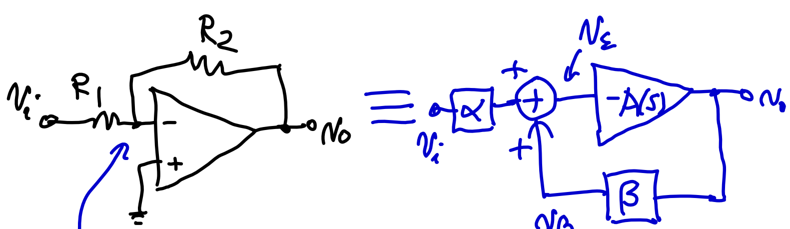
Lecture 8: Limiting, Finite R, and Slew Rate

- **Announcements:**
- HW#3 online and due Friday via Gradescope
- Lab#2 will be 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
- This Wednesday, 9/12: I will be out of town.
  - So no ground lecture that day
  - Make up will probably need to be by video recording and put online
- ------------------------------------
- Lecture Topics:
  - Limiting
  - Finite Input & Output Resistance
  - Slew Rate
- ------------------------------------
- **Last Time:** Finite gain-BW op amp circuits

Example: Inverting Amplifier

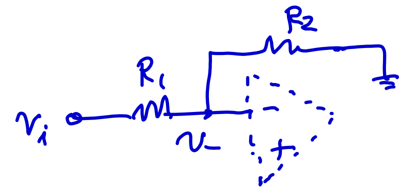


signals from v_o & v_I sum here

how much of each appears depends on α & β

Determine α:

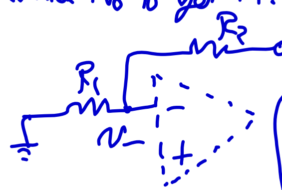
① Ground output & open loop
② Feed v_i forward to get T.F.



$$\frac{v_-}{v_i}(s) = \frac{R_2}{R_1+R_2} = \alpha$$

Determine β:

① Ground input, open loop
② Feedback v_o to get T.F.



$$\frac{v_-}{v_o}(s) = \frac{R_1}{R_1+R_2} = \beta$$

Now, get the T.F. for the system block diagram:

$$v_o = -A(s)v_\varepsilon, \quad v_\varepsilon = \alpha v_i + \beta v_o \quad \Big\} \quad v_o = -\alpha A(s) v_i - \beta A(s) v_o$$

$$v_o(1+\beta A(s)) = -\alpha A(s) v_i$$

$$\therefore \frac{v_o}{v_i}(s) = -\frac{\alpha A(s)}{1+\beta A(s)}$$

$$\left[A(s) = \frac{A_o}{1+\frac{s}{\omega_b}}\right] \Rightarrow \frac{v_o}{v_i}(s) = \frac{-\alpha \frac{A_o}{1+\frac{s}{\omega_b}}}{1+\frac{\beta A_o}{1+\frac{s}{\omega_b}}}$$

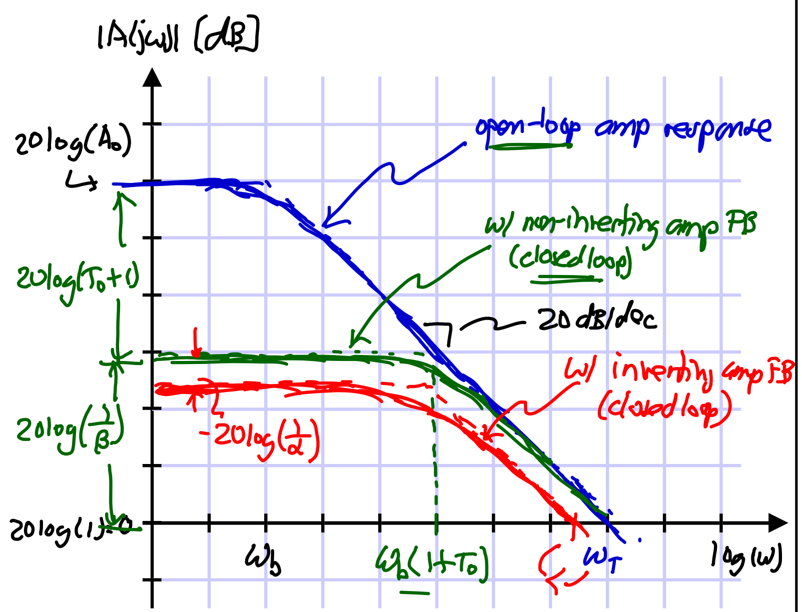
$$\frac{v_o}{v_i}(s) = \frac{-\alpha A_o}{1+\beta A_o} \cdot \frac{1}{1+\frac{s}{\omega_b(1+\beta A_o)}}$$

Remarks.

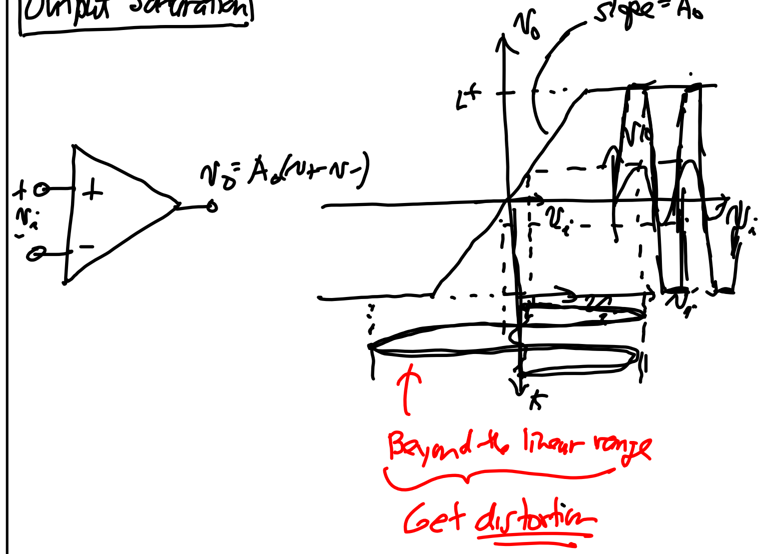
1. Closed loop DC gain now modified by α.
2. BW still $\omega_b(1+\beta A_o)$ → same as for non-inverting case
3. ω_T or Gain-BW product now smaller than that of open-loop amplifier:

$$\text{gain-BW} = \alpha\omega_T$$

[remember, $\alpha < 1$]

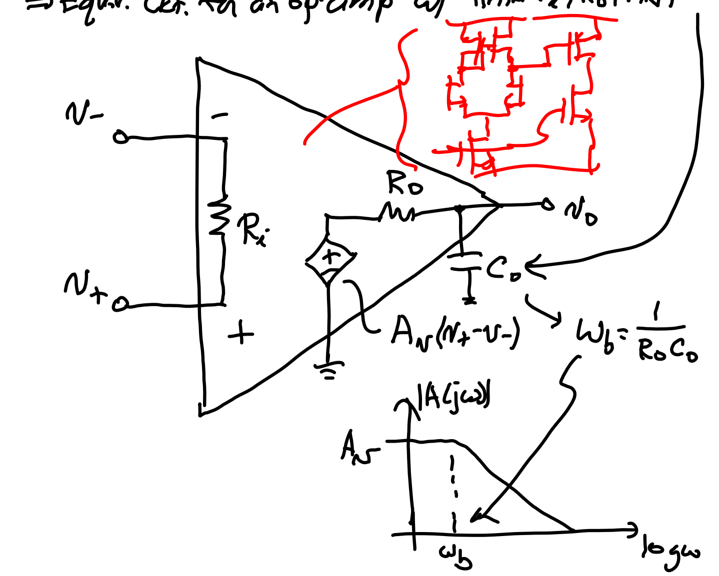


Output Saturation



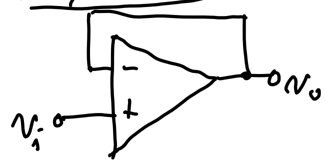
Finite Input & Output Resistance

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



Slew Rate

Unity Gain Follower -



$$\frac{v_o}{v_i}(s) = \frac{1}{1+\frac{s}{\omega_T}}$$

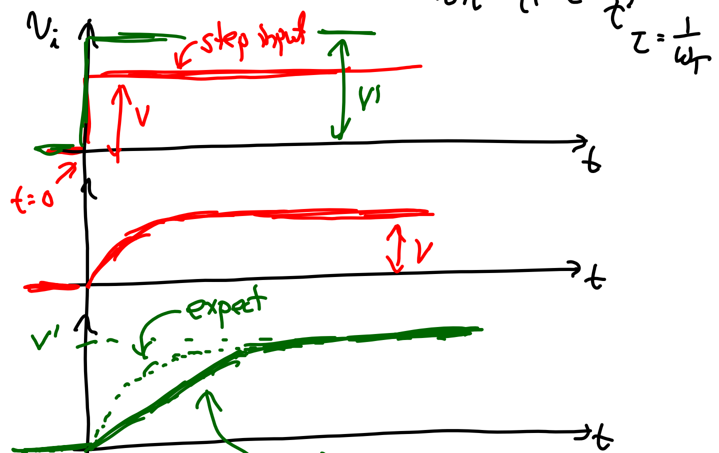
Step Response:

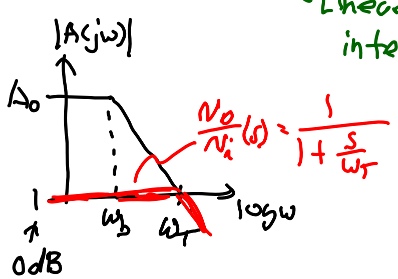
$$v_o(t) = v_o|_{t=\infty} - \left(v_o|_{t=\infty} - v_o|_{t=0}\right)e^{-t/\tau}$$

(assume = 0V)

$$= v_o|_{t=\infty}\left(1-e^{-t/\tau}\right)$$

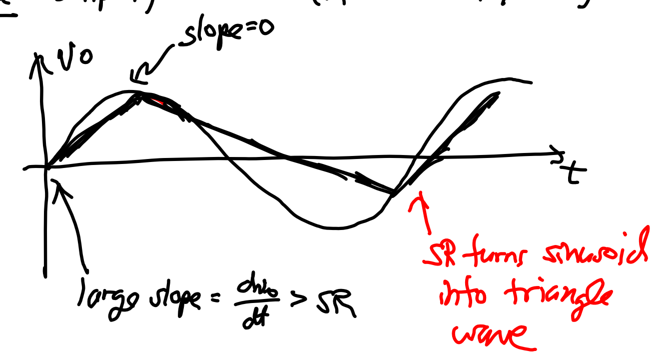
$$\tau = \frac{1}{\omega_T}$$





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

Example: Outputting a sinusoid (or at least try to...)



Full Power Bandwidth $\Rightarrow f_M$

- 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

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

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

$\omega V_{omax} = \left.\frac{dv_o}{dt}\right|_{max}$ of the max. expected signal

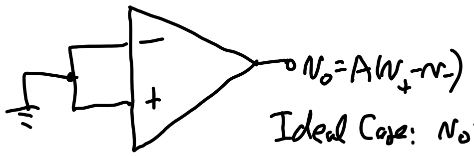
this must equal SR for sufficient tracking:

$$\omega_M V_{omax} = SR$$

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

← Full Power Bandwidth

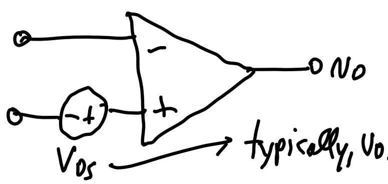
Input Offset Voltage, V_{OS}



Ideal Case: $v_o = 0V$

Reality: $v_o \neq 0V$
(usually, $v_o = L^+$ or L^-; it rails out)

Model this w/ equivalent input offset voltage, V_{OS}:



→ typically, $V_{OS} \sim 1mV - 5mV$

Effect of V_{OS} on Op Amp Ckt. -