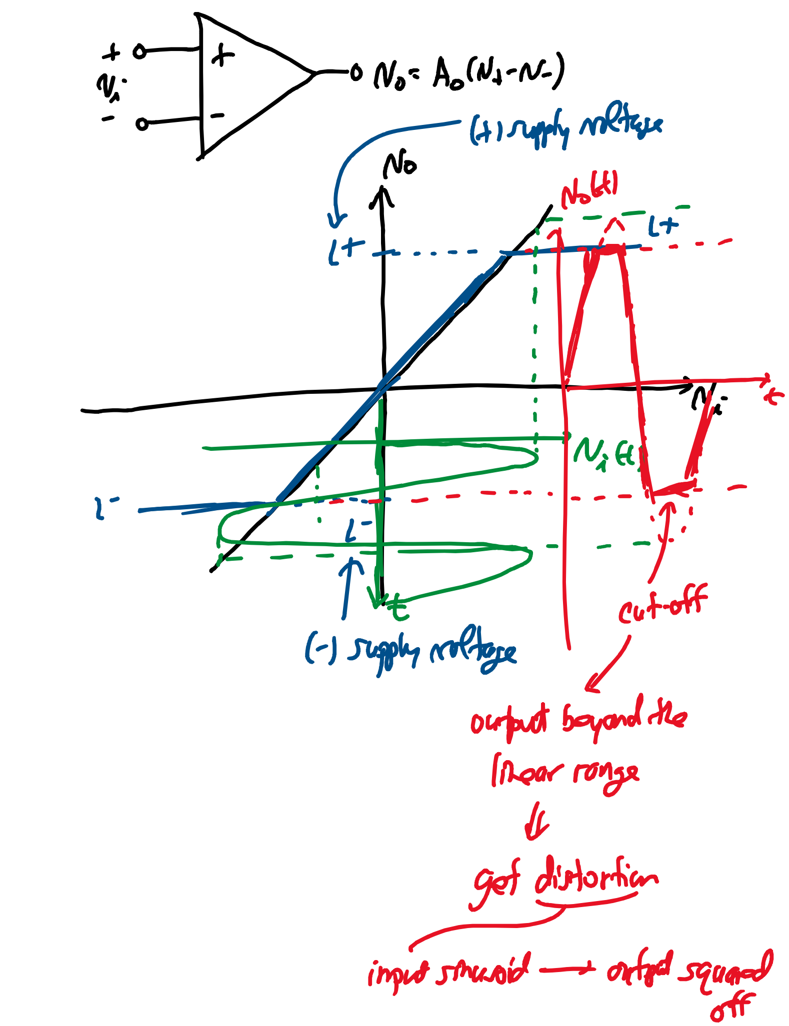
Lecture 8: Limiting, Finite R, and Slew Rate

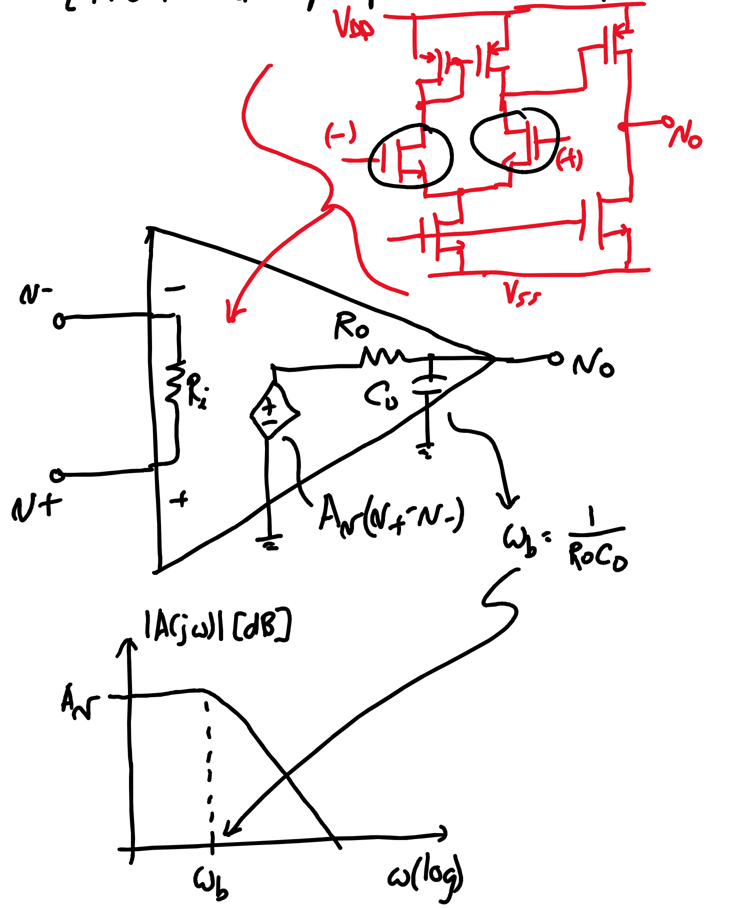
- Announcements:
- HW#3 online and due Friday via Gradescope
- Lab#2 is a two week lab
  - Prelab is due in the second week
  - But you should have proof of having started it when you go to lab this week
  - You will still do the lab this week and continue next week
- ------------------------------------
- Lecture Topics:
  - Limiting
  - Finite Input & Output Resistance
  - Slew Rate
- ------------------------------------
- Last Time:
- Finished finite gain-BW op amp circuits
- Started limiting
- Now, continue with this …

Output Saturation



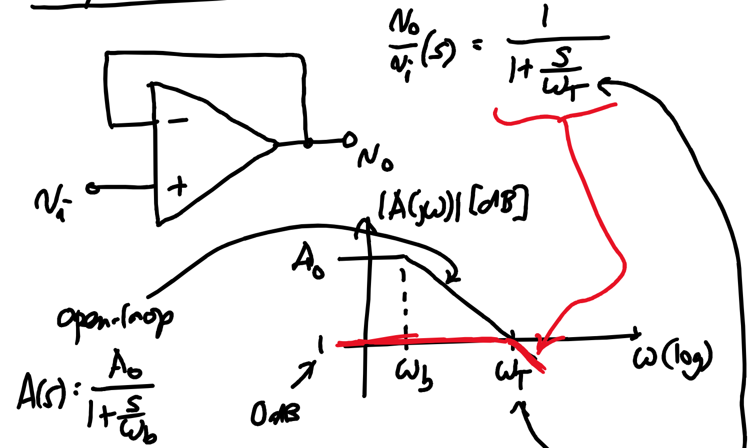
Finite Input & Output Resistance

⇒ Equiv. ckt. for an op amp w/ finite R_i, R_o, A_v, BW



Slew Rate

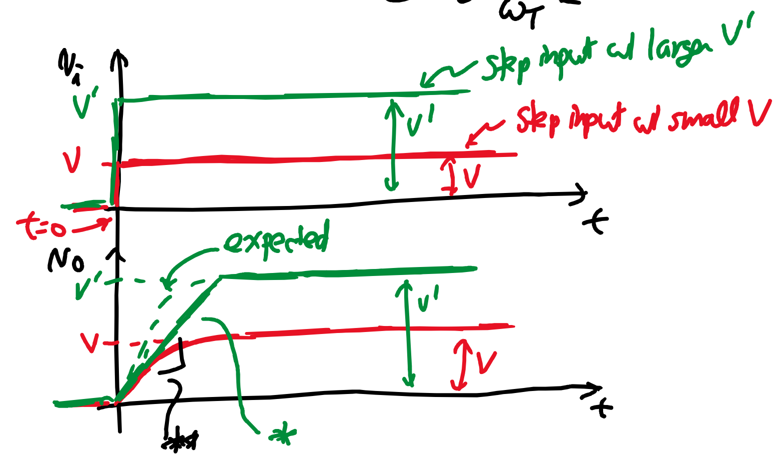
Unity Gain Follower -



Step Response:

$$v_o(t) = v_o|_{t=\infty} - (v_o|_{t=\infty} - v_o|_{t=0})\, e^{-t/\tau}$$

$$= v_o|_{t=\infty}(1 - e^{-t/\tau}) \qquad \tau = \frac{1}{\omega_T}$$



*

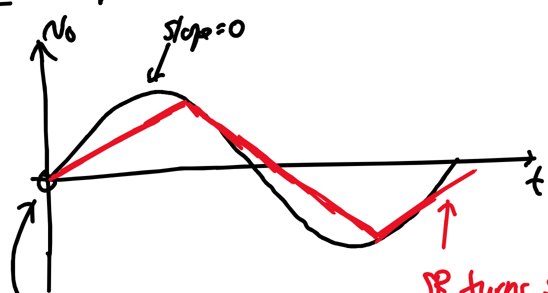
↘ Linear increase caused by internal op amp limitations (i.e., transistors) that constrain the output current of the op amp!

* — slope

↓

Max. Rate of change of output voltage } $\equiv$ Slew Rate $= SR = \left.\frac{dv_o}{dt}\right|_{max}$ [V/μs]

Example. Output a sinusoid (or at least try to...)



SR turns sinusoid into triangle wave

largest slope $= \frac{dv_o}{dt} > SR$

Full Power Bandwidth ← f_M

- Suppose you wanted your op amp circuit to output a signal with a maximum amplitude Vomax
- Then the full power bandwidth is the maximum frequency of this Vomax amplitude that the op amp can track without slewing

$v_o = V_{omax} \sin\omega t$

$\frac{dv_o}{dt} = \omega V_{omax} \cos\omega t$

$= \left.\frac{dv_o}{dt}\right|_{max}$ at the max. expected output

↓

this must equal the SR for proper tracking

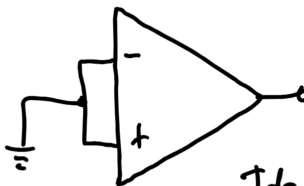
$\omega_M V_{omax} = SR$

↑ max frequency

$\therefore \boxed{f_M = \frac{SR}{2\pi V_{omax}}}$

↑ Full Power Bandwidth

Input Offset Voltage, V_{OS}

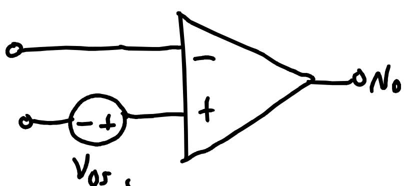


Ideal Case: $v_o = 0V$

Reality: $v_o \neq 0V$

(usually, $v_o = L^+$ or L^-)
↑ it rails out

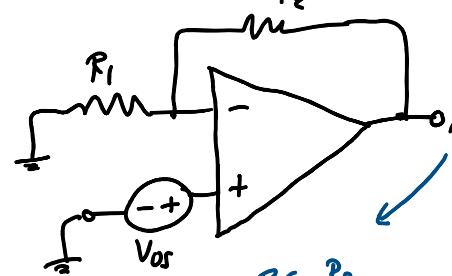
Model this w/ equivalent ckt:
↙ contains input offset V_{OS}:



typically, $V_{OS} \sim 1mV - 5mV$

Effect of V_{OS} on Op Amp Ckts

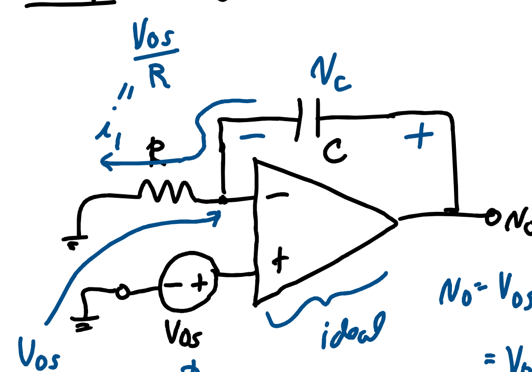
Example. Non-Inverting Amplifier



$v_o = \left(1 + \frac{R_2}{R_1}\right) V_{OS}$

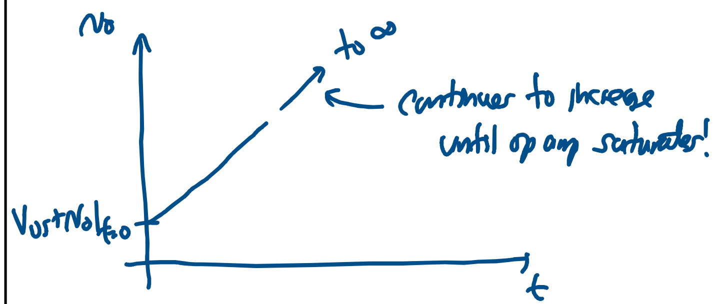
e.g., $\frac{R_2}{R_1} = 9$, $V_{OS} = 5mV \rightarrow v_o = 50\,mV$
(not so bad...)

Example. Integrator



V_{OS} ↑ models the non-ideality

$$v_o = V_{OS} + \frac{1}{C}\int_0^t i_1\,dt$$
$$= V_{OS} + \frac{1}{C}\int_0^t \frac{V_{OS}}{R}\,dt$$
$$= V_{OS}\left(1 + \frac{t}{RC}\right) + v_C\big|_{t=0}$$


v_o
to ∞
continues to increase until op amp saturates!
$V_{OS}+V_o|_{t=0}$
t