CMPE 306

Lab IX: Frequency Selective RC and RL Circuits

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April 2014

1. Purpose and Introduction

The purpose of this lab is to study simple frequency-selective first-order circuits consisting of resistors and capacitors (RC) or resistors and inductors (RL). These circuits are *frequency-selective* because the outputs due to input sinusoidal signals at certain frequencies have larger amplitude than the outputs due to input signals at other frequencies. Thus the circuit *selects* certain frequencies (the high amplitude ones) in preference to other frequencies (the low amplitude ones). Such frequency selective circuits are the most common use for RC and RL designs.

For the purpose of this lab, we concentrate solely on *low pass* and *high pass* filters. To get other sorts of filters, we need a second order circuit, which we will do in the Lab X. In a low pass filter, input signals at lower frequencies result in higher amplitude output signals than input signals at higher frequencies. Thus, we say the filter "passes" lower frequencies and attenuates higher frequencies. Similarly, in a low pass filter, input signals at higher frequencies result in higher amplitude output signals than input signals at lower frequencies. Thus, we say the filter "passes" higher frequencies and attenuates lower frequencies.

By the end of this labs session, students will be able to perform the following tasks:

1. Simulate and analyze prototype RC and RL circuits.
2. Predict circuit performance using complex impedances.
3. Construct low pass and high pass filters in simple RC and RL forms.
4. Collect and analyze data illustrating that the circuits have the desired frequency selective characteristics.

2. Pre-Lab

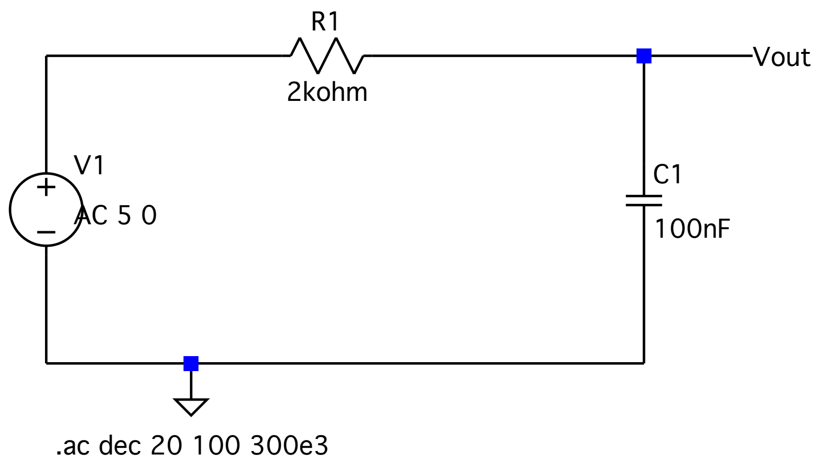

Figure 1 LTSPICE Circuit #1 Showing AC Voltage Source and AC Sweep Commad

1. Create the simple circuits shown in Figure 1. The voltage source is set to be an AC source (subtly different from a SINE source), with amplitude 5V and DC offset 0 volts. Selecting an AC source permits us to use the .ac directive in LTSPICE, as shown in the figure. The .ac command increments the frequency of the source with 20 steps per decade[1] ("dec 20") from 100 Hz to 300 kH. Run the simulation.
2. From plotting window (which should come up immediately), select the Add Traces option. Add the trace for V(n001) and V(vout). You should see a plot that looks like Figure 2. Collaborate with your lab partner to answer the following questions. Notice that the x-axis (the frequency scale) is logarithmic in nature, and the y-axis (the amplitude scale) is in decibels (dB).[2] Why is the green curve (V(n001)) constant? The solid blue curve is the output voltage. What is the impact of increasing the frequency of the sine wave? Does this make sense, given the DC characteristics of the capacitor? What does this suggest about the high frequency characteristics of the capacitor? The dotted blue curve is the phase. We'll come back to that late in this course.

   Figure 3 shows the *same* plot with the y-axis now in volts (not decibels) and a logarithmic x axis. You should recognize this as a semilog-x plot.

[1] A decade corresponds to an increase in frequency by a factor of 10, e.g., from 100 Hz to 1 kHz, or from 1 kHz to 10 khz. This sweep has slightly more than three decades (100 Hz – 1 kHz, 1 kHz – 10 kHz, 10 kHz – 100 kHz).

[2] A decibel (dB) is *also* a logarithmic unit. For voltages, $[v]_{\mathrm{dB}} = 20\log_{10}\left(\frac{v}{v_{\mathrm{ref}}}\right)$, where $[v]_{\mathrm{dB}}$ is the value of the amplitude of the voltage v given in decibels, and v_{ref} is some reference voltage. For the case of

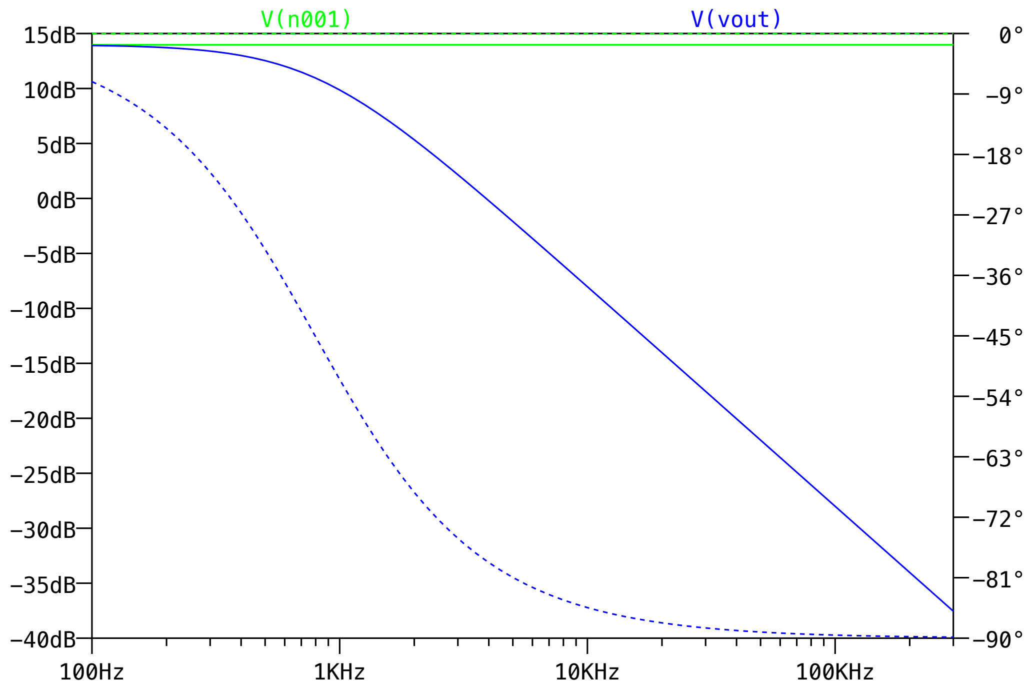

Figure 2: Log-Log (dB vs log(frequency)) Plot of Vout From Circuit of Figure 1

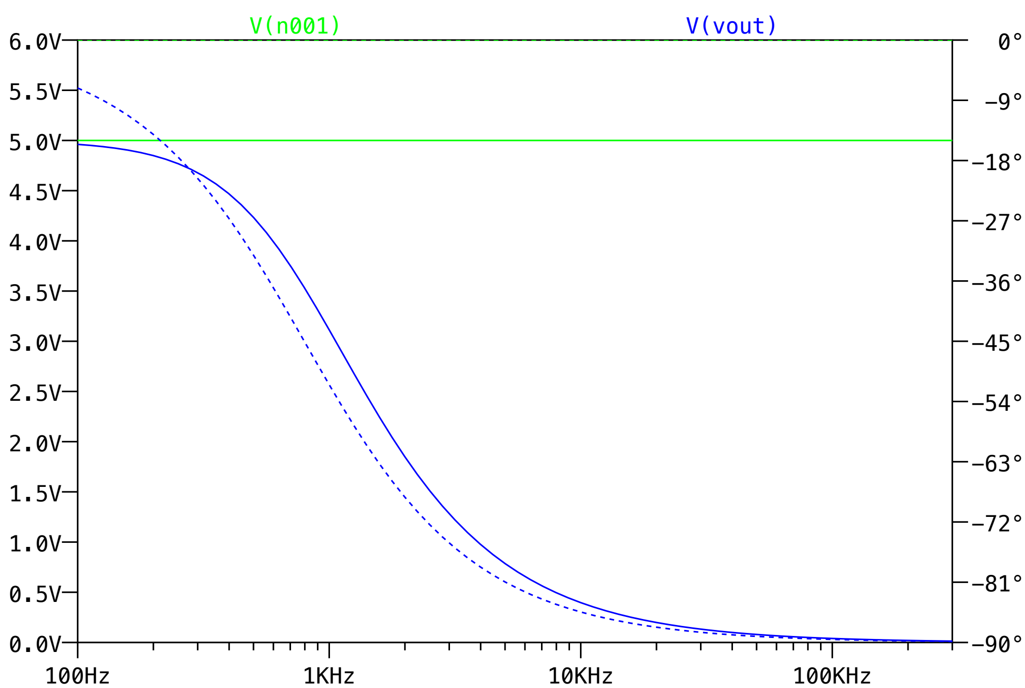

Figure 3 Semi-log Plot of Vout vs. Frequency

3. Using the definition of decibels, show that the blue curve is correct at the frequencies of 100 Hz, 10 kHz, and 100 kHz, using the formula: $\left|V_{out}\right| = \frac{1}{\sqrt{1+\left(2\pi fRC\right)^2}} \times \left|V_{in}\right|$.
4. Recognizing that the *power* in the sinusoid is proportional to the square of the voltage, use the expression given in Step 3 to write an equation for the frequency where $\frac{\left|V_{out}\right|^2}{\left|V_{in}\right|^2} = 0.5$. This frequency is called the *half power bandwidth*.
5. Repeat steps 1 and 2 for the circuits provided on Blackboard in files Lab9_Simple_RCHP.asc, Lab9_Simple_RLLP.asc and Lab9-Simple_RLHP.asc.
6. Show the circuits and your plots to the lab instructor before continuing. Get the instructor approval of your expression for the half-power bandwidth (or half power frequency).

3. Equipment

This lab exercise uses the following equipment:

1) Tektronix AFG310 Arbitrary Function Generator
2) Tektronix 2012 Digital Storage Oscilloscope
3) BNC-to-BNC cable
4) Two BNC-to-alligator cables.
5) 1kΩ, 2kΩ resistors, 100nF capacitor, 10mH inductor.
6) Multimeter

4. .Procedure

Before starting, use your multimeter to measure the resistance of the inductor. Record this value; you will need it in 4.3 and 4.4, below.

4.1. RC Low Pass Filter

1. Construct the circuit shown in Figure 1.
2. Use a 5V amplitude sinusoidal output (peak-to-peak 10V, offset 0V) of the function generator as the input voltage source.
3. Measure the output voltage for frequencies from 100Hz to 300kHz. Take at least eight points to plot a smooth curve. Make sure that the half-power frequency, as computed by Step 4 of the pre-lab, is one of the points measured.

4. Using MATLAB or EXCEL, plot the measured ratio of the amplitudes of the output sine wave to the input sine wave, $\frac{|V_{out}|}{|V_{in}|}$ (voltage ratio, not decibels!) on the y-axis vs. $\log_{10}(f)$ on the x-axis. The vertical magnitude should be from 0 to 1. Locate the half-power point calculated and identify it with a square on the plot.

4.2. RC High Pass Filter

1. Construct the filter shown in Figure 4. Assuming that the complex voltage ratio is $\frac{|V_{out}|}{|V_{in}|} = \frac{j2\pi fRC}{1 + j2\pi fRC}$, find the half-power frequency[3].
2. Repeat steps 2) to 4) of part 4.1.

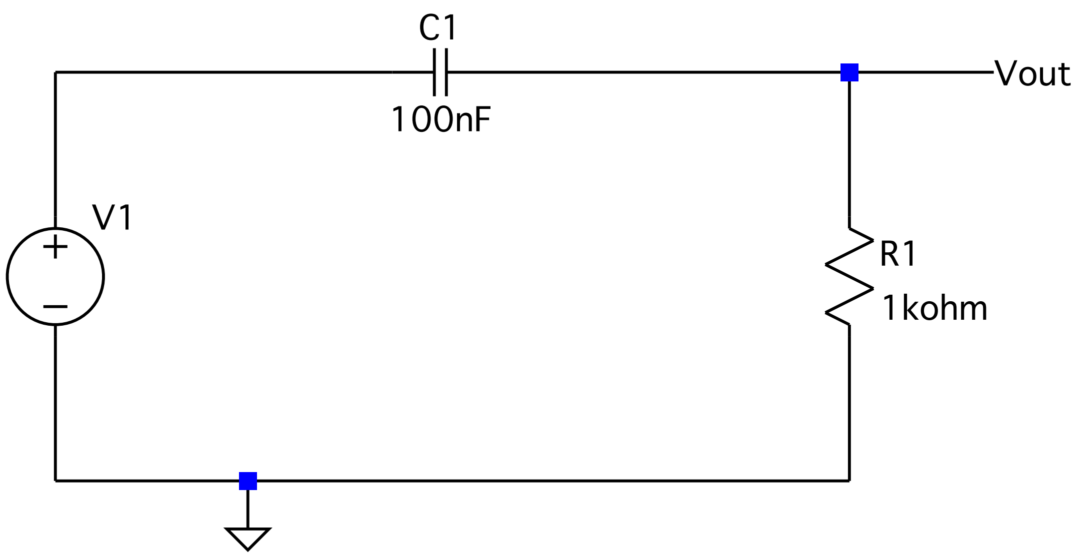

Figure 4 RC High Pass Filter CIrcuit

4.3. RL Low Pass Filter

1. Construct the filter shown in Figure 5. How should you adjust the form of Step 3 in the prelab section to account for the replacement of a capacitor with an inductor?[4] Use the modified form to solve for the half-power frequency. Don't forget to include the resistance of the inductor that you measured before starting the lab procedure.

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[3] Hint, for a complex number $z = x + jy$, $|z|^2 = z \times z^* = (x + jy)(x - jy) = x^2 + y^2$

[4] Hint: Rewrite the expression in Step 3 of the Prelab in terms of the time constant , τ.

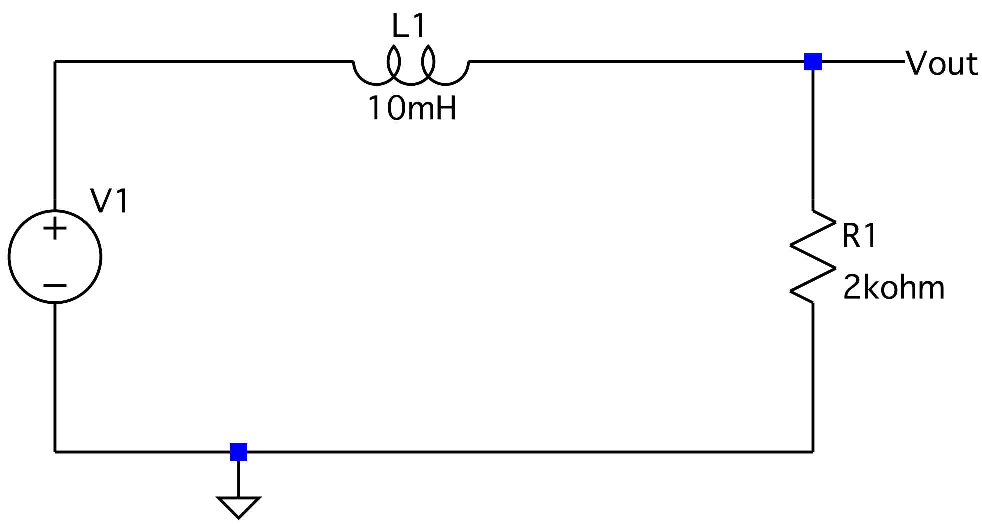

Figure 5 RL Low Pass Filter CIrcuit

2. Repeat steps 2) to 4) of A.
3. Calculate the inductance of the inductor used in the experiment from the plot of its frequency response and compare the value with 10 mH.

4.4. RL Hi Pass Filter

1. Construct the filter shown Figure 6. Using the same modification used in 4.3 to account for the replacement of the capacitor by the inductor and apply it to the formula given in 4.2. Then compute the half-power frequency. Include the resistance of the inductor.
2. Repeat steps 2) to 4) of A.

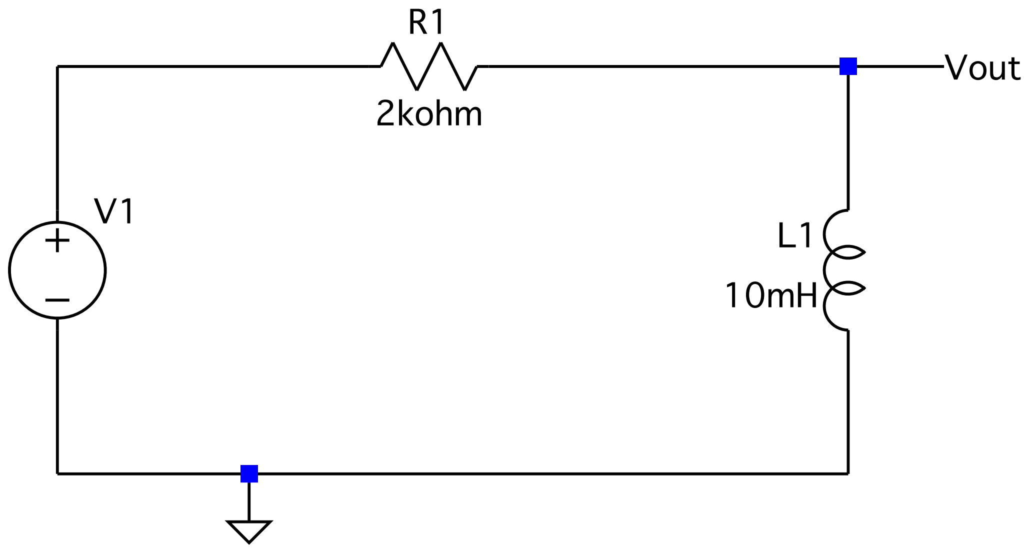

Figure 6 RL High Pass Filter Circuit

4.5. Preparation for Next Lab

I haven't finished the next lab yet. We're a little out of sync with the lectures, so I have to juggle things a little. I will attempt to have the new lab posted by Thursday evening.

For the lab report for this week, please include all of the plots that you were asked to save, and all of the values you were asked to record, and the computations you were asked to make. Partners should participate in the derivations. Please indicate in your report if your partner participated or not.

5. Tear Down and Clean Up

1. Turn off the power supply, AFG, and oscilloscope and set the multimeter to the OFF position. Return the multimeter to your TA for storage.
2. Save your images or data to your memory stick. Then close the program and sign off of the computer.
3. Put your resistors and capacitors chip back in your lab kit. Return your lab kit to the TA for storage.
4. Return the BNC cables and BNC-to-alligator cables and hang them neatly in their proper rack.
5. Police your lab area: leave it neat and clean.
6. If you're using your own laptop, there's nothing else to clean up.
7. If you're using the lab computer, save whatever work you want to your USB drive. Close LTSPICE if necessary. Eject your drive.