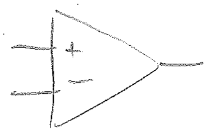
Lecture 11

First: Project

Over rest of semester, work on constructing a practical electronic instrument: instrumentation amp

Inst. Amp is what op amp seems like: high gain differential amp



$V_{out} = G(V_+ - V_-)$

But I.A. designed for use as standalone amplifier:

- G is large, not huge $G \lesssim 1000\times$
- G well-controlled by external components

Use IA to boost small signal

Differential is good, can measure small difference between two large signals

If you only have one small signal to measure, ground V_-

Circuit is very simple, but still involves a lot of work

Divide project into phases

1. Think about design (hw due next week)

   Next week I'll provide common design for everyone to use

2. Order parts and test circuit on breadboard

   I'll provide parts list. Should be < \$100

   Due 10/24 (3 weeks)

3. Solder components onto prototyping board

   I'll show you how

   Due 11/12 (2½ weeks)

4. Drill holes in case and mount components
   Due 11/26 (two weeks)

5. Wire board to case, test, and debug
   Prepare documentation: brief instruction manual
   Complete project due 12/13: Reading day during finals
   (2½ weeks)

Will have three project work days in class:
No lab, I'll teach things about project & let you work on them
But expect to put in some extra time. HW every other week now.

Grading categories as shown.
Main thing is whether it works
But it should look nice & be on time too.

First phase: design assignment
Pretty much like HW, due next week

Also today: op amp frequency response

Recall $V_{out} = G(V_+ - V_-)$

Ideally, G independent of signal frequency

But would require op amp to respond infinitely fast
- not possible

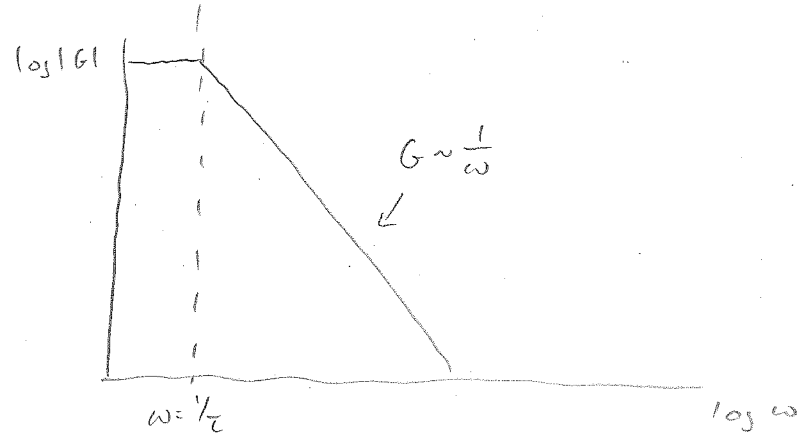
Must have $G \to 0$ as $\omega \to \infty$

Typically $G(\omega) = \dfrac{G_0}{1+i\omega\tau}$ ~ low pass filter

$\tau \sim 0.1\,s$

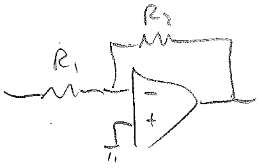
$G_0 \sim 10^5$

So Bode plot:



So at high frequencies, G not so big

Recall finite-G result we calculated earlier



$$V_{out} = \frac{-\frac{R_2}{R_1} V_{in}}{1 + \frac{1}{G}\left(1 + \frac{R_2}{R_1}\right)}$$

when $|G| \gg 1 + \frac{R_2}{R_1}$, get $V_{out} = -\frac{R_2}{R_1} V_{in}$

= Golden rule result

If $1 + \frac{R_2}{R_1} \gg |G|$ (and $\frac{R_2}{R_1} \gg 1$), get

$$V_{out} \to -\frac{\frac{R_2}{R_1} V_{in}}{\frac{1}{G}\frac{R_2}{R_1}} = -G V_{in}$$

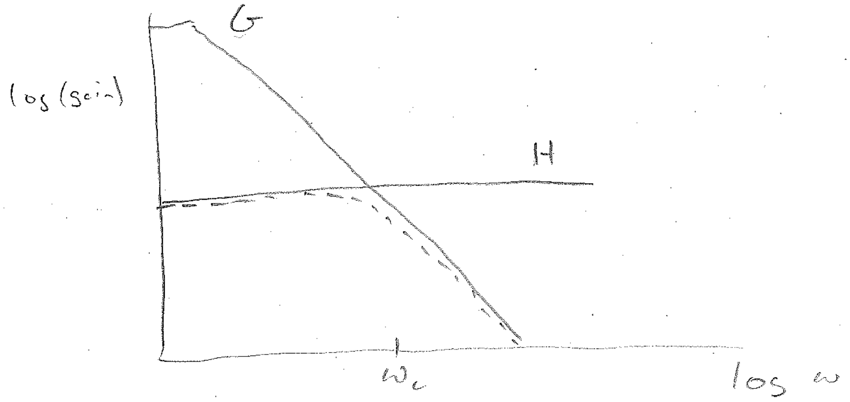
Generally true: if ideal circuit gain is H
(here $H = -\frac{R_2}{R_1}$)

then if $|G| \gg |H|$, actual circuit gain is H
if $|H| \gg |G|$, actual circuit gain is G

In other words, actual gain is smaller of H & G
(makes sense, since external components can only reduce net gain of circuit)

How does that interact with $G(\omega)$?

Plot G & H:



Actual circuit gain follows minimum
⇒ amplifier has bandwidth: signals faster than ω_c are attenuated

Should be clear that increasing H decreases ω_c

Can solve: usually $G \simeq \frac{G_{dc}}{i\omega\tau}$

$$|G| = |H| \text{ at } \omega_c = \frac{1}{|H|}\frac{|G_{dc}|}{\tau}$$

So if $|G_{dc}| = 10^5$ $\tau = 0.1\,s$, $|H| = 100$, get

$$\omega_c = \frac{10^5}{100 \cdot 0.1} = 10^4 \text{ rad/s}$$
$$= 1.6 \text{ kHz}$$

Not especially fast; can matter a lot!

Can get faster op amps.

Note that neither G_{dc} nor τ usually matters by itself

Just specify G_{dc}/τ

At $\omega = \frac{G_{dc}}{\tau}$, $|G| \to 1$

Define $\omega_1 = \frac{G_{dc}}{\tau}$ = "unity gain point"

= freq where $|G| \to 1$

More often $f_1 = \frac{G_{dc}}{2\pi\tau}$, in Hz

For LF411 op amp, $f_1 = 4$ MHz

Can get $f_1 \to 1$ GHz or more, but high speed circuit design is very challenging (very small inductors, capacitors important)

Given f_1, actual circuit bandwidth is

$$f_c = \frac{f_1}{|H|} \qquad (H = \text{ideal circuit gain})$$

Explore this today

Looking forward:

Fall break on Monday

After that, two labs on servo systems:

Circuits design to control a physical variable

Then shift gears to study digital electronics