Ballistocardiograph

In this lab you will construct a circuit which can sense your heart rate from an ordinary bathroom scale. Known as a ballistocardiograph (BCG), the principle is that the reaction force at the ground fluctuates a little bit as the heart impulsively ejects blood with each beat. There is a slight recoil which we can sense. Since the measurement is so sensitive, we will do a simulateous EKG which will help us identify and correlate the two signals. The EKG is prebuilt on a printed circuit board and is part of the setup with the scale. The EKG is the same circuit you already constructed so you can just use the signal from it. An example of the final result is shown in Figure 1.

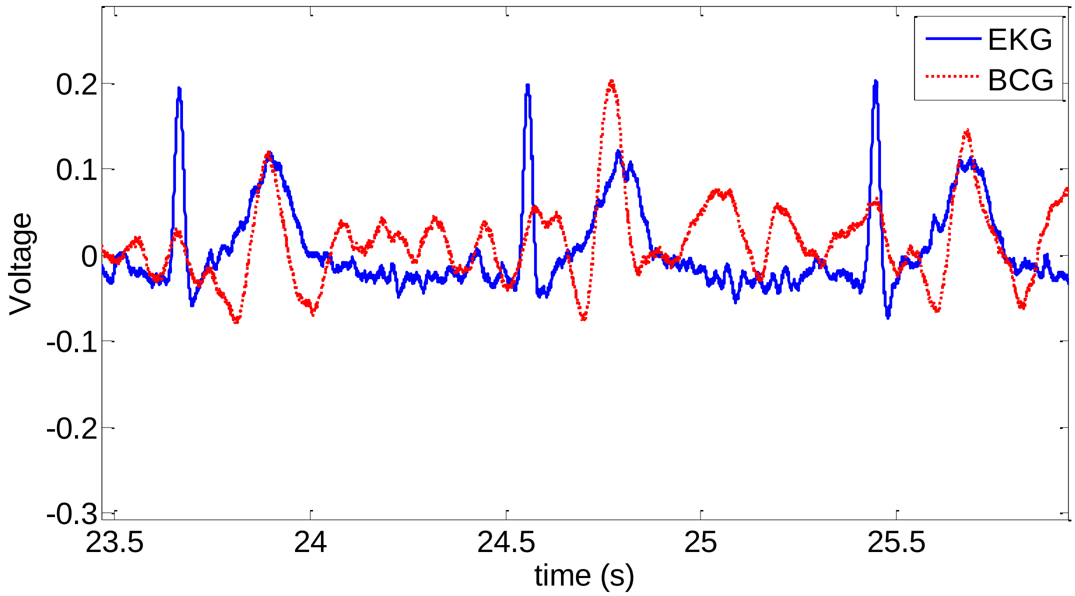

Figure 1: Comparison of EKG and BCG signal. Note the regular correlation between the second hump of the EKG signal and the impulse from the BCG.

The basic principle of the circuit is that we must very aggressively filter out both the noise at high frequencies (in this case, high relative to the ~1 Hz signal) and the DC offset from your constant mass. The filters must have a narrow frequency response in order to isolate your pulse. It is important in this circuit that you keep your wires clipped short and close to the breadboard.

A block diagram of the circuit is shown below in Figure 2. Since each block is essentially buffered by an op-amp, the blocks do not interact with each other and can be built, tested, and analyzed in isolation. You should build each block in turn and then test after each new additional block.

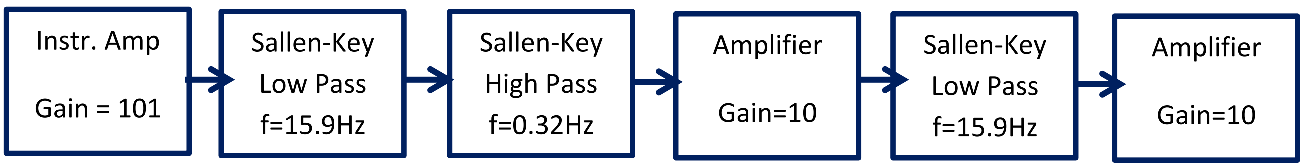

Figure 2: Block diagram of your circuit.

The first step is the bridge circuit and the instrumentation amplifier. This block works more or less the same as the lab last week. The only difference is that the resistors for the bridge are the strain gauges located in the each of the four legs of the bathroom scale. Last week, 1 resistor in the bridge was a strain gauge while the other 3 were fixed resistors. In the scale, the strain gauges are internal to the mechanical system and the 4 four wires come out of the can be wired as shown in Figure 3. Since the strain gauges are more precisely manufactured than standard resistors, there is no need to balance the bridge with a potentiometer. Since there are only a few scales to share among the class, you will need to build and debug your circuit and then come to the front of the class to test.

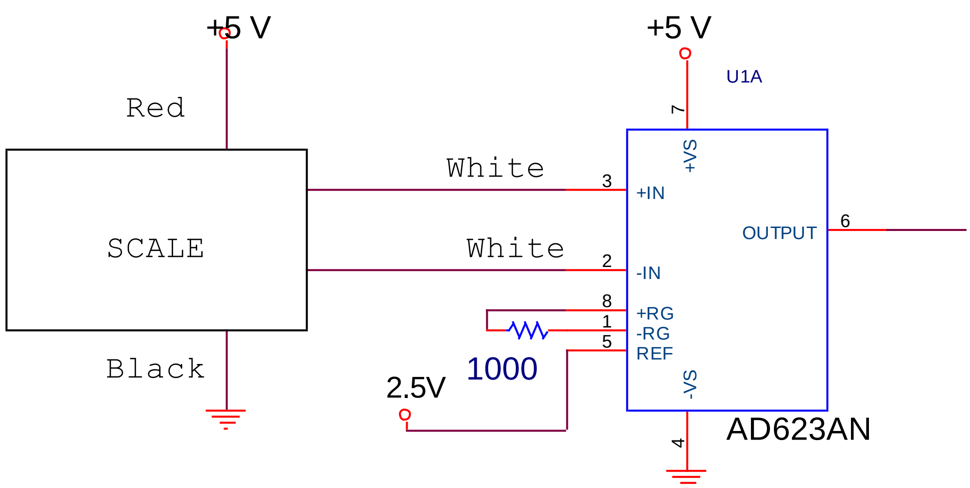

Figure 3: First stage of the circuit. Instrumentation amplifier interfacing with the strain gauges in the scale. The strain gauges inside the scale form the Wheatstone bridge.

Next you should build the first low pass and the high pass filter. The filter we will use has the Sallen-Key topology. This was discussed in Monday's lecture and you can also read about the filter on Wikipedia. The Sallen-Key is nice as the amplitude at high frequency decreases 2 orders of magnitude for every order of magnitude increase in frequency. Another nice feature of the Sallen-Key topology is that you can just switch the role of the R and the C to switch from a low pass to a high pass filter. The filters are shown in Figures 3 and 4. The output is buffered by the op-amp you can just connect the filters and they don't interact with each other.

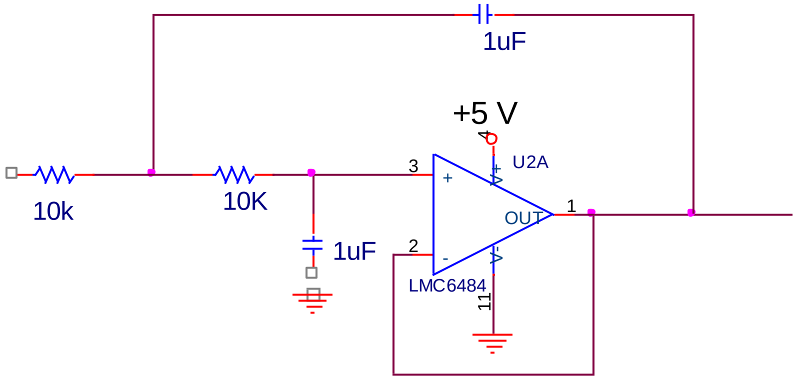

Figure 4: Sallen-Key low pass filter with a cutoff frequency of ~16 Hz.

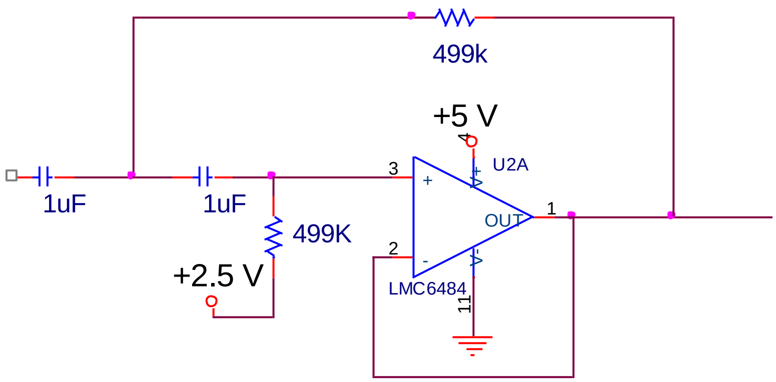

Figure 5: Sallen-Key high pass filter with a cutoff frequency of ~0.3 Hz.

Once you have the instrumentation amplifier and the two filters built you should test the circuit. Use the audio cable and the MATLAB script to automatically generate the Bode plot for the circuit, used in Lab 1. To hook up the audio cable, you will place the black and white wires from the audio cable into the + and – input of the instrumentation amp (the red wire can be free). You can then remove the 1K feedback resistor to reduce the amplifiers gain to 1. You should then set the frequency range for the Bode plot sweep to go above and below the cutoff frequency (who will need to modify the script). Make sure you turn up the volume on your computer so that you have an observable signal on the output. You will want to hook the output of the instrumentation amplifier into ai0+ and the output of the filter should go to ai1+. The negative input of both ai0 and ai1 should go to the 2.5 V reference, as usual. If things are working properly you should the amplitude decrease strongly below 0.3 Hz and above 16 Hz.

If things are working well, you can add the amplifier to boost the signal as shown in Figure 6. Finally add one more low-pass filter and amplifier with a gain of 10 (exactly is the previous ones you built). Since the second filter is the same first, if you build the first one cleanly, you can just copy the layout.

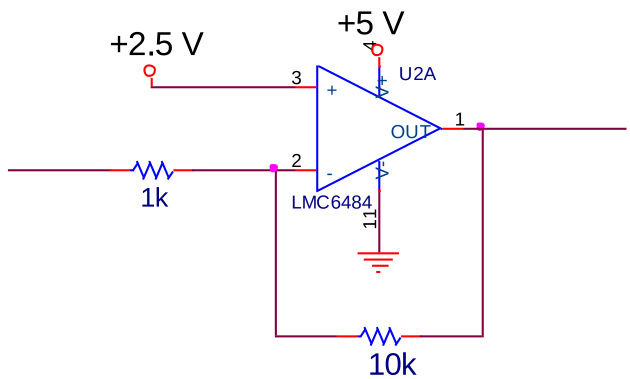

Figure 6: Amplifier with a gain of 10.

Once you have the second filter bank implemented, you can test your circuit on one of the scales. We will have three setups where you can just plug in your breadboard. The setup will have a battery pack for the power (not the USB) as it is less noisy, however the connector to the breadboard is identical to the own you have been using which is connected to the DAQ. We will also have an EKG built on a printed circuit board that you can hook up the test subject to do the simultaneous BCG/EKG measurement.

When running the test it is important that you stay very still on the scale. The BCG signal is very subtle and it is easy to lose the signal if you sway too much. Also, note that due to the high gain in the system, when you first stand on the scale it takes several seconds for the circuit to settle down and only display the regular heartbeat.

Note that the signal is quite sensitive to electrical noise in the room. We have found that you pick up a lot of noise from the room lights which is transmitted to the long wires in the strain gauges from your feet. We have found that if you use a conical shaped aluminum foil "hat" it will deflect the electromagnetic radiation from the room lights and improve the results; see Figure 7. While it may look silly, the results are much improved.

Figure 7: Example of aluminum foil used to shield your body from electrical noise from the lights.

Deliverables

1. Experimental bode plot of the first two stages of the filter. Your frequency sweep should go above and below the cutoff frequencies. The experimental results should be compared to the analytical result which you will derive. We will have derived this result in class, but you should work through the analysis yourself, put in the proper values of R&C for your filter. State the final equation that relates the filter input voltage to output voltage in your lab report.
2. A good final simultaneous EKG and BCG trace, similar to what is shown in Figure 1.
3. A picture of your beautiful circuit.

Grading

10 points for everything correct.

1) 2 points total for a good experimental Bode plot.
    a. 2 points off if result looks incorrect.
    b. 1 off for decent results but poor/unclear axis, plotting, or labeling
2) 3 points for a good analytical curve compared to the experimental Bode plot data points.
    a. 1 off if derivation is incorrect, but a reasonable effort.
    b. 1 point off if result looks good but you don't include the final equation.
3) 4 points for good EKG/BCG trace
    a. 2 points off if you took data, but the data looks poor.
    b. 1 point off if data looks fine, but plot is not well-labeled, no axis, no units, etc.
4) 1 point for off for a crappy circuit.