Lab5: 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

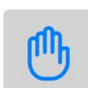
When your muscle cells contract, a charge imbalance is generated across the cell membranes. The heartbeat is initiated by a signal from the right atrium which produces a propagating wave of charge imbalance. We can detect the firing of the heart muscles by sensing voltage differences through electrodes placed on our skin.

In this lab, we'll sense a heartbeat with a 3-wire electrocardiogram (EKG). The three-wire connection is the simplest that will yield a usable trace (not just a heart rate). The resulting EKG can reveal the electrical activity of the heart. A full EKG involves the connection of 12 electrodes across the chest and on the extremities. The reading of an EKG is a medical sub-specialty and involves analysis of the shape of the resulting signal which can diagnosis various medical conditions. While our implementation of the EKG will be simpler than the one conducted in medical practice, the principles will be the same.

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.

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.

Overview: We will be building two stages of filtering for the heartbeat. You'll test each stage separately and then chain them together. We will use the Bode plot to qualify the behavior of each filtering stage.

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.**

1. Build the Stage 1 Circuit Shown

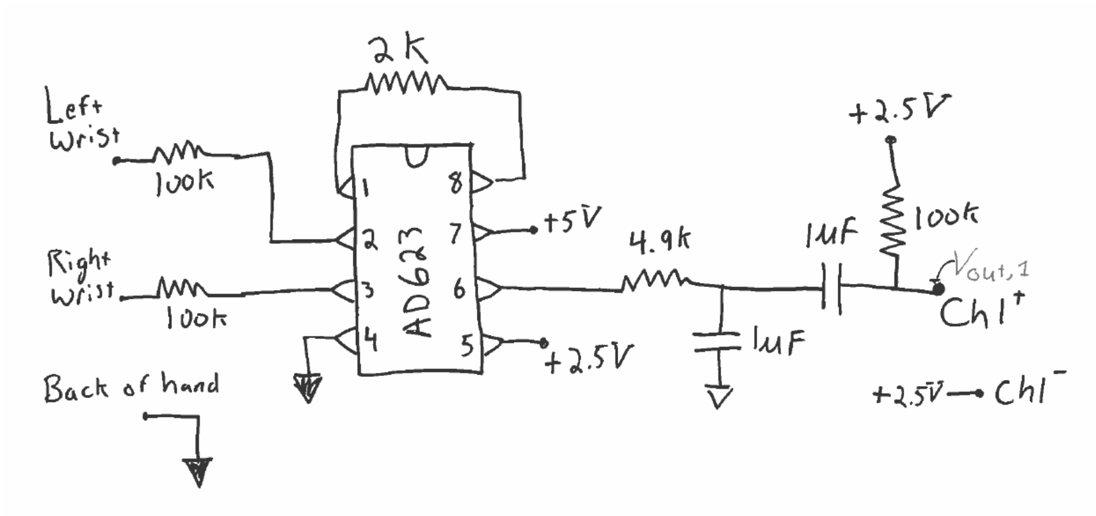
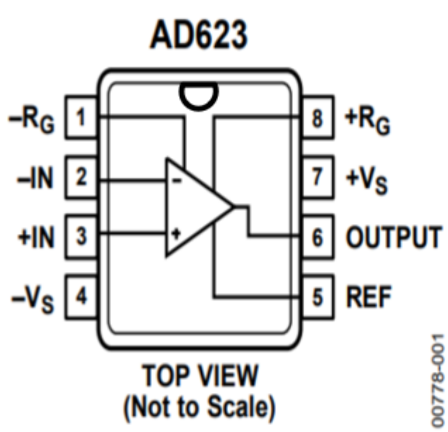


Figure 1: First Stage of the EKG circuit. Its output will be fed to the second stage.

There are two filters in this circuit. Draw a dotted line around each and identify what type of filter it is.

Think: What are the characteristic frequencies of each filter?

The circuit in Figure 1 uses the same instrumentation amplifier chip you used in the strain gauge lab. The connection AD623 connection diagram is shown below.



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

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

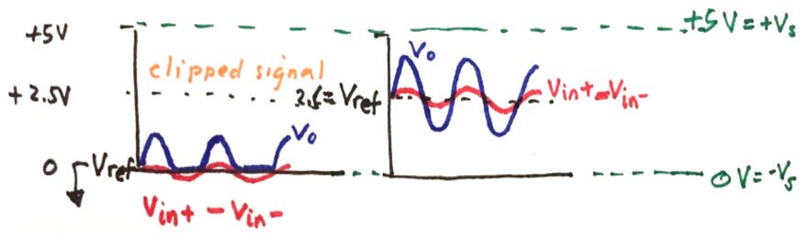
as described in the AD623 data sheet.

The chip provides an output which is simply,

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

Think: What are we using for V_{ref} in Figure 1?

How is the output affected by V_{ref}?



Because of setting V_{ref} to + _____ Volts, our 0-5 V AD623 power (-Vs to +Vs) 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 $(V_{in+} - V_{in-}) < 0$.

Before setting WaveGen, put Ch1 into HIGH RESOLUTION mode,

For Ch1 and Ch2, zoom in on the Y-axis.

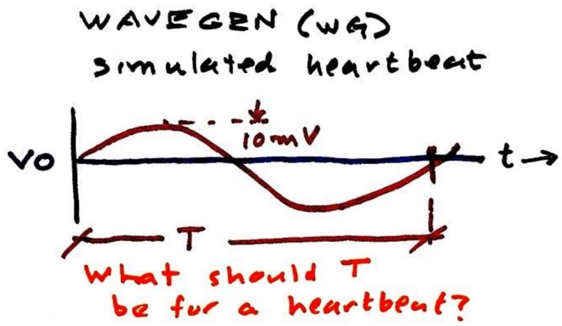
Decrease sampling rate to 200 S/s

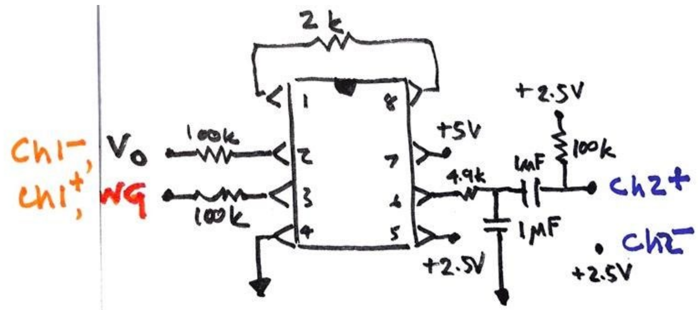
Zoom out in time to view the whole buffer.

2. Test Stage 1 as you build it.

We will use the WaveGen feature of the scope to simulate a heartbeat and test the circuit as you go.

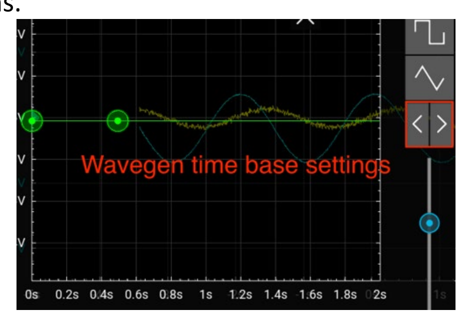
Run the scope and test Figure 1





To create this waveform, in WaveGen, you will need to use the display pullout settings to zoom in on the y-axis. You may also need to adjust the x-axis.

For this testing, you do not need to collect data for your lab report. Simply diagnose whether the circuit is acting as you expect. Make sure that you understand what the circuit is doing to different test frequencies and connect that expectation to your observations.



Keep the amplitude of the WaveGen fixed, adjusting the time base settings to frequencies greater than a heartbeat, less than a heartbeat, and equal to heartbeat. Monitor the circuit output.

Remember the ultimate goal will be to preserve relevant frequencies and remove frequencies associated with noise and other artifacts not associated with the EKG.

Now that stage 1 is working, **keep it (don't disassemble)!** Build the second stage nearby on your breadboard so that you can connect the two stages after you are sure that they are working properly.

Build the second stage of amplification and filtering

Think: What behavior do you expect from the two RC filters in series?

When you test the circuit stages, **decouple them**. The only connection to the O-Scope terminals (WG, V0, +1, -1, +2, -2) should be at the input and output of the circuit stages. When testing Stage 2 (Fig. 2), use WG & 1+ for Vout, 1- and V0 for pin 3.

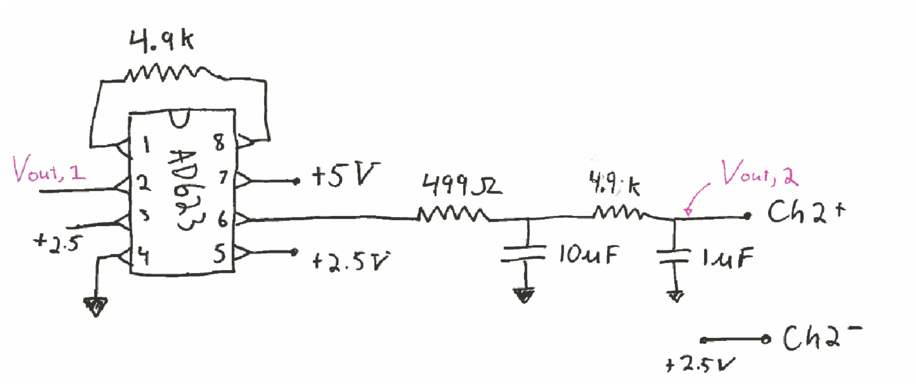
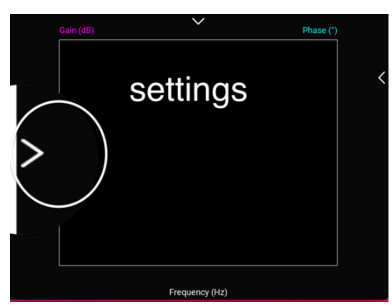


Figure 2: Second stage of the EKG circuit. The output of stage 1 is the input to this circuit.

Build the second stage, Figure 2. We suggest you test the circuit as the did the 1st stage, using WaveGen as the input. If you think the whole thing is working properly, **connect the two stages (Stage 1 [Figure 1] output becomes stage 2 [Figure 2] input).** Adjust the frequency to higher and lower values than 1 Hz. What do you expect to see at V_{out} if you input a 100 Hz signal? (Is that what you observe?) How do you expect to V_{out} to change if you input a 0.1 Hz signal? (Is that what you observe?). Continuously monitor the behavior using the sinusoidal WaveGen input until you believe everything is correct and you understand (at least qualitatively) the working of the circuit.

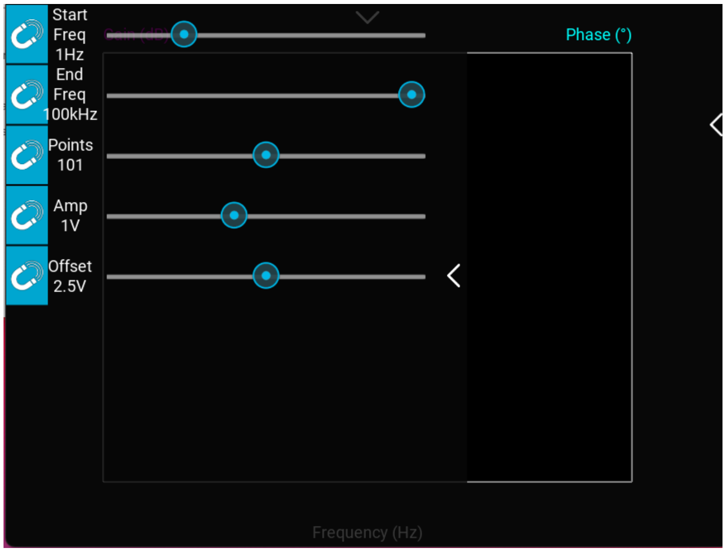
Once you are convinced things work, temporarily remove the R_G from both AD623 amplifiers and create and save a Bode plot (see the guidelines below). Removing **R_G** causes both chips to default to a gain of 1.

Use the pullout near the bottom of the screen to get the Bode Plot function.



Use the settings pullout. Reduce the Start Freq to 100mHz; the End Frequency to 10 kHz.

Warning: It may take about 10 minutes to collect the Bode data.



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). There is typically some constant voltage 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.

3. Replace R_G resistors and collect heartbeat data from a person

Now that you are convinced things work, prepare to take your heartbeat data. Reattach the R_G resistors. You will need:

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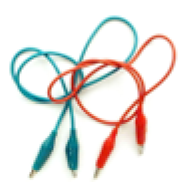
 3

 1

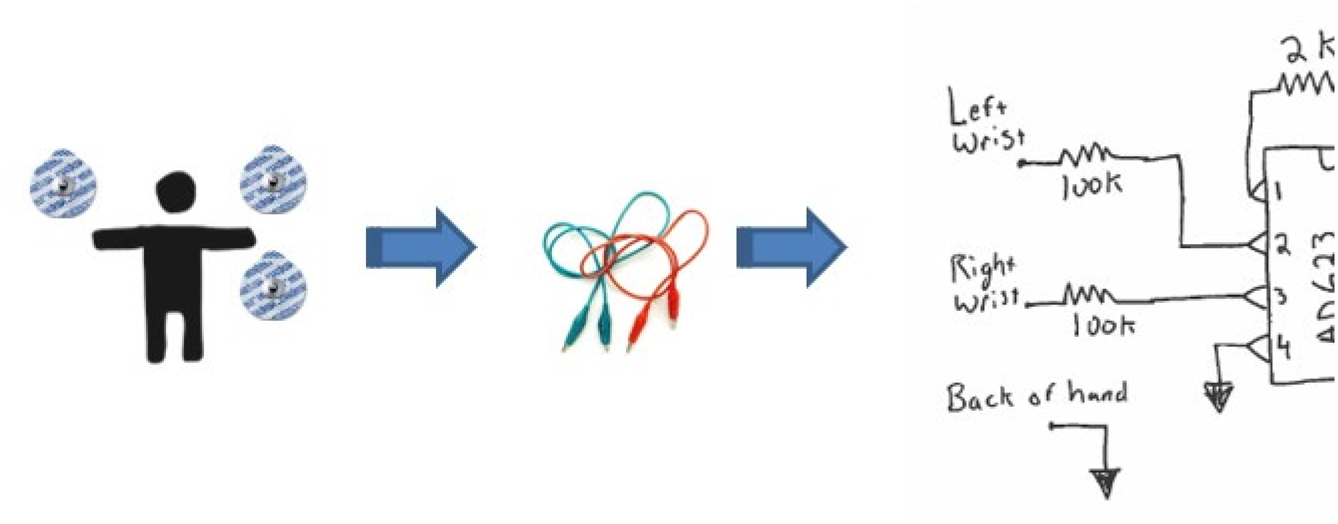
Willing data source – you or someone else

Caution
Shock hazard

Disconnect AC power
& earth ground

Use battery
power only

Connect electrodes to circuit



Pad placement:

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

Any electrode placement on the arms will work. The measurement will need to go across the body (i.e. left and right arms). The wrists, inside forearms, or close to your shoulder all work – depending on what you are comfortable with and whether you are wearing short or long sleeves today. Closer to your heart will typically yield a larger signal. Maintaining good skin contact is important. Take a screenshot that illustrates a few beats (e.g., Figure 3 shows a good trace with a few beats.).

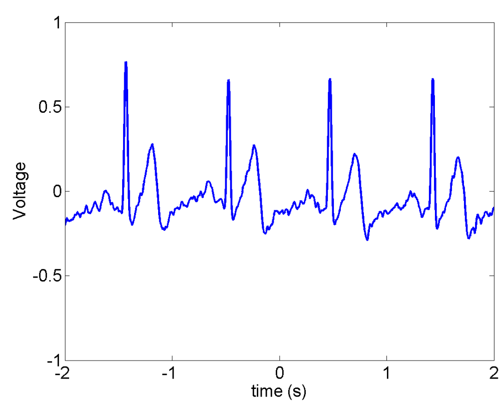


Figure 3: Sample EKG trace.

(*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.*)

Take a picture of your circuit.

Completion

Please turn in:

1 point. A Bode plot (Amplitude only) of the final circuit (stages 1 and 2 together) with labeled axes, units and caption. [Screenshot is fine. There is no need to re-plot it.]

½ point. A screenshot of an EKG trace and caption (You may also plot it if you prefer).

½ point. A picture of your built circuit using best breadboarding practices (no long loopy wires).

2 points. Description of how the circuit functions. For example, how many filters are used? What types of filters are these and what do they do? What are the characteristic frequencies? What is the overall amplification of the final circuit? **Note:** You can get most of this information from the Bode plot (Amplitude only, the phase information is not needed).