Lab 4: Frequency response and resonant circuits (version 1.2)

WARNING: Use electrical test equipment with care! Always double-check connections before applying power. Look for short circuits, which can quickly destroy expensive equipment.

Note: All the experiments in this lab are performed with the Elvis board and software on the computer. No external scope, function generator, or power supply are used.

High-pass filter

Build the following circuit on the breadboard. Choose values of R and C to provide a cutoff frequency of your choice; a value of $f_c = 1/(2\pi RC)$ in the range 5--10 kHz is fine but it is not critical. Use the Elvis board functions from Lab 3 to measure both component values. Record them in your notes.
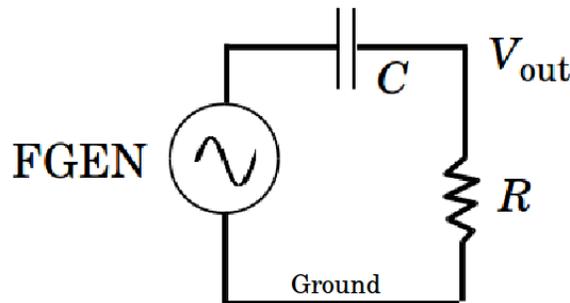
The sinusoidal input voltage is supplied by the function generator (FGEN) on the Elvis board. It is accessed with pin 33 on the left-hand outer board labeled FGEN. Wire a parallel connection from FGEN to BNC 1+, which is located on pin 42. This is the inner conductor of the external BNC 1 connection. Connect the outer conductor (BNC 1 –) on pin 43 to Ground. Connect V_{OUT} to BNC 2+ on pin 44 and the outer conductor of this port (pin 45) to Ground. Coaxial cable (consisting of an inner conductor, dielectric, outer braided shield, and plastic jacket) is much better than individual wires for reducing external noise in circuits.

Proper circuit operation can be verified with the Elvis oscilloscope. You will need two coaxial cables with BNC connectors on both ends. Connect one cable from the BNC 1 male connector to the Elvis scope Ch 0 input located on the outside upper left of the platform. Connect the second cable from BNC 2 to the Ch 1 scope input.

Turn on the Elvis board power. Launch the Elvis software function generator (FGEN) and Elvis Scope by clicking the appropriate buttons on the main Elvis interface. Set FGEN as follows: Waveform = Sine; Amplitude = 500 mV pp; DC Offset = 0; Modulation type = None; Signal route = Prototyping board. The frequency should be set well above the cutoff. Start the function generator by pressing the green RUN arrow.

Leave FGEN running and go to the oscilloscope window (SCOPE); press RUN to acquire

the input and output waveforms. The Elvis software scope does not have the full functionality of a stand-alone scope, but its controls behave the same. Use the Elvis scope to verify the presence of two nearly-equal amplitude sinusoidal signals that are slightly phase-shifted. Reduce the frequency below cutoff and verify high-pass operation. If you don't see this, troubleshoot your circuit and connections. Once a properly operating circuit has been established, stop both the Scope and Function Generator.

Leave the circuit as-is. Launch the Bode analyzer by clicking the button on the main Elvis interface. The analyzer requires a stimulus signal from the circuit input (FGEN on scope Ch 0) and a response signal at the circuit output (scope Ch 1). The Op-amp polarity should be on Normal and other values at their defaults. Set the start frequency well below f_c and the stop frequency well above it. The polarity should be on Normal and other values at their defaults. Start the Bode Analyzer and verify that it collects and plots amplitude and phase data at a minimum of 12 individual frequencies. More data is better, but not required.

Note that the the frequency axis is on a log scale and the amplitude data is plotted in units of dB defined by the formula $20 \log_{10}(|V_{OUT}/V_{IN}|)$. Save this data in a text file by using the LOG button on the Bode Analyzer interface. Before proceeding to the next circuit configuration, confirm the integrity of your .txt file by examining the stored data.

Parallel LC circuit

Modify your setup for the following circuit. Select values of L and C to produce a resonant frequency f_{RES} in the range 20—50 kHz (not critical) using the formula below. The resistor value R will establish the width of the resonance peak that can be seen in the frequency domain. You should experiment with this value; R in the range 100—1kΩ is a good starting point. If R is too small, the resonance peak will be very broad and wash out; if it is too big, the peak will be very sharp and approach a delta-function. Be sure to independently measure R, L, and C with the Elvis meter as was done in Lab 3. You will need these values for the analysis.

$$f_{RES} = \frac{1}{2\pi\sqrt{LC}}$$
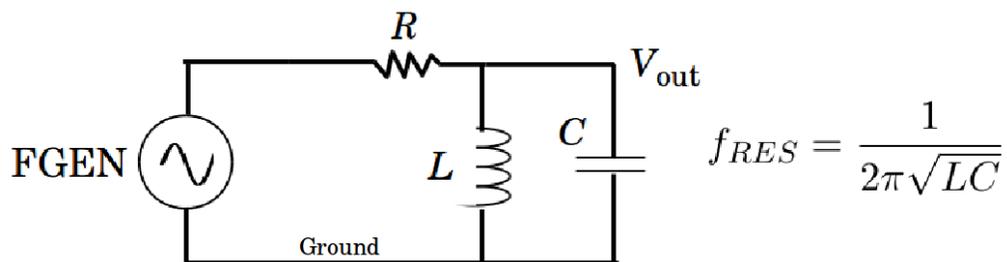
V_{OUT} is the voltage appearing across the parallel LC combination. Repeat the above Bode analyzer measurement, but choose a span of frequencies so that the resonance peak is well resolved. In particular, be sure there are enough points so that you can identify the −3 dB points (.707 of the peak magnitude) to obtain the circuit Q. If you are not getting

meaningful data, troubleshoot the circuit using the frequency generator and oscilloscope functions of the Elvis board. When acceptable Bode data for amplitude and phase is obtained, save it to a .txt file for later analysis.

Series LC circuit

Build the following circuit, but choose L and C to get a much higher resonant frequency, i.e. $f_{\text{RES}} \approx 300$ kHz. Reduce the amplitude of the FGEN signal to 100 mV and use a value of R in the range 5—10 Ω. V_{OUT} is measured across the resistor.
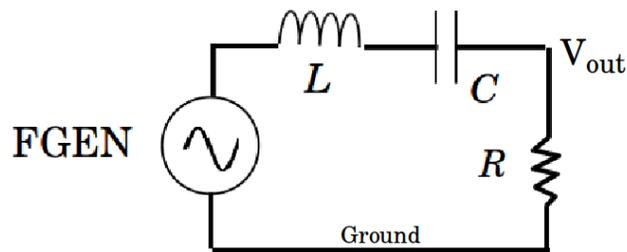
Perform a third Bode measurement for amplitude and phase; set the frequency range and number of data points to resolve the resonance peak.

Analysis and Writeup

Let the relation between output/input be written as G. For the high-pass filter:

$$G = \frac{V_{OUT}(\omega)}{V_{IN}(\omega)} = \frac{R}{R + 1/j\omega C}$$

For the parallel LC circuit:

$$G = \frac{j\omega L}{R\left(1 - \omega^2 LC\right) + j\omega L}$$

For the series LC circuit:

$$G = \frac{R}{R + j\omega L + 1/j\omega C}$$

The amplitude (dB) and phase (radians) are:

$$\text{Amplitude (dB)} = 20\log_{10}|G|$$

$$\text{Phase (rad)} = \text{atan}\left[\frac{\text{Im}(G)}{\text{Re}(G)}\right]$$

You will need to convert radians to degrees to match the Bode analyzer output. Make six plots (2 for each circuit) showing amplitude (dB) and phase (degrees) as a function of frequency (you may use a linear or log-10 scale for the x-axis) to compare with your data. Compare the calculated value of Q to your data for both resonant circuits.

As the circuit adds more components, the algebra needed to put the response in the form $G = a + jb$ becomes more difficult. You can use a program like MatLab, Scilab, or Octave that can handle the complex algebra of G automatically.

Produce six plots (amplitude and phase plots for 3 circuits) that compare data to theory. Determine Q for both resonant circuits and compare to the approximate frequency separation between the two – 3 dB data points. Send as a single file (.pdf preferred) to the instructor before the next class meeting.