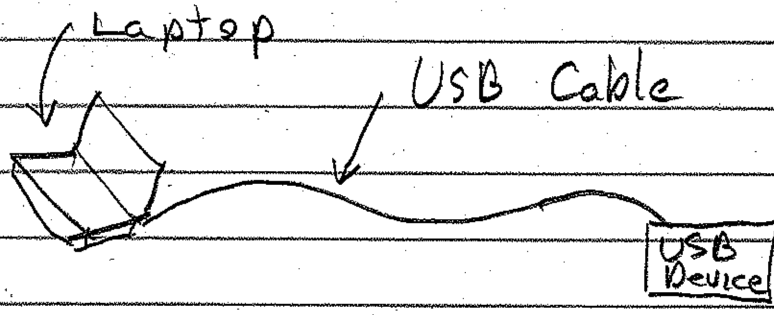
6.01 10/30/2007

Today

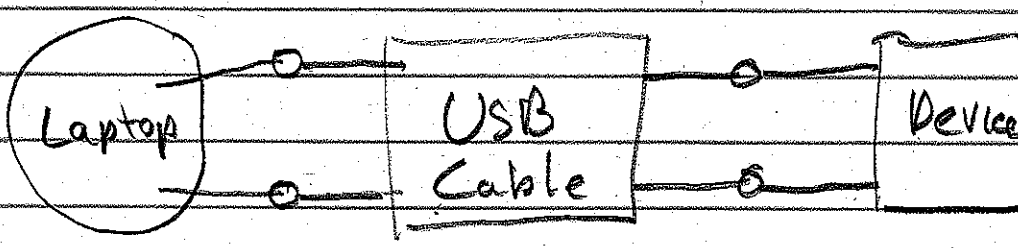
1) Using Thevenin Equivalents
2) Making Circuits Input/Output
3) Op-Amps
4) Basic Op-Amp Circuits

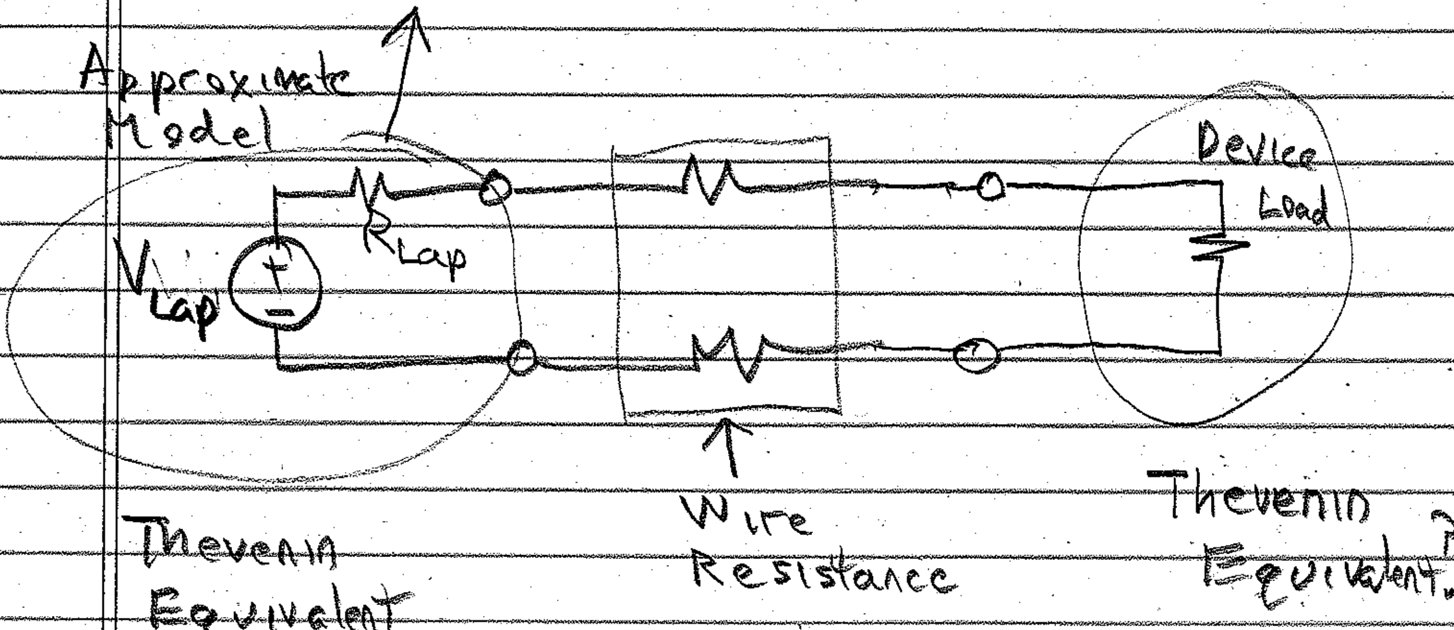
## Example Problem




**Question** How big a load can USB drive? Does it depend on cable length?

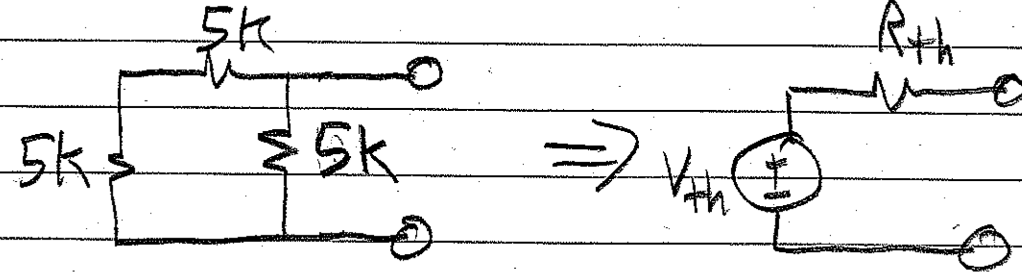
## Models



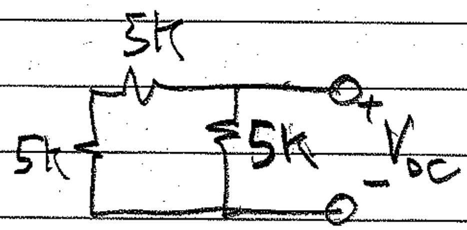
# Aside on Thevenin Equivalents

## Consider following Circuit

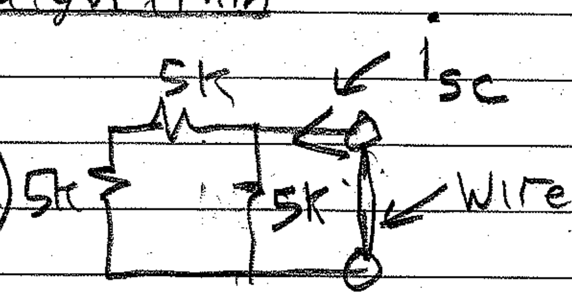



## Follow Standard algorithm

Step 1)




Step 2)

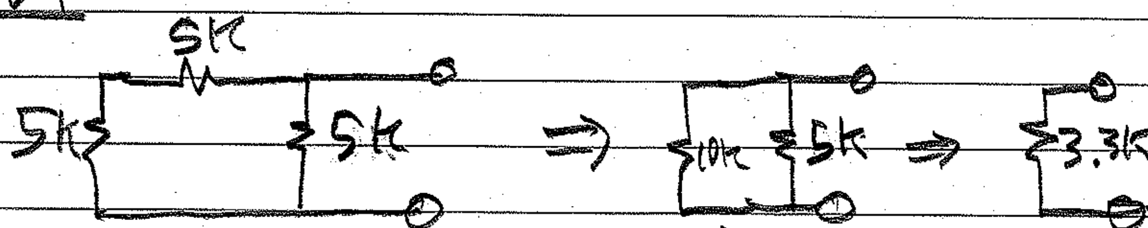


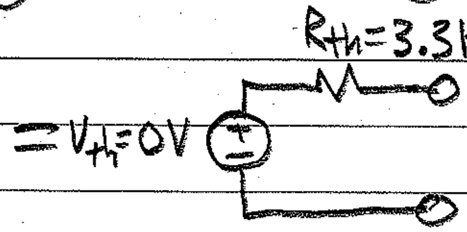

$V_{oc} = 0$ $\qquad$ $i_{sc} = 0$

$V_{th} = 0$ $\qquad$ $R_{th} = \frac{V_{th}}{i_{sc}} = ?$

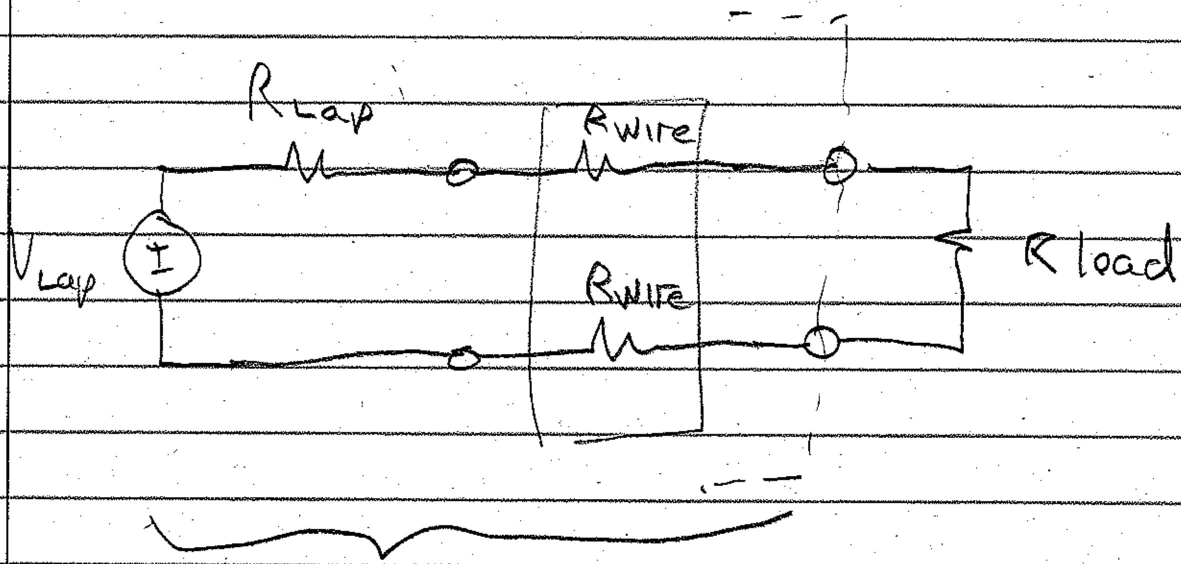
Method Fails!

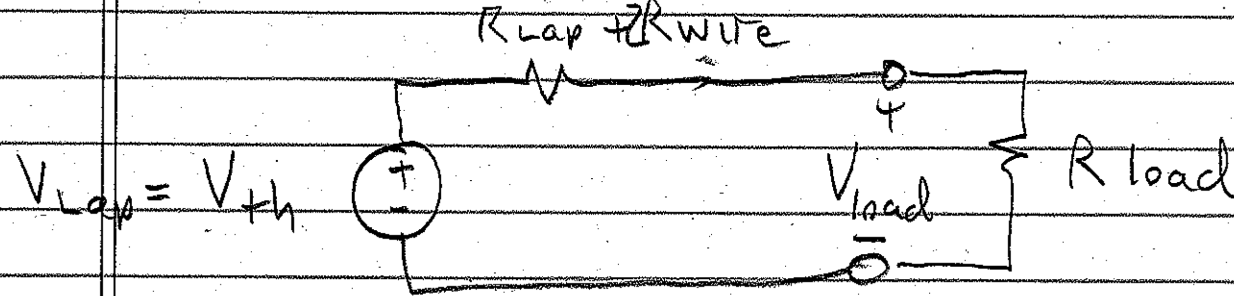
## But



## Back to USB problem




$$V_{load} = \frac{R_{load}}{R_{load} + R_{Lap} + 2R_{wire}} V_{Lap}$$

**Device Works** $R_{Lap} =$ [illegible]

$V_{load}$ is with 10% of $V_{lap}$

$$\Rightarrow \frac{R_{load}}{R_{load} + R_{Lap} + 2R_{wire}} > 0.9$$

Short Cable Case

$R_{lap} = 50\Omega \quad R_{wire} = 5\Omega$

Minimimum $R_{load}$?

$$\frac{R_{load}}{R_{load} + 60\Omega} \geq 0.9$$

$0.1 R_{load} = 54\Omega \Rightarrow R_{load} \geq 540\Omega$

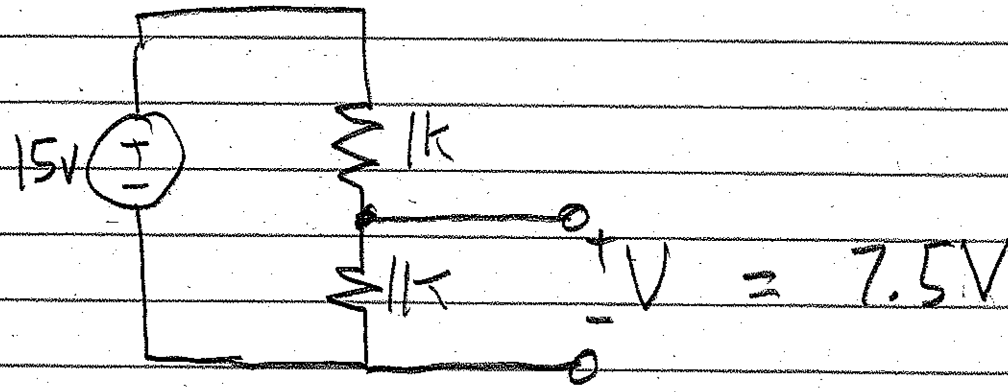
Long Cable Case

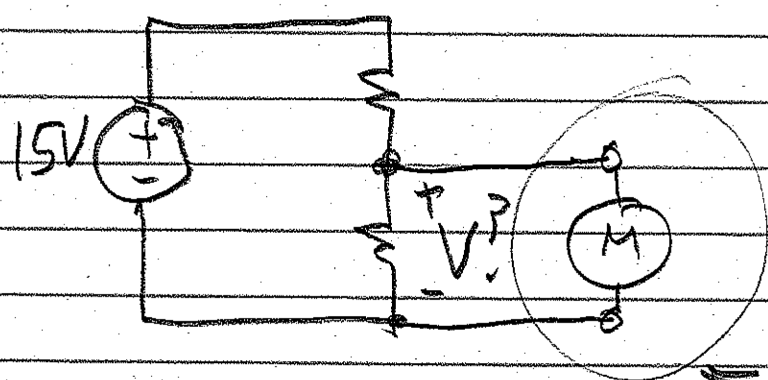
$R_{lap} = 50\Omega \quad R_{wire} = 25\Omega$

$$\frac{R_{load}}{R_{load} + 100\Omega} = 0.9$$

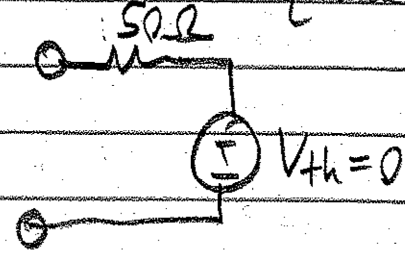
$R_{load} \geq 900\Omega$

## Driving a Motor




≈ Thevenin Equivalent




$\Rightarrow V \approx 0.75V$

## Motor Loaded the Divider

## Input / Output for Circuits

**Suppose**

```
def f(x):
    ~~~
    return z
```

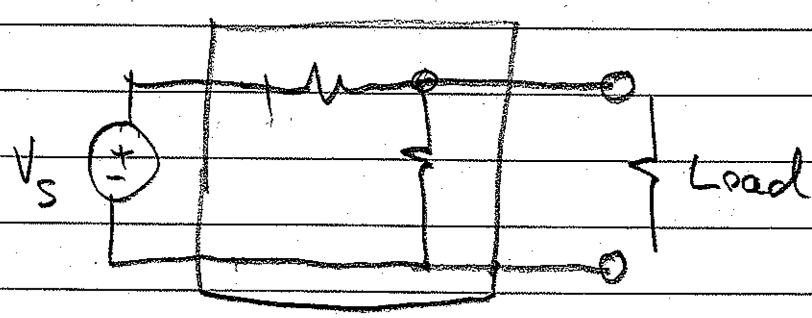
Could you design software if the Value Returned by f depended on how you used it

$$y = f(x_1) + f(x_2)$$

$$z = 3.0 * f(x_1)$$

**No!**

**But what about the Divider?**

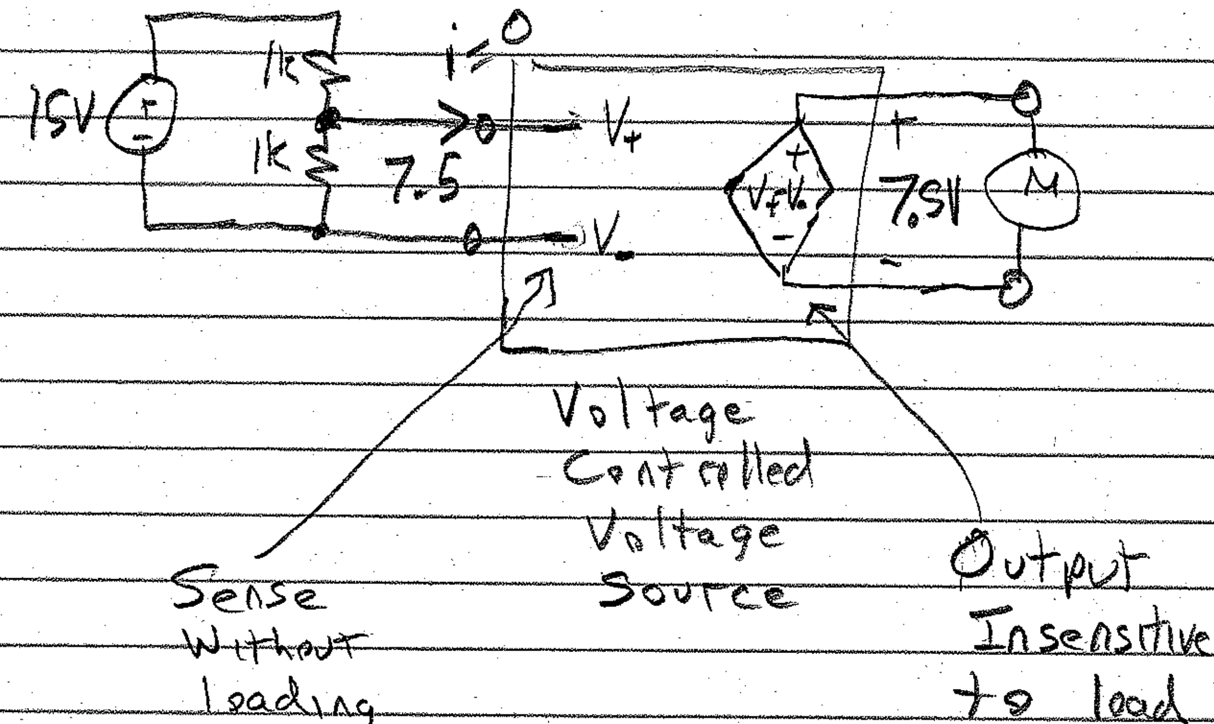



Divider

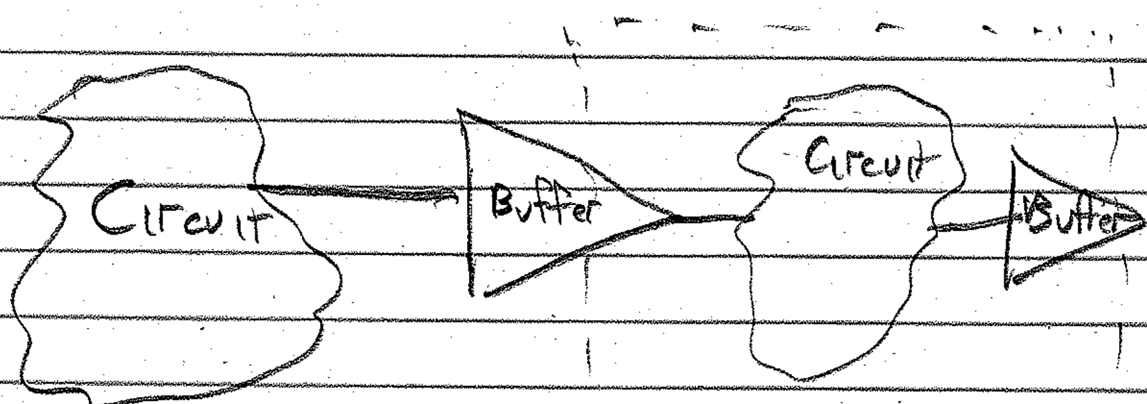
Divider result depends on how you use it!

## Need a "buffer"

## Voltage-Controlled Voltage Source

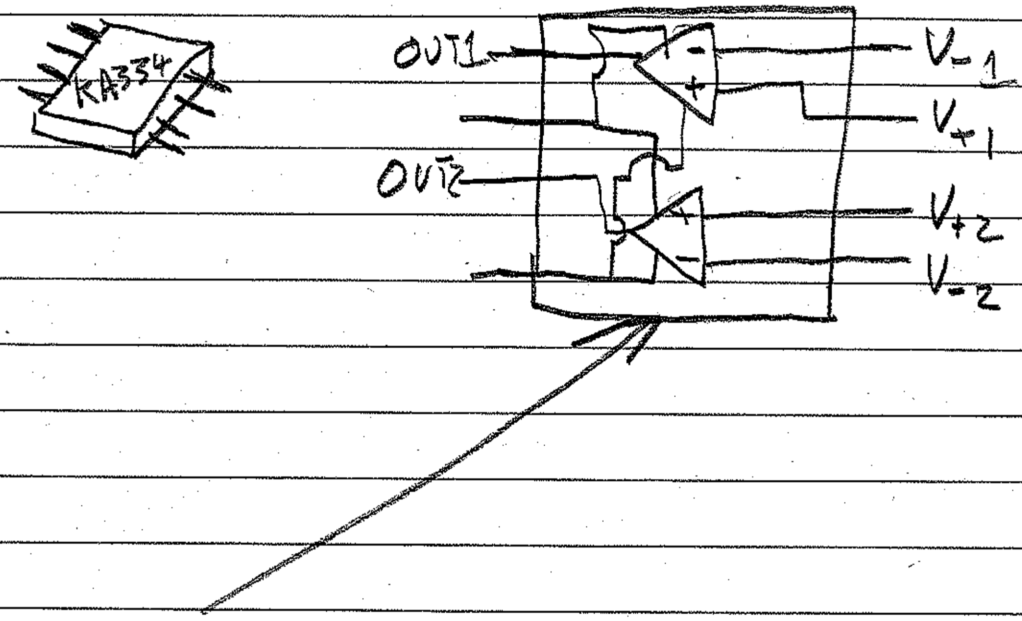



## With Buffers

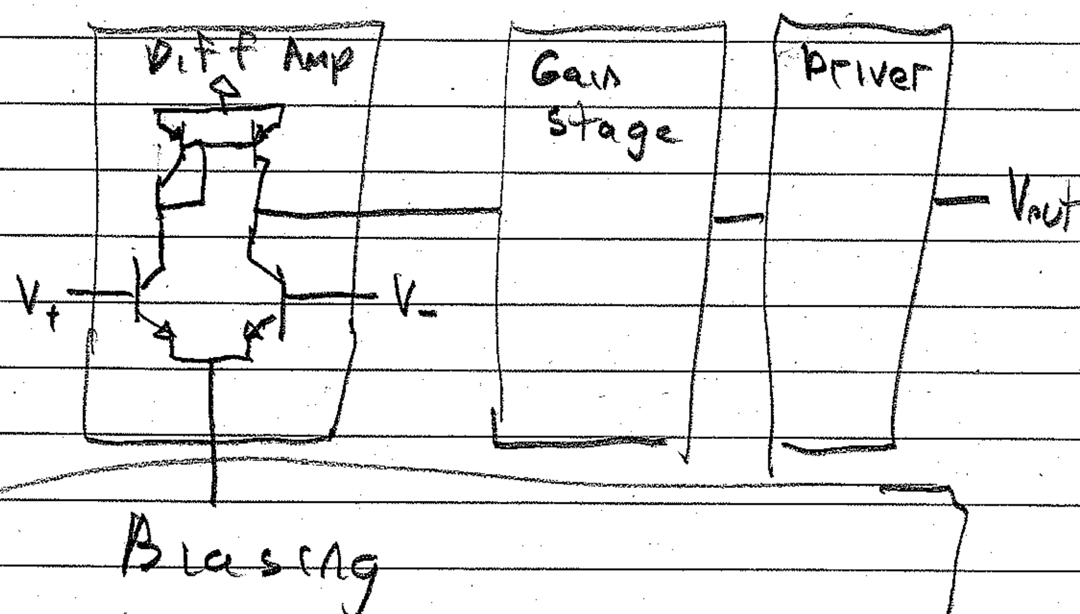



Restores Input / Output Description

# The Op-Amp

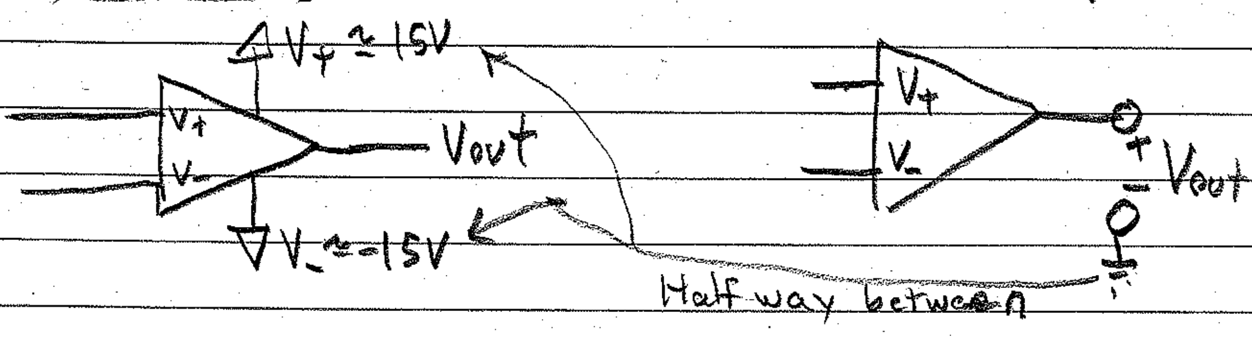



What's inside



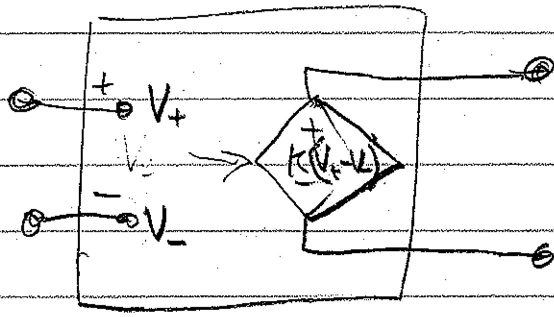

Op-Amp

Usual View

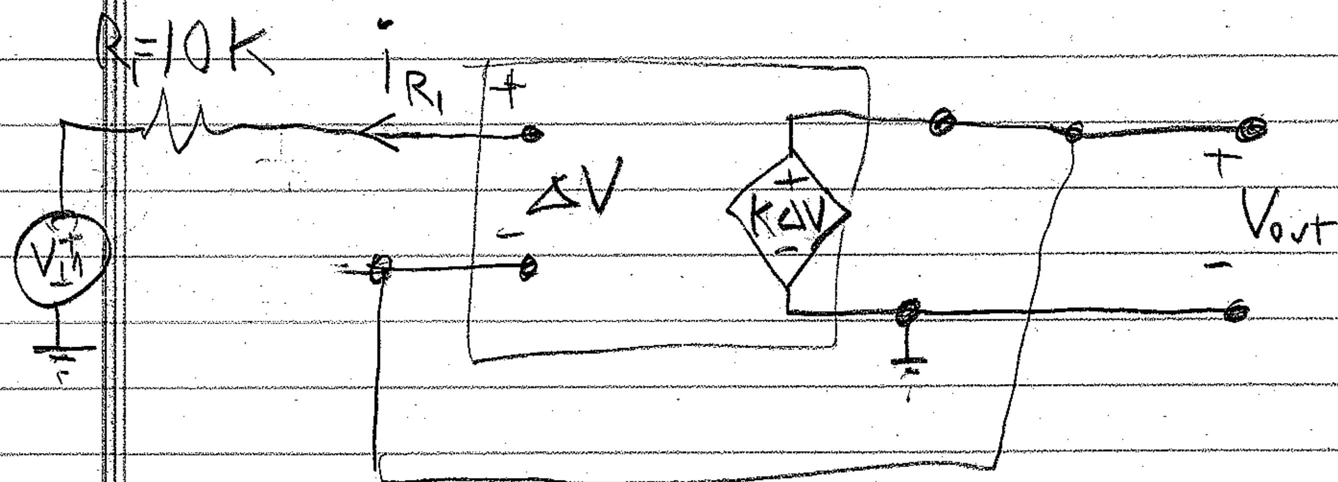


# The Op-Amp Model

$K \simeq 10{,}000$




## Simple Case - Buffer




$$i_{R_1} = 0 \Rightarrow V_+ = V_{in}$$

$$V_- = K\Delta V$$

$$\Delta V = (V_+ - V_-)$$

$$V_{out} = K\Delta V$$

$$\Delta V = \frac{1}{1+K} V_{in}$$

$$V_0 = \frac{K}{1+K} V_{in}$$

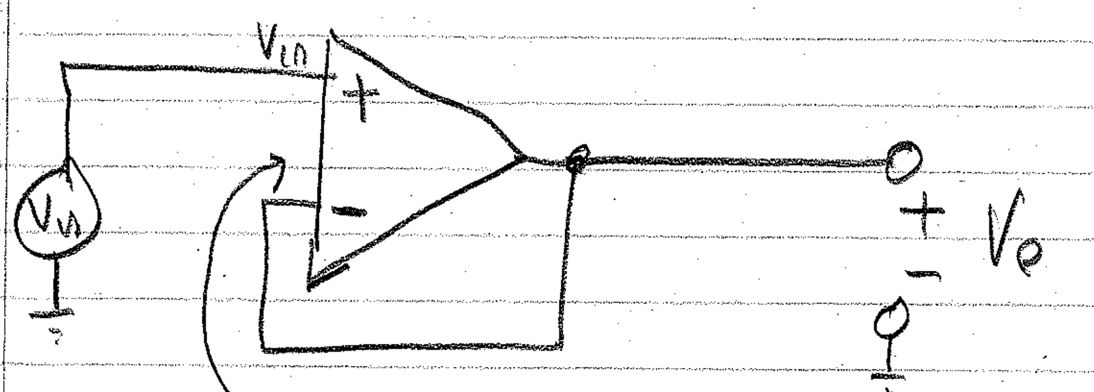
$$\simeq V_{in}$$

## 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

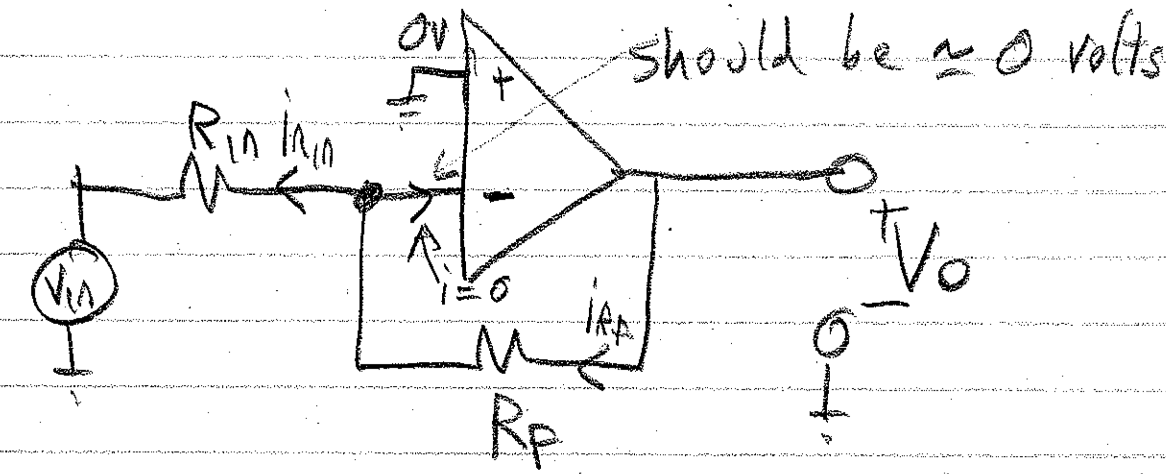
## Simple Circuit Follower




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

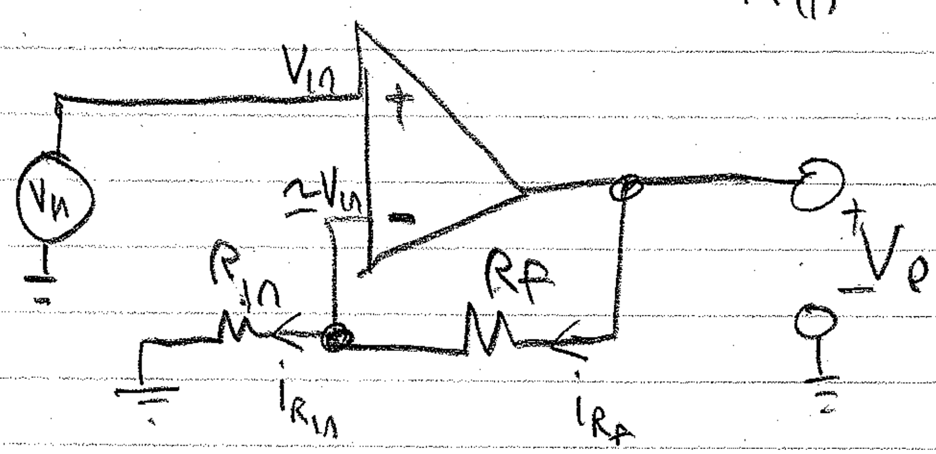
$$\Rightarrow V_o = V_{in}$$

# Simple Model is great for Design




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

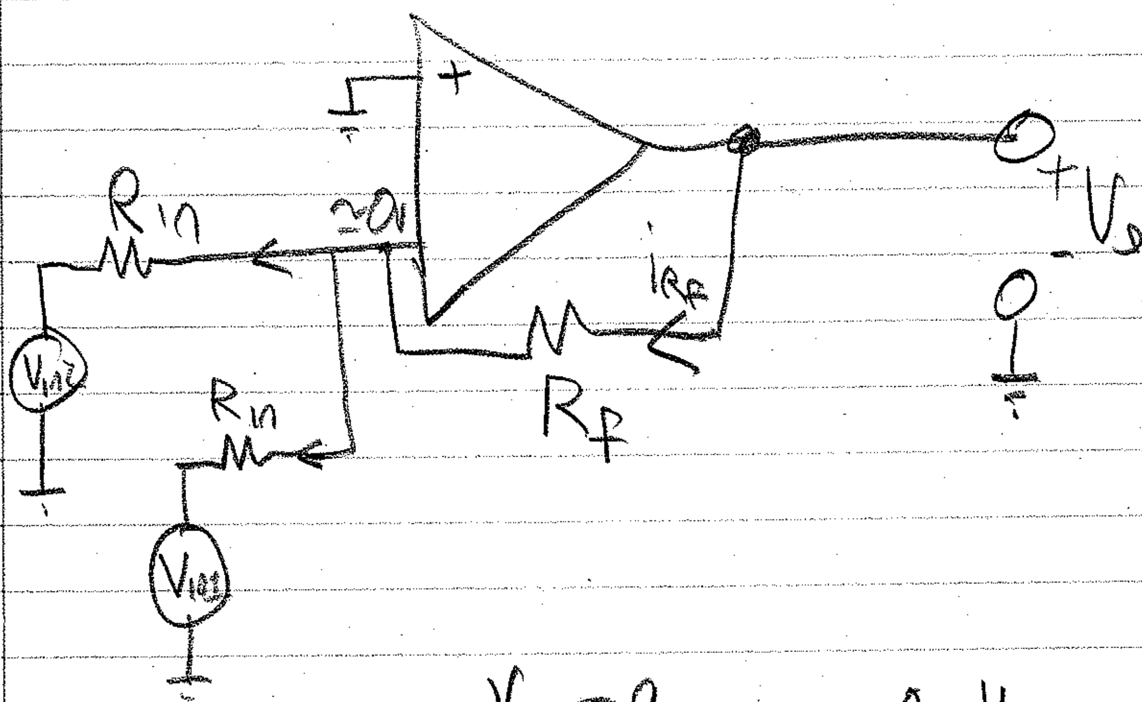
$$\Rightarrow V_o = -\frac{R_F}{R_{in}} V_{in}$$




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

# More Complicated Circuits

## Summer (Inverting)




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

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