Lab 5: Op-amps

This week we will experiment with a new component, the operational amplifier (op-amp). We learned about op-amps in lecture this week. When analyzing op-amp circuits we make two assumptions, which we will explore in a later lab. For now, remember that

1) The inputs to the op-amp draw no current.
2) When wired with negative feedback (i.e. the output of the op-amp is connected to the negative input) the two input voltages are equal.

In this lab, we will use these two properties to analyze a few useful circuits. The op-amp we use is the LMC6494.

Part 1: Op-amp as a buffer

The simplest op-amp circuit is called a voltage follower. The circuit was discussed in lecture and consists of simply wiring the op-amp output to the negative input. The output of the op-amp is then equal to the voltage at the positive 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 1.

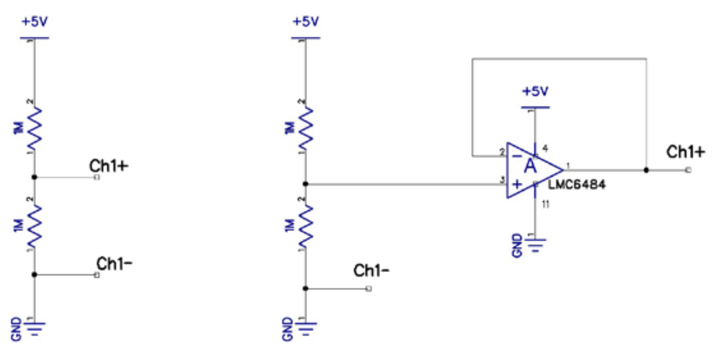

Figure 1: Simple voltage divider with and without an op-amp buffer.

Your first experiment is to measure the voltage between two 1 MΩ resistors, as shown on the left of figure 1. We expect the measured voltage to be 2.5 volts. Build the circuit and **report the voltage that you measure**. The reason that the voltage is different than expected is that current flows into the input of the Analog Discovery. Inside the Analog Discovery, there is a relatively large resistance between both the positive and negative inputs (Ch1+ and Ch1-) and ground. This is value is referred to as the device's input impedance. Based on your measurement, **what is the input impedance of the Analog Discovery (Hint, just imagine another resistor sits between ch1+ and ch1- in the figure)?** Repeat the experiment by replacing the two 1M resistors with two, 499K resistors. **What was the expected and measured value of the voltage with a 499K voltage divider?** Now build the circuit on the right with the op-amp acting as a buffer. **Report the**

measured voltage for this circuit. Explain why we haven't really noticed the effect of the Analog Discovery's input impedance in our previous labs.

Part 2: Inverting amplifier

Build the circuit shown in figure 2. Test the circuit by using the waveform generator and scope. Put a 100 mV amplitude signal with an offset of 2.5 volts into the circuit where the label denotes W1. With the scope, measure both the input and the output voltage. Adjust the amplitude and frequency (no need to go beyond 100 kHz) to get a feel for how this circuit behaves.

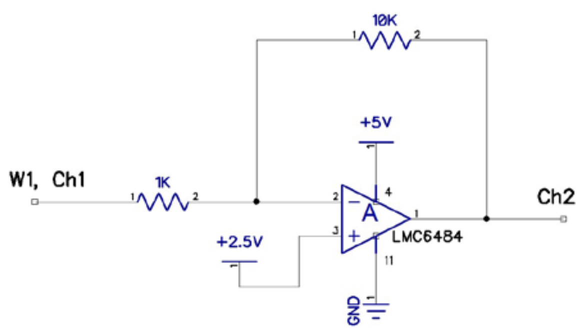

Figure 2: An inverting amplifier.

Now, adjust the output of the waveform generator to be a 2.5 volt amplitude triangle wave with a 2.5 volt offset. Adjust the frequency down to around 10 Hz. On the scope, add an x-y plot such that the voltage into the circuit is plotted on the x axis and the voltage out is plotted on the y-axis (there is simply a button that says "add XY"). Does this plot make sense? **Record at least one full period, and export the scope time data for both channels as a CSV file. In MATLAB plot channel 1 voltage data versus channel 2 voltage. Analyze the circuit and superimpose the expected behavior on the plot of measured behavior.**

Part 3: An op-amp filter.

Build the circuit shown in figure 3 (i.e. add a capacitor to the previous circuit). Create a Bode plot (Using the "Network Analyzer") for the circuit. You will need to adjust the "AWG Offset" to 2.5 volts and amplitude to around 100 mV. Set the frequency range to be from 10Hz to 100 kHz. **Export the Bode plot data as in the last lab. Analyze the circuit dynamics in response to sinusoidal forcing (hint: It will be nearly identical to the analysis last week and in the lecture notes). In your lab report, you will want to plot the measured Bode plot and compare it to your analysis. Comment on whether this is a low-pass or high-pass filter and denote the characteristic cutoff frequency.**

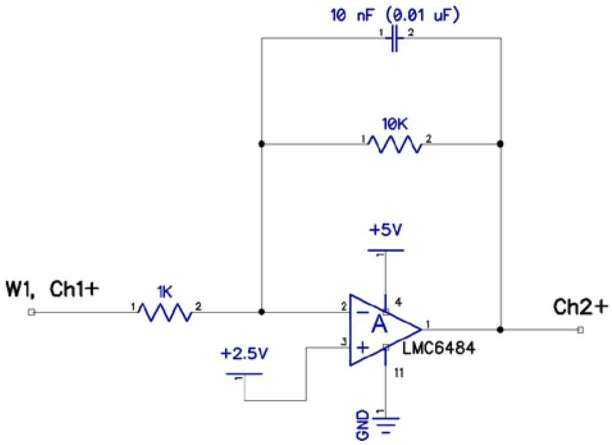

Figure 3: An active filter.

Part 4: Pulse measurement

Last week we confirmed you were not zombies by measuring your pulse by sensing the electrical activity of your heart. This week we will repeat this confirmation, but we will sense your pulse by measuring the light intensity through your finger. Your blood changes color (slightly) based on levels of oxygenation, and thus the intensity of light that passes through your finger fluctuates with your pulse. The complete circuit is shown in Figure 4, though you should build it in stages, from left to right, confirming the output after each functional component.

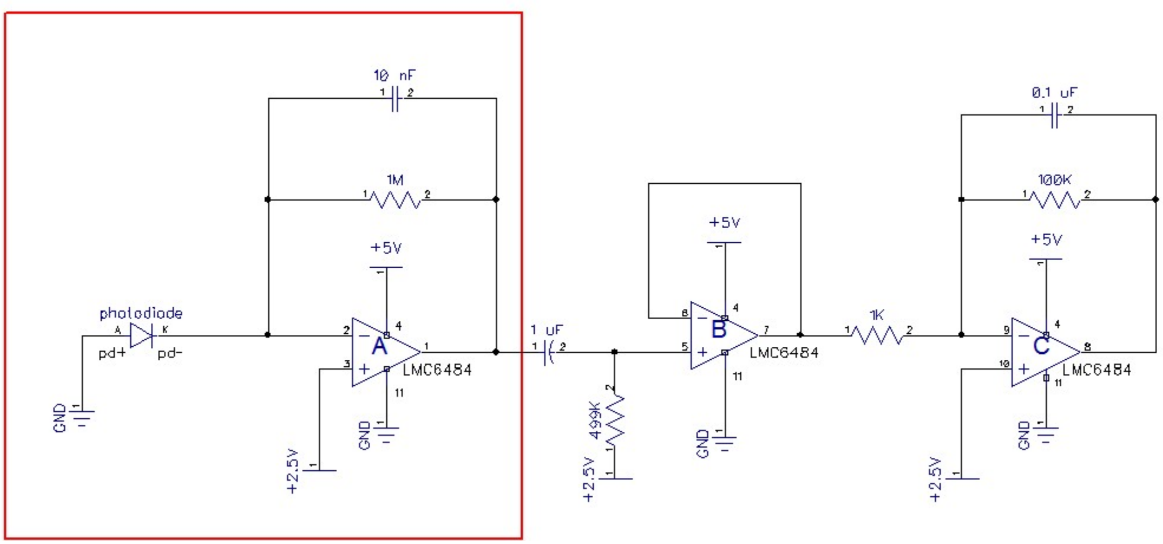

Figure 4: Circuit to measure light intensity through your finger.

Build the first section which is enclosed in the red box. You should get this piece working before progressing. The circuit in the red box is the basic light intensity circuit. The photodiode converts light (photons) into a current. This current is then transformed into a voltage at the output of the op-amp. If this aspect of the circuit is working you should see a signal related to light intensity (i.e. place your hand over the photodiode). The photodiodes we will use are those that are embedded in commercial pulse-oximeter probes which are commonly used in hospitals. We have connectors so these probes can easily be attached to your breadboard. Note the connecter has pd+ and pd- denoted for the positive and negative terminal of the photodiode and this marking is shown in the circuit diagram. You should connect the ground on the probe to the circuit's ground. The probe ground is connected to metal shielding around the probe's wire and your signal will be much cleaner with the ground attached.

Once you have confirmed that the first part is working, remove the capacitor and observe the difference with and without it. **You will want to explain the role of the capacitor in your lab report.** Now, add the next three components in turn – checking the result at each step. Add the high-pass filter, buffer, and low-pass amplifier. **NOTE:** The LMC6484 op-amp is a quad package – meaning there are 4 op-amps in a single 14 pin package. Which op-amp you use for which part of the circuit does not matter. We assumed a certain order for op-amps A, B, and C in the circuit (D is not used). You may find it more convenient to use a different order based on your breadboard layout.

Once the circuit is built you should lay the probe on the desk, place your finger over the photodiode, and aim up at the room lights. You should not press down hard as this will reduce the circulation to your finger. Just touch lightly. Hold still for a few seconds and your pulse should appear. This circuit is sensitive to the absolute intensity of light and thus you need to hold still. **Save the data for one good pulse measurement for your lab report. Take a picture of your final circuit.**

Deliverables:

The aspects for parts 1, 2, and 3 that you should include in your lab report are denoted above in red. For part 4, you should include your data along with an explanation of what the different parts of the circuit are doing. Be specific about how much the signal is amplified, what is the characteristic frequencies, etc of each functional component. Also, include a photo of your final product.