ECE 209: *Circuits and Electronics Laboratory*

Notes for Lab 3 (Operational Amplifiers and First-Order Circuits)

1. Comments on returned lab reports.
   - Course graded on curve. Highest “clump” of students *will* get an **A**.
   - In first lab report, all phase shifts should have been from **quadrant 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).
   - LaTeX users may want to look at the report templates on-line.
   - 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 = $1\,\mathrm{k}\Omega$
     - Brown-Black-Orange = **`103`** = 10000 = $10\,\mathrm{k}\Omega$
     - Yellow-Violet-Orange = **`473`** = 47000 = $47\,\mathrm{k}\Omega$
   - Capacitor codes are like resistor codes (digit$_1$/digit$_2$/number-of-zeros) but *typically* use unit pF
     - For example, **`105`** = $10\underbrace{00000}_{5}\,\mathrm{pF} = 1000\,\mathrm{nF} = 1\,\mu\mathrm{F}$
     - For this lab, $0.01\,\mu\mathrm{F} = 10\,\mathrm{nF} = 10000\,\mathrm{pF} = 103$
   - 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 versus expected; see course web page for MATLAB code help.

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 = -asin(deltaY./vopp)*180/pi;     % For LPF
% phase = asin(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 = angle(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.
subplot(2,1,1);
semilogx( f, gaindB, '.-', ftheory, gaintheorydB, '--' );   % dB Gain
grid on;                                                    % Add a grid

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

%%%%% Phase subplot: Measured and theoretical overlayed

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

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