EE 105 | Discussion 1

Kieran Peleaux & Qiutong Jin
Discussion Outline

• Ideal op-amp review
• Amplifier models
• Laplace domain transfer functions
• Fourier Series demo
Ideal Op Amps

- 3-terminal device (something’s missing from this symbol though!)
- Follows a set of rules
  1. \( v^+ = v^- \)
  2. \( i^+ = i^- = 0 \)
  3. \( v_o = A_v(v^+ - v^-) \) no matter what the load is
Ideal Op Amps

• Where do these rules come from?
• Derive from a different set of rules
  1. $A = \infty$
  2. $R_i^- = R_i^+ = \infty$
  3. $R_{out} = 0$

$V^+ = V^-$

$V_o = A(V^+ - V^-) \rightarrow$ only true if op amp is in finite negative feedback

$V_o = A(V^+ - V^-) \rightarrow$ only true if op amp is in finite negative feedback

Equivalent circuit of ideal op amp
Amplifier Models

- All amplifier models need 3 parameters specified
  - Gain (voltage, current, power) (unitless, e.g. $V/V$ or $A/A$ or $W/W$)
  - Input resistance
  - Output resistance
Analyzing Amplifier Models

- Consider the model shown below (what’s been added?)
  - $A_{v_o} = 100 \text{ V/V}$
- Find the overall voltage gain, $v_o/v_s$ when:
  1. $R_i = 10R_s$, $R_L = 10R_o$
  2. $R_i = R_s/10$, $R_L = R_o/10$

![Voltage amplifier model diagram]

\[ v_i = \frac{R_i}{R_i + R_s} v_s \]
\[ v_o = \frac{R_L}{R_L + R_o} \frac{A_{v_o} v_i}{(R_L + R_o)(R_i + R_s)} \]

Want $R_i > R_s$ and $R_L > R_o$ as $R_i \to \infty$ & $R_o \to 0 \Rightarrow \frac{v_o}{v_s} \approx A_{v_o}$
Deriving Amplifier Models

• How do we find the parameters below if not given?
  – Gain (voltage, current, power) → We will learn this soon!
  – Input resistance
  – Output resistance ⟷ Recall Thévenin equivalent circuits!

1. “Turn off” all independent sources (short-circuit voltage sources, open-circuit current sources)
2. Apply a test voltage source, \( v_x \) to the node of interest
3. Analyze the circuit to determine the current drawn from the test source, \( i_x \) in terms of \( v_x \)
4. Equivalent resistance is then: \( R_{eq} = v_x/i_x \)

If this is an ideal op amp, \( R_i = \infty \)
Finding $R_i$ & $R_o$

- Find the input resistance, output resistance and voltage gain of the op amp circuit below

\[ i_x = \frac{v_x - v^-}{10 \, k\Omega} = \frac{v_x}{10 \, k\Omega} \Rightarrow \frac{v_x}{i_x} = R_{eq} = R_{in} = 10 \, k\Omega \]

\[ R_{out} = 40 \, k\Omega \]
Laplace Domain Transfer Functions

• In the circuit below, derive the transfer function $V_i(s)/V_s(s)$. What type of frequency response does the circuit form and what is the 3-dB frequency?

$$s = j\omega \quad \text{rad/sec}$$

$$Z_c = \frac{1}{sC}$$

$$Z_L = sL$$

$$Z_R = R$$

$$Z_R || Z_L = \frac{1}{\frac{1}{Z_L} + \frac{1}{Z_R}}$$

$$Z_{RC} = \frac{sC}{1 + sR_iC}$$

$$\frac{Z_{RC}}{Z_c} = \frac{1}{sC + R_i}$$

$$\frac{V_i}{V_s} = \frac{R_i}{1 + sR_iC_i}$$

$$(Z_{RC} || Z_c) + R_s$$

$$V_s \frac{(Z_{RC} || Z_c)}{(Z_{RC} || Z_c) + R_s} = V_i \Rightarrow \frac{V_i}{V_s} = \frac{R_i/(1 + sR_iC_i)}{1 + sR_iC_i} + R_s = \frac{R_i}{R_i + R_s(1 + sR_iC_i)}$$
Fourier Series

- Any periodic signal can be decomposed into a sum of pure sinusoids
- The more terms of the Fourier series you use, the better the sum will approximate the actual signal
- See Matlab example