Basic op-amp circuits

Introduction

This week we will explore the behavior of the op-amp. Largely this lab will be about op-amp basics and not have much application focus. In the coming weeks we will see op-amp applications in a number of physical experiments. Also, you might notice a shift where we will start to be a little less prescriptive in what to turn in for your lab report and exactly what you should do at each step. Last week we started to ask you to pick your own component values. This week we will start easing off making the lab a step-by-step. The aim is to push you to more independence in your experimental capabilities and communicating your results. You can always seek out one of the instructors for advice.

Op-amp follower

One of the simplest and most useful op-amp circuits is called a voltage follower, described in section 5.3 of the book. The circuit consists of simply wiring the op-amp's output to the negative input. This circuit is useful since the input to the op amp draws no current, the follower can be added between components of a system in order to isolate the components from each other. A simple example is found in the difference between the two circuits shown in figure 1a and 1b.

Test the measurement of a simple voltage divider as shown in Figure 1 and see the difference between the circuit Figure 1a and 1b. Go back to the warmup problems you conducted in Lab 2 about the Analog Discovery input impedance. In your lab report succinctly explain your measurements of these two circuits and briefly explain why the op-amp follower eliminates the effect of the measurement devices input impedance.

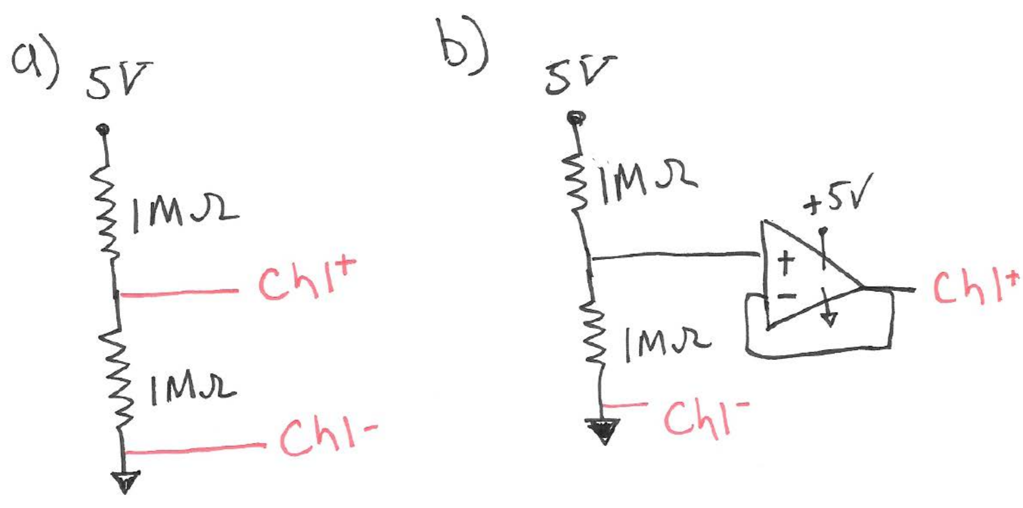

Figure 1: Measurement of a simple voltage divider with and without an op-amp follower.

Op-amp follower again

In Figure 2 we show a low-pass and high-pass filter in series. In Figure 2a we show the circuit with no op-amp follower between the low and high pass filters. In Figure 2b we use an op-amp follower as a buffer between the two components. Create the experimental Bode plot for both circuits.

The high-pass filter on its own has the amplitude of the output relative to the input theoretically as

$$A_{HP} = \frac{R_1 C_1 \, \omega}{\sqrt{1 + (R_1 C_1 \omega)^2}},$$

where the frequency in this formula is measured in radians/second. The low-pass filter on its own has the amplitude of the output relative to the input as

$$A_{LP} = \frac{1}{\sqrt{1 + (R_2 C_2 \omega)^2}}.$$

If there is no coupling between the two filters, then the total output amplitude of both circuits is given as the product, $A_{LP}A_{HP}$. Compare your experimental amplitude Bode plot data for the two circuits with the theoretical result with no coupling – all on the one plot. **Note: the amplitude and offset in the Network Analyzer is important, especially when using the op-amp. For both cases set the offset to be 2.5V and the amplitude to be 100mV. Reference Ch1- and Ch2- to 2.5 V as well.** The case with the op-amp should match the ideal case very well, while the case without the op-amp as a buffer may not look quite as expected due to the coupling between the two filters. Explain your results.

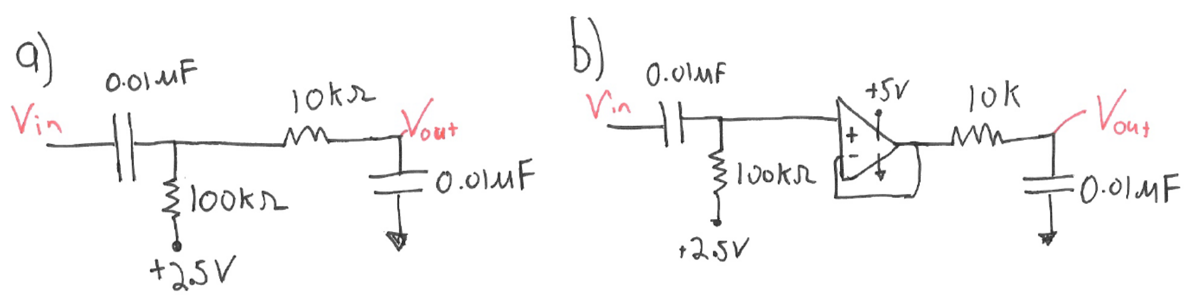

Figure 2: Filter with and without an op-amp buffer.

Amplifier

Build the amplifier circuit shown in Figure 3a. Test the circuit by using the waveform generator and scope on your Analog Discovery. Set the waveform generator to output a **100 mV amplitude sinusoidal signal with an offset of 2.5 volts**. With the scope, measure both the input and the output voltage, referencing Ch1- and Ch2- to ground. Adjust the scope time and volts/div scale so that you can see the signal clearly. In you lab report, provide your measured and theoretical relationship between the output and the input voltages. Explain your observations (you probably don't need a plot here).

Create a Bode plot for this circuit starting at around 10 Hz and going up to 1 MHz. Document at what frequency the ideal mode of the op-amp circuit breaks down. For the Bode plot, **100 mV amplitude sinusoidal signal with an offset of 2.5 volts. For this Bode plot, it will probably work best if you reference Ch1- and Ch2- to 2.5 V.**

Finally, switch the connection on R2 to ground instead of 2.5 V as shown in Figure 3b. Leave the input voltage on the waveform generator as it was previously to output a **100 mV amplitude sinusoidal signal with an offset of 2.5 volts.** Check the output of the circuit, referencing Ch1- and Ch2- to ground. Now change the offset of the input signal on W1 to be 0 volts (note, both input signals are shown schematically in Figure 3b). Check the output of the circuit. In your lab report include a short paragraph explaining the difference between referencing your circuit to 2.5 volts as in Figure 3a versus ground in Figure 3b. Explain why we will usually use the reference to 2.5V.

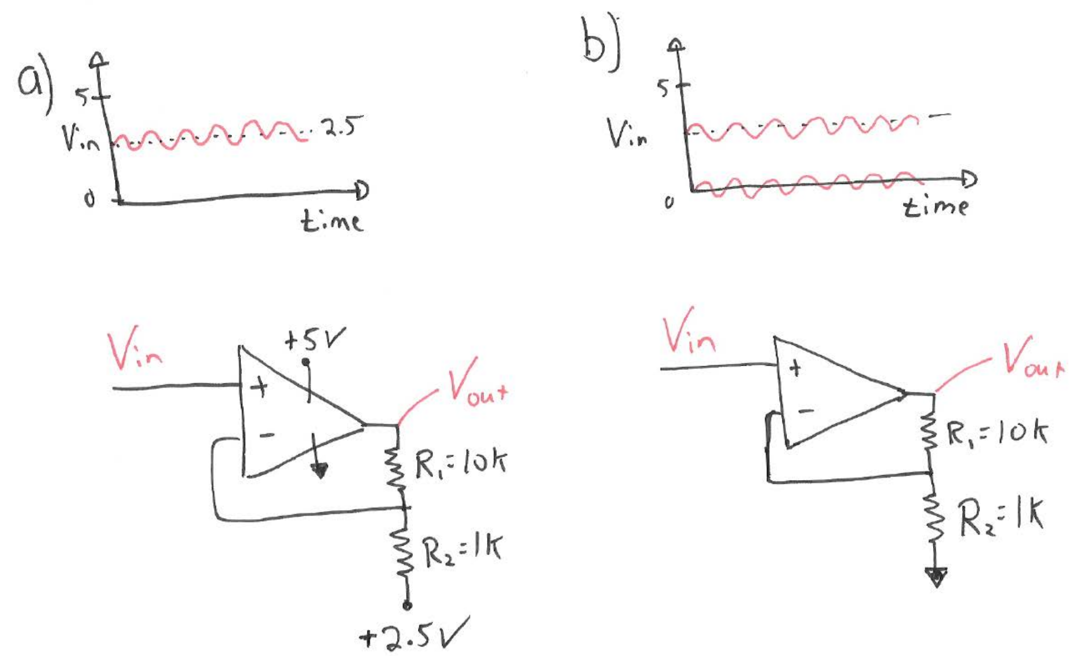

Figure 3: Amplifier circuit with 2.5 and ground reference

Set current, measure voltage

A useful circuit for exploring the relationship between voltage and current is shown in Figure 4. Here "Black Box" means I can place any analog component there. By controlling the input voltage and selecting an appropriate value of the resistor, I can control the current flowing through the "Black Box". By measuring the output voltage of the lower op-amp, I can measure the resulting voltage **across** the Black Box.

First, try to understand this general circuit using our rules when op-amps are wired in negative feedback

- No current flows into the op-amp's inputs.
- The input voltages are equal.

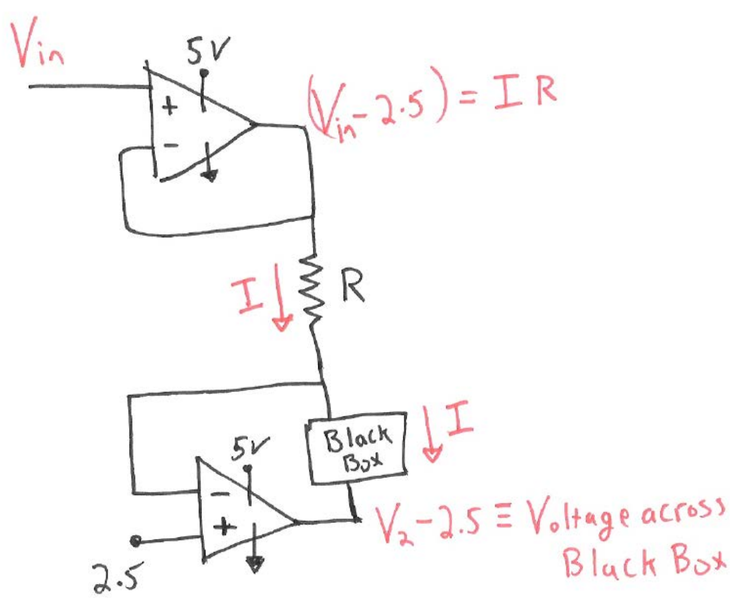

Figure 4: Generic source current, measure voltage circuit.

Now let's test the voltage and current relationship for two devices. First, is the capacitor. Build the circuit shown Figure 5a. For the components:

- Your "Black box" should be a 0.1 uF capacitor.
- Your resistor should be 1 M
- Your input voltage should be 1 V amplitude, 2.5 V offset, 0.5 Hz **square wave**.
- Measure the output of op-amp 1 with Ch1+ and output of op-amp 2 with Ch 2 +. Place Ch1- and Ch2- into 2.5 V.

For each step change in Vin (the current through the capacitor) you should observe that the voltage across the capacitor changes linearly, until the system saturates. Using the scope's cursor measure dV/dt for the voltage across the capacitor. Change the input amplitude to 5 different values (therefore changing the current through the capacitor) and measure dV/dt across the capacitor. **Note the max value the wavegen can output when plugged into only the computers USB is 5V – therefore do not make the amplitude greater than 2.5V**. Make a table that provides your different values of current, your measured dV/dt, and therefore the measured value of the capacitance. Did you verify our basic capacitor law, $C\frac{dV}{dt} = I$?

Second black box to test, is a light emitting diode, LED. Build the circuit shown Figure 5b. For the components:

- Your "Black box" should be a red LED.
- Your resistor should be 100 Ohms
- Your input voltage should be 1 V amplitude, 2.5 V offset, 10 Hz **SINE wave**.
- Measure the output of op-amp 1 with Ch1+ and output of op-amp 2 with Ch 2 +. Place Ch1- and Ch2- into 2.5 V.
- On the scope, add an x-y plot. Look up what a V-I curve for an LED is and check that your x-y plot makes sense to you.

Save the data for Channel 1 and Channel 2. In your lab report you will want to make a plot where voltage across the LED is on the x-axis and current through the LED is on the y-axis. Note that you are measuring only voltage, but you can infer the current since you know that the circuit has a 100 ohm resistor.

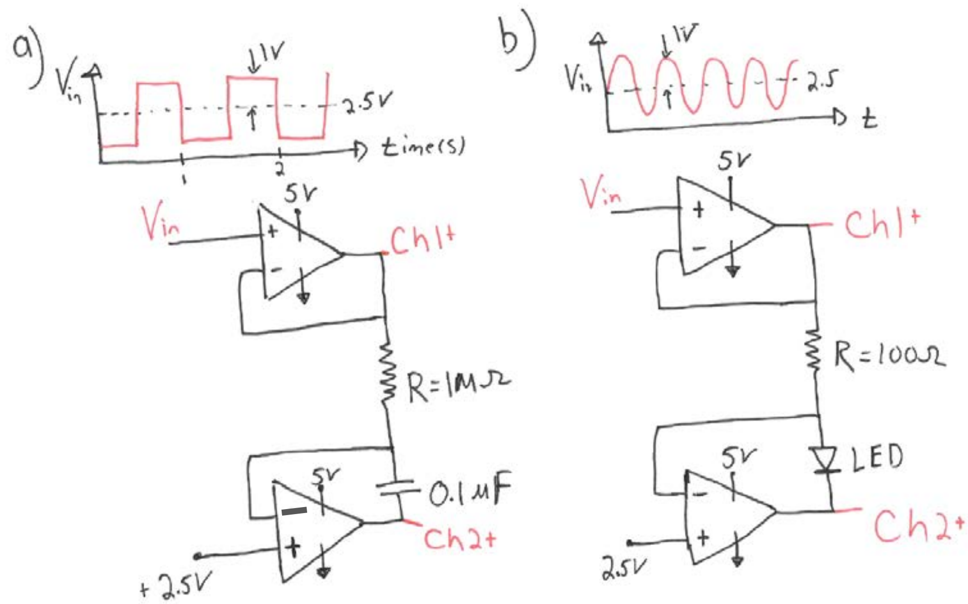

Figure 5: Check the V-I behavior of a capacitor and a LED.