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.

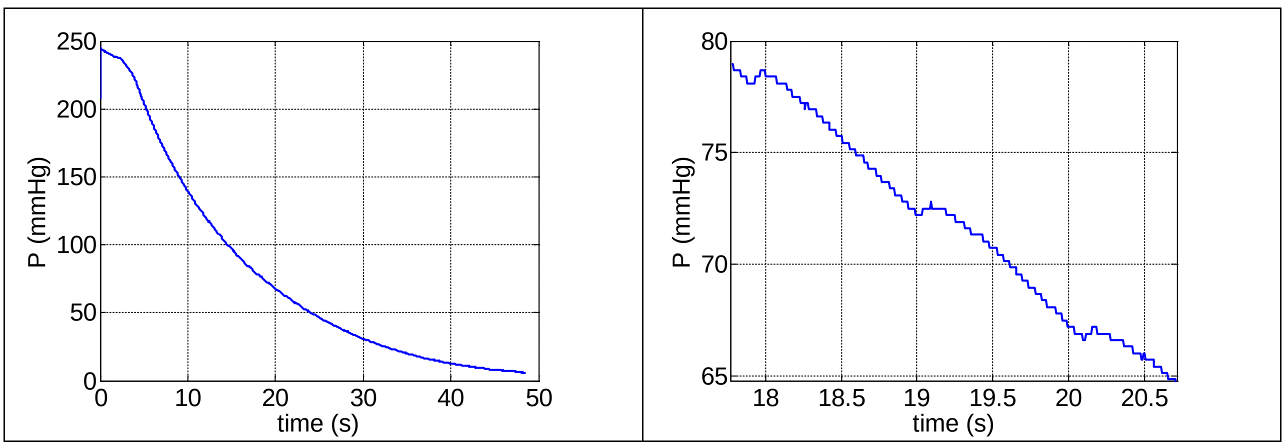


Figure 1: Raw pressure reading from blood pressure cuff and zoomed in around a few seconds.

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 the time when the pulse amplitude is a 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.

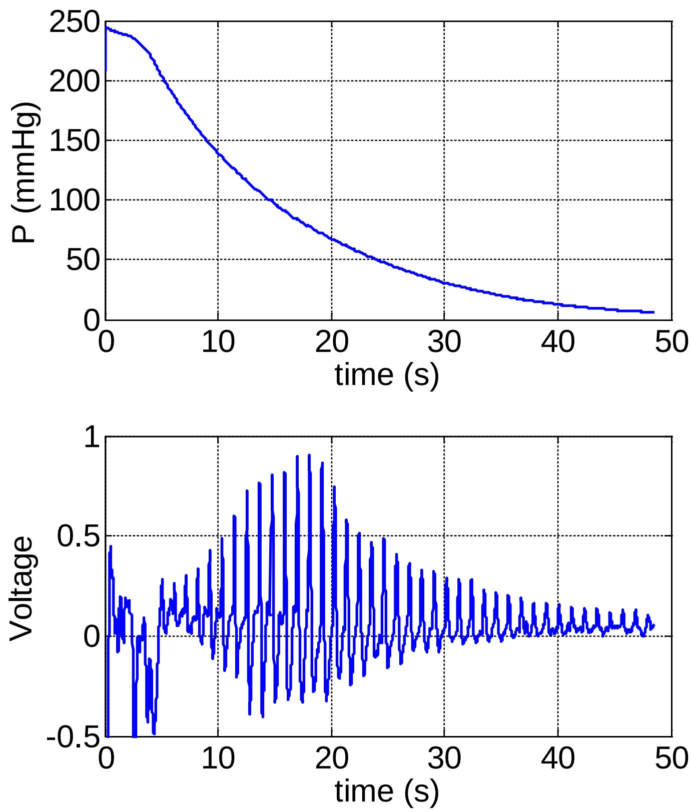


Figure 2: Raw pressure signal and processed signal. The oscillations in the lower figure are due to the patient's pulse.

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.

Basic setup

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

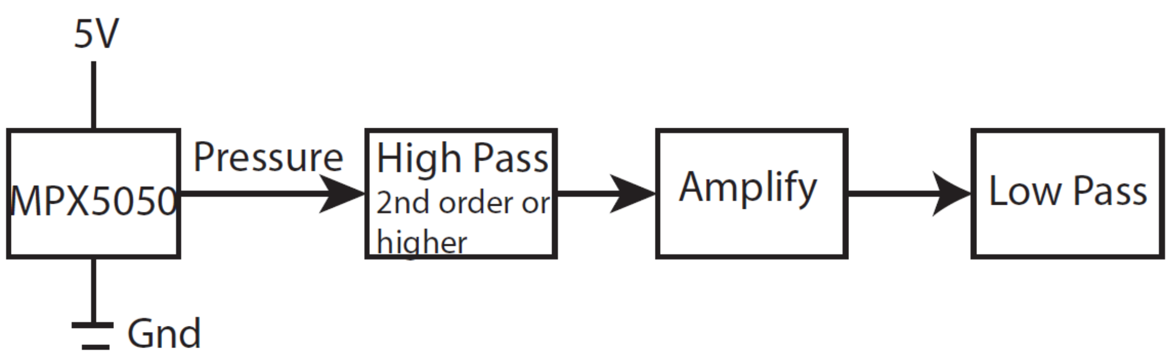
$$V_{out} = V_s(0.018\,P + 0.04)$$

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.

You should first get the basic sensor hooked up. Connect the analog discovery up directly to the white signal wire on the pressure sensor, run the scope, and pump up the cuff – just to get a feel for how things work.

Your task

Your task is to design and build a circuit capable of finding your mean blood pressure as in Figure 2. Conceptually, your circuit should have the following elements:



You should take the raw signal from the MPX5050DP, put it through a second order (or higher) high pass filter to remove the long time scale decay of the pressure. The high-pass filter should have a cutoff 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.

After the high pass, you should then amplify the result such that you get a reasonable level for the output signal. You can experiment with the gain that gives you a good result. You might then find that a low-pass filter will clean up the final signal quite nicely. You can use op-amps to act as a buffer between elements such that each functional block can be built and tested in isolation.

What? But what circuit do I build.

In this lab, you design the circuit. There are an infinite number of possible good solutions. If you look at the last few labs you will see examples of low-pass, high-pass, and amplification circuits. We suggest building things slowly in pieces, trying each section at a time. Getting the right cutoff values of the frequency and the right amplifications will take a little planning and little experimentation. Using op-amps between components is useful such that each functional block does not interfere with the next. Also, note that the range of available capacitor values is not as wide as the range of resistor values. When setting the cutoff frequency of the filters, set the capacitor value first, then select the resistor value that works with that capacitor.

Warning

Blood pressure measurement is a routine measurement. 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, ask one of the course instructors to be your patient.

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. The diagram should be complete enough that some other student in this class could replicate your circuit.

- A very short explanation of the function of each block. Note cutoff frequencies, gain, etc
- Data for the final BP measurement. Your version of figure 2.
- ONE SINGLE supporting plot showing your filter and amplify stage are working. You should generate a Bode plot of the whole circuit you designed (driven by the function generator instead of the pressure sensor) – i.e. you DO NOT necessarily need to show every stage in isolation is work. Annotate your Bode plot to show the different cutoff frequencies you designed for are represented in the result.