Lecture 7: Non-Ideal Op Amp Circuits

• Announcements:
  • HW#3 online soon and due Friday, 9/18, at 12 noon via Gradescope
  • Lab#1 prelab due before lab session next week:
  • Lab#1 (experimental part) online
  • Lab#2 will be online soon
  • You should have received or will soon receive your lab kits
  • Today's lecture is occurring on Friday, 9/11, at 12 noon, rather than our usual 2-3 p.m.
  • This is one of the days when I have a committee meeting that coincides
  • I am recording this lecture, so you'll be okay if you cannot make this time

• Lecture Topics:
  • Closed Loop Amplifier Freq. Response
    – Non-Inverting Amplifier
    – Inverting Amplifier

• Last Time:
  • Started analyzing a non-inverting amplifier using a non-ideal op amp
  • Now, continue with this …

Non-Ideal Op Amps

Finite Op Amp Gain & Bandwidth

For an ideal op amp, $A = \infty$

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

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

$\omega_r \overline{\text{unity gain freq.}} = \omega \text{ at which } |A(j\omega)| = 1$

At $\omega_r$, $|A(j\omega)| = 1 = \frac{A_0}{\sqrt{1 + \left(\frac{\omega_r}{\omega_b}\right)^2}} \Rightarrow \frac{A_0}{\omega_r} = \frac{\omega_r}{\omega_b} = 1$

$[\omega_r > \omega_b] \quad \omega_r = \frac{A_0 \omega_b}{\omega_r}$

Gain bandwidth
[For $\omega = \omega_c$, $A(s) = \frac{A_0}{C_3} = \frac{A_0 \omega_c}{s} = \frac{C_3}{s} = \frac{1}{\frac{s}{C_3}}$]

(an op amp ultimately is an integrator, $-\frac{1}{s}$)

$C_3$ in data sheets

Constant $2 \times \frac{1}{C_3}$

**Frequency Response of Closed Loop Amplifier**

Example: Non-Inverter Amplifier

Still assume $R_i = \infty$; $R_o = 0$

Find an expression for gain as a function of freq.

1. Brute force determination:

   KCL O: $\frac{N_o - N_i}{R_2} = \frac{N_i - N_o}{R_1} \Rightarrow N_i = N_o \left( \frac{1}{R_i} + \frac{1}{R_o} \right)$

   $\frac{N_o}{R_2} = (N_o - \frac{N_o}{A_0}) \left( \frac{1}{R_i} + \frac{1}{R_o} \right) \Rightarrow \frac{N_o}{R_2} = \frac{1 + \frac{R_2}{R_i}}{1 + \frac{1}{A_0} + \frac{R_2}{R_i}}$
Negative Feedback

\[ S_o = a S_e \]
\[ S_e = S_i - \beta S_o \]
\[ S_o \left(1 + a \beta\right) = a S_i \rightarrow \]
\[ \frac{S_o}{S_i} = \frac{a}{1 + a \beta} \]

\[ a \rightarrow \infty \Rightarrow \frac{S_o}{S_i} \approx \frac{a}{\beta} \Rightarrow \beta = \text{finite!} \]

Contrast w/ Positive Feedback

\[ S_o = S_i \]"
Plug in $\beta$:

$$\left[ \beta A_o \gg 1 \right] \Rightarrow \frac{V_o}{V_i}(s) = \frac{1}{\beta} \frac{1}{1 + \frac{s}{\omega_0 \beta A_o}}$$

$$\frac{V_o}{V_i}(s) = \left(1 + \frac{R_1}{R_e}\right) \frac{s}{\omega_0 \beta A_o (R_1 + R_2)}$$

Observations:

1. Closed loop DC gain $= \frac{A_o}{1 + \beta A_o} = \frac{A_o}{1 + \frac{\beta}{A_o}} \approx \frac{A_o}{T_o}$
   i.e., the closed loop gain is reduced from the open loop gain by $1 + T_o$ (shown on graph $[T_o \gg 1]$)

2. Alternatively, closed loop DC gain $\approx \frac{A_o}{\beta A_o} = \frac{1}{\beta}$ $[T_o \gg 1]$)

3. $\omega_{3dB}$ has increased from $\omega_b \rightarrow \omega_b (1 + \frac{\beta}{A_o})$ $= \omega_b (1 + T_o)$
   To draw the Bode plot, just find the DC gain, draw a horizontal line across, then follow the open loop response after running into it!

4. Gain-BW Product $= \frac{A_o}{1 + \beta A_o} \omega_b (1 + \frac{\beta}{A_o}) = A_o \omega_b = \omega_T$.
   $\therefore$ the Gain-BW product remains the same for the open and closed loop FB cases!

**Example: Inverting Amplifier**

- Signal from $V_o \neq V_i$ sum here
- Current sum
- How much of each appears depends on $\alpha \neq \beta$