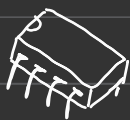
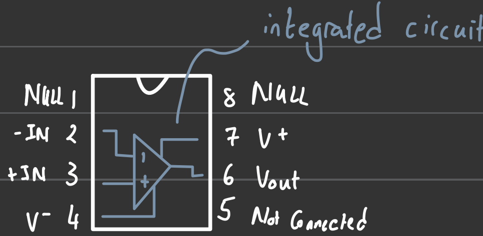
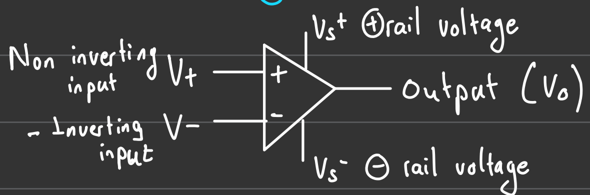
Operational Amplifiers:

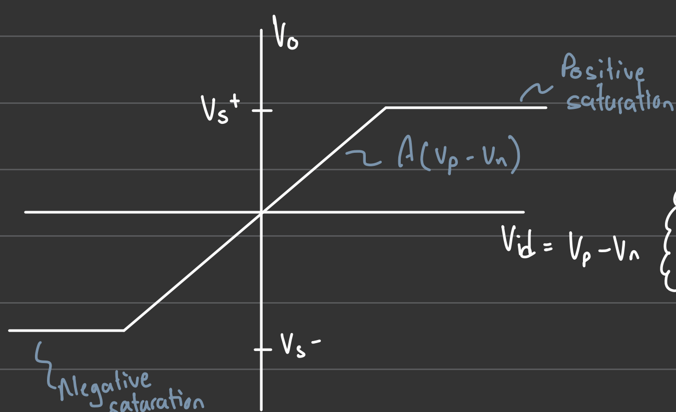




Symbol:

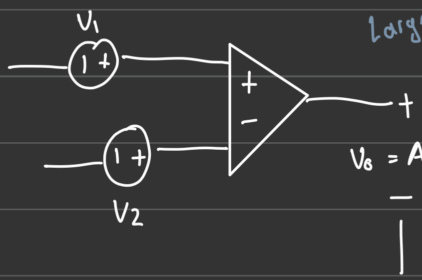


Plotting output V vs input differential V



$V_p = V+$
$V_n = V-$

Ideal Op Amp



Large open loop gain.

$V_o = A_{OL}(v_1 - v_2)$

$V_{icm} = \frac{1}{2}(v_1 + v_2)$

Avg. between v_+ and v_-

$V_{id} = v^+ - v^-$

$= v_1 - v_2$

Assumptions

Infinite input impedance

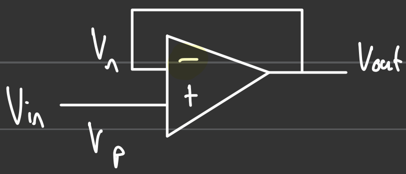
Infinite differential gain

Zero common-mode gain

Zero output impedance

Infinite bandwidth

Negative feedback



$V_o = A(V_{in} - V_o)$

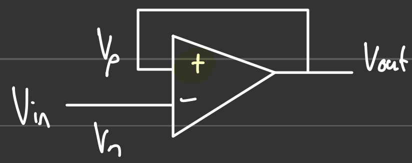
$V_{in} < V_o \Rightarrow V_o \downarrow$

$V_{in} > V_o \Rightarrow V_o \uparrow$

V_o tends to V_{in}

$\Rightarrow V_n = V_p$

Positive feedback



$V_o = A(V_o - V_{in})$

- $V_{in} < V_o \Rightarrow V_o$ ↗ +Rail
- $V_{in} > V_o \Rightarrow V_o$ ↘ −Rail

Method

1) Confirm negative feed back
   ↳ Looking at feedback loop.
2) Assume $V_n = V_p$ and $i_n = i_p = 0A$ (bc. ∞ input impedance)

   $V_p = 0$ if connected directly to ground.
3) Use standard circuit analysis to determine values. (A_v, R_i, R_{out}...)
   ↳ KCL, KVL .... (Usually KCL @ V_n)
4) Test that the op-amp is inbetween the linear region.

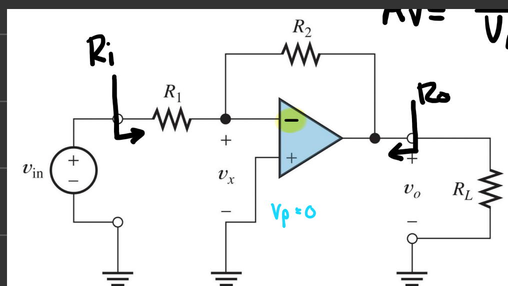
Inverting Amplifiers

From steps above:

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

Input R: $R_i = R_1$

Output R: $R_o = 0\Omega$



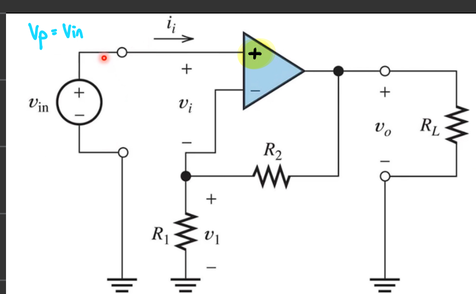
↳ Vin goes to ⊖ side

Non-inverting Amplifiers

Gain: $A_v = 1 + \frac{R_2}{R_1}$ } not always?

$R_i = \infty$

$R_o = 0\ \Omega$



↳ Vin goes to ⊕ side

Inverting summing Amp.

V_o is sum of V_A and V_B

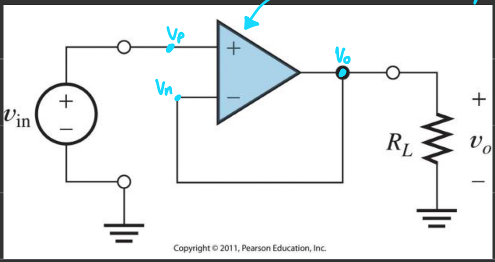
Voltage follower / buffer

"protects equipment for surges"

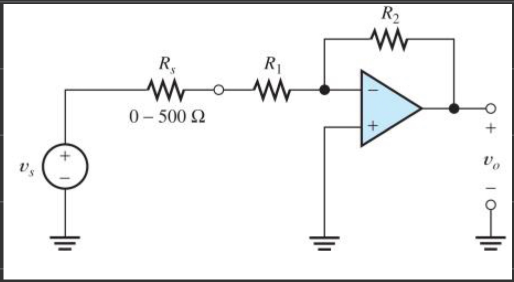
$V_o = V_{in}$

$R_{in} = \infty$

non-Inverted amp.



Designing a simple amplifier



non-Inverting

Gain ⊕ ⊖

Inversing

use $A_v =$ ___ to find R

...

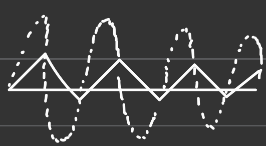
Non-linear limitations: (cutoffs)

Recall $A_v = 1 + \frac{R_2}{R_1}$

- Output swing : V_o will clip at the rail voltage. "around" for real amps.
  This can be asymetric if top and bottom rail voltages differ.

- Output current limits : Clipping occurs if the max output current limit is reached. $\left(I_o = \frac{V_o}{R}\right)$

- Slew-rate : $SR = \left| \frac{dV_o(t)}{dt} \right| = V_{om} \, 2\pi f_{FB}$ [V/s]



- full power BW : Range of freq for which op-amp can produce an undistorted sinusoidal output with peak amplitude equal to the guarenteed maximum output.

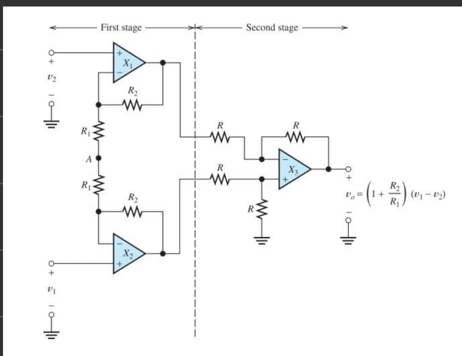
$$f_{FP} = \frac{SR}{2\pi V_{om}}$$ guarenteed max output

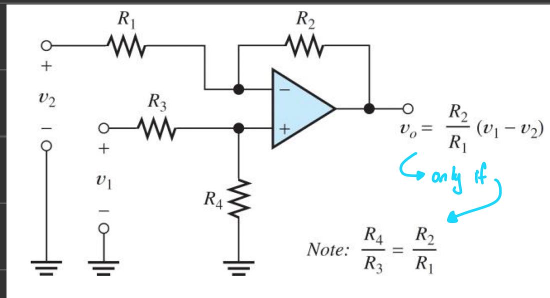
↳ so above this freq, we will hit slew rate

Differential op-amp

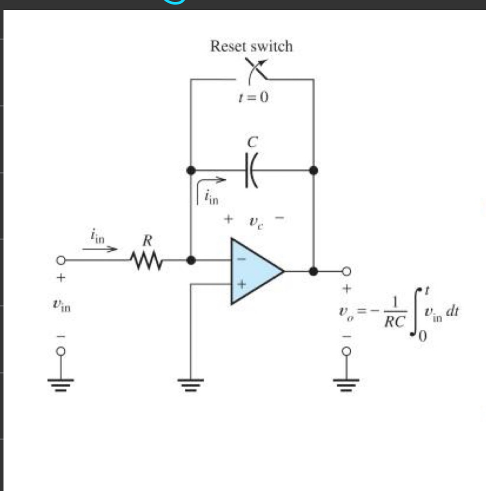
not Inverst or non-invert.

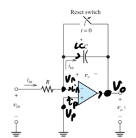
To use this safely with instruments:





Integrators





1) ⊖ feedback ✓

2) $V_n \triangleq V_p$ & $i_p = i_n = 0$

3) Std circuit analysis

KCL @ V_n:

$$-i_{in}(t) + i_c(t) + \cancel{i_n}^{\,0} = 0$$

$$i_c(t) = i_{in}(t)$$

We know:

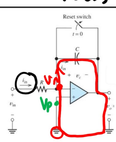
$$i_c(t) = C \cdot \frac{dV_c(t)}{dt}$$

$$V_c(t) = \frac{1}{C}\int_0^t i_c(t)\,dt + V_c(0)$$

$i_c(t) = i_{in}(t)$

$V_c(0) = 0\,V$

$$\Rightarrow V_c(t) = \frac{1}{C}\int_0^t i_{in}(t)\,dt \quad \ldots(1)$$



from the diagram, with the help of KVL

$$V_o(t) = -V_c(t) \quad \ldots(2)$$

using ohms law $i_{in}(t) \to V_{in}(t)$

$$i_{in}(t) = \frac{V_{in}(t) - \cancel{V_n}}{R}$$

$$= \frac{V_{in}(t)}{R} \quad \ldots(3)$$

Sub (3) & (2) in (1) $\quad V_c(t) = \frac{1}{C}\int_0^t i_{in}(t)\,dt$

$$V_o(t) = -\frac{1}{RC}\int_0^t V_{in}(t)\,dt.$$

Differentiator