

Second-order filter circuits

This time, we measure frequency response plots for second-order filters. We start by examining a simple 2nd-order RC low-pass filter. Then we look at the various arrangements of *RLC* 2nd-order circuits. Next we build two op-amp-based second-order filters. We finish by looking at one of the weirder op-amp circuits that we will come across – a pseudo-inductor. This is a busy lab, but if you come prepared and work efficiently, you should be able to complete the lab without much trouble.

Prior to Lab

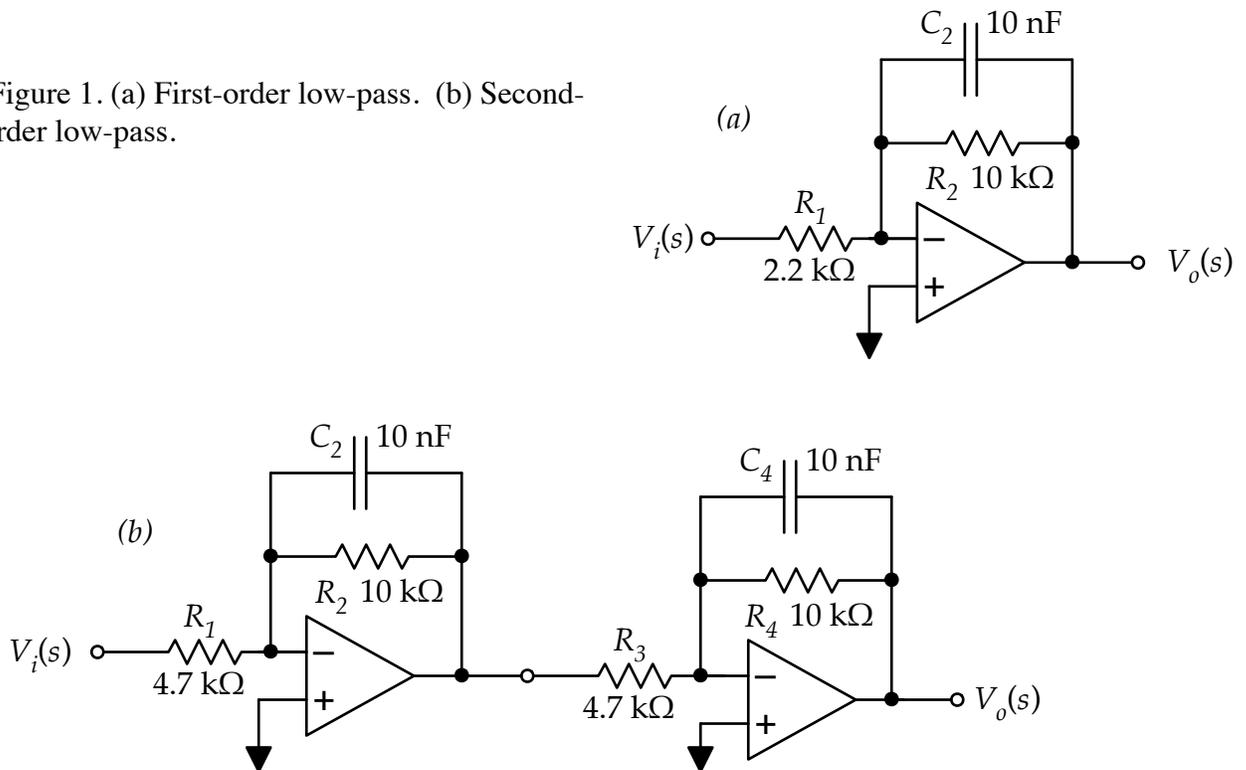
1. Calculate the transfer functions, and the values of ω_0 , Q_P , and G_o , for each of the circuits. (Note: In this lab, we use real frequency f_o rather than ω_o , as usually done in class examples. Be sure to make the appropriate adjustment when comparing doing calculations.)
2. Review the theory for the inductor simulation circuit. You may also want to build this one before coming to lab, since the wiring for it is a bit fussy.
3. Make sure that you have a flash drive or some other means for saving data.

General comments

1. All frequency response measurements will be done manually, so it will be a busy lab.
2. For all frequency response measurements, use at least 5 points per decade. (More is better, but of course more points also means more measurement time.) Use a pseudo-logarithmic distribution of points so that curves will be smoother. If measuring with 5 points per decade, measurements spaced at 1, 1.5, 2.5, 4.0, and 6.5 within the decade should work OK. If using more points, then decrease the spacing accordingly.
3. When measuring higher- Q_P filters, it may be necessary to increase the number of points per decade in the region near f_o . If the spacing of measurement points is far apart, it is possible to miss the details of the “hump” of a low- or high-pass circuit or the sharp peak of a bandpass circuit. Slow down a bit and take more points to map out the curves in the fast-changing regions.
4. One trick to speed up the data collection process is to measure two (or more) circuits simultaneously. Build the circuits next to each other on the breadboards and apply the input signals to both (or all) at the same time. Then each time that the frequency is changed, move the voltmeter and oscilloscope probes to the various outputs and record the data. When multitasking like this, it is a good idea to check the input voltage level frequently to make sure that the input is not changing.
5. All magnitude frequency response plots should be Bode plots (decibels on the vertical axis).
6. Record measurements directly into the Excel spreadsheet as you take them. This saves the trouble of copying them over later. And since the plot will be drawn immediately, you can see right away if there are any problems.

A. Low-Q low-pass active filters

Figure 1. (a) First-order low-pass. (b) Second-order low-pass.



- Calculate the expected f_c and G_o for first order circuit in Fig. 1(a) and the f_o , Q_P , and G_o for the second-order circuit of Fig. 1(b).
- Build the two circuits using LMC 660 op amps with $\pm 8\text{-V}$ power supplies and a sinusoidal input voltage. Set the input amplitude low enough so that the output does not clip — $0.25 \text{ V}_{\text{RMS}}$ should be fine.
- Measure the magnitude and phase of each circuit from 10 Hz to 100 kHz, with at least 5 measurement points per decade.
- Graph the magnitude response for each circuit together on one Bode plot. Graph the phase response of each circuit together on one plot.

B. RLC 2nd-order filters — high Q.

The three circuits shown in Fig. 2 – 4 use the same components, but with different configurations to give the various types of filter response. For each of the circuits, calculate f_o , Q_P , and G_o . Then measure the frequency response of the magnitude for each. (Ignore the phase this time.) Measure over a range from 10 Hz to 1 MHz with at least 5 points per decade. If needed, take even more points in the region around f_o in order to get a smooth curve.

Figure 2. Low-pass.

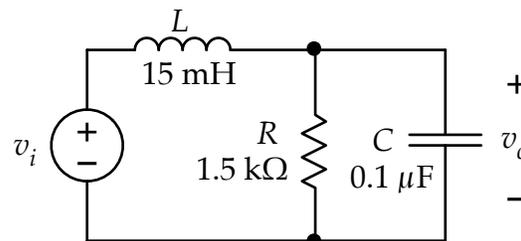


Figure 3. High-pass

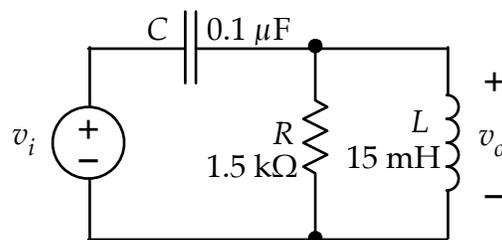
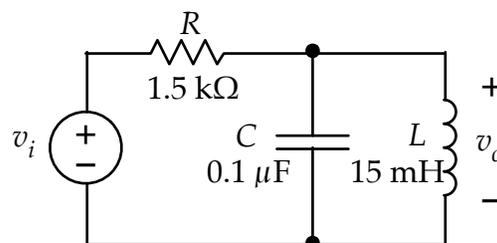


Figure 4. Band-pass



C. Active Bi-quads

Below are two (out of several possible) active filters that provide second-order responses without the need for inductors. Both are from the category of *single-amp biquad* (SAB) circuits. The first is a low-pass filter, in a configuration known as *Sallen-Key* circuit. The second is a band-pass filter, sometimes known as the *Delyiannis-Friend* circuit.

For each circuit, calculate f_o , Q_P , and G_o . Then build the circuit with your choice of op amp (LM324, LMC660, or TL082) and measure the magnitude frequency response from 10 Hz to 100 kHz. Include the plots in your report.

Note: Pay attention to power supply limits for your choice of op amp – the 324 and 082 can work with ± 15 V supplies while the 660 is limited to ± 8 V. Use the oscilloscope to watch for clipping. If clipping occurs, reduce the input amplitude accordingly.

Figure 5. Sallen-Key low-pass. Note that you can make a 50 nF capacitor using two 100-nF caps in series.

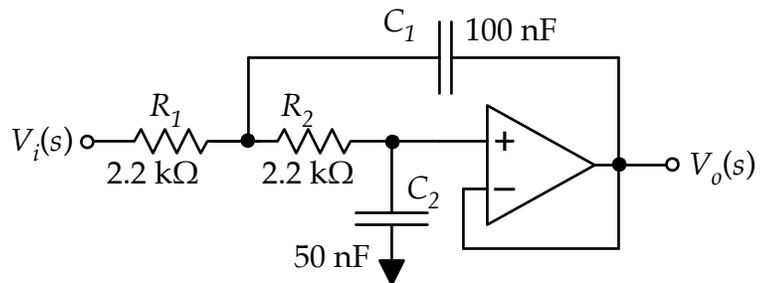
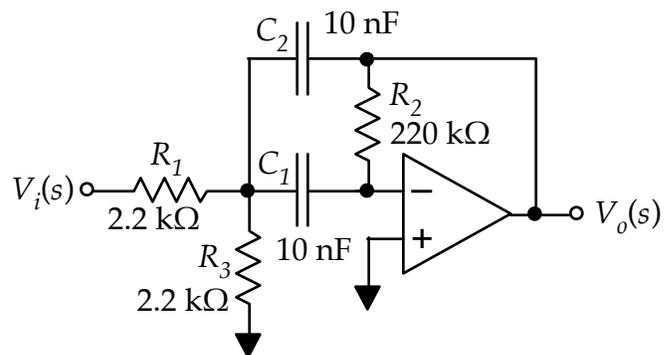
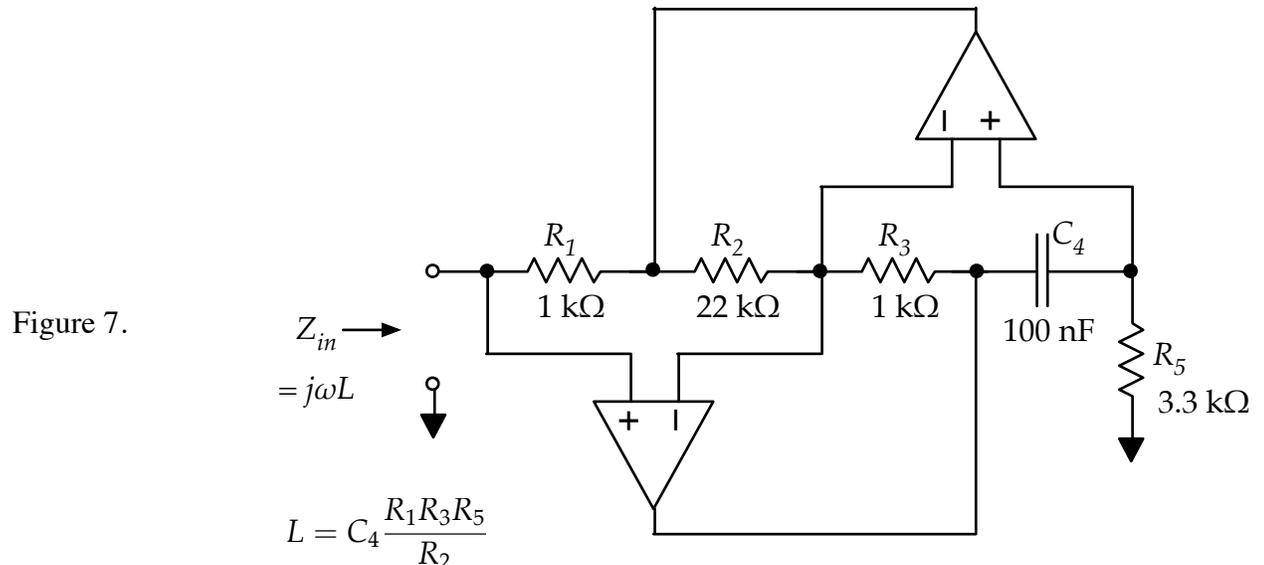


Figure 6. Delyiannis-Friend band-pass.



D. Psuedo-inductor circuit

We have said several times that bulky, lossy inductors are usually avoided in electronic circuits. Yet, inductance can be very useful in some applications, particularly in filter circuits. The circuit shown in Fig. 7 simulates the impedance of an inductor. The impedance seen at the input terminals increases with frequency, just like an inductor. The equivalent inductance is determined by the resistors and capacitor of the circuit.



- Calculate the expected value of the simulated inductance. (It should be close to a familiar value.)
- Build the inductor simulation circuit using 660 op amps with ± 8 -V power supplies. Check the connections carefully.
- Replace the real inductor of the RLC band-pass circuit used in part B with the pseudo inductor. (Remove the real inductor from the circuit of Fig. 4. Then connect the input port of the mock inductor of Fig. 7 in parallel with the capacitor.)
- Measure the magnitude frequency response of the the circuit with the psuedo-inductor over the frequency range 10 Hz to 1 MHz.
- Plot the two magnitude frequency responses together in a single Bode plot — one curve taken in part B with the real inductor and the other taken here with the psuedo-inductor.

Reporting

Prepare and submit a report after you have finished the lab – a template is available. Each lab group is required to submit a report (i.e. one report for two people). Be sure to include all of the frequency response graphs and answer any questions specified in the template. The report is due in one week at your normal lab time.

Comment regarding inductor series resistance

Real inductors always have some series resistance due to the resistivity of the wire in the coil. For high-quality inductors, the series resistance may be less than $1\ \Omega$ and will probably have negligible effect in many applications. For the 15-mH inductors that are being provided, the series resistance should be around $10\ \Omega$. This may have noticeable effects on the measurements. (You should measure the series resistance for your inductor using the ohm-meter.) This higher resistance will show its effect by making the bandpass frequency-response curve asymmetric and by introducing extra loss whenever the inductor is carrying higher currents, like when it is in series with the source. If you see these effects in your measurements, you should make note of them in your report.