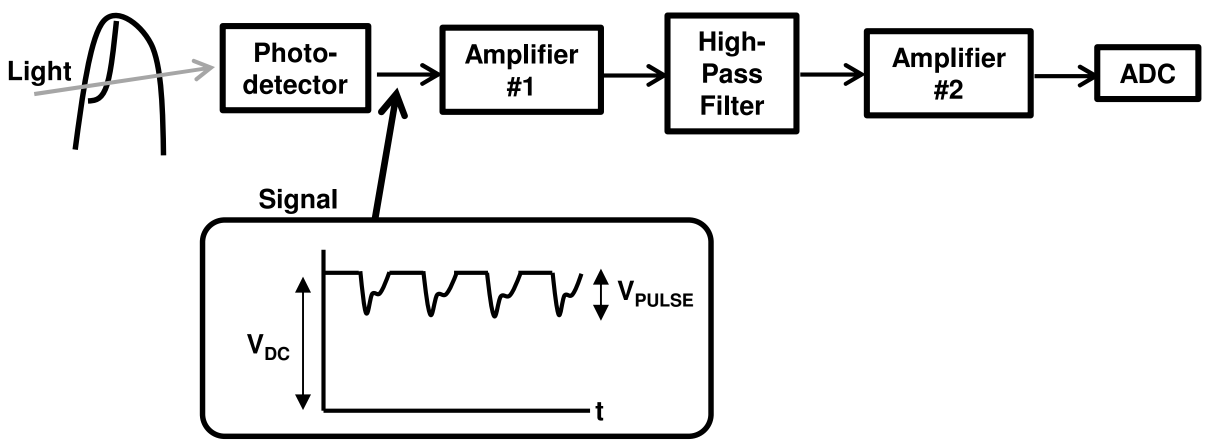
HW5: Circulation
(10 problems for 100 pts)

Optical Heart Rate Monitor

You are asked to design an optical heart rate monitor that can measure 30 to 300 beats/min. The photodetector signal goes through an amplifier, an RC high-pass filter, a second amplifier, and finally the ADC. Both amplifiers are powered by +/- 5V, so assume their outputs are limited to +4V (max) and -4V (min). The ADC operates from -5V to +5V.



- The DC component V_{DC} of the photodetector signal varies from 30 to 300 mV.
- The pulse component V_{PULSE} of the photodetector signal varies from 0.01% to 0.1% of V_{DC}.

- Problem 1: Suppose Amplifier #1 has V_{REF} = 0V and can have a gain A_1 = 10, 20, 50, or 100. Which is the best choice for A_1? Show all work. Hint: It is less than 50.

- Problem 2: Suppose that a frequency is passed by the high-pass filter if $|V_{OUT}/V_{IN}| \geq 0.9$. The available capacitor values are C = 3.3 uF, 2.7 uF, 1 uF, 330 nF, and 270 nF. Assuming the filter uses a 220 kohm resistor, which capacitor is the minimum acceptable value? Show all work. Hint: It is more than 1 uF.

  Hint #1: The filter has a transfer function given by $\frac{V_{OUT}}{V_{IN}} = \frac{jf/f_H}{1+jf/f_H}$, where $f_H = 1/(2\pi RC)$.

  Hint #2: Think carefully about the frequency content of the pulse signal compared to the filter's response.

- Problem 3: Suppose Amplifier #2 has V_{REF}= 0V and can have a gain A_2 = 100, 200, 500, 1000, or 1500. Which is the best choice of amplifier gain A_2? Show all work. Hint: It is more than 500.

Blood Pressure

Consider a blood pressure measurement system consisting of a pressure cuff, piezoresistive sensor, instrumentation amplifier, ADC, and a computer. The amplifier is powered by +10V and GND, so you can assume the amplifier output is limited to 1V (min) and +9V (max). The amplifier has a voltage reference V_{REF} = 2 V. The ADC operates from 0 to +10 V, and the maximum expected pressure is 240 mmHg.

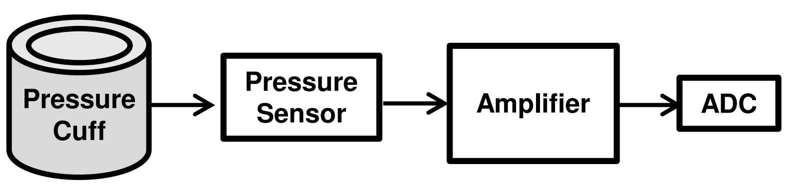
- Problem 4: Suppose the pressure sensor has a responsivity $\Delta V/\Delta P$ = 9 mV/psi. You must choose between A_d = 100, 150, 200, 250, 300, 350, 400, 450, and 500. Which one would you choose? Hint: Less than 250.

- Problem 5: Using your chosen value for Ad, what are the pressure values that produce Vmeas = 3V and 7V, respectively? Express your answers in mmHg.

- Problem 6: Assume that the output noise voltage of the instrumentation amplifier is V_N = 5 mV. Compute the number of bits needed to ensure the ADC vertical resolution is smaller than half the noise voltage.

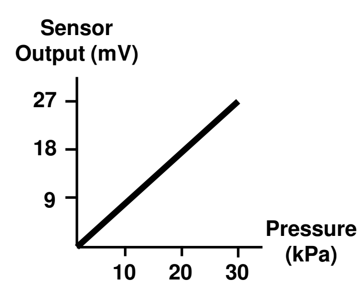
- Problem 7: Assuming $\Delta V_{MIN} = V_N$, compute the minimum detectable pressure change in your system. Express your answer in mm Hg. Hint: You should get around 0.2mmHg.

You are asked to upgrade a blood pressure measurement system to satisfy specifications of P_{MAX} = 220 mmHg and ΔP_{MIN} = 0.15 mmHg. The pressure sensor is powered by +10V and GND. The amplifier is powered by +/-10V.



The "old" system uses:

- 12-bit ADC (0 to 5V range) and $V_{N,RMS}$ = 3 mV
- Amplifier with A_d = 200, V_{REF} = 1V, and $V_{N,RMS}$ = 1.5 mV
- Pressure sensor with a calibration curve shown to the right:



NOTE:

- Assume any amplifier has a maximum output signal 1V less than the power supplies (e.g. +9V and -9V for the "old" amplifier).

- The total noise from two components is computed by: $V_{N,TOTAL} = \sqrt{{V_{N1}}^2 + {V_{N2}}^2}$

- Problem 8: Does the old system satisfy one, both, or neither of the desired specifications? Show all work! Hint: You should find that one spec is OK, while the other is not.

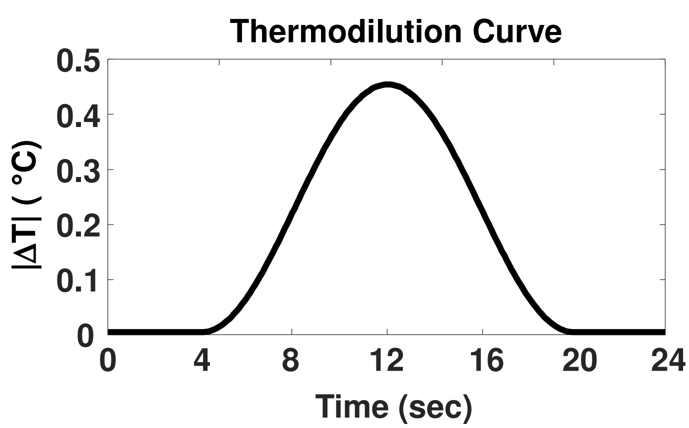
- Problem 9: Suppose you also have available:
  - Pressure sensor with a responsivity 1.5 times larger than the "old" sensor.
  - 12-bit ADC (0 to 10V range) with $V_{N,RMS} = 5$ mV.

  What combination(s) of components satisfies the desired specs? You can mix together any components (e.g. old sensor, old ADC). You must also show why the other combinations do NOT work.

Cardiac Output

Assume that blood temperature is normally 37 °C. A thermodilution measurement is performed by injecting a 10 mL bolus of 4 °C saline into the patient's right atrium. The measured thermodilution curve is shown in the figure. The magnitude of the temperature change (in °C) can be described by the following:

$$|\Delta T(t)| = \begin{cases} 0.45 \times \left(\frac{1}{2} + \frac{1}{2}\cos\left(\frac{2\pi(t-12)}{16}\right)\right) & when\ 4 < t \le 20s \\ 0 & otherwise \end{cases}$$



- Problem 10: What is the cardiac output? To make things easier, assume the same density and specific heat for saline and blood. Hint: It is between 5 and 6 L/min.

(End of HW5)