Blood Pressure

This week you will build a system to estimate your mean arterial pressure (blood pressure). Typically a doctor or nurse will measure the systolic and diastolic pressure. These pressures correspond to the maximum and minimum pressures in the arteries when the heart beats. It is known that high blood pressure is a risk factor for a number of diseases, thus blood pressure monitoring is one of the most common measurements in health care. Many of the automated blood pressure machines that you see for sale at the pharmacy don't measure the systolic and diastolic pressures directly, but calculate these pressures empirically from the resulting oscillations in your pulse.

The simplest oscillometric technique is as follows. If you inflate a cuff on your arm above the systolic pressure and then deflate the cuff, you will feel the pulse in your arm increase quite dramatically as the pressure is lowered. If we monitor the total pressure on the cuff, we will see the overall decay of the pressure signal (figure 1 left), but embedded in this decay is the small pressure change due to your pulse (figure 1 right). In Figure 1 we show a raw trace of the cuff pressure and then a zoomed in version at a certain time. In the zoomed in version we see the slight signature of the pulse.
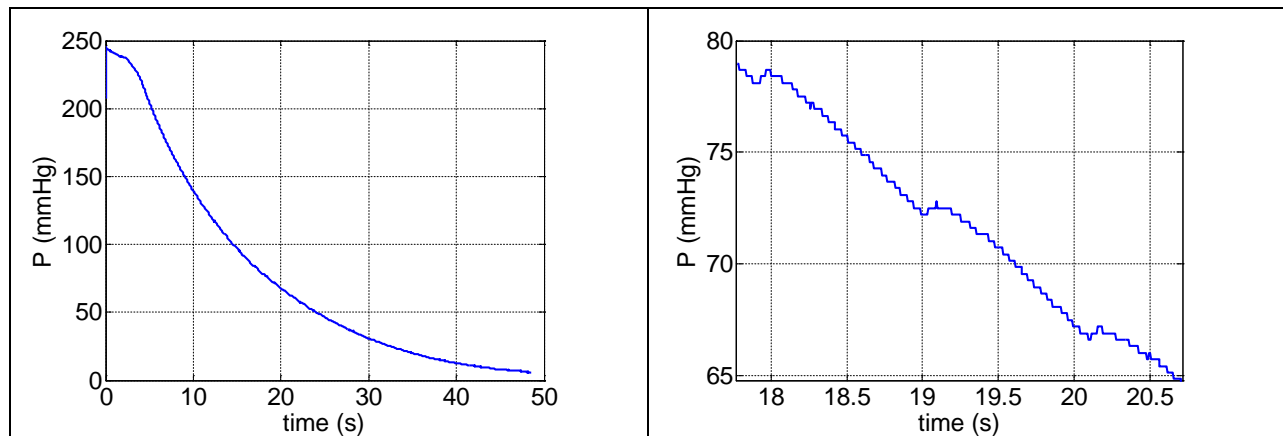

Figure 1: Raw pressure reading from blood pressure cuff and zoomed in around a few seconds.

If we process the pressure signal to remove the slow decay (a high pass filter), clean up the noise (a low pass filter), and amplify, we can obtain a result as seen in Figure 2. In Figure 2, the upper signal shows the raw pressure signal while the lower signal shows the processed signal which isolates the pulse. The pulse amplitude grows as the cuff pressure releases, then the pulse amplitude decreases. It is at the time when the pulse amplitude is maximum that we call that pressure the mean blood pressure. The figure shown in Figure 2 is what you will feel, your pulse intensifies and then decays.

We look at the time where the pulse amplitude is a maximum; in this case around 18 seconds. If we then look at the total cuff pressure at this time, we find the cuff pressure was about 78 mmHg. This

value of the pressure is then assumed to be the mean arterial pressure. The mean blood pressure is taken to be about 2/3 of the diastolic plus 1/3 of the systolic.

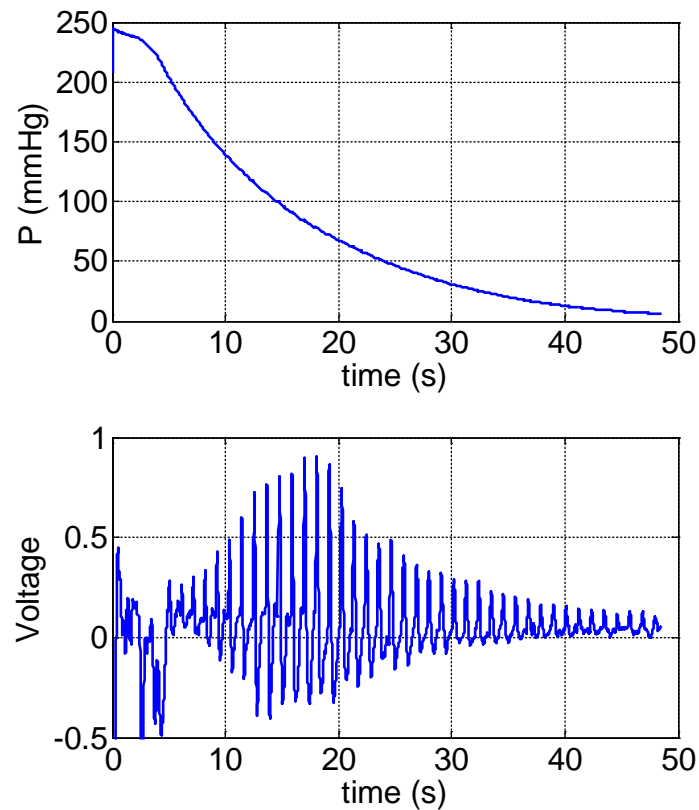**Figure 2: Raw pressure signal and processed signal. The oscillations in the lower figure are due to the patient's pulse.**

Disclaimer

With all our bio-measurements, and as we have explained before, your blood pressure is private medical information. If the privacy of this information in anyway makes you uncomfortable please ask one of the instructors to serve as your patient. The reliability of the measurement is also questionable, so please don't interpret your measurement to diagnose high blood pressure. You should get in the habit of having a regular physical anyway, so please have your pressure measured at your next visit.

Pressure measurement

We will make our blood pressure measurements using a standard blood pressure cuff; however we will remove the dial gauge for a manual measurement and replace it with a digital pressure sensor. The pressure sensor is the MPX5050DP. This pressure sensor requires 5 volts for power, ground, and provides a calibrated voltage proportional to pressure. It is a very easy sensor to use. The

sensors are pre-wired such that the red wire should be attached to 5 volts on your breadboard, the black wire should be connected to ground, and the white wire is the signal.

If you look in the data sheet for the sensor you will see that the output voltage is given as

$$V_{out} = V_s(0.018\,P + 0.04)$$

Where Vs is the supply voltage (5V for us) and P is the pressure in kPa (kilopascals). Typically blood pressure is given in units of millimeters of mercury (mmHg). Multiply the pressure in kPa by 7.5 to get pressure in mmHg.

Initial Testing

Rather than using the actual blood pressure cuff initially, we will have you use the WaveGen set up to output actual pressure sensor data measured from one of your instructors. You will import the data and have WaveGen play it back for testing purposes. This testing step is used for simplicity and your safety. While measuring your blood pressure is safe, measuring several times in a row is not great. The WaveGen has the ability to play back recorded data. Using this playback feature will dramatically improve the amount of time it takes to debug and develop your circuit. To use this playback mode,

1. Download the BPdata.csv file from the ISIM website.
2. Open the WaveGen in the Waveforms software.
3. Next to the run button, pull the drop down menu and select "custom".
4. Click import.
5. Select the BPdata.csv file from your saved directory.
6. Click Ok.
7. Set the frequency to 16.6 mHz or 0.0166 Hz. This will change the signal to repeat every minute (the rate it was recorded).
8. Click "Run".
9. Open the Scope.
10. Connect the wire for CH1+ to the wire for W1 and the wire for CH1- to the analog discovery GND.
11. Set the Scope time scale to 6s/div and the y-axis to 1 V/div.
12. Run the scope and confirm that W1 is outputting the saved blood pressure cuff voltage data.

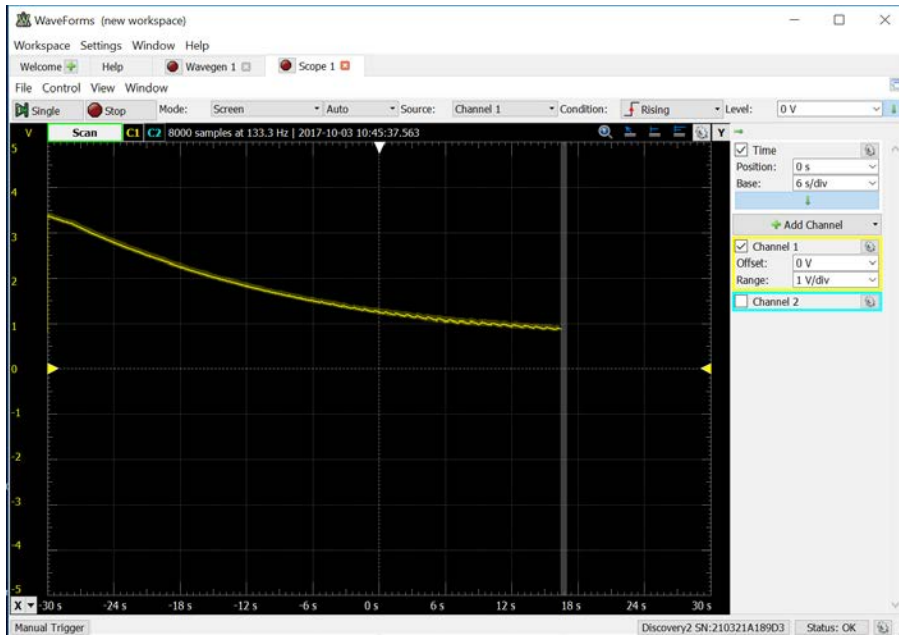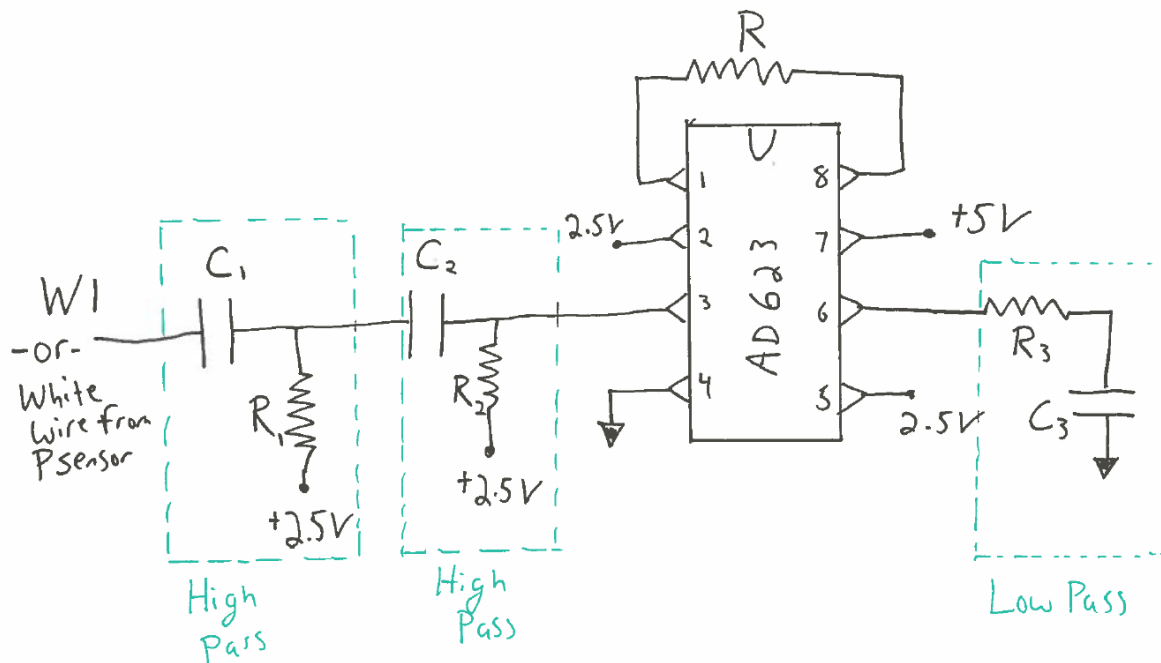You should see something like Figure 3. If so, it's good. Move on.

Figure 3: Actual data from the pressure sensor played back on WaveGen.

Your task

Your task is to design and build a circuit capable of finding your mean blood pressure as in Figure 2. The circuit is shown below. Note that you will need to select component values this week!

You should take the played-back pressure signal from W1, put it through two RC high-pass filters in series to remove the long time scale decay of the pressure in the cuff. The high-pass filters should have cutoff frequencies such that your pulse gets through (about 1 Hz), but the long decay from the release valve is removed (removes less than about 0.2 Hz). Since the slow decay and the pulse are not that widely separated in time scales, it is useful to have a strong high-pass filter – second order or higher. A second order high pass filter means that for every factor of 10 in frequency you go below the cutoff, you get a factor of 100 decrease in amplitude. You can get a second order high pass filter by simply chaining two normal RC high pass in a row. Note that there is a range of cutoff frequencies that will work well, so maybe try a few different values and see what you like. Remember, to compute the cutoff frequency of a filter, $\omega(Hz) = \frac{1}{2\pi RC}$.

After the high pass filters, you should then amplify the result such that you get a reasonable level for the output signal. We found an amplifier gain of about 25 worked well. You can experiment with the gain that gives you a good result. You will then find that a low-pass filter will clean up the final signal quite nicely. You will need to decide the cutoff frequency for the final low-pass filter.

To build and debug the circuit it is best to build and test as you go. Leave W1 playing continuously and monitor the output as you build complexity. You are trying to get an output that looks similar to Figure 2.

Final test

If you would like to test your system in real-time on yourself, get one of the blood pressure cuffs. If you don't want to test on yourself, that is fine and you can just use the playback data. If you want to test, remove W1 and replace it with the white wire coming from the pressure sensor. The red wire should go to 5V and the black wire to ground. Before testing on your arm, close the valve on the cuff, pump some air in, and press on the cuff to make sure the pressure signal is responding. Once it is responding it may be helpful to have a nurse (i.e. one of your friends or an instructor help you)

1. Set the scope to 6s/div.
2. Put the cuff around your arm.
3. Close the valve.
4. Run the scope.
5. Pump up until the cuff is tight – you don't have to overdo it!
6. Stop and restart the scope so you get a clean screen.
7. Release the valve very slightly.
8. Hold as still as possible.
9. Let the cuff fully deflate.
10. Stop the scope and export the data.

Warning: Blood pressure measurement is routine. It is safe and you can buy a number of kits at the pharmacy to do this at home. However, note that when you take the measurement you shut off arterial flow to your arm. Therefore:

- Please ask one of the instructors to show you how to work the blood pressure cuff if there is any question after the demo we will do in lab.
- DO NOT continue to repeat the experiment over and over pressurizing the cuff to a high pressure. You can test everything without putting the cuff on your arm or by inflating on your arm to a low pressure. Once you have things working, one or two tests should be sufficient to get your data.
- DO NOT leave the cuff inflated on your arm. There is a release valve that you loosen to allow the pressure to release slowly.
- DO NOT sit around with the cuff on your arm while you work, even if it is uninflated. For a small number of people the cuffs can irritate your skin. It is OK, and perhaps even recommended to have the cuff over your shirt sleeves.
- If anything feels uncomfortable, STOP.

Bode plot

You will want to confirm that your final circuit is working as you expect by creating a Bode plot. Since we are operating at low frequencies, the network analyzer will take a very long time to create the Bode plot automatically, so let's record the amplitude part of the Bode plot by hand.

- Put the yellow wire for W1 on the input to your circuit.
- Remove the pressure gauge.
- In Waveforms, set the WaveGen for W1 back to "simple" and set to be a pure sine wave.
- Set the amplitude to 100 mV. Set the frequency to 1 Hz, just to get started.
- Put Ch1 onto the input of your circuit (where the W1 wire is) and Ch2 on the output of the circuit. Ch2 should be measured relative to 2.5V.
- Run the scope.
- Set the time scale to be 1 s/div
- Add a measurement of the amplitude of both Ch1 and Ch2.
- Adjust the frequency and write your measured numbers down in the following table.

Frequency	Amplitude Ch1 (should be constant)	Amplitude Ch2
0.1 Hz		
0.2 Hz		
0.5 Hz		
1 Hz		
2 Hz		
5 Hz		
10 Hz		
50 Hz		
100 Hz		

Deliverables

For this lab, you should include

- Your final circuit schematic (can be drawn by hand). Denote the values of the resistors and capacitors that you used.
- A very short explanation of the overall circuit and explain the cutoff frequencies and gain that you used. Explain why the resistors on the two high-pass filters are connected to 2.5 V.
- Data for the final BP measurement. Your version of figure 2. You may want to include the playback data as well as your own measurement if you took both.
- Generate a Bode plot of the whole circuit you designed. Annotate your Bode plot to show the different cutoff frequencies you designed for are represented in the result. Your amplitude Bode plot should plot amplitude of output divided by amplitude of input versus frequency. Your plot should have log-log axis. This plot will be generated from your table data – if you wish to collect more data to get a cleaner Bode plot, that is great but the table data is sufficient.