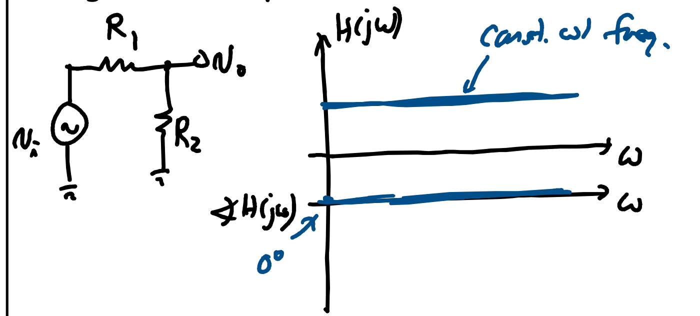
Lecture 4: Amplifiers

- Announcements:
- HW#2 online and due next Friday
  - Need to run software, so make sure you can access the software
  - Go to discussion for help with Spice
- Lab#1 online
- Labs start next week
  - You will need to do your prelabs for Lab 1 before your lab period
- ------------------------------------
- Lecture Topics:
  - Finish Bode Plots
  - Amplifiers
  - Amplifier Models (2-port networks)
  - Input R_i
  - Output R_o
  - Ideal Voltage Amplifier
- ------------------------------------
- Last Time:
- Going through procedure for doing a Bode plot
- Now, continue with this …

- For a purely resistive network, the frequency response is constant (i.e., a straight line), both magnitude and phase



- The addition of reactive (energy storage) components, e.g., capacitors, inductors
  - Shapes the frequency response
  - Adds singularities, i.e., poles and zeros
  - Yields the general transfer function:

$$H(s) = \frac{v_o(s)}{v_i(s)} = \underbrace{H_o}_{\text{resistive term (scalar gain term)}} \frac{(s-z_1)(s-z_2)\cdots(s-z_m)}{(s-p_1)(s-p_2)\cdots(s-p_n)} = H_o \frac{\prod_{j=1}^{m}(s-z_j)}{\prod_{i=1}^{n}(s-p_i)}$$

where

$z_j = \sigma_{zj} + j\omega_{zj}$; $\sigma_{zj} = Re(z_j)$, $\omega_{zj} = Im(z_j)$

$p_i = \sigma_{pi} + j\omega_{pi}$; $\sigma_{pi} = Re(p_i)$, $\omega_{pi} = Im(p_i)$

$v_i(s) \triangleq$ input variable (not necessarily a voltage)

$v_o(s) \triangleq$ output variable (" " " ")

$\Rightarrow$ Given this, you should be able to generate a Bode plot!

Bode Plot

① Plot magnitude in decibels (dB) vs. log (freq.)

$$[H(s): H(j\omega)] \Rightarrow |H(j\omega)| = H_o \frac{\prod_{j=1}^{m} |j\omega - z_j|}{\prod_{i=1}^{n} |j\omega - p_i|} =$$

$$= H_o \frac{\prod_{j=1}^{m} |j(\omega - \omega_{zj}) - \sigma_{zj}|}{\prod_{i=1}^{n} |j(\omega - \omega_{pi}) - \sigma_{pi}|} = H_o \frac{\prod_{j=1}^{m} \sqrt{(\omega - \omega_{zj})^2 + \sigma_{zj}^2}}{\prod_{i=1}^{n} \sqrt{(\omega - \omega_{pi})^2 + \sigma_{pi}^2}}$$

Convert to dB → allow combination by addition instead by multiplication
⇒ easier to graph

$$20\log|H(j\omega)| = 20\log H_o + \sum_{j=1}^{m}(20\log|j\omega - z_j|) - \sum_{i=1}^{m}(20\log|j\omega - p_i|)$$

② Plot phase vs. log (freq.)

$$\measuredangle H(j\omega) = \sum_{j=1}^{m}[\angle(j\omega - z_j)] - \sum_{i=1}^{n}[\angle(j\omega - p_i)]$$

where $\angle(j\omega - s) = \tan^{-1}\left(\frac{\omega - \omega_s}{-\sigma_s}\right)$

$[s = \sigma_s + j\omega_s]$

- Because everything reduces to addition, one can determine the plot for each term then add/substract them together
- Basically, can use superposition for both the magnitude and phase plots

Bode Plot Step-By-Step Procedure

① Get all factors into the form s or $(1 + \frac{s}{a})$

e.g., $s + b = b(1 + \frac{s}{b})$

② Plot the Bode plot for each factor, one factor at a time. (Note that there are only a few cases.)

③ Sum all decibel magnitude plots to obtain the total magnitude plot.

④ Sum all phase plots to obtain the total phase plot.

Example

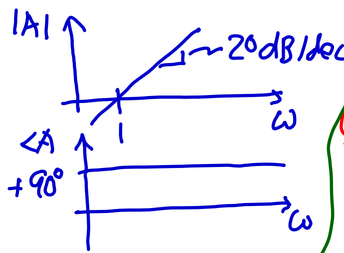
$$H(s) = \frac{100s(s+10^5)}{(s+10)(s+10^3)} = \underbrace{\frac{100(10^5)}{(10)(10^3)}}_{10^3 = H_o} \frac{s(1+\frac{s}{10^5})}{(1+\frac{s}{10})(1+\frac{s}{10^3})}$$

$10^3 = H_o$ → factoring brings out the scalar gain term

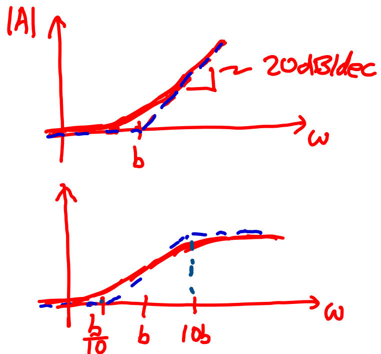
Case: constant value
⇒ constant amplitude = $20\log H_o$
⇒ constant phase = $0°$

$$H(s) = 10^3 \cdot \frac{s\left(1+\frac{s}{10^5}\right)}{\left(1+\frac{s}{10}\right)\left(1+\frac{s}{10^3}\right)}$$

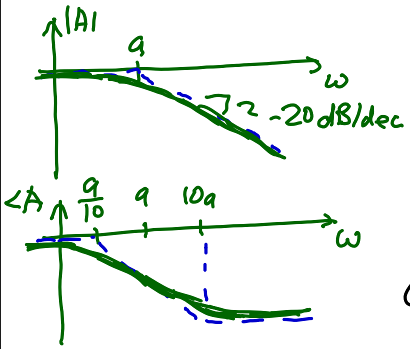
Case: zero @ origin: $A(s) = s$



Case: first order zero: $A(s) = 1 + \frac{s}{b}$

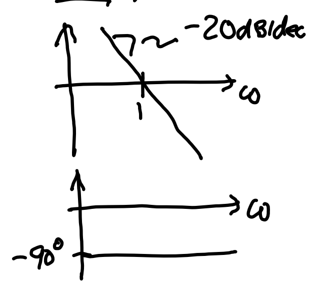


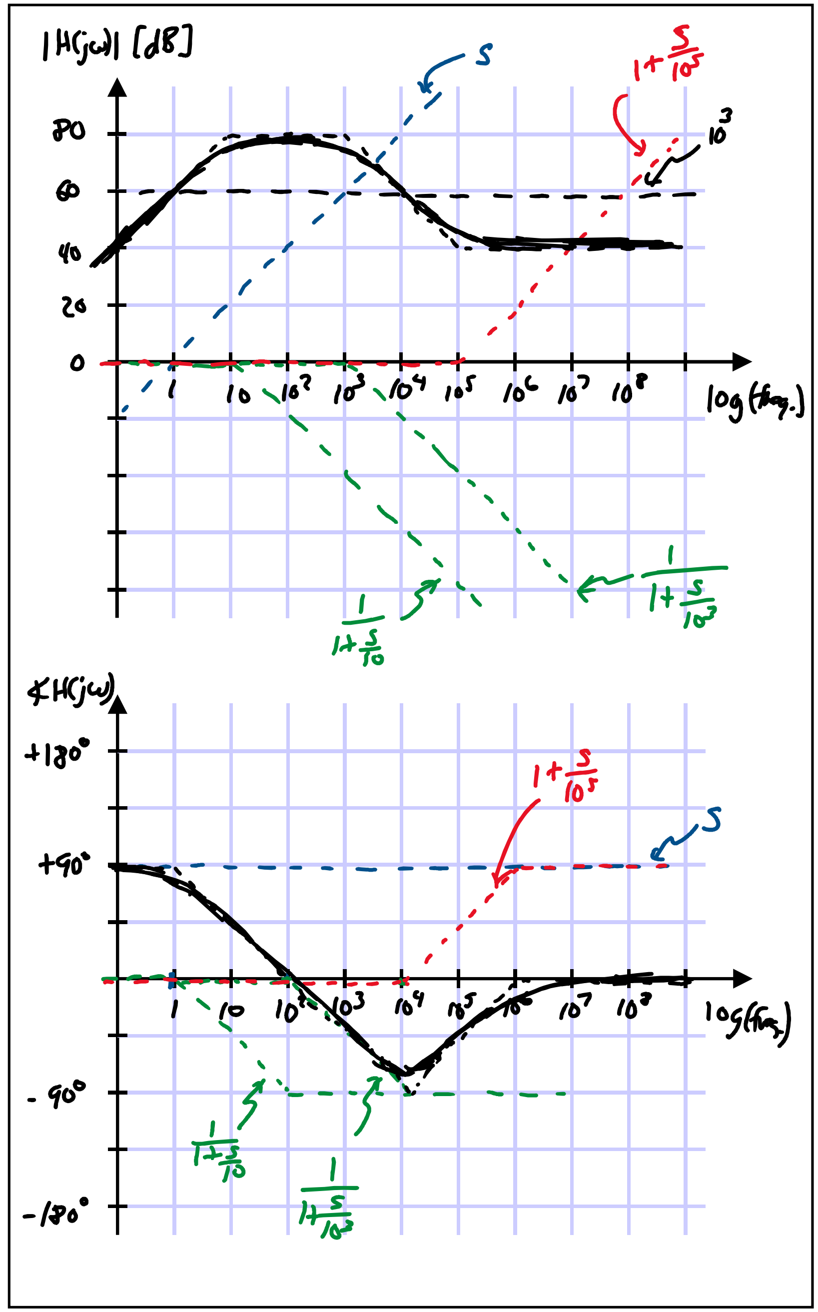
Case: first order pole $A(s) = \frac{1}{1+\frac{s}{a}}$



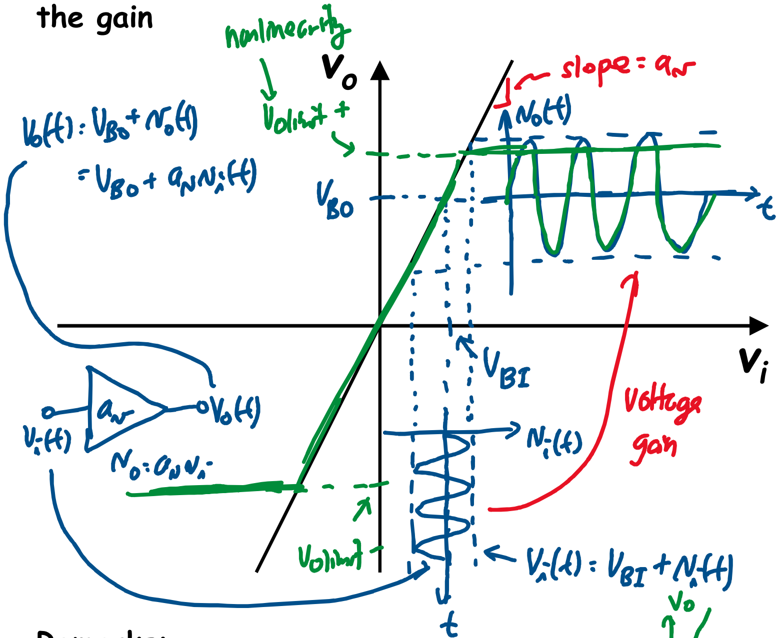
Another useful case (not in this transfer function):

Case: pole @ origin: $A(s) = \frac{1}{s}$

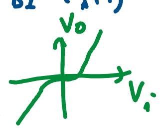




- **Amplification**:
- Really just boils down to creating a transfer function with a large slope, where the slope equals the gain



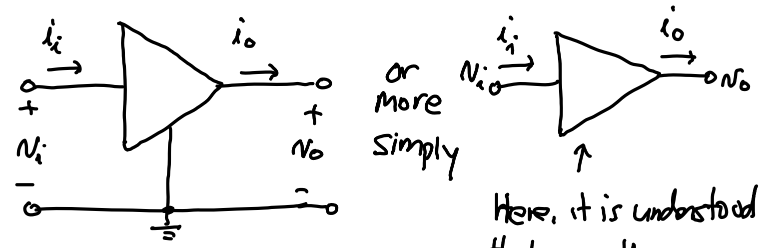
- **Remarks**:



- The large slope does not come for free
  - ↳ generally requires power if you want power gain
- Ideal amplifier generally has an infinite linear line transfer function
- Power and device non-ideality prevent a truly ideal amplifier
  - ↳ Power rails limit the acceptable input/output range
  - ↳ Device nonlinearity limits the linear range
  - ↳ Noise limits the minimum detectible signal
  - ↳ Parasitic elements, e.g., capacitors, limit the frequency range (i.e., the bandwidth)

Amplifier Models

→ generally given the symbol:



Here, it is understood that everything refers to the same ground

We can interpret a given amplifier as any of four types:

1. Voltage Amplifier: $v_i \rightarrow v_o$ (g-parameter model fits best)
2. Current Amplifier: $i_i \rightarrow i_o$ (h-parameter model fits best)
3. Transconductance Amplifier: $v_i \rightarrow i_o$ (y-parameter model fits best)
4. Transresistance Amplifier: $i_i \rightarrow v_o$ (z-parameter model fits best)

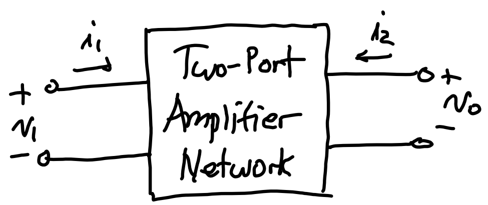
This class will mainly see these

- All of these are equivalent representations, each comprising a gain factor along with an input and output resistance that model the resistance seen looking into the amplifier terminals
- Take for example a voltage amplifier:

$\boxed{\text{Voltage Amplifier}}$

$\Rightarrow$ most appropriate general model is the g-parameter model $\rightarrow$ Defining Equations:

Note the matrix form $\longrightarrow$
$$\begin{cases} i_1 = g_{11} v_1 + g_{12} i_2 \\ v_2 = g_{21} v_1 + g_{22} i_2 \end{cases}$$



$$\equiv$$