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. 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.

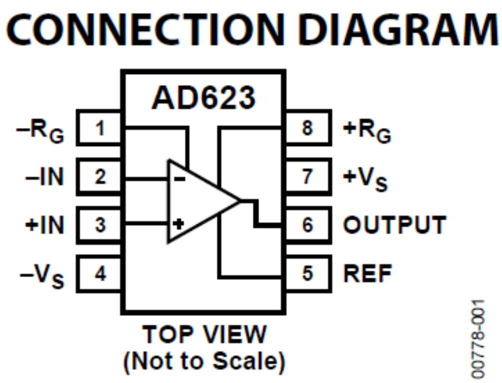
While it would be extremely unlikely for a failure to occur whereby you could be injured by the electrical connection through the computer's USB, please unplug your laptop to comply with the AAMI regulations.

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.

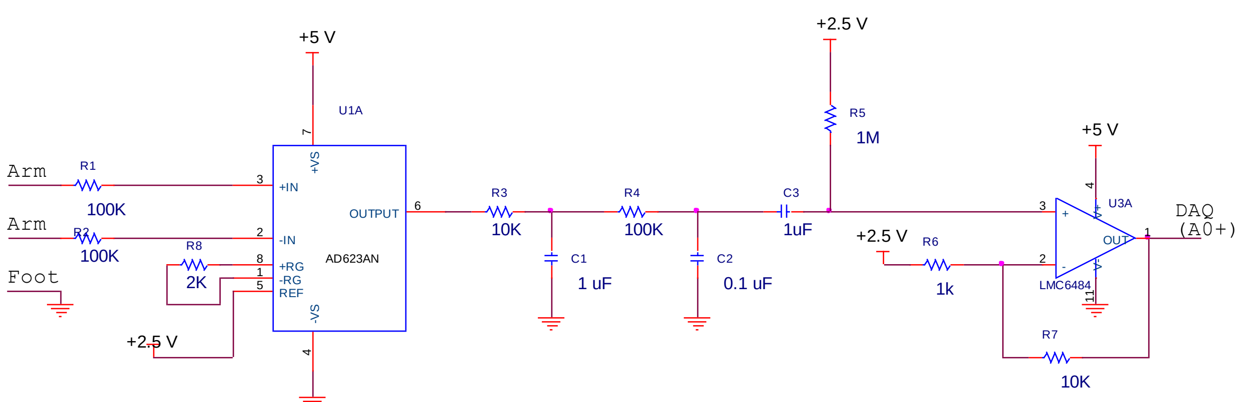
The circuit

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:



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 $R_G = 100\ k\Omega/(G-1)$. 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 characterize 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.



Testing the ECG

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 program provided on the website; `DAQacquire_continuous.m.`

For your lab writeup you need to include a snapshot of a clean ECG (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.

Experimentally characterize the filter – the Bode Plot.

In order to experimentally characterize the filter section of the circuit, we will connect the circuit to the computers audio port to send sine waves of particular frequencies. In order to do this you will need to modify the circuit in three ways:

1) You do not need the 100K resistors on the input. They can be removed at this time.
2) Reduce the gain of the instrumentation amplifier to unity by removing the 2K resistor. Leave pins 1 and 8 unconnected, an infinite resistance.
3) Reduce the gain of the final amplifier to one by replacing the 1K resistor with a 10K.

Now take one of the stripped audio cables and plug the white wire into the positive input of the instrumentation amp and the black wire into the negative input. The red wire can be free. Wire channel AI0 on the DAQ to measure the output of the instrumentation amp relative to 2.5V and wire channel AI1 to measure the output of the final op-amp, also relative to 2.5V.

Run the program `bodeplot_exp.m` found on the course website. This program will automatically create a Bode plot (something we will discuss in lecture and in class). The Bode plot is comprised of 2 plots. Both plots put the frequency on a logarithmic scale on the x-axis. One plot puts the ratio of the amplitude of the output sine wave to the amplitude input size wave on the y-axis; plotted logarithmically. The other plot puts the phase angle between the input and the output on the y-axis. For a linear system where an input sine wave means the output is also a sine wave, only a different amplitude and phase, thus the Bode plot contains all the information about the system.

The program is setup to automatically sweep the frequency on the audio output from 1 to 1000 Hz in increments. You may want to adjust this range to make more or less points or change the range. You will need to make sure that your audio is not on mute. Also, watch as the program runs it will display a snapshot of the raw signals for you on one graph. You should see two sine waves. If the sine waves are saturated at the top, reduce the volume on your computer. If the input sine wave is too low in amplitude, you can increase it till it is something like 0.25 volts.

Deliverables

You should turn in a plot of the ECG trace. You should include a picture of your working breadboard circuit. You should turn in a Bode plot showing amplitude and phase as a function of frequency. No need to turn in any code this week. Your ECG plot should be a well-labeled plot which clearly shows a clean trace of few consecutive heartbeats. Your Bode plot should also be well-labeled. Provide a short explanation of the Bode plot. In terms of the values of R and C in the three filters, explain the features in the amplitude response.

Grading

As with all labs, the grade is out of 10 total points. 5 points for the circuit and a good ECG trace. 5 points for the Bode plot and good explanation.

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) Bode plot. Full credit for good analysis and correct, well-labeled plots.
    a. 3 points off for incorrect results but you made an effort
    b. 1 point off for missing axis labels or other problems with the graphical presentation.
    c. 1 point off for poor explanation of the Bode plot.