Optical Laser Communicator
Module #2

EE115 - COL Squire

Introduction
Recall last lesson you began building the optical laser receiver shown below in Figure 1 by building and testing the first module which used a photodiode to convert light into a proportional current, and R1 to convert the current into a proportional voltage (as described by Ohm’s Law) ready for further processing. In module 2 you will design, construct, and test a high-pass filter that passes only the part of the signal that changes and blocks any constant signal offset, leaving a zero-centered signal (figure 2).

Figure 1: EE115 Laser Communication Receiver’s complete schematic.

Figure 2: The highpass filter you construct in Module #2 will take a voltage signal with some non-zero average value from the output of Module #1, shown above in the left panel, and convert it into a 0V centered signal shown in the right panel.
Module #2: High pass filter design to zero-center a signal

Theory
When you tested the output of Module 1 in the last lesson, you noticed that it was usually 0V, but when illuminated it increased to a maximum of what was being used to power the circuit, 5V. In some extreme cases you may even have noticed a voltage greater than 5V, indicating that the photodiode was actually generating a voltage in a manner similar to a solar cell. Regardless, the voltage was never negative (below 0V).

This will become a problem when we try to amplify the signal in Module #3 because even when silent, the laser will cause some non-zero output (Figure 2, left panel). This is a problem because we need to amplify the signal to allow us to hear it. For example, say we have a small signal 0.2V in height sitting on a constant 2V signal—that is, the signal extends from 1.9V to 2.1V. If we want to amplify (multiply) the signal to make it audible by 10x to make it 10x0.2V = 2V in height, we make the entire received signal 19V to 21V—probably not what we want! Worse, since we are powering our signal from ±5V supplies, trying to amplify it to 19V to 21V will actually just cause it to saturate at a constant +5V.

The solution is to build a highpass filter in Figure 3 that removes the constant signal, leaving the changing signal to move from 1.9V to 2.1V down to -0.1V to +0.1V. Then the x10 amplification stage you will build in Module #3 will make it -1V to +1V, exactly as we want. Remember the formula to determine the cutoff frequency of a highpass filter from an earlier lecture is

\[ f = \frac{1}{2\pi RC} \]

where C is C1 in the circuit of Figure 3 and R is the resistance C1 "sees" as current goes through it. Since most current must go through both R1 and R2, \( R = R_1 + R_2 \), and the formula becomes specifically

\[ f = \frac{1}{2\pi(R_1 + R_2)C_1} \]

You will need to design R2 so that the cutoff frequency f is roughly 3.6Hz. This is low enough to pass any audible signal since we cannot hear lower than 20Hz, yet high enough to make it settle relatively quickly at 1/3.6 seconds, or approximately one third of a second. To understand the way it works using our water pipe analogy think of the capacitor as a stretchable rubber wall separating the voltage pressures to the left of the capacitor from the right. If the left side has a constant, say, 2psi pressure pushing on it, it will over time cause the capacitor to stretch to the right and discharge some water through R2. The constant 2psi pressure on the left will be taken up by the stretching of the C2 wall, leaving 0V of pressure on the right. Small, quick changes of pressure that occur too quickly cause the C2 wall to stretch much will be transmitted across C2. Therefore it passes high frequencies like voice, but removes constant voltage offsets that do not change in time.
What is ground?
You will notice the ground symbol \( \equiv \). Once upon a time in the golden age of radio it meant a physical connection to the earth, but in modern (post WWII) electronics, it means something different. It is not a component, but an agreement to do three things: 1) measure all voltages with respect to ground, and 2) tie all the points marked with the ground symbol together and 3) make sure any power symbols like \( +5V \) provide voltages relative to the ground wire. The first part means we can talk about the "voltage at the output of the capacitor C1" rather "the voltage difference between the output of the capacitor C1 and ground". It is just a convenient shortcut. The second is also a shortcut, but one designed to simplify the schematic instead of simplify discussion. One could replace every \( \equiv \) symbol with a single wire connecting all the \( \equiv \) together, as long as one also replaces every \( +5V \) symbol with a single wire connected to the positive terminal of a 5V battery whose negative terminal is connected to the ground wire, and also connects every \( -5V \) symbol together to a more negative side of a 5V battery with the battery's more positive side connected to the ground wire, as in Figure 4 below.

Figure 3: Highpass filter made of C1 and the combination of R1 and R2 to remove a constant offset voltage and make the signal centered around zero Volts.

Figure 4: The same schematic as in Figure 1 but without using the ground symbol. Which is clearer?
Do This
1) Determine what R2 must be using the formula above and setting f = 3.6Hz. Need a calculator? Matlab!

2) Then construct it on your breadboard. Note that the 2.2uF capacitor is polarized; if it is connected backwards, it will not work. The standard symbol for polarized capacitors includes a + symbol to indicate the more positive sides, although oddly many capacitors are physically marked with only a - symbol; the + side is obviously the other terminal. Check to make sure there are no wiring errors before connecting it to the Cadet II.

3) Electrically connect the breadboard to the Cadet II and turn it on.

Test It
To test it (and as always, it isn't complete until it is tested)

1) Verify that what you built last class works first.
   a. Connect a black cable to the DMM and the mini-grabber to a spare wire connected to your protoboard's ground wire.
   b. Similarly connect a red grabber wire between the DMM and your protoboard's +5V wire. Turn on the Cadet II. Check to make sure you read +5V on your DMM...if not, fix the power connections.
   c. Move the red DMM mini-grabber lead to the top (non-grounded) side of R1. Your DMM should read close to 0V when the photoresistor is dark, and perhaps a few tens of millivolts under fluorescent lights. If not, remove the C1 and R2, and get your circuit back to the state it was in when you were checked off at the end of last class, before replacing C1 and R2.

2) Verify that what you built this class works.
   a. Move the red DMM mini-grabber lead to the left side of C1 and verify you get the same behavior as you did in the previous step 1c. If not, your C1 and R2 are incorrectly connected.
   b. Move the red DMM lead to measure the voltage at the right side of C1. It should read 0V if the light is steady. Alternatively cover and uncover the photoresistor; you should see small (tens of millivolts) positive and negative voltages.
   c. Get checked off by your instructor.

Note: Do not be concerned about the specific values read by the DMM, just whether they are 0V or changing. The DMM samples the values at its input leads about twice a second, and the value it displays is therefore a function of where the light happened to be relative to the photoresistor at one of the sampling moments. The lesson is that DMMs are excellent to measure unchanging or slowly-varying voltages, but poor choices to measure rapidly-varying voltages like this. Next module you will learn to use an oscilloscope, an instrument specifically designed to measure rapidly-varying circuit voltages.