Lecture 6: Finite Gain & Bandwidth

- Announcements:
  - HW#2 online and due Friday, 9/11, at 12 noon via Gradescope
  - Lab#1 Prelab online
  - Labs start next week (1st one: Monday, 9/14)
  - Lab kits have been sent
  - To get one, you must have filled out the google form for lab kits (from David Au on Piazza)
  - Friday lecture, 9/11, will be at 12 noon
    - This is one of the days when I have a committee meeting that coincides
    - Of course, the lecture will be recorded, so you'll be okay if you cannot make this time

- Lecture Topics:
  - Ideal Op Amp Circuits
  - Non-Ideal Op Amp Bode Plot
  - Finite Gain & Bandwidth
  - Closed Loop Amplifier Freq. Response
    - Non-Inverting Amplifier
    - Inverting Amplifier

- Last Time:
  - Review of the ideal op amp
  - Now, continue with this and move towards op amp circuits and non-ideality

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Perhaps the best way to define an op amp is via its equivalent clkt:

![Op Amp Equivalent Clkt]

Properties of Ideal Op Amp:

1. \( R_0 \to \infty \)  \( \rightarrow \)  4. \( i_+ = i_- = 0 \)
2. \( R_e = 0 \)
3. \( A_v = \infty \)  \( \rightarrow \)  5. \( V_+ = V_- \), assuming \( V_0 = \text{finite} \)
4. \( f_{3dB} = \infty \)

\( \text{Why?} \)  \( \inf \) \( V_0 - N_+ - N_0 \leq \text{finite} \)

- \( V_0 - N_+ = 0 \)  \( \rightarrow \)  7. \( V_+ = V_- \)

**Big Assumption!!**

\( \text{Only holds when we have negative feedback!} \)
**Remarks:** (on neg. FB)
- Neg. FB can insure $v_o = \text{finite}$ even with $a=\text{infinity}$
- Overall closed-loop gain (or transfer function) is dependent only on external components (e.g., $\beta$)
- Overall closed-loop gain $S_o/S_i$ is independent of amplifier gain $a$
- This is very important, since it's easy to get large amplifier gain, but it's hard to get an exact value
  - If you're shooting for $a=50,000$, you might get 47,000 or 60,000 instead
  - But it won't matter much in the feedback ckt.

**Example: Inverting Amplifier**

1. Verify that we have neg. FB: $\checkmark$, ideal op amp rules apply!
2. $v_o = \text{finite} \rightarrow v_o = v_i \rightarrow \text{virtual ground}$
3. $i_i = 0$
   - $i_i = \frac{v_i - 0}{R_1} = \frac{v_i}{R_1} = i_2$
   - $v_o = -\left(\frac{V_i}{R_1}\right)R_2 = -\frac{R_2}{R_1}V_i$
   - $v_o = -i_2R_2$

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CTN 9/9/20
Non-Ideal Op Amps

Finite Op Amp Gain & Bandwidth

For an ideal op amp, \( A = \infty \)

In reality, the gain goes as: \( A(s) = \frac{A_0}{1 + \frac{s}{\omega_0}} \)

\[ |A(j\omega)| \text{ [dB]} \]

- Open-loop op amp response
- \( 20 \text{dB/dec} \)
- \( \omega_0 = \text{unity gain frequency} = \text{freq @ which } |A(j\omega)| = 1 \)
- \( A(\omega) = \frac{A_0}{\sqrt{1 + (\omega/\omega_0)^2}} \Rightarrow \frac{A_0}{\omega} = 1 \)
- \( \omega_0 = A_0 \omega_b \)
- \( \omega_T \gg \omega_b \) gain bandwidth
[For \( \omega \gg \omega_t \)]

\[ A(s) = \frac{A_0}{s} \Rightarrow \frac{A_0 \omega_t}{s} = \frac{\omega_t}{s} \Rightarrow \frac{1}{s} \]

\[ \frac{s}{\omega_t^2} \approx 1 \]

(An op amp ultimately is an integrator \( \sim \frac{1}{s} \) with time constant \( R \cdot C = \frac{1}{\omega_t} \))

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**Frequency Response of Closed Loop Amplifier**

**Example. Non-Inverting Amplifier**

\[ \Delta V_p \rightarrow \Delta V_n \rightarrow \Rightarrow \text{neg. FBV} \]

\[ \Delta V_p \rightarrow \Delta V_n \rightarrow \Rightarrow A(s)(V_p - V_n) \]

\[ N = A(s) \frac{V_p}{A(s)} \]

\[ N = \frac{V_p}{A(s)} \]

Find an expression for gain as a function of freq.