BME/ECE 386 EXAM #2 (W19) **NAME:** Solutions

4 problems for 100 pts

Problem #1: Short Answers (25 pts)

(a) EEG and PPG (5 pts): Choose true or false for each of the following statements. **If you choose false, then provide the correct statement.**

(i) EEG electrodes are placed on the scalp according to the 12-24 system.

(ii) In EEG, the gamma waves are associated with frustration.

(iii) In photoplethysmography, the photodetector monitors the change in wavelength of the transmitted light.

(iv) In a hemoglobin molecule, oxygen binds to the magnesium atom contained in each meme group.

(i) False 10-20

(ii) False Theta

(iii) False Change in intensity

(iv) False Iron atom contained in each heme group

(b) Blood Pressure (4 pts): Choose true or false for each of the following statements. **If you choose false, then provide the correct statement.**

(i) A systolic pressure of 3 psi is indicative of hypertension.

(ii) In the auscultatory method, diastole is the pressure corresponding to the fourth Beethoven sound.

(iii) The incisor and molar valves are shut during systole.

(i) True $3\,psi \times \frac{760\,mmHg}{14.7\,psi} = 155.1\,mmHg$

(ii) False Fifth Korotkoff

(iii) False Mitral + Tricuspid valves shut

(c) Cardiac Output (3 pts): Choose true or false for each of the following statements. **If you choose false, then provide the correct statement.**

(i) For an adult at rest, a typical cardiac output is 30 mL/sec.

(ii) In the thermodilution method, the patient's cardiac output is determined by injecting a bolus of hot saline into the left atrium and measuring the blood salinity in the aorta.

(i) False $\frac{.030\,L}{s} \times \frac{60\,s}{min} = 1.8\,L/min$ (tiny)

(ii) False Bolus of cold saline, right atrium, blood temperature pulmonary artery

(d) Respiratory system (4 pts): Choose true or false for each of the following statements. **If you choose false, then provide the correct statement.**

(i) Gas exchange occurs between the aioli and arterioles.

(ii) Inspiration involves relaxing the diaphragm and raising the rib cage to increase chest cavity volume.

(iii) Asthma and chronic bronchitis are common obstructive respiratory diseases.

(i) False — alveoli and capillaries

(ii) False — contracting the diaphragm

(iii) True

(e) Spirometers (4 pts): Choose true or false for each of the following statements. **If you choose false, then provide the correct statement.**

(i) The maximum change in lung volume is called expiratory reserve capacity.

(ii) The mesh screen in a Fleisch pneumotachometer provides an approximately quadratic relationship between flow and differential pressure.

(iii) Obtaining volume from flow is simply a matter of differentiation.

(i) False — Forced Vital Capacity

(ii) False — Mesh screen in Lilly, linear relationship

(iii) False — integration

(f) Absolute Lung Volume (5 pts):

(i) What does FRC stand for?

(ii) Whole-body plethysmography uses ~~Avogadro's~~ what gas Law to determine FRC.?

(iii) Consider a body box procedure where P_{MOUTH} = 101 kPa, ΔP_{MOUTH} = 1.7 kPa, and ΔP_{BOX} = 1.8 Pa. Assuming the body box calibration is 0.04 Pa/mL, compute the FRC in liters.

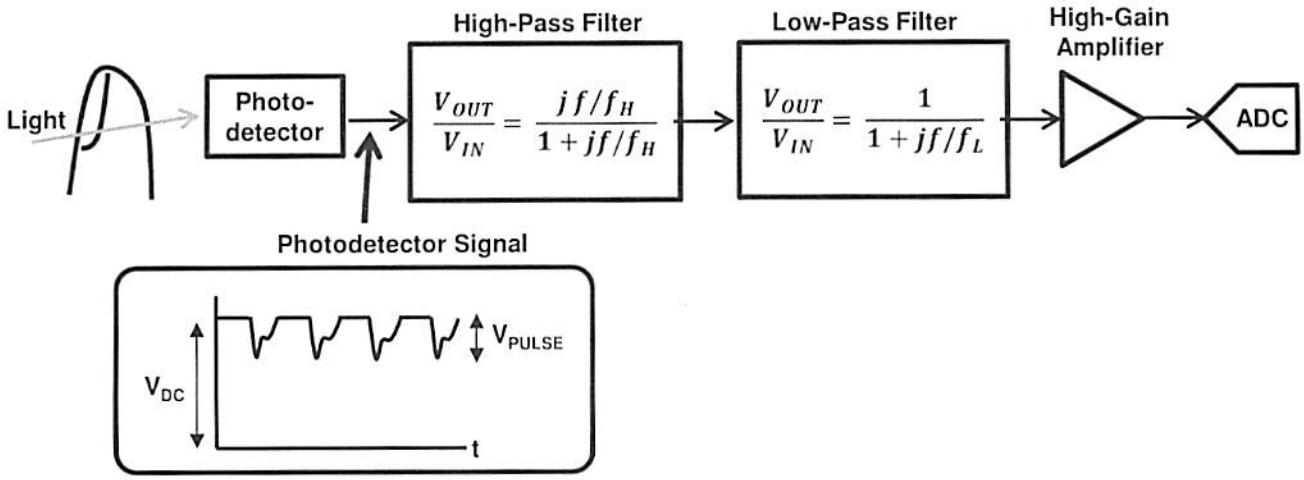
(i) Functional Residual Capacity

(ii) Boyle's Law

(iii) $$FRC = \frac{P_M - \Delta P_M}{\Delta P_M} \times K \Delta P_{box} = \frac{101 - 1.7}{1.7} \times \frac{mL}{.04 Pa} 1.8 Pa = \boxed{2.63 L}$$

Problem #2: Optical Heart Rate Monitor (25 pts)

You are asked to design an optical heart rate monitor that can measure 45 to 180 beats/min. The photodetector signal goes through a high-pass filter, then a low-pass filter, and finally a high-gain amplifier before reaching the ADC. The amplifier is powered by 5V and GND, so you can assume the amplifier output is limited to within 1V of the power supplies. The ADC operates from 0 to 5V.



- The DC component V_{DC} of the photodetector signal varies from 40 to 400 mV.
- The pulse component V_{PULSE} varies from 0.03% to 0.3% of V_{DC}.

(a) The high-pass filter has a transfer function V_{OUT}/V_{IN} with a corner frequency given by $f_H = 1/(2\pi RC)$. Let the resistor be R = 1 Mohm. The available capacitor values are C = 0.1 uF, 0.33 uF, 0.47 uF, 0.68 uF, and 1.0 uF. Assuming a frequency is passed if $|V_{OUT}/V_{IN}| \geq 0.9$, **which C is the best value?** Show all work!

(b) The low-pass filter has a transfer function V_{OUT}/V_{IN} with a corner frequency given by $f_L = 1/(2\pi RC)$. Let the capacitor be C = 100 nF. The available resistor values are R = 100 kohm, 220 kohm, 330 kohm, 560 kohm, and 1.0 Mohm. Assuming a frequency is passed if $|V_{OUT}/V_{IN}| \geq 0.9$, **which resistor is best?** Show all work.

(c) Suppose the high-gain amplifier has V_{REF}= 2.5V and can have a gain G = 200, 500, 1000, or 1500. Which is the best choice for G? Show all work.

(a) +9

$\left|\frac{V_{OUT}}{V_{IN}}\right| \geq 0.9$

$\frac{x}{\sqrt{1+x^2}} \geq 0.9 \rightarrow \frac{x^2}{1+x^2} \geq 0.81$

$x^2 \geq .81(1+x^2)$

$.19x^2 \geq .81$

$x \geq \sqrt{\frac{.81}{.19}} = 2.065$

$45 \frac{\text{beats}}{\text{min}} \times \frac{1\text{ min}}{60\text{ s}} = .75\text{ Hz}$

let $x = \frac{.75\text{ Hz}}{f_H} = 2\pi RC(.75)$

$2\pi RC(.75) \geq 2.065$

$C \geq \frac{2.065}{2\pi(10^6)(.75)} = 4.38\times10^{-7}\text{ F}$

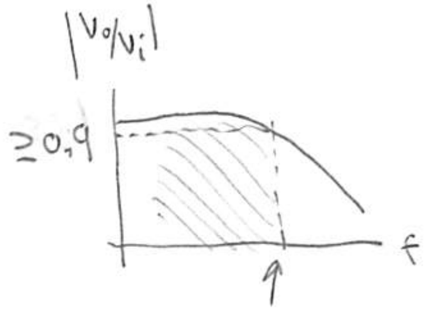
$\leftarrow C \geq 0.44\ \mu F$

Choose $\boxed{C = 0.47\ \mu F}$

(extra sheet for work)

$$\left| \frac{V_{OUT}}{V_{IN}} \right| \geq 0.9$$

(b)



$$\frac{y}{\sqrt{1+y^2}} \geq 0.9 \Rightarrow \frac{1}{1+y^2} \geq .81$$

$$1 \geq .81(1+y^2)$$

$$0.19 \geq .81y^2$$

$$180 \frac{\text{beats}}{\text{min}} \times \frac{1}{60} = 3 \text{ Hz}$$

$$y \leq \sqrt{\frac{.19}{.81}} = 0.484$$

let $y = \frac{3}{f_L} = 3 \times 2\pi RC$

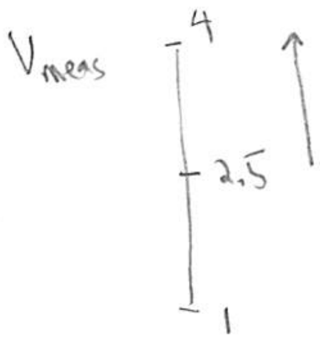
$$3 \cdot 2\pi RC \leq .484$$

$$R \leq \frac{.484}{3 \cdot 2\pi (0.1 \times 10^{-6})} = 2.57 \times 10^5$$

(+9) Choose $\boxed{R = 220\,K\Omega}$

$$\leq 257\,K\Omega$$

(c)



(+7)

$$1.5V \geq G \times (\max V_{pulse})$$

$$\geq G \times (.3 \times 10^{-2} \times 0.4V)$$

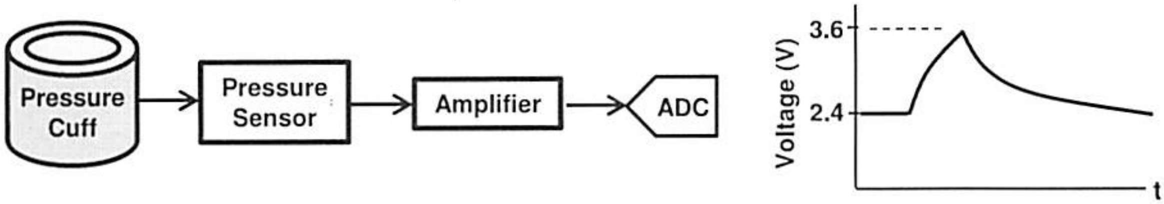
$$G \leq \frac{1.5V}{.3 \times 10^{-2} \times .4V} = 1250$$

Choose $\boxed{G = 1000}$

Problem #3: Blood Pressure (25 pts)

You are asked to design a blood pressure measurement system that operates from 0 to 220 mmHg with a sensitivity of 0.25 mmHg. The electronic hardware consists of a piezoresistive pressure sensor, instrumentation amplifier, and analog-to-digital converter (ADC). The ADC operates from 0-to-5V with 10 bits.

- The amplifier is powered by +5V and GND. As usual, assume the amplifier output is limited to within 1V of each power supply.
- Using a scope, you measure the amplifier output noise voltage to be 2 mV_{RMS}.
- You do NOT know the amplifier gain nor the sensor responsivity. ☹
- However, you DO have a calibrated air pump! You perform a calibration experiment where you inflate the pressure cuff to 2.5 psi and let the cuff deflate. You use a scope to measure the amplifier output voltage (see right figure).



(a) Does your current system satisfy one, both, or none of the design requirements? Show all work!

(b) You have the option of replacing the ADC with a more expensive chip that operates from 0-to-10V with 14 bits. Should you replace the ADC? Show all work!

(c) Suppose you can change Vref to be 3.0, 1.5, or 0.5V. Which value (or values) of Vref are OK, and which ones do not work? You must explain why a particular Vref value is OK or not OK. Show all work!

(a) $V_{meas} = A_d \Delta V + V_{ref}$

$= A_d S P + 2.4 \leftarrow$

+12

$3.6V = A_d S \left(2.5\,psi \cdot \frac{760\,mmHg}{14.7\,psi}\right) + 2.4V$

$A_d S = 9.28 \times 10^{-3} \frac{V}{mmHg}$

- $P_{max} = \frac{4 - 2.4V}{9.28\times10^{-3} \frac{V}{mmHg}} = \boxed{172\,mmHg}$ X (Too low)

OR

$Max\ V_{meas} = \left(9.28\times10^{-3}\frac{V}{mmHg}\right)(220\,mmHg) + 2.4 = \boxed{4.44V} \overset{?}{\leq} 4V$ X (Too high)

- Check sensitivity! $\Delta V_{ADC} = \frac{5-0V}{2^{10}-1} = 4.9\,mV \leftarrow \Delta V_{min}$

$V_N = 2\,mV$

$\Delta P_{min} = \frac{4.9\times10^{-3}\,V}{9.28\times10^{-3}\,V/mmHg} = \boxed{0.53\,mmHg}$ X (too big)

☆ None of requirements are satisfied ☹

(extra sheet for work)

(b) P_{max} does not change ☹

+6 Sensitivity?: $\Delta V_{ADC} = \frac{10 - 0V}{2^{14} - 1} = 0.61\,mV < V_N = 2mV$

$$\Delta P_{min} = \frac{.002V}{9.28 \times 10^{-3}\ V/mmHg} = \boxed{0.22\ mmHg}$$ ✓

(c) $V_{Meas} = A_d S P + V_{ref}$

+7 Want $4 \geq (9.28 \times 10^{-3} \frac{V}{mmHg})(220\ mmHg) + V_{ref}$

$V_{ref} \leq 4 - 2.04$

$\leq \underline{1.96V}$

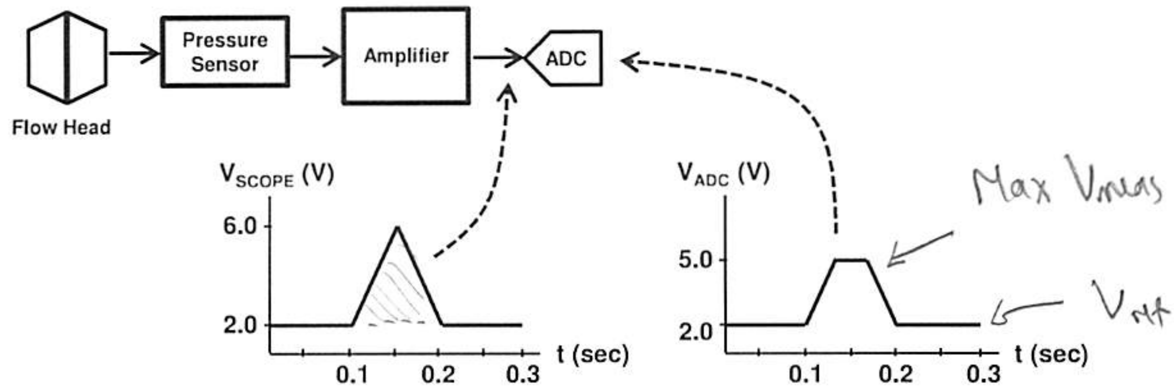
$V_{ref} = 3V$ Too high X
$V_{ref} = 1.5V$ OK ✓
$V_{ref} = .5V$ below 1V minimum X

limited by amplifier output

oops, supposed to be 25 L/s

Problem #4: Spirometer (25 points)

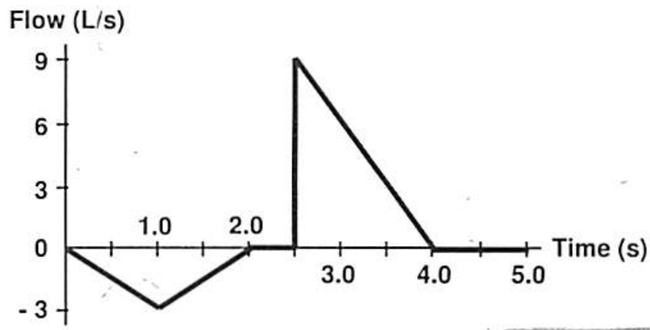
You are asked to assess whether a flow spirometer system can measure a max positive flow of $F_{MAX(+)} = +20$ L/s and a sensitivity of $|\Delta F_{MIN}| = 0.025$ L/s. You don't know any specifications for the pressure sensor and amplifier. However, you do have a motorized syringe that can inject 1.5L of air within 0.1 seconds (that's fast!). You use a scope to record the voltage V_{SCOPE} going into the ADC. You compare this to the voltage V_{ADC} that comes out of the ADC. The total system noise voltage is measured to be 2 mV.



(a) Does the spirometer satisfy one, both, or none of the design specifications? Show all work! NOTE: Assume that $\Delta V_{MIN} = V_{NOISE}$.

(b) You have the option of changing V_{REF} to be 1.75, 1.5, or 1.25V. Which value (or values) of V_{REF} are OK, and which ones do not work? You must explain why a particular V_{REF} value is OK or not OK. Show all work!

(c) Suppose we measure a patient taking a deep breath and forcefully exhaling into the spirometer. The resulting plot of both the inhalation and exhalation is shown on the right. Sketch the resulting curve for volume vs time. Make sure to label your axes and include the value of the patient's FVC!



+12

(a) $V_{meas} = A_d SRF + V_{ref}$

$\int (V_M - V_{ref})\,dt = A_d SR \int F\,dt$

$\frac{1}{2} 4V \cdot .1s = .2\,Vs = A_d SR \cdot 1.5L$

$A_d SR = \frac{.2\ V\cdot s}{1.5L} = .133 \frac{V\cdot s}{L}$

$.133\ V\cdot s/L\ (20\ L/s) + 2 = \boxed{4.66V < 5V}$ ✓

OR

Max Vmeas

$F_{max} = \frac{5 - 2V}{.133\ V\cdot s/L} = \boxed{22.6\ L/s}$ $> 20\ L/s$ ✓

$\Delta F_{min} = \frac{.002V}{.133\ V\cdot s/L} = \boxed{.015\ L/s}$ ✓ $< .025\ L/s$

Both are OK!

(extra sheet for work)

(b) want $F_{max} = \frac{5 - V_{ref}}{.133\ V \cdot s/L} \geq 20\ L/s$

(+6)

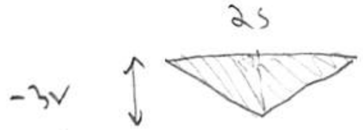
$5 - V_{ref} \geq (20)(.133) = 2.66\ V$

$V_{ref} \leq 5 - 2.66 = 2.34\ V$

$V_{ref} = 1.75V$ ✓
$V_{ref} = 1.5V$ ✓
$1.25V$ ✓
All OK

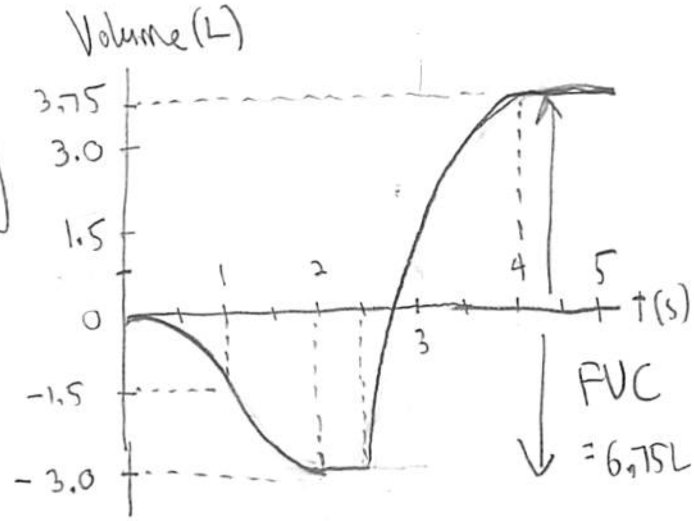
(c)

(+7)



$\text{Area} = \left[\frac{1}{2}(-3\tfrac{L}{s})(1s)\right] + \left[\frac{1}{2}(-3\tfrac{L}{s})(1s)\right]$
$= (-1.5) + (-1.5)\ L$

Integral of linear fn is quadratic!



$\text{Area} = \frac{1}{2}\, 9 \cdot 1.5$
$= 6.75\ L$