ECE 209: Circuits and Electronics Laboratory
Notes for Lab 3 (Operational Amplifiers and First-Order Circuits)

1. Comments on returned lab reports.
   - In first lab report, all phase shifts should have been from quadrants III and not quadrant I.
   - Lab reports should be formatted like reports (i.e., not lists).
   - Use kHz — not KHz or KHZ. Small k is kilo; big K is Kelvin (temp. matters to circuits).
   - For hand-drawn figures, use engineering graph paper, and write on the side with no grid lines. Photocopies will be clear of any distracting grid lines.

2. Operational amplifiers: see supplementary document for more information.
   - Op. amps are useless when not in a feedback configuration.
   - Extremely-high-gain negative feedback causes \( V_- \) to track \( V_+ \).
   - Set \( V_- \) node to \( V_+ \) signal; assume no current goes into the OA, and solve rest of circuit.

3. Linear systems: see supplementary document for more Laplace- and frequency-domain information.
   - Each input signal instant is like scaled impulse that causes system output to “ring” like a bell.
     - “Convolution” is the sum of all of the effects of each impulse.
     - Before convolving, we must know the “impulse response” to find each of those effects.
     - Impossible to generate an impulse in the lab. So we generate step response and differentiate.
     - For a first-order circuit, can determine all that matters (gain and time constant) from either impulse response or step response.
   - LTI systems with input sinusoids have shifted and scaled output sinusoids.
     - See supplementary document on sources of phase shift in LTI systems.
     - By finding magnitude and phase shift at every frequency, can rebuild impulse response without generating impulse or step.
     - Because signals can be represented as sums (or integrals) of sinusoids, can find output signal without doing convolution.

4. Introduce and complete the Operational Amplifiers and First-Order Circuits lab.
   - If 741-type operational amplifier is not available, use 747 (two 741-type OAs on one chip).
     - 747 (and 741) part pinout on supplementary document.
     - Note the supply rails! Op. amps need power from both sides to be able to work.
   - Resistor color codes: Black, Brown, ROYGBV, Gray, White correspond to digits 0–9
     - Brown-Black-Red = 102 = 1000 = 1 kΩ
     - Brown-Black-Orange = 103 = 10000 = 10 kΩ
     - Yellow-Violet-Orange = 473 = 47000 = 47 kΩ
   - Capacitor codes are like resistor codes (digit1/digit2/number-of-zeros) but typically use unit pF
     - For example, 105 = 1000000 pF = 1000 nF = 1 μF
     - For this lab, 0.01 μF = 10 nF = 10000 pF = 103
   - Make sure to use dual ±12 V supplies with a common ground in OA circuits.
   - Step response of high-pass filter has 2 V peak because it is initially charged to 1 V.
     - The previous 1 V-to−1 V step left the capacitor with 1 V charge to make the output 0 V.
     - Note that the magnitude of the −1 V-to-1 V step matches the 2 V output jump.
   - For lab report: Measured (experimental) versus expected (theoretical).
Sample Code

```
% % % % % Data from Measurements
%
\% Store the frequency, measured input Vipp, output Vopp, and Lissajous vertical
\% intersection data.
f = [1 2 10 20 30 40 50 60 70 80 90 100]*100;
vipp = [2.0 2.0 2.0 2.0 2.0 2.0 2.0 2.0 2.0 2.0 2.0 2.0];
vopp = [1.996 1.984 1.694 1.245 0.937 0.739 0.607 0.513 0.443 0.390 0.349 0.314];
deltaY = [0.125 0.247 0.901 0.975 0.828 0.687 0.578 0.496 0.432 0.383 0.343 0.310];

\% Calculate gain vector (in dB) and phase (.\ is element-by-element division).
gaindB = 20*\log10( vopp./vipp );
phase = -\asint( deltaY./vopp)*180/pi; \% For LPF
phase = \asint( deltaY./vopp)*180/pi; \% For HPF

% % % % % Theoretical Predictions (from transfer function)
%
\% For theoretical curves, 1000 j-omega points in frequency range.
ftheory = \linspace( min(f), max(f), 1000 );
s = j*2*pi*ftheory;

\% For transfer function, store R and C values (change as necessary!).
R = 10000;
C = 0.01e-6;

\% Evaluate transfer function at each ftheory.
H = 1./(s*R*C + 1); \% For LPF
H = s*R*C./(s*R*C + 1); \% For HPF

\% Find theoretical gain (dB) and phase (degrees).
gaintheorydB = 20*\log10( abs(H) );
phasetheory = \asint( H )*180/pi;

% % % % % Bode plot of measurements and expectations
%
%%%% Magnitude subplot: Measured and theoretical overlayed

% Put magnitude plot in top row of 2 row by 1 column figure.
\textbf{subplot}(2,1,1);
\textbf{semilogx}( f, gaindB, '\-\-', ftheory, gaintheorydB, '\--\'); \% dB Gain
\textbf{grid on}; \% Add a grid

% Add axis labels (with units!) and title.
\textbf{xlabel}('Frequency (Hz)'); \textbf{ylabel}('Gain (dB)'); \textbf{title}('Gain magnitude');

%%%% Phase subplot: Measured and theoretical overlayed

% Put phase plot in bottom row of 2 row by 1 column figure.
\textbf{subplot}(2,1,2);
\textbf{semilogx}( f, phase, '\-\-', ftheory, phasetheory, '\--\');
\textbf{grid on};

% Add axis labels (with units!) and title.
\textbf{xlabel}('Frequency (Hz)'); \textbf{ylabel}('Phase shift (degrees)'); \textbf{title}('Phase shift');

% Use the figure's "File" menu to save the figure in a desirable
% file format (e.g., EPS or PNG) for inclusion in your report.
```