Pulse Oximeter

In this lab, you will build a pulse oximeter. This is a common device found in every hospital room which monitors a patients pulse and overall oxygen saturation. The device you will build is similar to how some of the original designs worked.

Given the two holidays over the next two weeks and the complexity of this experiment, you will have two weeks to obtain the final results. You should at least turn in the results requested for week 1 on time. If you are able to complete everything in one week (it's not that bad!), then you can use the time in other classes. The lab will be worth 15 points over the two weeks rather than the usual 10.

This circuit has a lot of components, so it is important to read through the lab just to see how many components to make and how they fit together. You will want to think a little about how to layout the circuit ahead of time. One suggestion to get you started is shown below in Figure 1, which shows only the circuits described in Figure 2, 3, and 5. The pulse oximeter probe plugs into the small breakout board which can attach to your breadboard and is seen in the upper left of the photo.

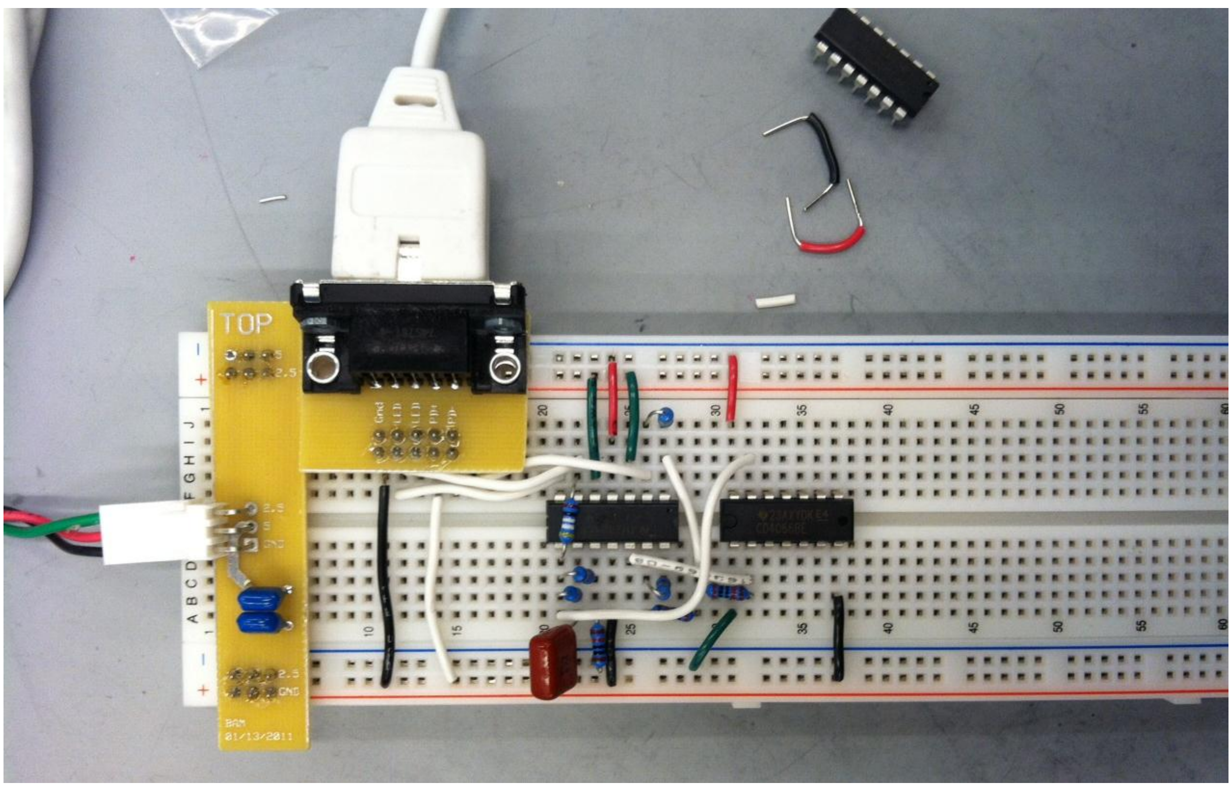

Figure 1: Possible layout for the pulse oximeter. This figure only shows the circuits described in Figures 2, 3, and 5. The chip to the left is the LMC6484 and the one to the right is the CD4066B.

First build a hysteric oscillator circuit shown in Figure 2 (start with just the circuit schematic on the left). We will discuss this circuit in class on Monday, but you should have built something like this last semester. Build the circuit and test that it works by hooking the oscillator output into one of your DAQs analog inputs. The output square wave should be from 0 to 5 volts at about 1 kHz. You do not need to record any data for your lab report; just confirm that it is working before moving forward.

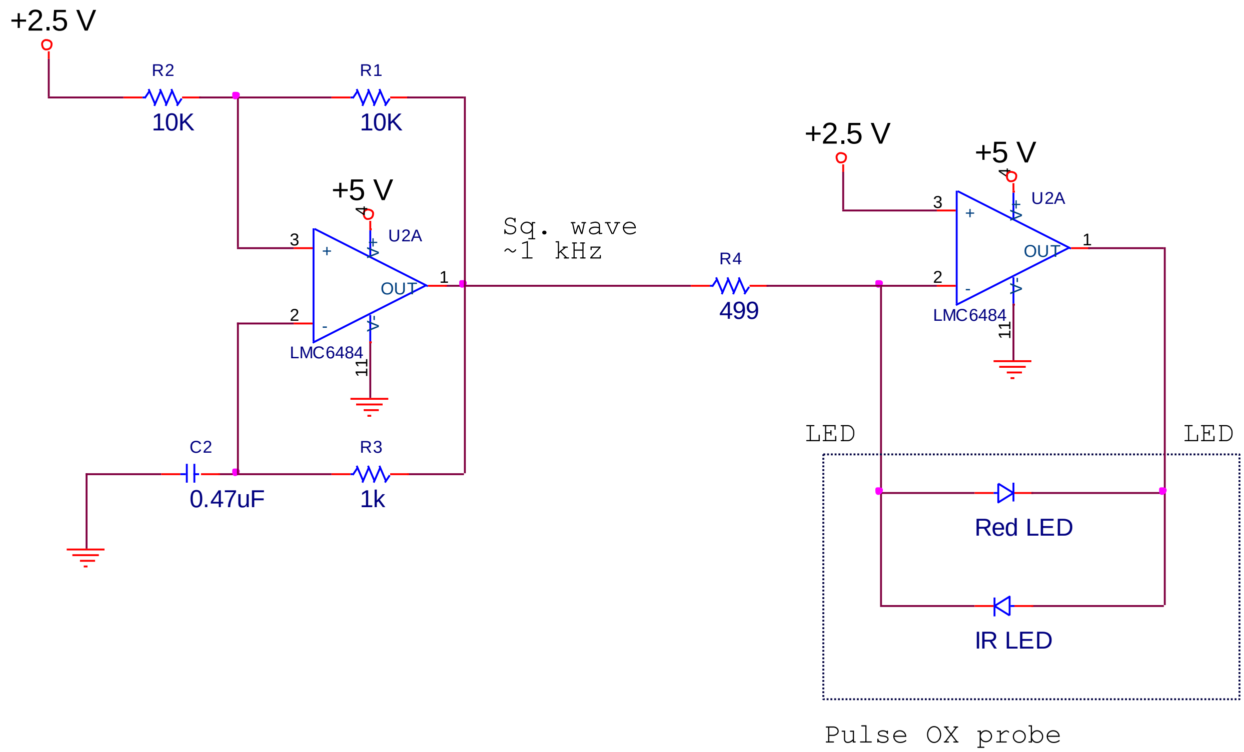

Figure 2: LED driver circuit. On the left is the hysteric oscillator. The output of the oscillator is a square wave between 0 and 5 V. The period of oscillation is 2.2RC, where the RC values used in the calculation is the 0.47 microfarad capacitor and 1K resistor. On the right is the LED circuit. This circuit drives the LEDs in the pulse oximeter probe. The LED inside the probe is actually two LEDs with a single pair of wires. The LEDs are switched in direction inside the probe as shown in the diagram. Since the orientation of the red or IR LED is arbitrary, you can wire your circuit into the two LED leads on the breakout board. Both circuits can be put on one quad LMC6484.

Once you have built the oscillator and have confirmed that it is working, build the LED driver shown in Figure 1 on the right. Once this circuit is built the red LED should appear on. Since it is blinking faster than your eye can sense, it will simply appear on. You may be able confirm the IR LED is working by looking at it with a cell phone camera (though the older the camera, the better it can see IR – iPhones don't seem to work well in this regard), though it may be hard to see with the red on as well. If you want to slow the oscillation down so you can see better, you could temporarily replace the 1K resistor in the oscillator with 1M. Note that the order of the LEDs does not matter, thus we don't bother to distinguish between them on the LED labels of the oximeter probe breakout board.

Now build the photodetector circuit as shown in Figure 3. Once you build the circuit, test the detector by aiming the photodiode up at the room lights, point it towards and away from the blinking LED. You should get an output signal that makes some sense. Make sure to ground the pulse oximeter probe to your breadboard. Pay attention to the labels on the oximeter probe breakout board, the + and – on the photodiode must be placed in the right order. The photodector and LED driver circuit are not electrically connected, but are coupled through the light which passes through your finger.

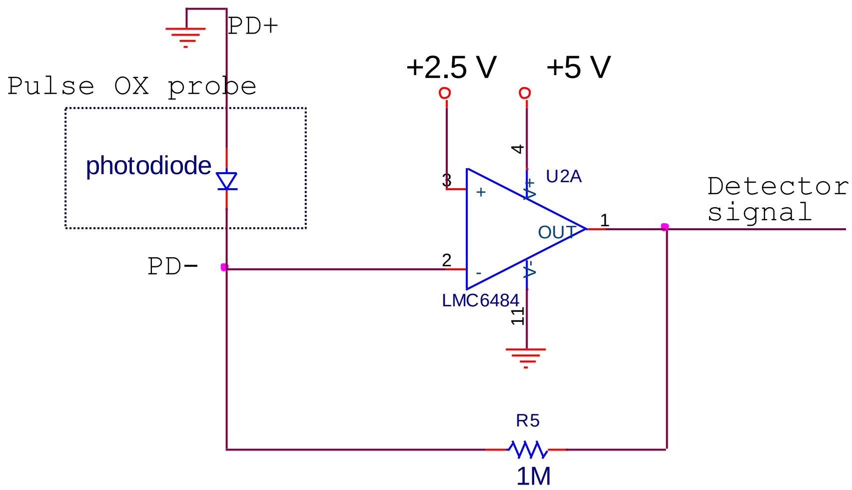

Figure 3: Photodetector circuit.

Now we will take the output of the photodector and multiply by plus or minus one, depending on whether the red or the IR LED is on. We will discuss why we are doing this in class next Monday in more detail. The basic principle is that we are looking for a method to eliminate changes in the ambient light. In order to do the plus/minus one multiply, we will use a switch. The chip we will use is the CD4066B, a CMOS quad bilateral switch. Since we only need one switch on the chip, most of the pins will be neglected. We will use switch A. The switch chip is powered by connecting 5V to VDD and ground to VSS.

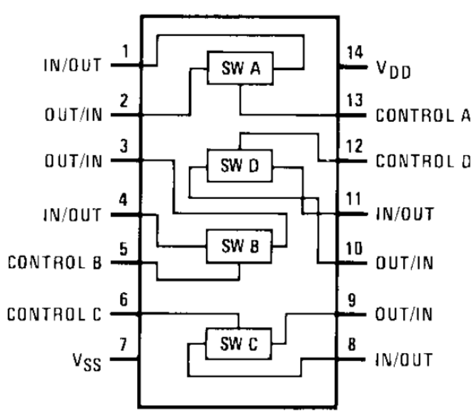

Figure 4: Connection diagram for the CD4066B, the quad bilateral switch.

The circuit to perform the plus or minus one multiply is shown in Figure 5. You connect the output of the hysteretic oscillator into the control input for the switch. The oscillator will open and close the switch. The detector signal will go into a unity gain amplifier as shown in Figure 5. The gain of the amplifier swaps between plus 1 or minus 1 as the switch is opened and closed. The output of Figure 5 should be measured relative to 2.5 V.

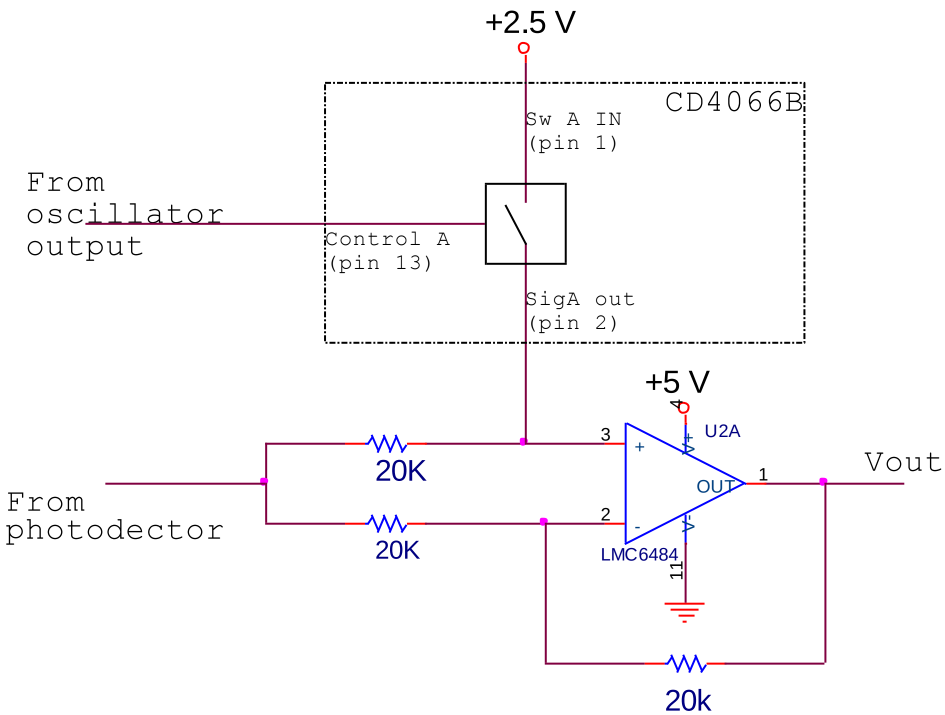

Figure 5: Plus or minus one multiply circuit. The switch is controlled by the hysteretic oscillator. The photodetector signal goes into an amplifier whose gain alternates between plus 1 and minus 1 depending on whether the switch is open or closed.

Once you have performed the plus or minus one multiply, we will need to filter or average the signal. The whole point of the multiply is to reject or cancel the ambient room light. The room light will get multiplied by plus and minus one at a 1 KHz time scale, thus slow changes not associated with the driven LEDs will average out to zero. The red light on the other hand will get multiplied by one, and the IR by minus one. Those signals will not average to zero since the plus one multiply only occurs when the red light is on. Thus the average of the photodetector signal will be the difference between red and IR intensity. This quantity is related to the oxygenation of the blood.

You will now need to build the circuit to do the averaging – i.e. a low pass filter. We will use two first order filters. We select the topology shown in Figure 6; we could have chosen a number of different filter designs to accomplish the same thing. We then split the first stage of low-pass filtered signal into two branches. The upper branch takes the signal through a high pass filter (to find the fluctuating part, your pulse) and then further low-pass filters and amplifies the signal. This output is the “patient’s” pulse. The lower branch further averages the signal on a long time scale to provide an output which varies with the oxygenation of the blood.

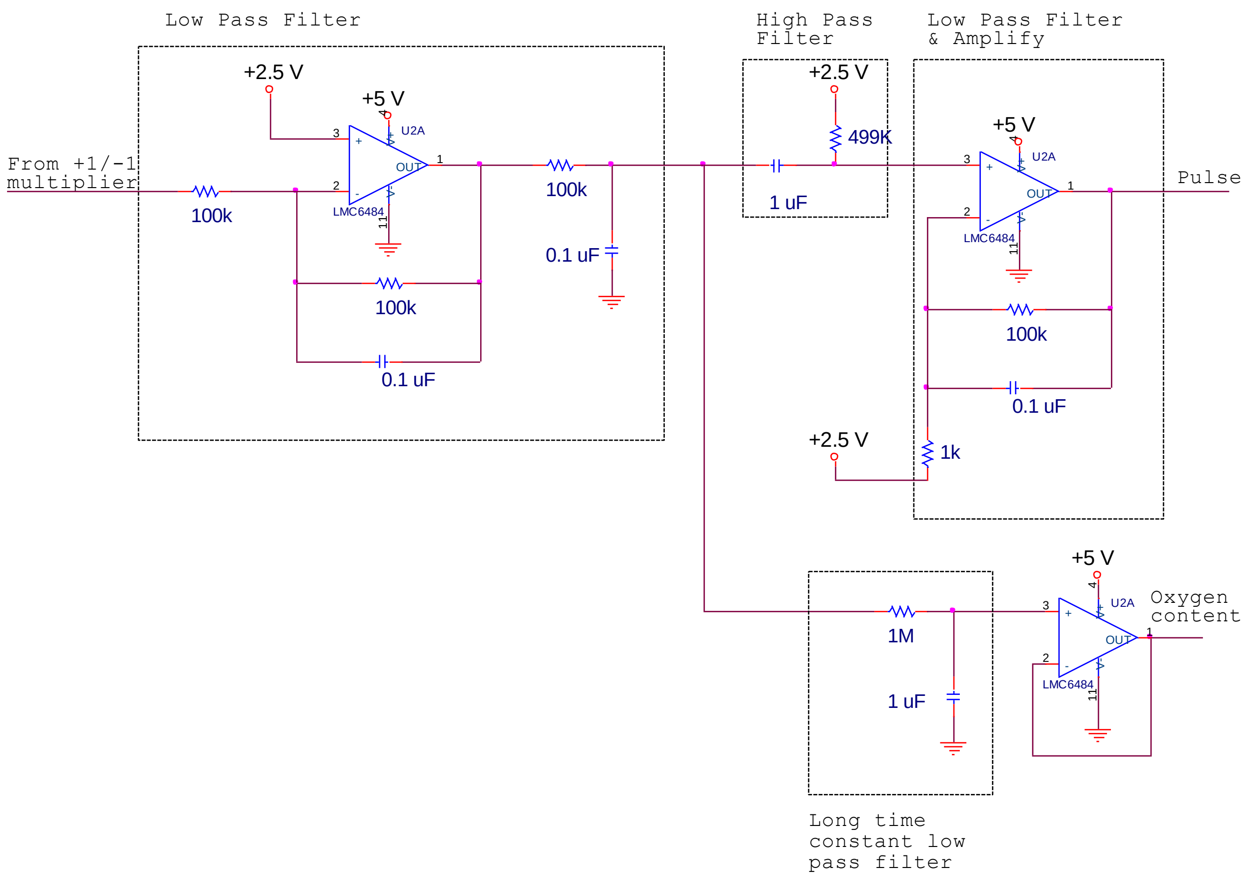

Figure 6: Filters to isolate the pulse and average oxygen content.

To test the circuit, take one of the pulse oximter probes. If it is a new unopened probe, carefully remove the protective plastic piece. Replace this piece with a small piece of kitchen plastic wrap (cut to fit). Cover the entire adhesive area with the wrap (this will let the probes be reusable for the other class sections). Then, take some of the cloth first aid tape and have a nurse (or the person sitting near you) tightly tape the probe to your finger. The photodiode (denoted on the probe) should be pressed firmly against the fleshy part of your finger. The light should shine through your nail.

Check that the circuit isolates your pulse. This pulse signal should be quite clear. The signal should be robust to how much light is shining in the room and if you move around.

Next check the oxygen content. One way to test is to collect data for about a minute. The data will look better if you hold your probe finger relatively still. Over the minute of collecting data breathe in and out very deeply. Try to keep an even pace of inhaling deeply for 5 seconds and them exhaling deeply for 5 seconds. Keep this up for the entire minute. You should see the slight periodic oscillation in your oxygen content which correlates with the frequency of your deep breathing.

You can also try collecting data while holding your breath. Typically you need to hold your breath a while to get a good change (please don't pass out!). Sometimes you need to start feeling a little stressed for air before you will see the signal really change – but you don't need to push that hard. You can ask an instructor to try this for you if you are not at all comfortable. Also, you may observe a several second time delay between how you feel and are breathing and the response at your finger. It can take some time for your body to respond which can make interpreting the signal a little difficult. Example data are shown below. The pulse data is very clear. In the breath test, the patient waited about 25 seconds and then held their breath for about 45 seconds. The absolute value of the signal is in arbitrary units.

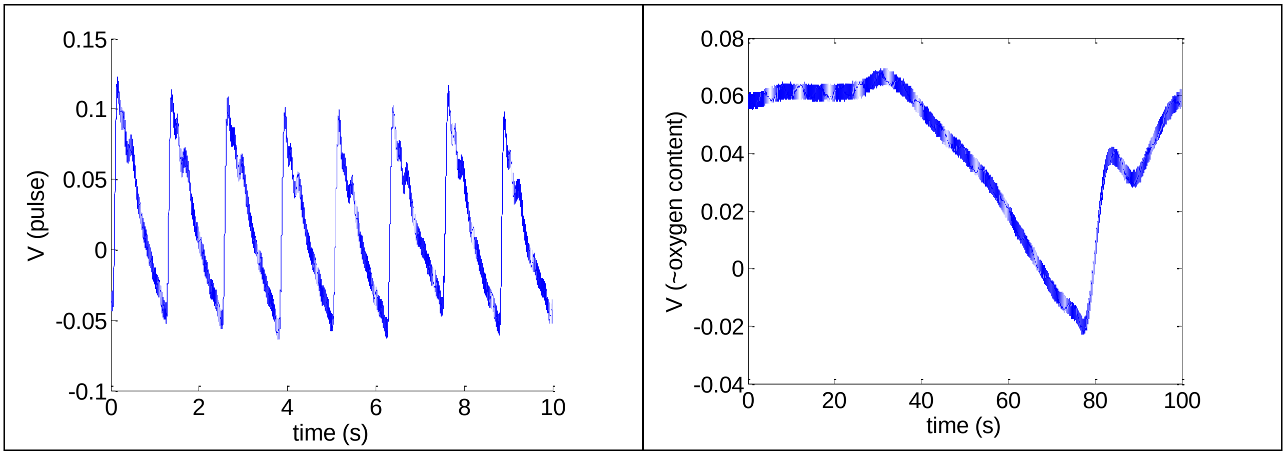

Figure 7: On the left is the pulse signal. On the right is a test where the subject held their breath after 10 seconds. They held their breath for about 1 minute and then began breathing (heavily).

Deliverables:

2 points for each deliverable in week 1. In week 2, 3 points for a good pulse, 4 points for a good O2 signal.

Week 1:

- A short explanation, in words, of how the photodetector circuit works. Note that a photodiode turns photons (light) into current. The current generated by the photodiode increases with light intensity.
- A short explanation of how the ±1 multiply circuit works. Explain the behavior of the circuit when the switch is open and closed.
- A plot of some representative data from the circuit after the ±1 multiply. The data should show the raw photodetector signal and the ±1 multiply on the same plot. Your plot should clearly show that the multiply is working properly.
- A theoretical Bode Plot for the filter chain shown in Figure 6 which isolates the pulse. You don't need to test the filter experimentally this week.

Week 2

- Data from the final oximeter circuit. You should have one clear trace showing your pulse. You should also have one clear trace showing that the oxygen content measurement is working. Either use data from a controlled deep breathing or from a breath hold (don't pass out!).