NAME ______________________________

EET 2259 Lab 13

Studying Frequency Response with LabVIEW

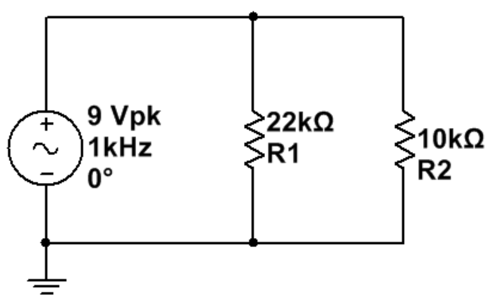
OBJECTIVES

-Write LabVIEW programs to measure and display frequency response curves of components, filters, and amplifiers studied in previous electronics courses.

Part 1. Review: An AC Current Divider

To write this first program you'll need to remember skills you learned in Lab 12. In particular, you'll need to remember how to produce sinusoidal AC voltages and measure AC currents. You may want to use either Lab12ACVoltageDivider.vi or Lab12MeasureACCurrent.vi as a starting point for your program**.**

1. Using your knowledge of AC circuits, predict the ***peak-to-peak*** currents through R1 and R2 in the circuit shown below. Record your predictions in the spaces provided.



Predicted Peak-to-Peak Currents: *I1*_________________ *I2*_________________

Hardware Setup:

2. Remembering what you learned in Lab 12 about building AC circuits, build the circuit on the breadboard. (Since we're going to measure current, don't forget to include sensing resistors, which are not shown in the schematic diagram.)

LabVIEW Program:

3. Create a new VI whose front panel contains two numeric indicators labeled **I1** and **I2**. Configure them to display their values in engineering notation with three significant digits.

4. Write a program that produces the required AC voltage and measures the two peak-to-peak currents.

5. Run the program, and make sure that the values displayed on your program's front panel agree with your predictions from above. Save this VI as **Lab13ACCurrentDivider.vi** and **show me your working program**.

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INTRODUCTION TO FREQUENCY RESPONSE PROGRAMS

From previous courses you know that a component's behavior of may or may not depend on frequency. For example, a resistor's resistance is frequency-independent; so a given voltage across a resistor will always result in the same current, regardless of the voltage's frequency. Thus, frequency does not appear in the equation for Ohm's law ($I = V \div R$).

On the other hand, a capacitor's (or inductor's) reactance depends on frequency. If we know a capacitor's capacitance and voltage drop, we still don't have enough information to predict its current unless we also know the voltage's frequency. That's why frequency f appears in the formulas we use to predict a capacitor's current: $I = V \div X_C$, where $X_C = 1 \div (2\pi fC)$.

This frequency dependence makes capacitors very useful for building filters and other circuits whose behavior depend on frequency. For example, we might want a filter that blocks signals of frequency less than 100 Hz but passes higher-frequency signals. Capacitors let us build such a filter.

In other circuits, though, frequency dependence can be a disadvantage. In an amplifier, for example, we might want the gain to be constant over a wide range of frequencies; but this so-called "flat response" may be difficult to achieve because of the effect that changing frequency has on the components inside the amplifier.

In this lab you'll use LabVIEW to explore frequency dependence. Why is LabVIEW useful here? Because with LabVIEW it's easy to write a program that will vary a voltage source's frequency over a range of values, make measurements in the circuit, and then plot the results of these measurements on a graph. This is similar to how we used LabVIEW in Lab 11 on characteristic curves. But there, we varied a voltage's **magnitude** and measured what effect this had on current. In this lab we're not interested in the effect of a changing magnitude, but rather the effect of a changing **frequency**. Here's another difference between this lab and Lab 11: in Lab 11 all of the voltages produced by the DAQ Assistant were DC voltages. Once we start talking about frequency, we're in the realm of AC—so you'll need the skills that you learned in Lab 12 on generating and measuring AC voltages.

Let's start with a small program that will serve as a building block for this lab's main programs. This building-block program will simply vary the frequency of a sinusoidal voltage over a range of frequencies.

Part 2. Producing a Sinusoid Whose Frequency Varies

Recall from Lab 12 that the **Simulate Signal Express VI** lets us generate waveforms of desired shape, frequency, amplitude, etc. Then, if we want a real-world version of this waveform, we can send the **Simulate Signal**'s output data directly a DAQ Assistant to generate the signal on an analog output channel. Let's start by reviewing what you already know.

1. Create a VI whose front panel has a numeric indicator labeled **Frequency**. On the block diagram, use a **Simulate Signal** Express VI to produce a sine wave with an amplitude of 1 V pk and a frequency of 1 kHz. (You'll probably get a warning message, which you'll know how to fix if you recall Nyquist's theorem.) Use a DAQ Assistant to send this sine wave out to the myDAQ's analog output channel AO0. (You may wish to review Lab 12 to recall how to configure this DAQ Assistant.) Display the sine wave on an oscilloscope and verify that its shape, peak voltage, and frequency are correct.

2. Modify the block diagram so that the sine wave's frequency increases every three seconds, stepping through the following list of frequencies: 10 Hz, 20 Hz, 40 Hz, 80 Hz, 100 Hz, 200 Hz, 400 Hz, 800 Hz, 1 kHz, 2 kHz, 4 kHz, 8 kHz, 10 kHz, 20 kHz, 40 kHz. In other words, the program should produce a 10 Hz sine wave for three seconds, then a 20 Hz sine wave for three seconds, and so on. (*Hint*: Use a For loop. You could generate the right frequencies by applying some math to this loop's iteration terminal, but an easier way is to create an array containing the list of desired frequencies, and then have your loop step through this list.) Display the frequency on the front panel.

3. Run the program, and use an oscilloscope to monitor the shape and frequency of the signal produced on the myDAQ's AO0 analog output. The frequency should step through the values listed above. Save this VI as **Lab13VaryingFrequency.vi** and **show me your working program**.

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Part 3. Frequency-Independence of Resistors

Now that you know how to vary the frequency of an AC voltage, you're ready to plot the frequency response of components. Our goal is to make a graph with the component's resistance or reactance on the vertical axis and frequency on the horizontal axis. (Recall that for resistors, dividing voltage by current gives the resistor's **resistance**, but for capacitors or inductors, dividing voltage by current gives the component's **reactance**.) Here's an outline of the general procedure we'll use:

A. Connect a sensing resistor in series with the component.
B. Using an analog-out DAQ Assistant, generate an AC voltage of a known frequency across the series combination (resistor-plus-component).
C. Using an analog-in DAQ Assistant, measure the voltage across the component and the current through it. Then divide voltage by current to find resistance or reactance. This provides one data point (with resistance or reactance as the y-coordinate and frequency as the x-coordinate) on the frequency-response curve.
D. Collect additional data points by repeating steps B and C several times, changing the frequency of the AC voltage each time.
E. Create a table that lists the data values. Also plot the data points on an XY graph (with resistance or reactance on the vertical axis and frequency on the horizontal).

If you compare this outline with the outline for plotting a resistor's characteristic curve in Lab 11, you'll see a lot of similarities. The main difference is that:

- In Lab 11 we plotted *current versus voltage* in a *DC* circuit.
- Now we want to plot *resistance or reactance versus frequency* in an *AC* circuit.

Let's start by plotting the frequency response of a 4.7-kΩ resistor. As you know, a resistor's resistance does not depend on frequency. **In the space below, sketch the graph** you'd expect to get if you plotted resistance versus frequency for a resistor. Include horizontal and vertical axes with labels.

Hardware Setup:

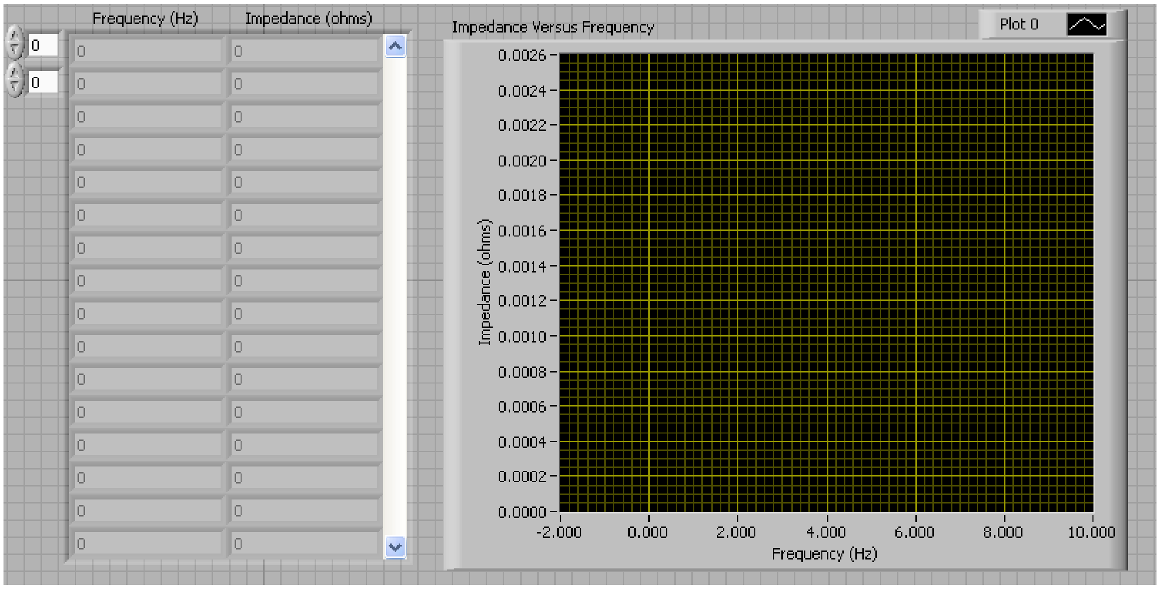
1. Place a 4.7-kΩ resistor on a breadboard. In series with it place a 10-Ω sensing resistor. Connect the myDAQ's analog output AO0 across the series combination of these two resistors.

2. Run wires from the two ends of the sensing resistor to the myDAQ's AI0+ and AI0− analog inputs.

3. Run wires from the two ends of the 4.7-kΩ resistor to the myDAQ's AI1+ and AI1− analog inputs. *Since the myDAQ's analog output is a grounded voltage source, don't connect jumper wires between the myDAQ's AGND terminal and any of its other terminals.*

LabVIEW Program:

4. Write a program to plot a graph of resistance versus frequency. I suggest that you start by saving a copy of your program called **Lab11ResistorCharacteristicCurve.vi** under the new name **Lab13ComponentFrequencyResponse.vi**. Then the major changes you'll need to make are these:
    a. Change the labels on your array and graph, as shown in the picture below.



    b. Your original program generates a **DC** source voltage and then varies this voltage's **magnitude**. The new program must generate an **AC** source voltage and then vary this voltage's **frequency**. Use **Lab13VaryingFrequency.vi** as your model for this part of the program.
    c. Your original program measures DC current and DC voltage, and then plots current versus voltage. The new program must measure AC current and AC voltage, then compute resistance, and then plot resistance versus frequency. Use **Lab12MeasureACCurrent.vi** as your model for this part of the lab.

5. Run the program, and you should find that the resistor's resistance is almost unchanged as the frequency varies. If y-axis auto-scaling is enabled on your XY-graph, the small variations in resistance will appear much greater than they really are. Fix this by turning off auto-scaling and setting the minimum value on the y-axis to 0. This should result in a nearly flat line for your plot.

6. Get a printout of the front panel, and **turn it in** with this lab. Save this VI as **Lab13ComponentFrequencyResponse.vi** and **show me your working program**.

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Part 4. Frequency-Dependence of Capacitors and Inductors

The same program will let us explore the frequency response of other two-terminal components, such as capacitors and inductors. As you know, a capacitor's reactance is inversely proportional to frequency: $X_C = 1 \div (2\pi f C)$. **In the space below, sketch the graph** you'd expect to get if you plotted reactance versus frequency for a capacitor. Include horizontal and vertical axes with labels.

Hardware Setup:

1. Replace the 4.7-kΩ resistor on the breadboard with a 0.33 μF capacitor.

LabVIEW Program:

1. Run the program, and you should get a plot similar to the one you predicted above. Get a printout of the front panel, and **turn it in** with this lab. Also **show me your working program**.

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As you know, an inductor's reactance is directly proportional to frequency: $X_L = 2\pi f L$. **In the space below, sketch the graph** you'd expect to get if you plotted reactance versus frequency for an inductor. Include horizontal and vertical axes with labels.

Hardware Setup:

1. Replace the 0.33 μF capacitor on the breadboard with a 10 mH inductor.

LabVIEW Program:

2. Run the program, and you should get a plot similar to the one you predicted above. Get a printout of the front panel, and **turn it in** with this lab. Also **show me your working program**.

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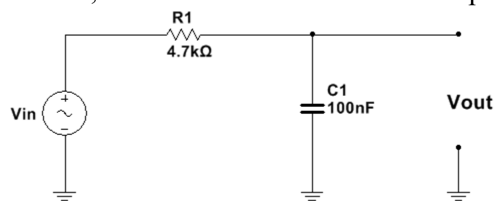
Part 5. Frequency Response of Filters and Amplifiers

Your previous program plotted a component's **resistance or reactance** versus frequency. When we talk about the frequency response of a filter or amplifier, we're usually talking about a plot of **gain** versus frequency. And usually the gain that interests us is voltage gain A_v, which is equal to the circuit's output voltage V_{out} divided by its input voltage V_{in}. In equation form, $A_v = V_{out} \div V_{in}$. A minor modification to your previous program will make it suitable for plotting gain versus frequency.

Shown below is a simple RC filter, which should be familiar from previous courses.



Is this a low-pass filter or a high-pass filter? ________________________________

Calculate this filter's cut-off frequency. (Recall that this is the frequency at which the gain has a value of 0.707). Show your calculation below.

cut-off frequency=_________________

In the space below, sketch the graph you'd expect to get if you plotted gain versus frequency for this filter. Include horizontal and vertical axes with labels.

Hardware Setup:

1. Build the filter shown above on a breadboard. Connect the myDAQ's analog output AO0 as the circuit's input voltage.

2. Run two wires so that the myDAQ's AI0 analog input measures the circuit's input voltage.

3. Run two wires so that the myDAQ's AI1 analog input measures the circuit's output voltage, which is just the voltage across the capacitor. Don't connect jumper wires between the myDAQ's AGND terminal and any of its other terminals.

LabVIEW Program:

4. Save a copy of **Lab13ComponentFrequencyResponse.vi** under the new name **Lab13FilterFrequencyResponse.vi**. The changes you'll need to make are minor:
   a. Your original program measures current and AC voltage, then computes resistance or reactance, and then plots resistance or reactance versus frequency. The new program must measure input voltage and output voltage, then compute gain, and then plot gain versus frequency.
   b. Recall that when we plot frequency responses of amplifiers, we typically use a logarithmic scale (instead of a linear scale) on the horizontal axis. In the Properties dialog box for your X-Y graph, figure out how to make the horizontal scale logarithmic.

5. Run the program, and you should find that the plotted curve has roughly the shape that you predicted above, and that the gain has fallen to about 0.707 at the cutoff frequency that you predicted above. Use a free-dragging cursor to locate the cutoff frequency.

6. Get a printout of the front panel, and **turn it in** with this lab. Save this VI as **Lab13FilterFrequencyResponse.vi** and **show me your working program**.

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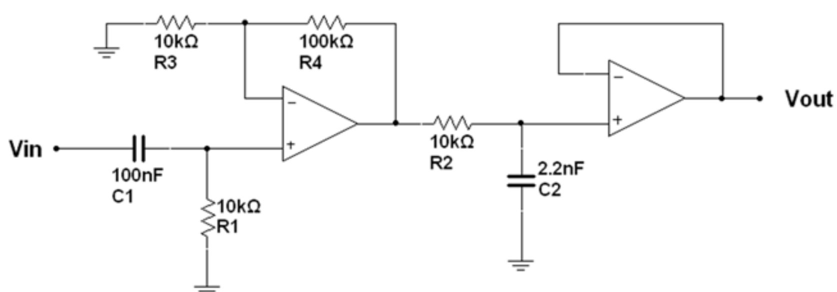
You've now used LabVIEW to plot a passive filter's frequency response. With no changes to the program, you can also use it to plot the frequency response curve of an amplifier or an active filter. (Recall that **passive filters** use only passive components—resistors, capacitors, inductors—and cannot amplify the input voltage. **Active filters**, on the other hand, contain active components—transistors or op amps—that can amplify the input signal so that the filter may have a gain greater than 1 at some frequencies.)
Consider the active band-pass filter shown below.



Based on your knowledge of active filters, calculate this filter's lower and upper cut-off frequencies. Show your calculations in the blank space.

Lower cut-off frequency=________________

Upper cut-off frequency=________________

Also calculate the circuit's maximum gain, showing your calculation.

Maximum gain=________________

In the space below, sketch the graph you'd expect to get if you plotted gain versus frequency for this filter. Include horizontal and vertical axes with labels.

Hardware Setup:

1. Build the filter shown above on your breadboard, using either two single op-amp chips such as the LM741 or a dual op-amp chip such as the LM747. Connect the myDAQ's analog output AO0 as the circuit's input voltage. (Don't forget to provide your op-amps with power, using the myDAQ's +15 V and −15 V terminals.)

2. Connect the myDAQ's AI0 analog input to measure the circuit's input voltage.

3. Connect the myDAQ's AI1 analog input to measure the circuit's output voltage.

LabVIEW Program:

4. Run **Lab13FilterFrequencyResponse.vi**, and you should find that the plotted curve has roughly the shape, maximum gain, and cutoff frequencies that you predicted above.

5. Get a printout of the front panel, and **turn it in** with this lab. Also **show me your working program**.

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***** This lab had 4 named programs for me to check. If you didn't finish all of these during class, finish them after class. Then upload all 4 programs, along with any related subVIs, to the website by the due date. Also turn in your lab sheets at the beginning of class.******