Lab 4: Frequency response and resonant circuits (version 1.4)

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

Summary

Introduction to frequency response of RLC circuits, inductor, and resonance circuits.

Learning Outcomes

- Understand the relationship between charge and voltage on the capacitor and inductor.
- Build AC circuits with resistors, capacitors, and inductors.
- Realize and analyze measurements of location and width of resonances.
- Understand Bode plots and the dB scale.

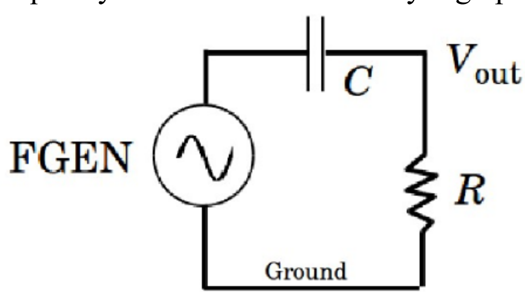
Partial list of equipment needed:

Digital oscilloscope and probes
Function generator
Breadboard and components: resistors, capacitors, and inductors.

Experiment/Procedure:

<u>High pass filter</u>

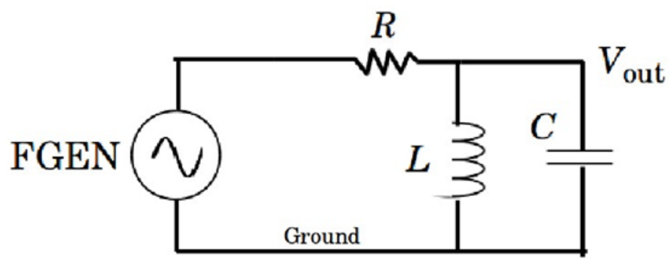
Build the following circuit on the breadboard. Choose values of R and C to provide a cutoff frequency $f_c = 1/(2\pi RC)$ in the range 5-10 kHz. Measure components and record the values before you assemble the circuit. Use the function generator to generate a Sine waveform with amplitude = 500 mVpp, and DC Offset = 0, with a frequency well above the cutoff. Reduce the frequency below cutoff and verify high pass operation.



Measure the amplitude and phase of V_{out} **relative** to the V_{in} as a function of frequency using the two channels of the oscilloscope. Use a frequency range starting well below f_c and ending well above it to provide enough data to map out the response (you may want to use a non-linear sampling step–consider how the data will look like on a log-log plot!). Collect data at a minimum of 12 individual frequencies for amplitude and phase. These data will be used to build Bode plots, where the frequency axis is on a log scale and the amplitude (in decibels) is given as $20 \log_{10}(|V_{out}/V_{in}|)$.

Parallel RLC 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 (exact value is not critical). 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 0.1 - 1 kΩ is a good starting point. If *R* is too small, the resonance peak will be very broad and washed 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*, which will be needed for the analysis of this lab. (*If L cannot be measured, assume a reasonable value.*)

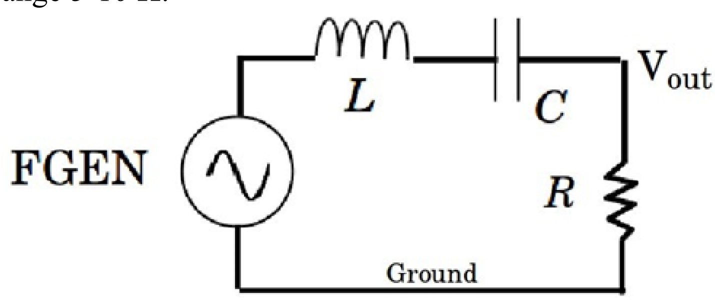


$$f_{RES} = \frac{1}{2\pi\sqrt{LC}}$$

For data collection, choose a span of frequencies so that the resonance peak is well resolved. Make sure there are enough points so that you can identify the −3 dB points (.707 of the peak magnitude) to obtain the circuit *Q*. Plot the circuit's amplitude and phase response and fit the data to a theoretical (Lorentzian) curve for a resonant circuit.

Series RLC circuit

Build the following circuit, but choose *L* and *C* to get a much higher resonant frequency, i.e. $f_{RES} \approx 300$ kHz. Reduce the amplitude of the input signal to 100 mV and use a value of *R* in the range 5-10 Ω.



Perform measurements of amplitude and phase to collect enough data to build a Bode diagram for this circuit. Choose a frequency range and number of data points to resolve the resonance peak with enough resolution.

Analysis and Writeup

For the analysis in your lab notebook, derive/use the response functions $G(\omega) = V_{out}/V_{in}$ for the three R-C and RLC circuits to model the amplitude and phase responses of the circuits you built.

Using the fact that the response function $G(\omega)$ is a complex number $a + jb$, obtain expressions for the frequency-dependent amplitude and phase response of each circuit.

Make six theoretical plots (2 for each circuit) showing amplitude (dB) and phase (degrees) as a function of frequency (use a log10 scale for the xaxis). Plot them together with your data to compare them with your observations. Include your equation formulas on each plot and the component values.

For the two RLC circuits, determine the theoretical value of Q for both resonant circuits, where $Q = f_0/\Delta f$ and Δf is the frequency range between the -3 dB locations, and compare them with your data.

Use Mathematica, MATLAB, Python, or another plotting software to plot your data on the same plot (amplitude and phase plots for 3 circuits). Paste this into your lab book and discuss the results.