_{k=0}^{n-1} \left(\frac{999}{1000}\right)^{((n-1)-k)} \left(V_+[k] - V_-[k]\right)$$

$$V[1] = \left(V_+[0] - V_-[0]\right)$$

$$V[2] = \frac{999}{1000}\left(V_+[0] - V_-[0]\right) + \left(V_+[1] - V_-[1]\right)$$

Eventually

$$V_0[n] = V_0[n-1] = V(*) \quad (\text{for large } n)$$

$$V[*] - \frac{999}{1000} V[*] = 0.01$$

$$= \frac{1}{1000} V[*] = 0.01$$

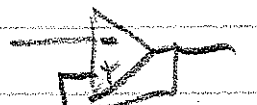
$$V[*] = 1000$$

Now Back to the question

$$V[n] = \frac{999}{1000} V[n-1] + (V_+[n-1] - V[n-1])$$

$$V[n] = -\frac{1}{1000} V[n-1] + V_+[n-1]$$

Net freq < 1



$$V[n] = \frac{999}{1000} V[n-1] + V_+(V[n-1] - V[n-1])$$

$$V[n] = \frac{1.999}{1000} V[n-1] - V[n-1]$$

Net freq > 1