Lab: Using filters to build an electrocardiograph (ECG or EKG)

Goal: Use filters and amplifiers to build a circuit that will sense and measure a heartbeat.

You and your heartbeat

Did you know that we humans are basically a bag of ions? These charged molecules ("electrolytes") move in and out of cells to produce charge differences (i.e., potential differences); they also move to communicate these potential differences to adjacent tissue or fluids.

For example, your heart muscle cells contract by producing a charge imbalance across their cell wall membranes; the beat is initiated by a signal from the right atrium; this produces a ripple effect, propagating a tiny "wave" of charge imbalance throughout the body. We can detect these ripples as voltage differences by placing electrodes on our skin.

In this lab, we'll sense a heartbeat with 3-wires: +V, -V and ground. The three-wire connection is the simplest that will yield a usable trace (not just a heart rate). The resulting electrocardiogram will reveal the electrical activity of the heart. A full ECG involves the connection of 12 electrodes across the chest and on the extremities. We will only be connecting electrodes to the arms.

Disclaimer

We are not medical doctors.

Please don't attempt to interpret anything other than possibly your heart rate (beats per minute) from your EKG.

Your privacy rights

The EKG plot could be construed as medical information protected under privacy laws. If you are AT ALL concerned about submitting your personal EKG with your lab report, YOU DO NOT HAVE TO DO SO. You may borrow one of the instructors who will happily serve as your data source if you wish.

Disconnect your laptop from the lab
Power supply to eliminate shock hazard

We are performing an Association for Advancement of Medical Instrumentation (AAMI) Type B connection to the body, since we are potentially connecting a direct ground to a person.

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 from the power strip to comply with the AAMI regulations. Use only battery power.
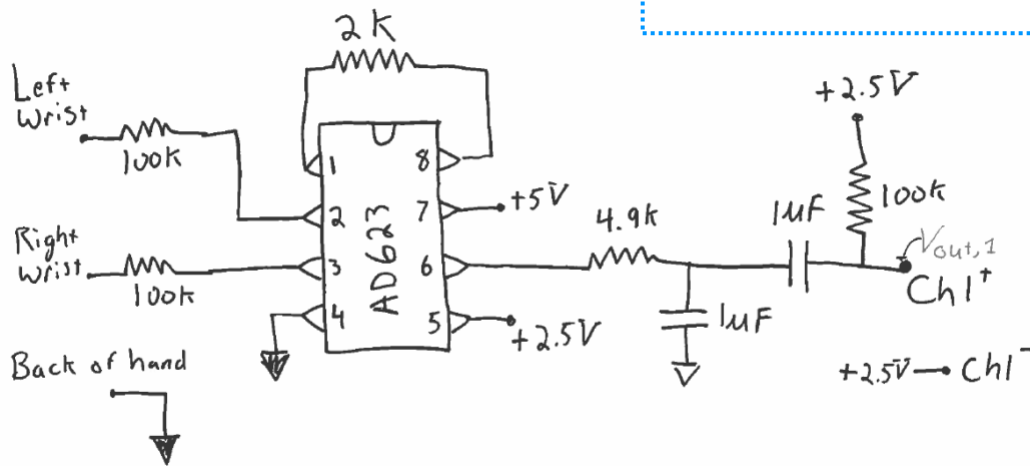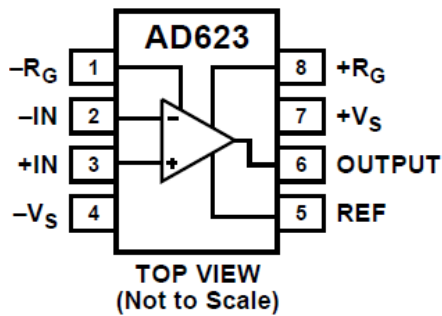
1. Build the circuit shown

Figure 1: First section of the EKG circuit.

We will make use of the same instrumentation amplifier chip you used in the strain gauge lab. The connection AD623 connection diagram is shown below.

CONNECTION DIAGRAM

The resistor between pins 1 and 8 set the gain of the amplifier,

$$G = \frac{V_{out}}{V_{in}} = 1 + \frac{100\ k\Omega}{R_G},$$

or

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

as described in the AD623 data sheet.
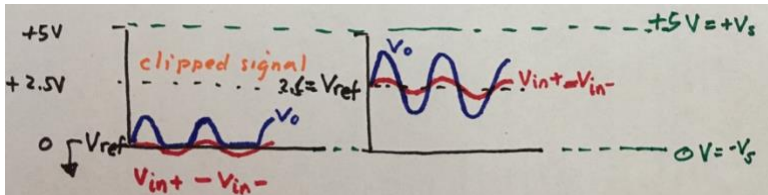
The chip provides an output which is simply,

$$V_{out} = V_{ref} + G(V_{in+} - V_{in-}).$$

What is output voltage, V_{out}, when $V_{in+} = V_{in-}$?

How is the output affected by V_{ref}?

When there is no difference in the inputs, $V_{in+} = V_{in-}$, and $V_{out} = V_{(what\ is\ here?)} = (How\ many?)$ Volts.

Because of setting V_{ref} to + _____ Volts, our 0-5 V power can amplify the signal when $(V_{in+} - V_{in-}) > 0\ and$ $(V_{in+} - V_{in-}) < 0$.

If we used the ground as the reference, then we would only be able to see anything when $V_{in+} > V_{in-}$; we would lose the signal when $(V_{in+} - V_{in-}) < 0$.

2. Test as you build with a simulated WaveGen heartbeat

The EKG schematic is broken into two sections: Figure 1 and 2. **BUILD SLOWLY AND TEST AS YOU ADD FEATURES. DO NOT GO ON TO FIGURE 2 UNTIL YOU BELIEVE FIGURE 1 IS WORKING.**

We will use the WaveGen feature of the Analog Discovery to simulate a heartbeat and test the Figure 1 circuit.

Connect Discovery

Ensure the Discovery and circuit share a ground.
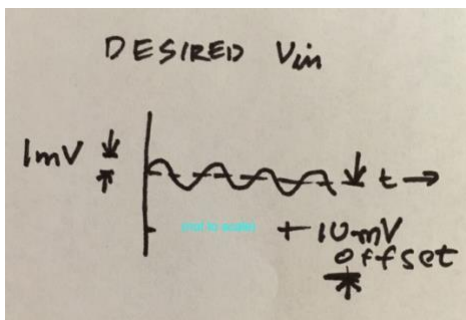Use Wavegen 1 as V_{in+} or V_{in-}.
Ground the other V_{in};

Use Channel 1+ to monitor the input signal;

Use Channel 2+ as a probe at points in your circuit to see if you are getting the signal you expect.

Where should you connect Channel 1-?

Channel 2-?

Set up Wavegen input signal

What would be a good choice for a simulated heartbeat frequency in Hz?

►Run and sample test points in Figure 1

Possible test points
- Unfiltered output
- Output after first filter
- Output after second filter

What are you expecting to see?

There are many possible variations of this EKG circuit that would probably work equally as well as the one here. We have used two stages of amplification (Figure 1 & Figure 2) as there is typically some constant offset in the EKG that is best to remove with a high pass filter before full amplification.

Here we selected gains that worked well on our trial run. It is possible that you may want to adjust these for yourself as each of you will have a different signal. The use of 3 low pass and 1 high pass filters seems to work well, though the EKG signal is observable with less filtering and may even be somewhat apparent in your raw signal after the first instrumentation amplifier.

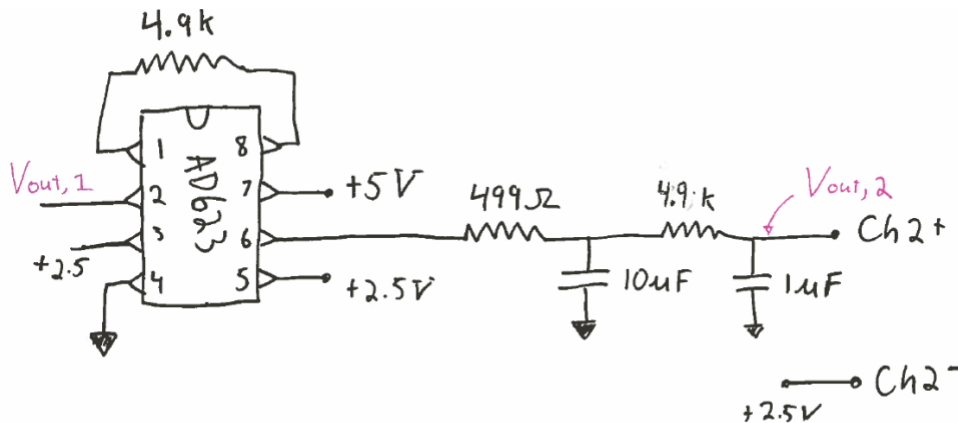## Build the second stage of amplification and test as you go.

Figure 2: Second section of the EKG circuit. The output of figure 1 is the input to this circuit.

Continue to add Figure 2, again testing as you add the amplifier and two low pass filters in turn. If you think it is working properly adjust the frequency to higher and lower values than 1 Hz. Theoretically, what do you expect to see at V_{out} if you input a 100 Hz signal? (Is that what you get?) How do you expect to V_{out} to change if you input a 0.1 Hz signal? (Is that what you get?)

Once you are convinced things work, create a Bode plot with the network analyzer for your lab report.

As you add the next amplifier, beware of leaving a measurement point internal to the circuit. The input impedance of the measurement device may mess up your result. When you conduct the final experiment, any internal test points should only be on the output of one of the instrumentation amplifiers.

Use +2.5V as Ch1- and Ch2- reference

You can set the low frequency limit to around 1 Hz, otherwise it will take a long time to create your Bode plot (Why?). This Bode plot will really only show half of the circuit's frequency response, but that is OK.

3. Collect heartbeat data from a person

Now that you are convinced things work, you will need:

3   3   1   *Willing data source – you or someone else*
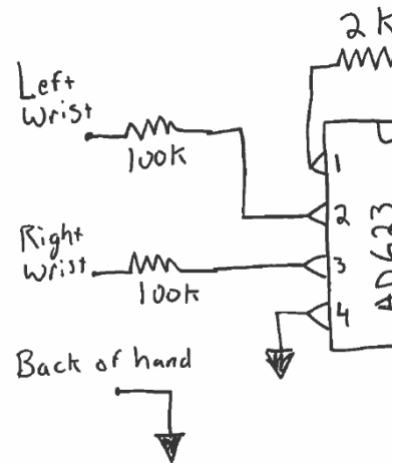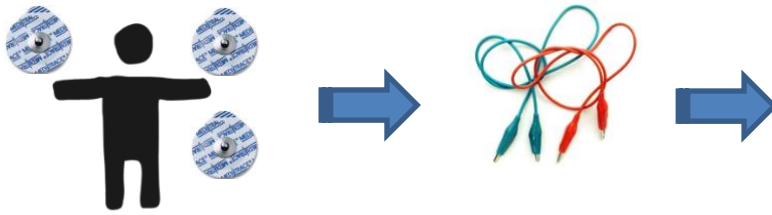
| caution | Shock hazard | Disconnect AC power & earth ground | Use battery power only |

Connect electrodes to circuit

Pad placement option*:
- inside of the wrists to the AD623 through the 100K resistor;
- ground electrode can be on the back of your hand.

*See attached appendix for an alternative

(*The 100 K resistor is for safety to isolate you from the power sources. This extra resistor is to comply with medical electronics standards; the risk of shock through the computers USB power supply is exceedingly low.*)

For your lab writeup you need to include a snapshot of a reasonably clean EKG, so be sure to save some data before you close down for the day. See below for a sample of what a "good" trace looks like. You will also include a photo of your working circuit on the breadboard.

Deliverables

You should include a test Bode plot of the final circuit, a clean EKG trace, and a picture of your beautiful, clean circuit with no long loopy wires.
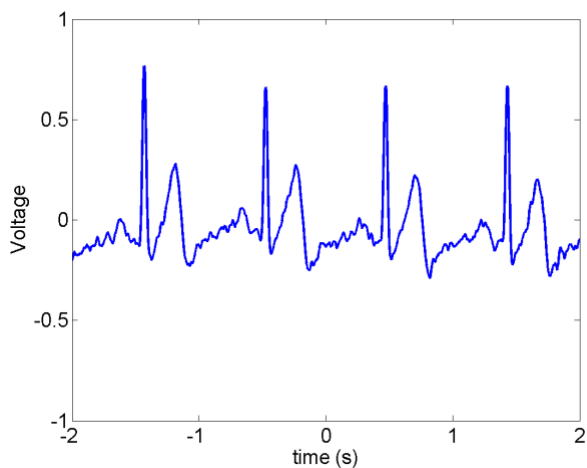

Figure 3: Sample EKG trace.

Appendix: Optional Electrode Placement

The voltage signals from the heart will be strongest near the source. Any voluntary movement of muscles will introduce additional signals, so you will want your person to be still to detect only the heartbeat. Note that one input is up and the other is down. This is to monitor the signal from top to bottom of the heart.
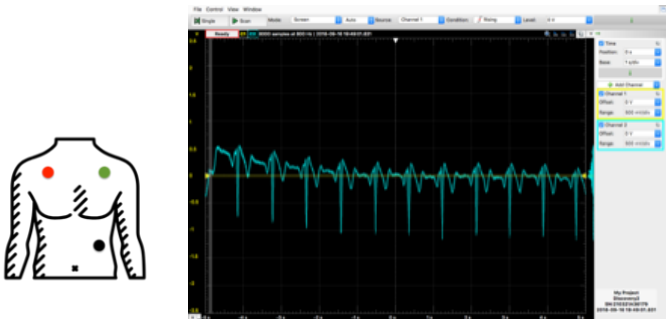
If you choose any of these, do so only if you can take the measurements fully clothed.

In these images: ● = V_{in-}, ● = V_{in+}, ● = $Ground$

Option 1:

Option 2

Same data source, same scale, with wrist electrode configuration: