

EKG/ECG

We are going to build a fully-operational 3-wire ECG instrument. The three-wire connection is the simplest that will yield a usable trace (not just a heart rate). The resulting ECG will reveal all the electrical activity of the heart, only lacking the benefit of ECG signals measured between other body contact points. A full ECG diagnosis involves the connection of 12 electrodes across the chest and on the extremities. We will only be connecting electrodes to the arms and ankle.

<http://en.wikipedia.org/wiki/Electrocardiography>

Disclaimer

WE ARE NOT MEDICAL DOCTORS and neither are you. Please don't attempt to interpret anything other than possibly your heart rate (beats per minute) from your ECG. Experts on ECG interpretation form an entire specialization.

About Safety

Medical instrumentation safety standards are regulated in the USA by the Association for Advancement of Medical Instrumentation (AAMI), American National Standards Institutes (ANSI), and Underwriters Laboratories (UL). AAMI standards have been adopted as official practice by the American Medical Association.

We are performing an AAMI Type B connection to the body, since we are potentially connecting a direct ground to the patient (you). This is considered risky because of the possibility of a ground loop if any other Type B medical instrumentation is connected that may have a different ground connection. Our ground connection is established through the 5 VDC USB power supply in your notebook computer, which may (but usually doesn't) connect to the building wiring ground via the power brick's wall plug ground prong. To fully comply with AAMI recommendations:

1. **Unplug the power brick from your notebook computer, and run the notebook on its batteries during the ECG experiment.** This converts the connection to a Type BF (fully floating) connection.
2. Don't connect yourself to any other AC-powered instrumentation while you are doing this experiment. Do not connect yourself to ground by holding onto an earth connection such as a water fixture.

While it would be extremely unlikely for a failure to occur whereby you could be injured by the electrical connection through the computer's USB, please unplug your laptop to comply with the AAMI regulations.

About Privacy

If you are AT ALL concerned about submitting your personal ECG with your lab report, YOU DO NOT HAVE TO DO SO. The ECG plot could be construed as medical information protected under Federal HIPAA privacy laws, i.e.,

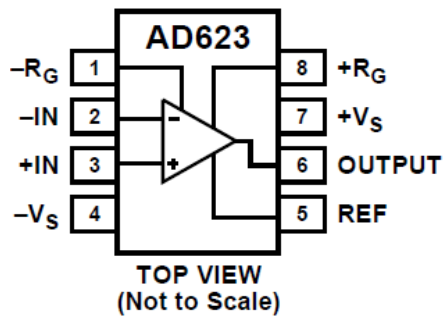
<http://www.hhs.gov/ocr/privacy/hipaa/understanding/index.html>.

You may alternatively borrow one of the instructors who will serve as your patient.

Circuit – the experiment

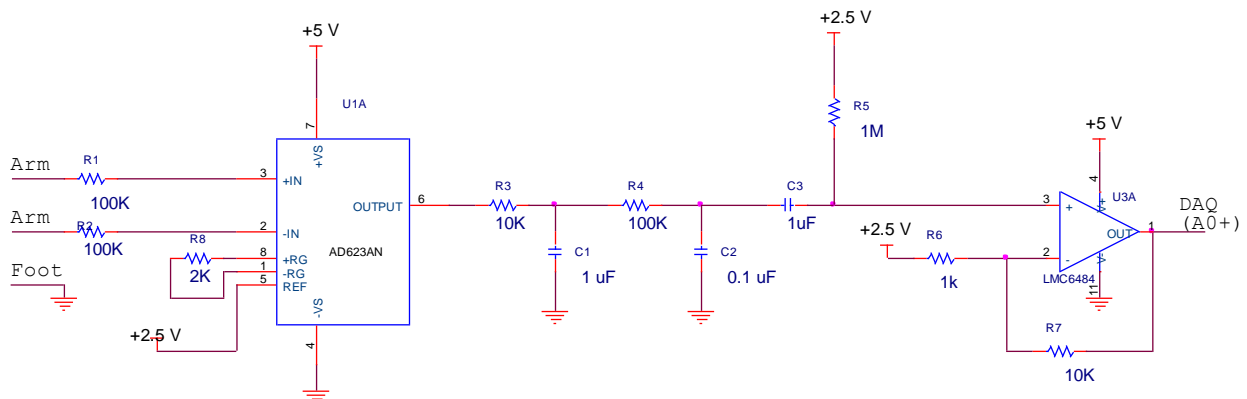
The circuit is really quite simple. We will make use of a new chip, an instrumentation amplifier. The instrumentation amplifier, http://en.wikipedia.org/wiki/Instrumentation_amplifier, is really an arrangement of three op-amps. While we could easily build the circuit found on the Wikipedia page, the instrumentation amplifier is conveniently sold as a single IC chip. We will use the AD623 by Analog Devices. The connection diagram is shown below:

CONNECTION DIAGRAM



The chip is very easy to use. You simply place a resistor between pins 1 and 8 to set the gain of the amplifier. If you look through the data sheet you will find that the gain resistor, R_G , is related to the amplifier gain G , by $R_G = 100 \text{ k}\Omega / (G - 1)$. The chip provides an output which is simply, $V_{out} = G(V_{in+} - V_{in-})$. Pin 5, the reference, is the zero reference you would like to use, i.e. the output voltage when there is no difference at the inputs. We will set the reference voltage to 2.5. This way, we get 2.5 volts when the inputs are equal and have room with the 0-5 V power to have the voltage difference of the inputs to be positive or negative. If we used the ground as the reference, then we would only be able to see anything when the positive input was greater than the negative one.

The entire schematic is shown below. Following the amplifier are two low-pass filters and one high pass filter. You will analyze these filters in your lab report, but for now you can just build them. Finally there is a second amplifier. The reason for two stages of amplification is that some people will have a relatively large, but real, DC voltage difference between your arms. If the first gain is too large, you may saturate your amplifier. In fact, since all people are different, you may need to adjust the gains of the two amplifier stages from what we have selected here. Also, on the DAQ, AO- should be connected to the 2.5 V reference – 2.5 V is your “zero”.



To connect to the circuit you will need a patient (yourself if you would like, or one of the course instructors), three of the adhesive electrode pads, and three alligator clip leads. Two of the pads should be placed on the inside of the elbow. The third should be on the ankle. The alligator clip leads will connect to the metal tab on the electrodes. The other end will grab a short piece of wire and connect to your protoboard. Your ankle should connect directly to the ground on the protoboard. The arms should connect to the AD623 through the 100K resistor. The 100 K resistor is for safety to isolate you from the power sources on the DAQ.

The output of the circuit should go to the DAQ and you should measure the output relative to 2.5V. Since we are operating on the 0-5 V power supply through the USB, 2.5 V serves as our arbitrary “zero”.

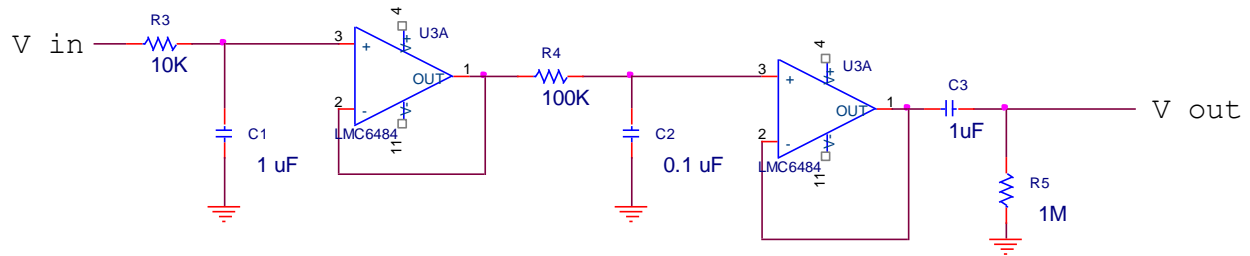
For this week it is useful to have a program which runs and plots continuously, like an oscilloscope, so you can see what is happening with the ECG in real time. You can start with the template provided on the website. You should actually look at the code and see if you can figure out how it is working. This version is slightly more complicated than last week.

For your lab writeup you need to include a snapshot of a clean EKG (you should not identify the “patient” in your lab report), so be sure to save some data before you close down for the day. You will also include a photo of your working circuit on the breadboard.

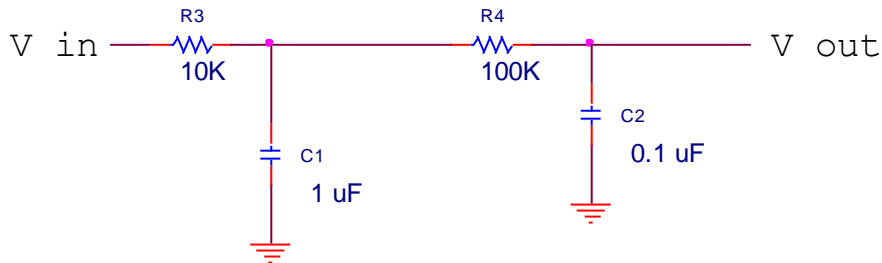
A little analysis

In addition to building and testing the circuit, there is a little analysis to do for this lab.

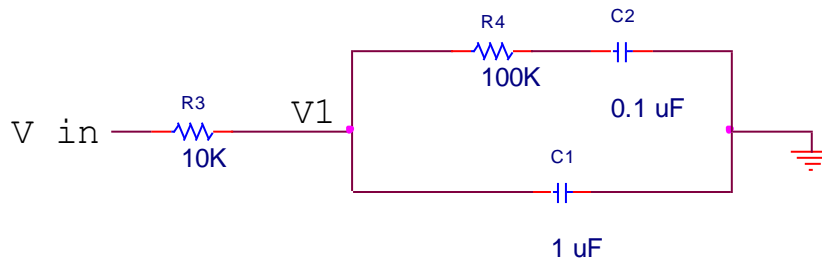
- 1) The instrumentation amplifier circuit which is inside the AD623 is essentially built from 3 op-amps and some resistors; http://en.wikipedia.org/wiki/Instrumentation_amplifier. Using the schematic of the 3 op-amp circuit on the Wikipedia page, derive the formula for the overall amplifier gain that is also provided. Hint: we basically did this in class.
- 2) Consider the three filters in the circuit. Assume we put an op-amp follower between each filter as shown in the schematic below. If we did this, then the overall effect of the three filters would be simple because the no current would flow from one filter to the next. We could analyze each filter independently then combine the results for the overall effect of the three filters. Using complex impedances (you may need to review your notes from last semester; see lecture 4 - <http://wb.olin.edu/mc/fall2011/Reading.shtml>), derive and plot the amplitude of V_{out}/V_{in} as a function of frequency on a log-log scale (don't worry about the phase). Note that the op-amps are put in this circuit to simplify the analysis, even though they make the circuit look more complicated. Also, note that for simplicity, the resistor in the high-pass is tied to ground rather than 2.5 in the actual circuit – consider V_{in} is centered around 0 ground. In the actual circuit the 2.5 V is used to center the signal on the 0-5 V range. For your analysis just assume everything is centered on zero just for simplicity.



- 3) Consider the circuit below where the filters are not buffered. Consider just the two low-pass filters in sequence. Using complex impedance, derive the relationship and create a plot of the amplitude of V_{out}/V_{in} as a function of frequency.

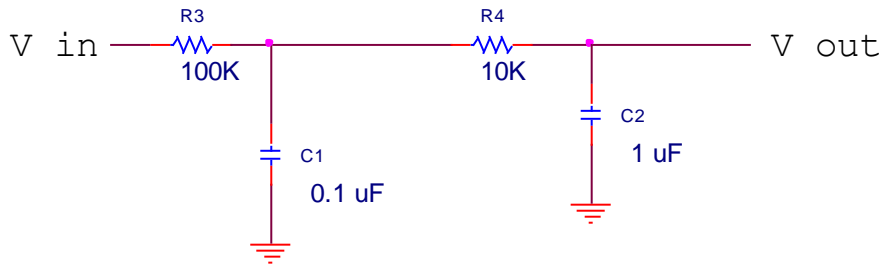


If you have trouble getting started with the analysis, realize that the circuit below is equivalent to the one above. The three impedances on the right can be combined using the rules for resistors (impedances) in series and in parallel. You can then derive V_1/V_{in} as an intermediate step.



Once you know V_1/V_{in} , you can then just consider that the input voltage to the second low-pass filter to get the overall filter response. Compare the result you got to the case where the two filters are buffered and you will find that the result is nearly identical

- 4) In the previous problem, swap the order of the filters as shown below and replot the result. Now you should find the result comparing the circuit below to one where the two filters are buffered are very different. Can you explain why? Can you intuitively explain why the filter in question 2 with the op-amps buffering the individual filters would perform about the same if the buffers are removed, as in the actual circuit which you built.



Deliverables

You should turn in a plot of the ECG trace. You should include a picture of your working breadboard circuit. No need to turn in any code this week. Your plot should be a well-labeled plot which clearly shows a clean trace of few consecutive heartbeats. You should include your analysis and related plots to the questions in the analysis section. Notes can be handwritten or typed – though they should be neat either way. You do not need to include every step of the analysis in what you turn in, but it should be clear what you have done. The plots for the analysis should be clearly labeled (axis, denote which curve is which, etc).

Grading

As with all labs, the grade is out of 10 total points. 4 points for the circuit and a good ECG trace. 6 points for the analysis,

- 1) Experimental ECG trace. Full credit for a clean looking signal with a well labeled plot and a picture of a carefully constructed circuit with nice short wires and everything tight to the breadboard.
 - a. 3 points off if the data looks nothing like an ECG trace – but it looks like you built something reasonable.
 - b. 1 point off for missing axis labels or other problems with the graphical presentation.
 - c. 1 point off if the photo of the circuit shows a spaghetti mess of wires and parts, resistors aren't clipped, long loopy wires crossing, or otherwise lame breadboarding.
- 2) For the analysis. One point for problems 1 and 4. Two points for problems 2 and 3. Full credit for good analysis and correct, well-labeled plots.
 - a. Half credit if analysis is correct but plots are wrong.
 - b. $\frac{3}{4}$ credit if everything is basically correct, but a small mistake was made somewhere.
 - c. $\frac{1}{4}$ credit if you made a good attempt, but the analysis was faulty.
 - d. Other partial credit at the discretion of the grader.