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- Lecture 8 - 07/09/04

Finish Op-Amps

Next week → Midterm Week

Mon: Bart's Review

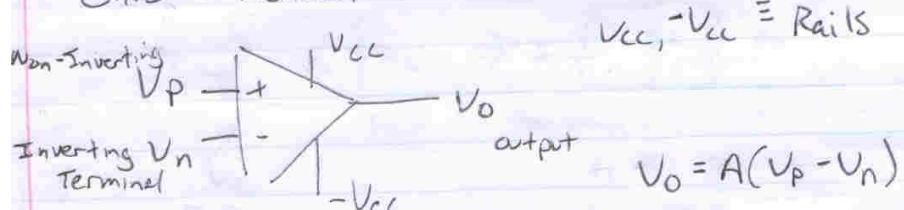
Wed: Justin's Review

Extra Off: Ashwin W:2-4 → Labs = Q&A w/ TAs

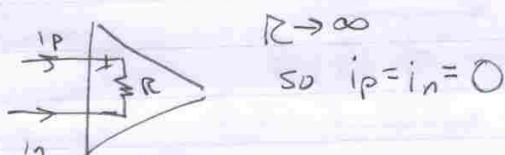
Midterm: Chapters 1-5

4 Problems (maybe 5)

Ch.5 : Recall

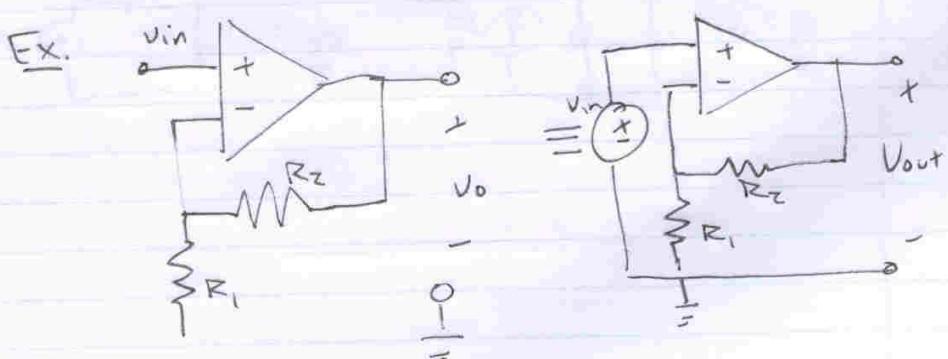


Ideally  $A \rightarrow \infty$   $v_p \approx v_n$  ( $v_o$  is finite)



Need to use feedback to keep circuit stable.

Ex.



(1)

(2)

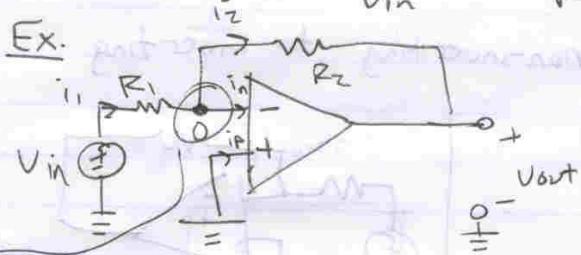
2 Steps  $\rightarrow$  Analyzing using negative feedback

(1) Use  $V_p = V_n$  (use  $i_p = 0$ )

(2) Write KCL @  $V_n$  & use  $i_n = 0$

$$\text{Find: } \frac{V_{out}}{V_{in}} = 1 + \frac{R_2}{R_1}$$

Ex.



Assume ideal

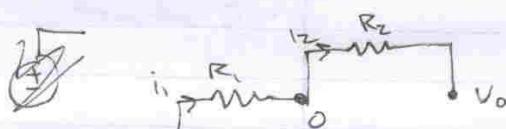
i.e.: ignore rails  
(power supply)

Step 1:  $V_p \approx V_n = 0$

Virtual Ground because  $V_n = 0$  due to op-amp

Step 2: KCL @  $V_n$

$$i_1 = i_2 + i_n \xrightarrow{i_n=0} i_1 = i_2$$



$$i_1 = \frac{V_{in} - 0}{R_1}$$

$$i_2 = \frac{0 - V_o}{R_2}$$

$$i_1 = i_2 \Rightarrow \frac{V_{in}}{R_1} = -\frac{V_o}{R_2}$$

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

Inverting because of negative

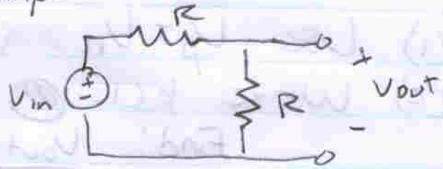
(1)

(3)

Ex. Circuit w/  $V_o = \frac{1}{2} V_{in}$

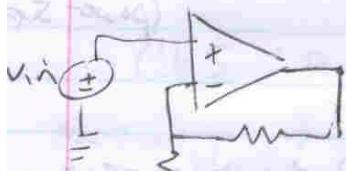
Can't use op-amps

Use 2 resistors

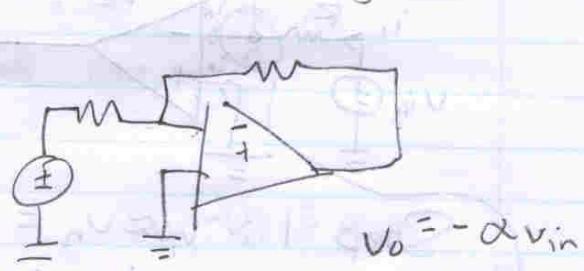


Let's compare non-inverting to inverting

Non-Inverting



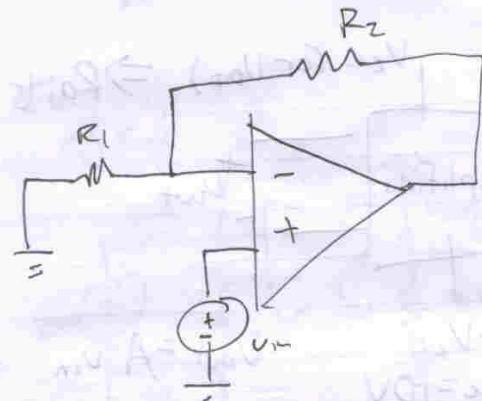
$V_{in}$  comes into non-inverting terminal



$V_{in}$  comes into inverting terminal

$$V_o = -\alpha V_{in}$$

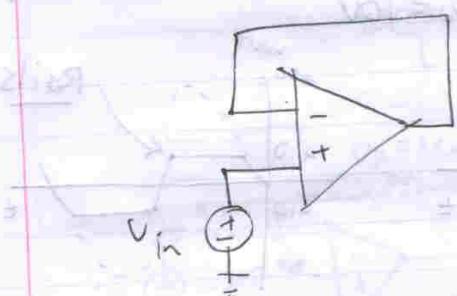
(4)



Non-inverting

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

Voltage Follower:



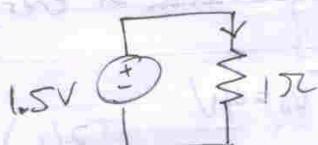
SAME

let  
 $R_1 \rightarrow \infty$

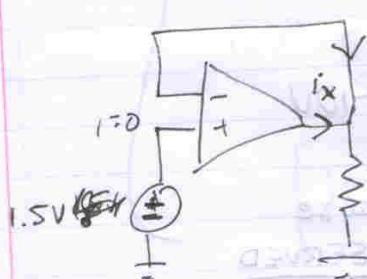


No current  
 flow into  $R_2$   
 so  $v_o = v_n$

Voltage follower does not suck up current  
 from the source



Not possible w/ a AA battery

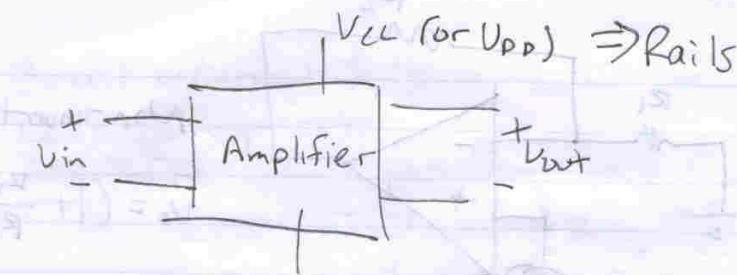


$$v_p = v_n = 1.5 = v_o$$

$$i_x = 1.5 \text{ A}$$

Cp-amp provides 1.5A  
 Battery provides 0A

(5)

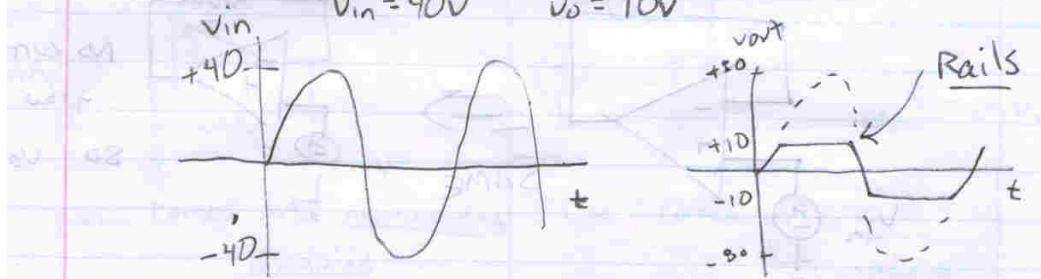


$$\text{If } A=2, \quad V_{cc} = 10V \quad V_{out} = A V_{in} \quad A \geq 1$$

Theoretically  $V_{in} = 40V \quad V_o = 80V$

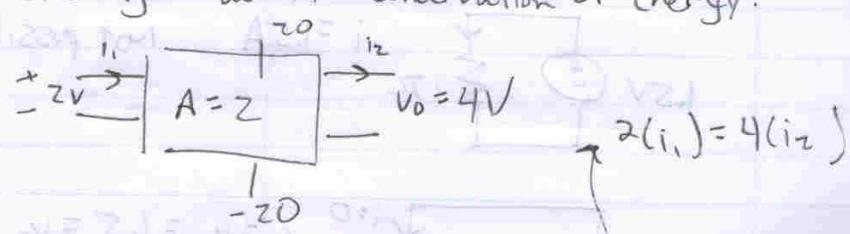
Realistically, cannot amplify more than power supply

$$V_{in} = 40V \quad V_o = 10V$$



Why? Amplifier uses power from power supply to actually amplify

Are we violating Law of Conservation of Energy?



$$\text{If } V_{in} = -5V, \quad V_{out} = -10V$$

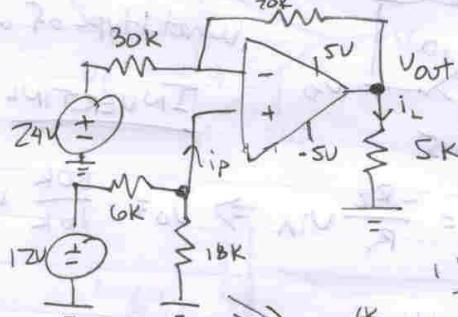
Are we violating law of energy?

Energy is conserved because  
POWER IS CONSERVED

DON'T MAKE SIGN ERRORS!!!

Ex. (P. 5.2)

Q) Find  $i_L$  in  $\mu A$



If  $v_o = 20$ ,

set  $v_o = 5$  due to rail

$$1) i_p = 0$$

$$\text{Use voltage divider}$$

$$v_p = 12 \left( \frac{18}{18+6} \right) = 9V$$

\*Note: the kilo-ohms cancelled

$$\text{So: } v_o = v_p = 9V$$

$$i_1 = i_2 + i_o \rightarrow 0$$

$$i_1 = \frac{24-9}{30,000} = \frac{15}{30,000} \text{ mA} = 0.5 \text{ mA}$$

$$0.5 \text{ mA} = i_1 = i_2 = \left( \frac{9 - v_o}{20,000} = 0.5 \text{ mA} \right) \times 1000 \Rightarrow \frac{9 - v_o}{20} = 0.5 \text{ A}$$

$$9 - v_o = 0.5(20) = 10 \text{ A}$$

$$v_o = -1V$$

Is  $-5 \leq -1 \leq 5$  True? YES  $\Rightarrow$  NO RAILING

$$i_L = \frac{v_o - 0}{5000} = \frac{v_o}{5000} (\text{A}) = \frac{v_o}{5} (\text{mA}) = -\frac{1}{5} \text{ mA}$$

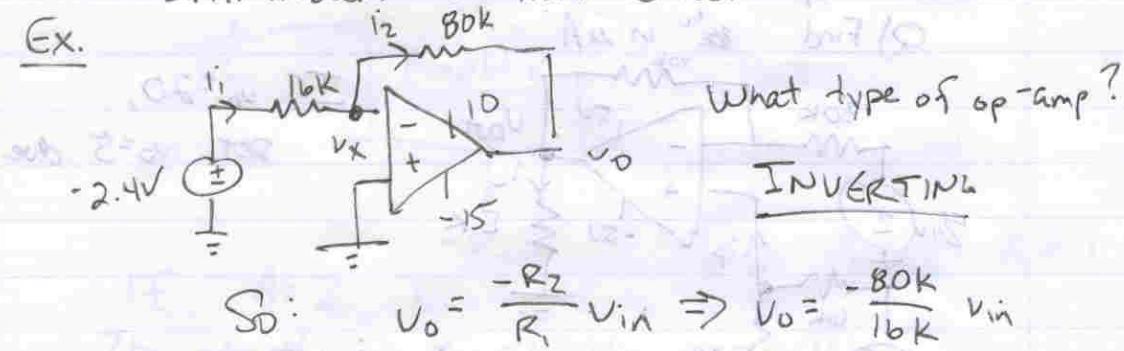
$i_L = -0.2 \text{ mA}$
<del>0.2</del> mA
$i_L = -200 \mu A$

7

Don't make mistakes!!!

Drill Problem 5.1 from the book

Ex.



$$\text{So: } V_0 = \frac{-R_2}{R} V_{in} \Rightarrow V_0 = \frac{-80k}{16k} V_{in}$$

$$V_0 = -5 V_{in}$$

$$= V_{in} = -2.4 \quad V_0 = -5(-2.4) = +12V$$

Is 12 between -15 & 2? NO

Because of RAILING, so  $V_0 = 10V$

What about  $V_x$ ?  $V_p = 0 = V_n = V_x$ ?

$V_x = 0$ ? NO We had railaling

Proof: Apply KCL @  $V_n$  we have been tricked!

$$i_1 = i_{n+} + i_2 \Rightarrow i_1 = i_2$$

$$i_2 = \frac{V_x - V_o}{80k} = \frac{V_x - 10}{80k}$$

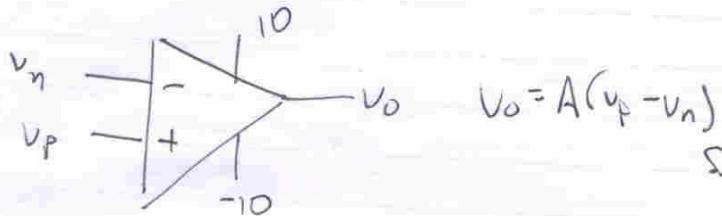
$$\frac{V_x - 10}{80} = -\frac{2.4 - V_x}{16}$$

$$V_x = -\frac{1}{3}V$$

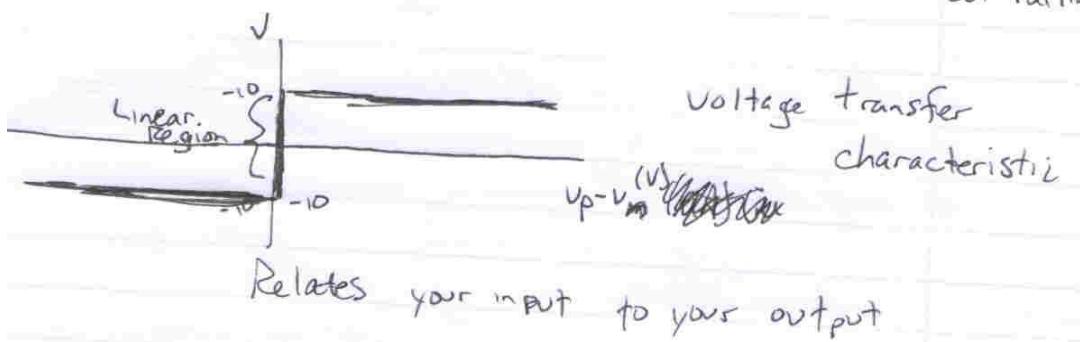
So, why is  $V_x$  not  $0$ ?

(8)

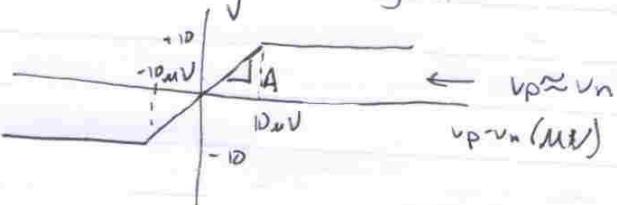
Explanation



Suppose  $v_p - v_n = 30 \mu V$   
 $v_o = 30$   
 but racing



If we zoom in on linear region:



In linear region, op-amp successfully has  $v_p \approx v_n$

In the horizontal regions, called the saturation regions,  ~~$v_p \approx v_n$~~  is no longer valid

$$v_o = \begin{cases} V_{cc} & \text{if } A(v_p - v_n) > V_{cc} \\ A(v_p - v_n) & \text{if } -V_{cc} < A(v_p - v_n) < V_{cc} \\ -V_{cc} & \text{if } A(v_p - v_n) < -V_{cc} \end{cases}$$