Lecture 3: Frequency Response

Announcements:
- HW#1 online and due this Friday
- Discussions this week
- Labs start next week
  - Monday, Sept. 7 is a holiday, so the Monday lab will start one week later
  - The Tuesday lab starts Sept. 8
- Lab#1 Prelab online soon

Lecture Topics:
- Finish Digital Communications Example
- Review Impedance
- Frequency Response
- Bode Plots

Last Time:
- Going through an example digital communication transmitter as motivation
- Now, continue with this ...

Review of Analog Circuit Concepts:
- We assume you understand the following concepts from previous courses:
  - Transfer functions
  - Gain (voltage, current, power)
  - Input resistance
  - Output resistance
  - Two-port models for amplifiers
  - Bode plots
  - Ideal op amp ckt design and analysis
- We'll review some of these now to jog your memory

Review of Impedance

\[ \begin{align*}
\mathbf{V} &= V \cos(\omega t + \phi) \\
\mathbf{I} &= I e^{j\phi}
\end{align*} \]

And impedance: \[ z = \frac{\mathbf{V}}{\mathbf{I}} \]

Resistor:
\[ R = \frac{N(t)}{i(t)} \quad R = \frac{V}{I} \]

Capacitor:
\[ \frac{V}{I} = \frac{1}{j\omega C} \quad I = C j\omega V \]

Substitute: \( s = j\omega \)

\[ z = \frac{1}{sC} \]
Time and Frequency Domains:

- Most signals of interest to us can be broken down into sums of sinusoids at various amplitudes and frequencies.
- Knowledge of the frequencies and amplitudes of these sinusoids conveys as much about the information content as knowledge of time-varying amplitude.
- Time Domain description: often conveyed by a plot of amplitude versus time.
- Frequency Domain description: often conveyed by a plot of amplitude (and phase) versus frequency.
Frequency Response:
- To measure the frequency response of a given network:
  - Excite the network with a variable-frequency, sinusoidal, constant amplitude source
  - Measure the magnitude and phase of the output signal for different values of input frequency

\[ N_1 : V_i \cos \omega t \]

\[ N_0 : V_o \cos(\omega t + \phi) \]

\[ |N_0(j\omega)| = V_o : \text{magnitude} \]
\[ \angle V_o(j\omega) = \phi : \text{phase} \]

- The frequency response of a given network is commonly described by a plot of magnitude and phase versus frequency. Usually, such a plot is of the transfer function of a given network:

\[ H(j\omega) = \frac{N_o(j\omega)}{N_i(j\omega)} \]

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

\[ H(j\omega) \]

- 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:

\[ H(s) = \frac{V_o(s)}{V_i(s)} = \frac{H_0}{(s-p_1)(s-p_2) \ldots (s-p_m)} = \frac{H_0}{\prod_{j=1}^{m} (s-z_j)} \]

\[ z_j = \rho_j + \omega_j j \]
\[ \rho_j : \text{Re}(z_j), \quad \omega_j : \text{Im}(z_j) \]