

## ENGR 1121 Lab 2 EKG/ECG

February 3, 2014

This week, you are going to build a fully-operational 3-wire ECG instrument. The three-wire connection is the simplest that will yield a usable trace (i.e. 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. You can check out the article at <http://en.wikipedia.org/wiki/Electrocardiography> for basic background information.

### Disclaimer

WE ARE NOT MEDICAL DOCTORS and neither are you. Please do not attempt to interpret anything other than possibly your heart rate (beats per minute) from your ECG. Experts on ECG interpretation form an entire medical 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 does not) 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. Do not 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.,

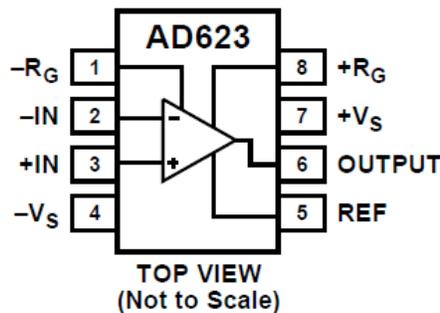
<http://www.hhs.gov/ocr/privacy/hipaa/understanding/index.html>.

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

## The circuit

The circuit you will be making is really quite simple. We will make use of a new chip, an instrumentation amplifier ([http://en.wikipedia.org/wiki/Instrumentation\\_amplifier](http://en.wikipedia.org/wiki/Instrumentation_amplifier)), which is really an arrangement of three op amps and some precision resistors. While we could easily build the circuit found on the Wikipedia page, the instrumentation amplifier is conveniently sold as a single IC chip whose performance is much better than we could construct with the 1%-tolerance we have around the lab. We will use the AD623, which is made by Analog Devices. The full AD623 datasheet is available on the course website. For convenience, 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 datasheet you will find that the gain resistor,  $R_G$ , is related to the amplifier gain  $G$ , through

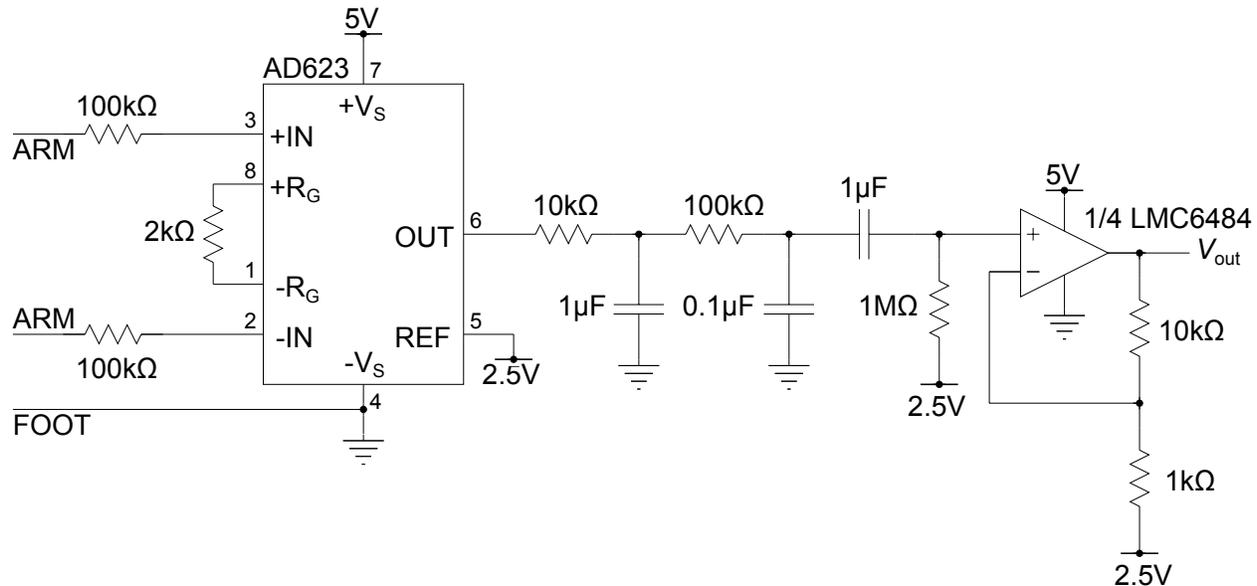
$$R_G = 100\text{k}\Omega / (G - 1).$$

The chip produces an output which is given by

$$V_{\text{OUT}} = G(V_{+\text{IN}} - V_{-\text{IN}}) + V_{\text{REF}},$$

where  $V_{\text{REF}}$  is the voltage applied to pin 5, and corresponds to the output voltage when there is no difference between the inputs. We will set the reference voltage to 2.5V. 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 separate 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 solderless breadboard. Your ankle should connect directly to the ground on the breadboard. Each of your arms should connect to the AD623 through a 100-kΩ resistor. These resistors are for safety, limiting the current that can flow to you from the power sources in your circuit.

The output of the circuit should go to the Analog Discovery and you should measure the output relative to 2.5V. Since we are operating on a single-ended 0-5V power supply through (you should use your USB cable to power the rails of your breadboard), the 2.5V mid-rail voltage will serve as our voltage level corresponding to zero signal. You should use the oscilloscope instrument of the WaveForms software to acquire your ECG trace with the timebase set to an appropriately long value.

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.**

Next, you will use the network analyzer instrument in WaveForms to experimentally characterize the frequency response of the filter in your EKG circuit. In order to do so, you will need to modify the circuit in two ways:

1. Disconnect the 10-k $\Omega$  resistor from the output of the AD623. You will apply your input signal directly to this 10-k $\Omega$  resistor, effectively bypassing AD623.
2. Reduce the gain of the final non-inverting amplifier to two by replacing the 1-k $\Omega$  resistor with a 10 k $\Omega$ .

Apply a sinusoidal input signal to the filter input with W1 on the Analog Discovery. Observe the input signal with analog input channel 1. Observe the output with analog input channel 2 referenced to 2.5V. Using the network analyzer instrument, measure the frequency response of your filter circuit. You should set the starting frequency to be low enough that you can see some of the highpass filter's attenuation at low frequencies (start from 1Hz or a bit below). You might also need to reduce the amplitude of the input waveform to 1V or 2V (the default value may be 5V) so that the output waveform does not get clipped by the op amp saturating at its rails.

### **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.