Lab #3 – Transfer Functions of RC/RL/LRC Circuits

The purposes of this lab are

- to introduce the concepts of the transfer function (both amplitude and phase)
- to introduce resonance and the concept of Q
- to further illustrate the differences between real capacitors and inductors and their idealized models.

Equipment at each station:	Centrally available:
digital oscilloscope	wire and wire cutters/stripper
2 multimeters	red and black banana plug cables
2 power supplies	alligator clips
signal generator	assorted resistors
breadboard with power connections	assorted capacitors
potentiometer	10mH inductors

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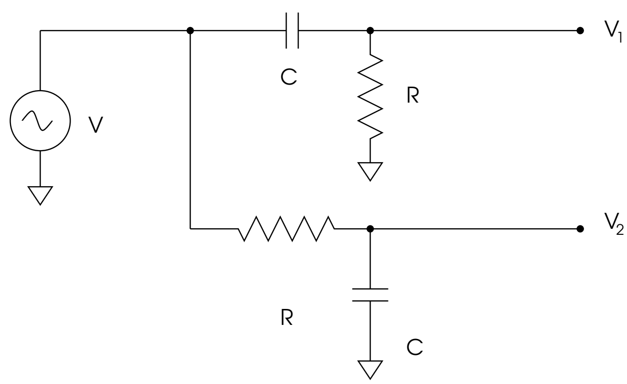
1. Transfer Function, H(f), of RC Circuit

- Construct a low-pass RC filter with the corner frequency (f_c) at ∼1 kHz. (Beware of factors of 2π floating around...)
- For this circuit:
    1. Dial your frequency rapidly up from very low to very high and note qualitatively that the circuit behaves as a low-pass filter with approximately the right corner frequency.
    2. Measure the corner frequency, f_c (also called the "3-dB point"), by adjusting the amplitude to a round number, say 1.0 V_{pp}, at very low frequencies, then increasing the frequency until the output is ∼0.707 V_{pp} ($1/\sqrt{2}$), then measuring the frequency. How well does is compare with what you calculated?
    3. Estimate the drop-off beyond the passband (in "dB per decade") by making measurements of the output at frequencies a factor of ten apart. (Both frequencies must be sufficiently above the passband so that the drop-off goes as f^{-1}.)
    4. Finally, measure the magnitude of H(f) from very low to very high frequencies, clustering many points around f_c in order to resolve the shape of the corner. Include a measurement of as high a frequency as possible to resolve the "skirt" of H.
    5. Make a rough plot of H(f) in your lab notebook.
- After lab (or during, if time permits) make a careful plot of the magnitude of H(f) versus f using your measurements. On the same graph plot the expected transfer function based on the values of R and C. Note how close to ideal the RC filter behaves.
- Additional Ideas (optional):
    1. Try building an RL low-pass filter.
    2. Try building a filter with a much higher f_c and note the inherent problems (e.g., at high frequencies inductances in R may become apparent).
    3. Try switching the R and C to construct a high-pass filter.
    4. Try cascading your filter with that of your neighbor or a second filter. Think about what will happen when you feed the input of one filter into another. (See Fortney pp. 108–112 for a discussion of cascading filters).

2. RLC and Resonance

- Construct a series RLC circuit as analyzed in class.
- Measure the amplitude of $H(f)$ versus f. Note that with C=20 nF and L=10 mH you should use R=220 Ω; a larger value of R will damp out any resonance. Be aware that the internal resistances of the inductor and the signal generator may not be insignificant compared with 220 Ω.
- For this circuit:
  1. Dial your frequency rapidly up from very low to very high and note qualitatively that the circuit has a resonance near the expected frequency.
  2. Tune to the resonant frequency and measure it. Adjust the amplitude so that the output is some round number, say 1 V_{pp}, then increase and decrease the frequency, respectively, to find the upper and lower "3-dB points", ω_1 and ω_2. Using these values compute $\Delta\omega$ and thus estimate $Q \approx \omega_r/\Delta\omega$. Compare this to the expected value, $\omega L/R$.
  3. Measure the amplitude and phase of $H(f)$ versus f, packing points fairly densely around the resonance and "3-dB points", but be sure to sample some very high and very low frequencies.
  4. Make a rough plot of $H(f)$ in your lab notebook, but record these numbers carefully in your notebook. You will need them for one of the homework problems.
- Additional Ideas (optional):
  1. Try to increase Q by decreasing R as much as possible, and note that Q is ultimately determined by the internal R of the inductor. Determine the intrinsic Q of the inductor, and thus, estimate the internal R of the inductor. How does this value compare to that measured with the ohmmeter?

3. "Quadrature Maker"



- Construct the 'quadrature maker' that you designed in the homework. Measure the phase difference to verify that it is $\pi/2$.
- Using the XY mode on your scope observe the Lissajous figures to see whether the outputs are indeed in quadrature.