Lecture 17 - Op-amps intro.

Administrivia → (1) No HW this week ☺

(2) midterm graded!

Today → op-amps intro.

→ pass midterm

Thursday: Justin lecture ≡ op-amps!

Chapter 5 - Operational Amplifiers aka Op amps.

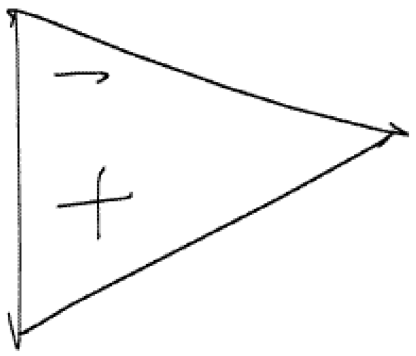
Caution: op-amps are difficult to comprehend (initially). Many reasons, however

PRACTICE PROBLEMS!

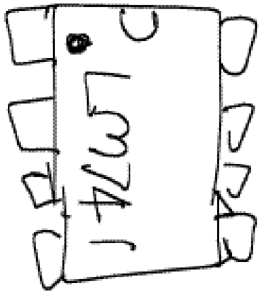
Also, concept of feedback ⇒ talk about this after SPRING BREAK

5·1- Introduction

Op-amp → Circuit symbol



Actually:

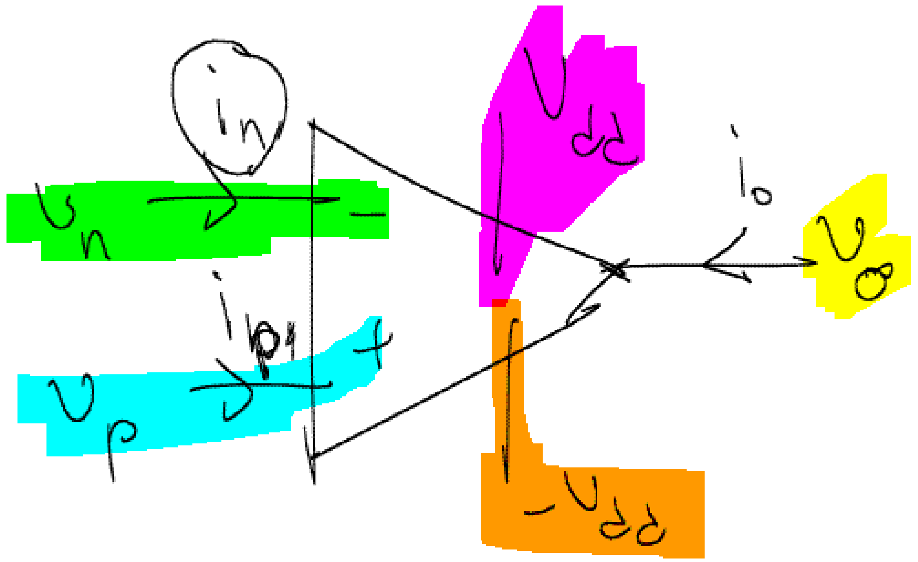


Why op-amps?

is VERY useful since we can implement mathematical operations (like adders, integrators etc &

amplifier (voltage current etc). To understand how op-amps work:

Step 1:- Circuit terminology / model



(1) Has three terminals:

(a) Output terminals

(b) inverting terminal

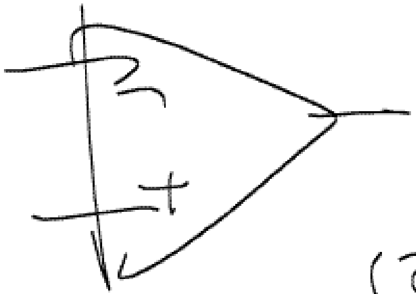
(c) non-inverting terminal

(d) positive rail

(e) negative rail

Note:

Can draw an op-amp any way you want!

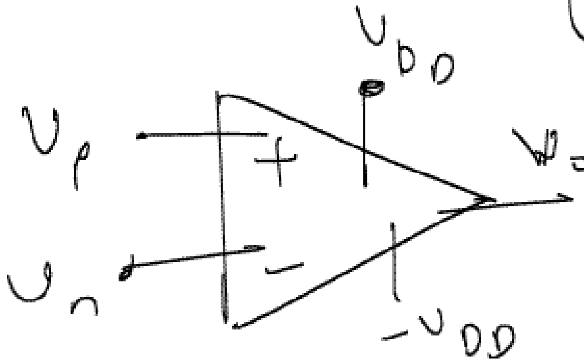


(OR)

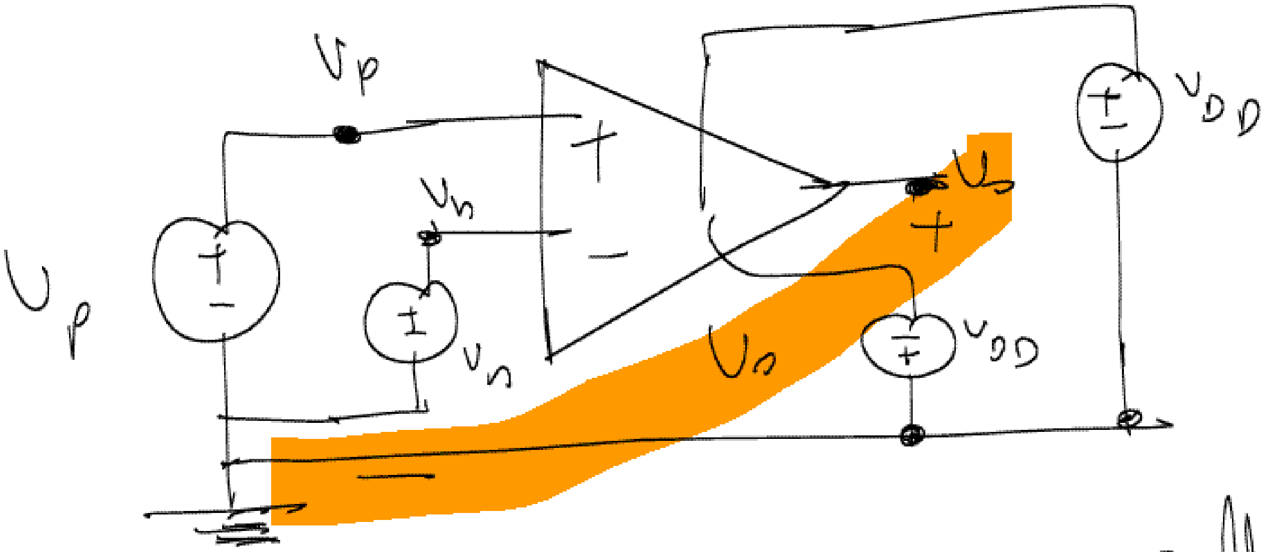
(OR)

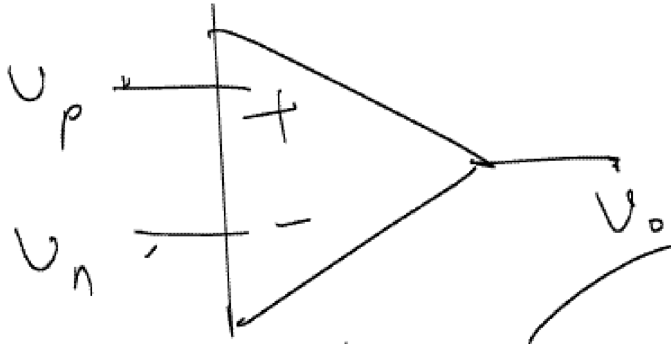
Op-amp model: → ideal op-amp model → 90% of our time

→ non-ideal op-amp model



⟵ Shorthand circuit notation } get used to it



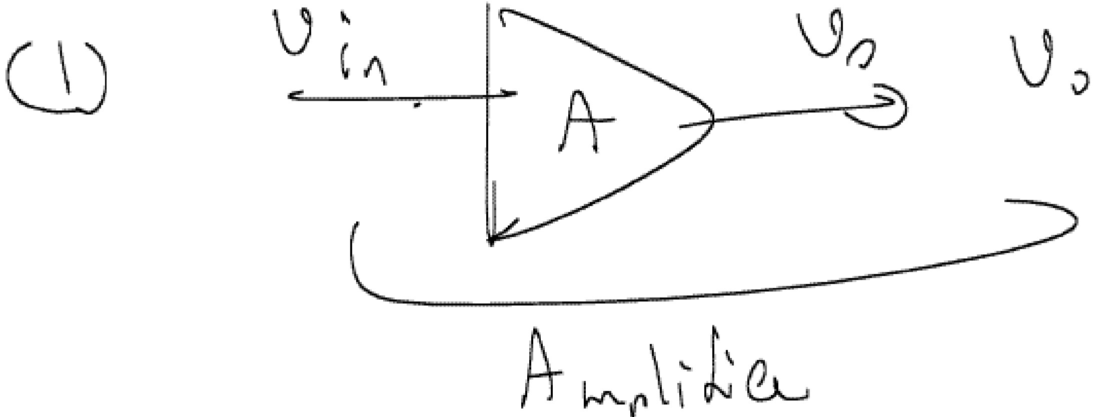


$$v_o = A\underbrace{(v_p - v_n)}, \quad ①$$

usually 10^6

An op-amp is a high-gain differential amplifier

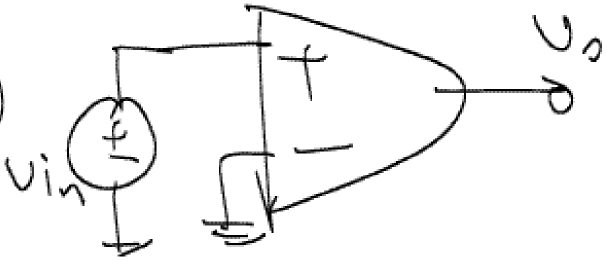
Why differential amplifier?



$v_o = Av_{in}$ — ②

Notice ② is a subset of ① v_{in} o

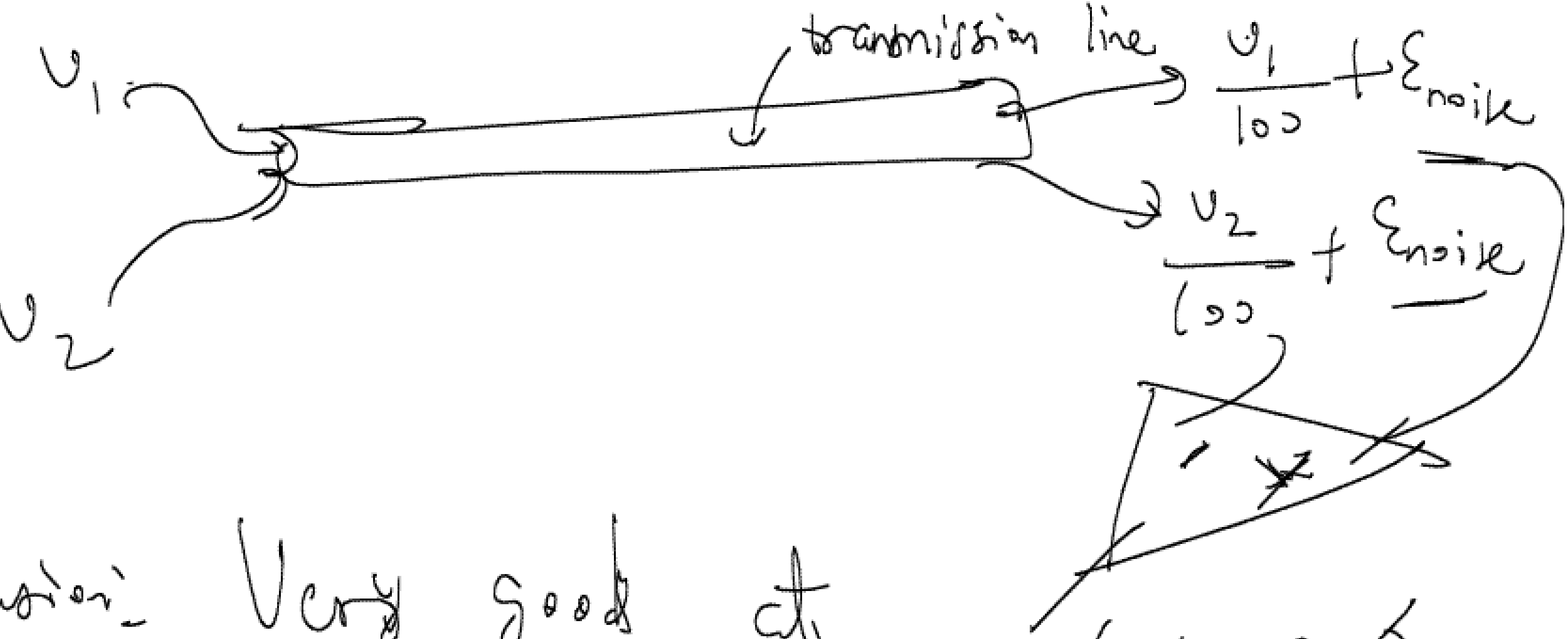
If $v_n = 0 \Rightarrow$



$v_o = A(v_p - v_n)$

$v_o = Av_{in}$

(2)



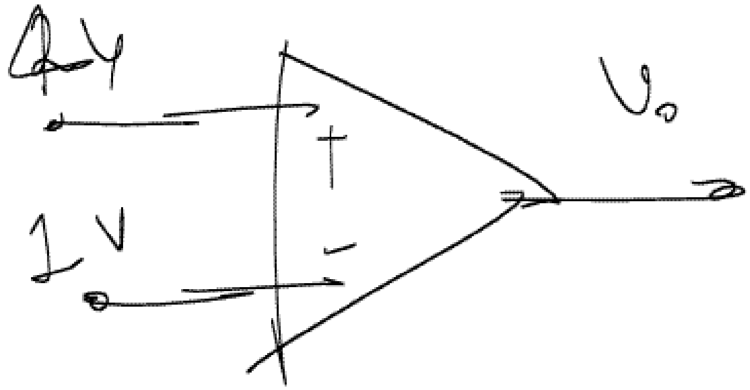
$$v_o = A\left(\left(\frac{v_1}{100} + \cancel{E_{noise}}\right) - \left(\frac{v_2}{100} + \cancel{E_{noise}}\right)\right)$$

Conclusion: Very good at eliminating noise

Two problems :

(1) $A = 10^6$

Eg:



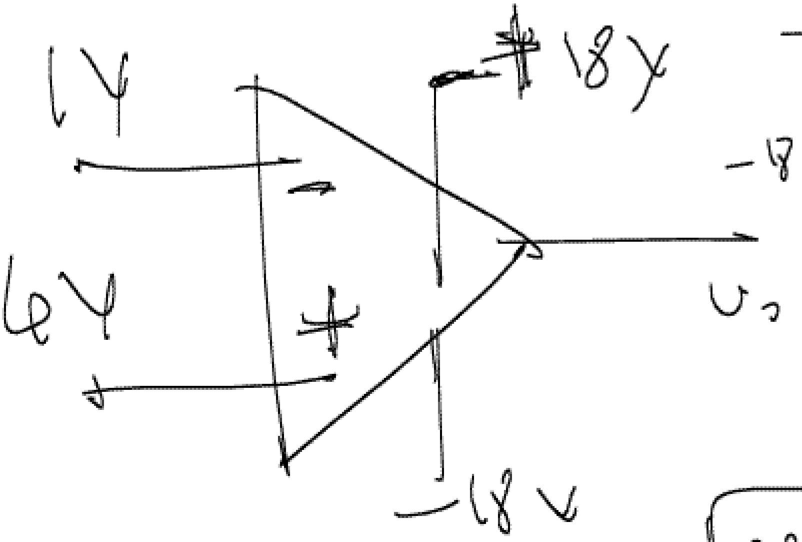
$$V_o = 10^6(4-1)$$

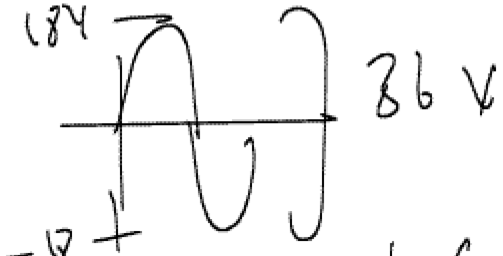
$$= 3\times10^6$$

$$= 3 \text{ MV}$$

physically VERY difficult

In reality, the op-amp can amplify only upto the rail voltage

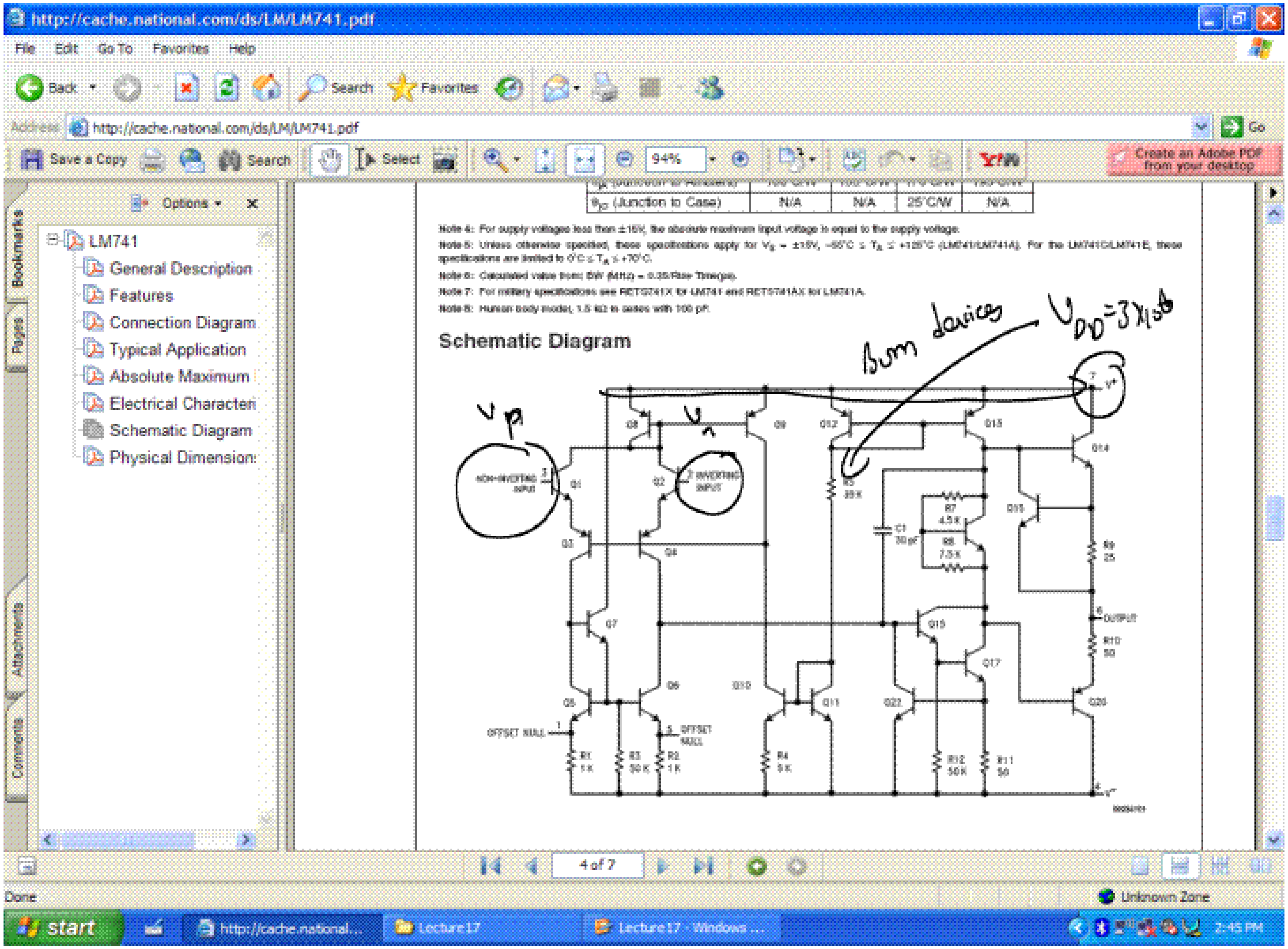




$$v_o = 10^6 (4 - 1)$$

$$= 3 \times 10\cancel{^{6}\,V}$$

$$\boxed{v_o = 18\text{ V}}$$



θ_{JC} (Junction to Case)	N/A	N/A	25°C/W	N/A

Note 4: For supply voltages less than ±15V, the absolute maximum input voltage is equal to the supply voltage.

Note 5: Unless otherwise specified, these specifications apply for $V_S = \pm15V$, $-55°C \le T_A \le +125°C$ (LM741/LM741A). For the LM741C/LM741E, these specifications are limited to $0°C \le T_A \le +70°C$.

Note 6: Calculated value from: BW (MHz) = 0.35/Rise Time(µs).

Note 7: For military specifications see RETS741X for LM741 and RETS741AX for LM741A.

Note 8: Human body model, 1.5 kΩ in series with 100 pF.

Schematic Diagram

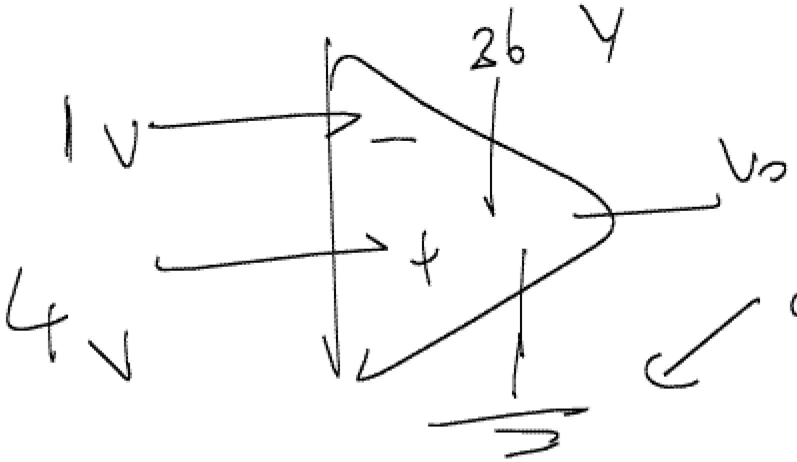
Vp

Vn

Burn devices

$V_{DD} = 3\times10^{8}$

Eg 2:



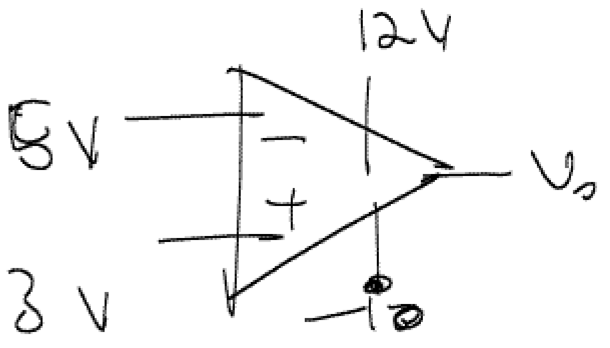
do not put +5 V!

$$V_o = 10^6 (4 - 1)$$

$$= \cancel{10^6 (3)} = \leftarrow$$ Bigger than +36 V [the positive supply]

$$\Rightarrow \boxed{V_o = 36\ V}$$

Eg 3 :

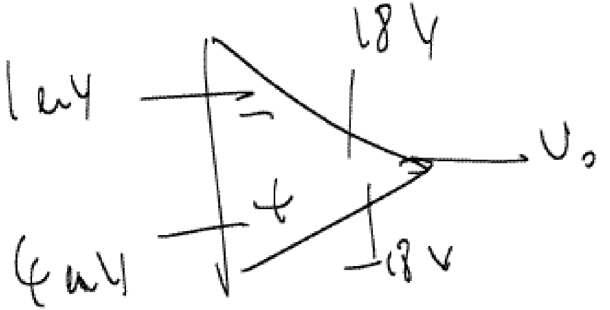


$$V_o = A(V_p - V_n)$$
$$= 10^6(3-5)$$
$$= \cancel{-2\times10^6\ V}$$
$$\boxed{V_o = -10\ V}$$

Notice: op-amp in this configuration its not very useful. It does not amplify, just rails

i.e.. $V_o = V_{DD}$ or $-V_{DD}$

So, to make use of the op-amp as an amplifier, we need to make sure that:



$$V_o \in [18, -18]$$

$$V_o = 10^6 \underbrace{(V_p - V_n)}_{\text{should be in } \mu V}$$

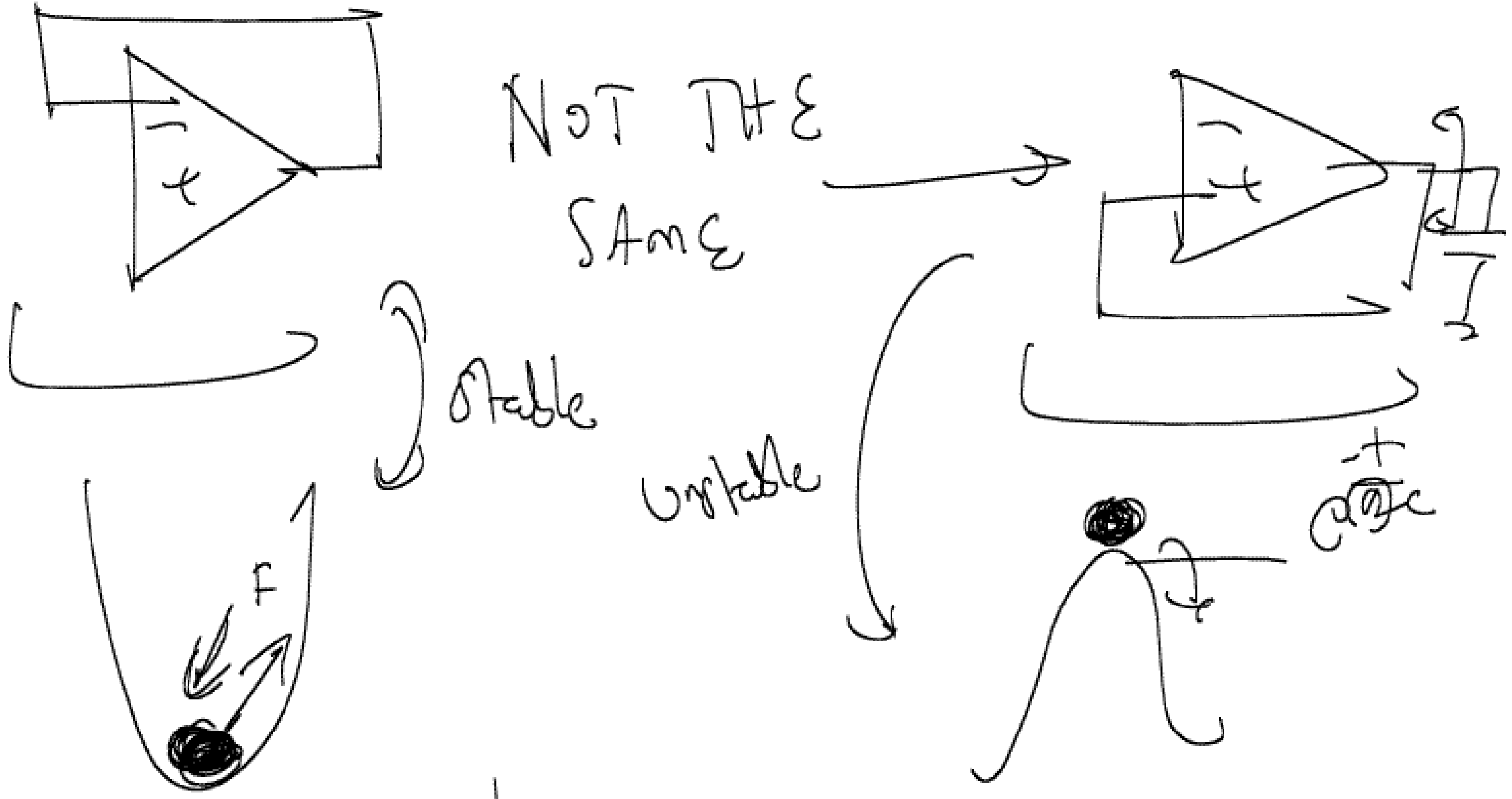
$$V_o = 10^6 (4 \mu V - 1 \mu V)$$

$$= 3 V$$

ok, "real signals" are in the volts range (like you put 3 V into an amplifier, you get like 6 V outputs

ANSWER: NEGATIVE FEEDBACK!

i.e.,



Analogy:

For now, we will deal only with negative feedback

After spring break ⇒ positive feedback !!!!!

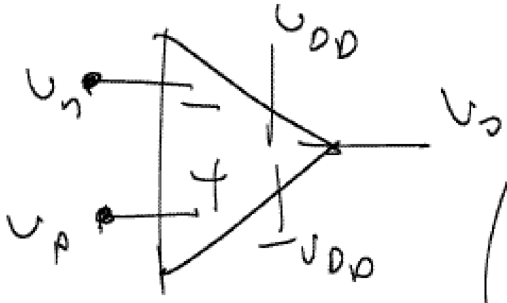
So why does negative feedback work in amplifiers ⇒

GOLDEN RULE. FOR SOLVING AN OP-AMP CIRCUIT IN NEGATIVE FEEDBACK

Caution: Difficult to understand

THE RULE

(1) $v_p \simeq v_n$ if op-amp is not railing!



$v_o = A(v_p - v_n)$

[note! $v_o \in [V_{DD}, -V_{DD}]$]

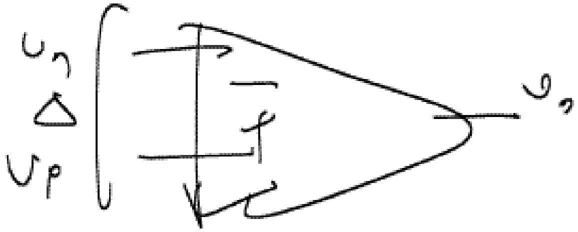
$\frac{v_o}{A} = v_p - v_n)$

10^6

Open-loop gain

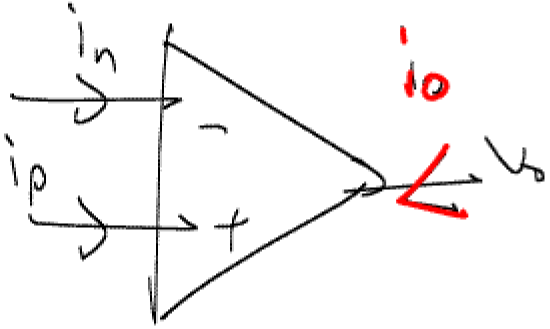
$\boxed{v_p \simeq v_n}$

Open-loop:



$\Delta \simeq mV$

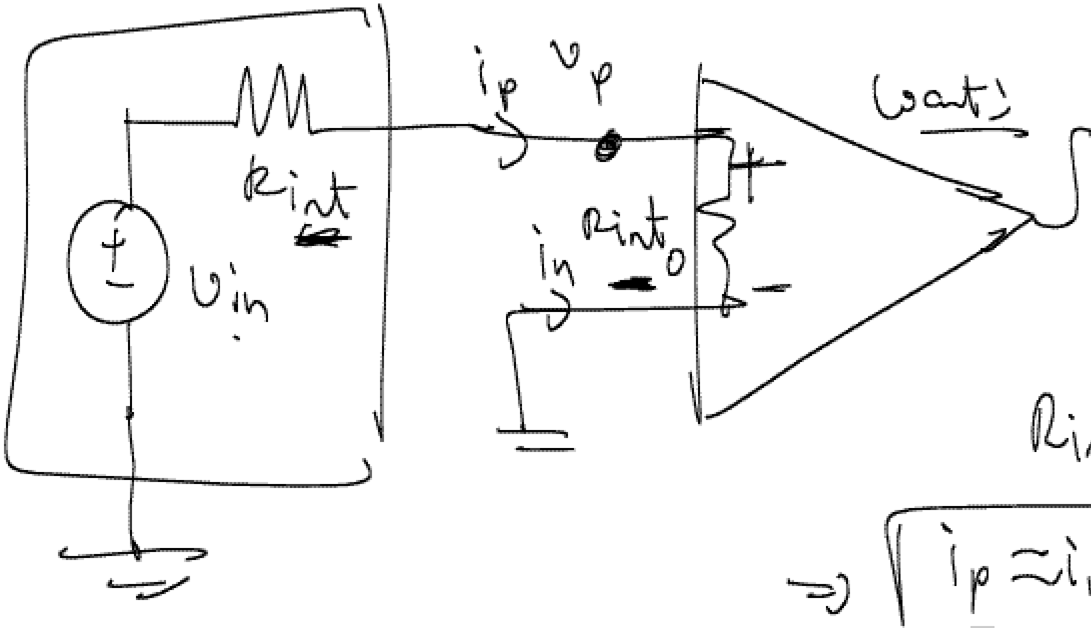
(2)



$i_n \approx 0$ & $i_p \approx 0$

But $\boxed{i_o \neq 0}$

This is because of the way an op-amp built!



want: $v_o = A v_{in}$

i.e.. $v_p = v_{in}$

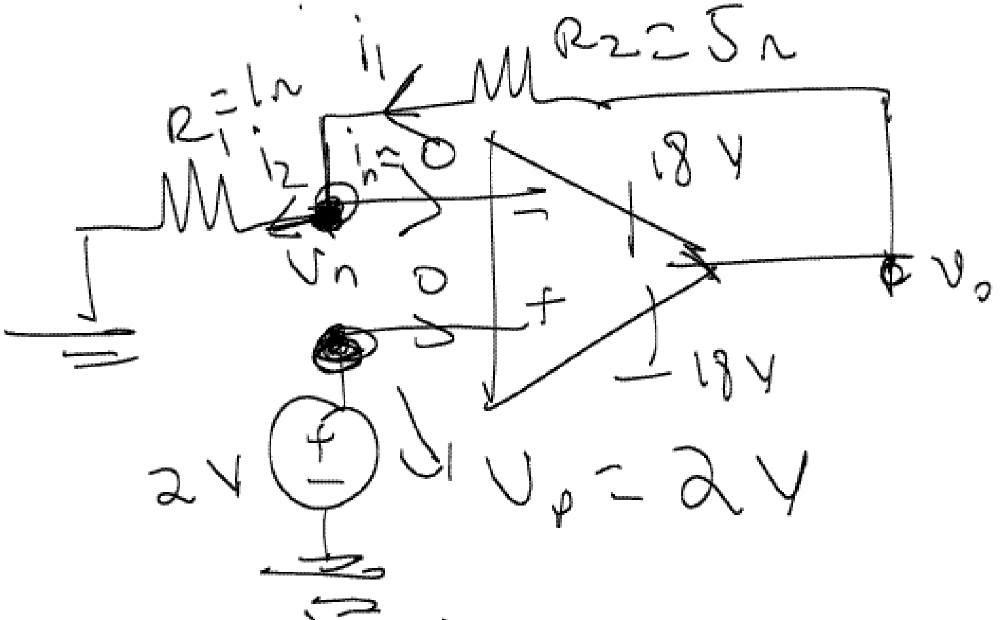
$R_{int_0} \to \infty$ (usually $10^9 \Omega$)

$\Rightarrow \boxed{i_p \approx i_n \approx 0}$

Conclusion: (1) $i_p \simeq i_n \simeq 0$ [Note: $i_o \neq 0$]

(2) $v_p \simeq v_n$ [if op-amp does not rail]

Eg:



(Q:) Find $v_o = f(v_{in})$

Steps: (1) $i_p = i_n = 0$ KCL @ v_n: $i_1 = i_2 + \cancel{i_n}^{0}$

$\Rightarrow \quad \boxed{i_1 = i_2}$ — ①

(2) Assume op-amp does not rail! $\Rightarrow \boxed{v_p \approx v_n}$

find v_o. If $\underset{18V}{\underset{||}{V_{DD}}} > v_o > \underbrace{-V_{DD}}_{-18V} \Rightarrow$ ☺

If not, ☹, $v_p \neq v_n \Rightarrow \boxed{v_o \text{ is railing}}$

$\therefore \; v_p \approx v_n \Rightarrow v_n \approx 2\,V$

From ① $i_1 = i_2 \overset{\text{Ohm's law}}{\Rightarrow} \dfrac{v_o - v_n}{R_2} = \dfrac{v_n - 0}{R_1}$

$$\Rightarrow \frac{v_o - v_{in}}{R_2} = \frac{v_{in}}{R_1}$$

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

In our case:

$V_{in} = 2V, \quad R_2 = 5\,\Omega$

$R_1 = 1\,\Omega$

$\therefore V_o = (1+5)2 = 12V$

$(1 + R_2/R_1) \rightarrow$ closed loop gain