BME/ECE 386 EXAM #2 (W20) NAME: Solutions

4 problems for 100 pts

Problem #1: Short Answers (25 pts)

(a) EEG and PPG (4 pts): Choose true or false for each of the following statements. **If you choose false, then make corrections.**

(i) The four lobes of the human brain are the femoral, parental, oriental, and tropical lobes.

(ii) In EEG, the Hawaiian waves are associated with deep sleep.

(iii) In pulse oximetry, nitrogen saturation in the blood is measured by the stimulated emission of two different intensities of light.

(i) False Frontal, parietal, occipital, temporal

(ii) False delta

Transmission also OK

(iii) False oxygen, absorption, wavelengths

(b) Respiratory system (4 pts): Choose true or false for each of the following statements. **If you choose false, then make corrections.**

(i) Tonal velocimetry (TV) is the change in lung volume during normal breathing.

(ii) Air enters the lungs by passing through the trachea, broccoli, brachioles, and finally the ravioli where stock exchange occurs.

(iii) Expiration involves relaxing the diaphragm and contracting the external intercostal muscles.

(i) False Tidal Volume

(ii) False bronchi, bronchioles, alveoli, gas

(iii) False relaxing

(c) Electrical Safety (4 pts): For any true/false question, if you choose false, then make corrections.

(i) (True or False): Aortic devibration is the major cause of death due to electric shock.

(ii) Briefly explain why a microshock can be dangerous, despite involving very small currents.

(iii) Briefly explain why a 3-prong power outlet is safer than the old-fashioned 2-prong power outlet.

(i) False Ventricular fibrillation (V-Fib)

(ii) Small current is carried directly to heart by catheter device!

(iii) Ground fault current flows through earth ground wire instead of the person.

(d) Spirometers (4 pts): For any true/false question, if you choose false, then make corrections.

(i) (True or False): In spirometry, the patient is asked to perform a voluntary meditational maneuver.

(ii) (True or False): The max measured volume change is called the free residual concentration (FRC).

(iii) Suppose the helium dilution method is used on a patient. The spirometer has a volume of 10L and the initial helium concentration is 5%. At the end of the procedure, the final helium concentration is 4%. What is the patient's FRC? Express your answer in liters.

(i) False: Forced expiratory maneuver (FEM)

(ii) False: Forced vital capacity (FVC)

(iii) $C_S V_S = C_{LS}(V_S + V_L) \rightarrow \frac{C_S}{C_{LS}} V_S = V_S + V_L \rightarrow FRC = \frac{C_S - C_{LS}}{C_{LS}} V_S = \frac{5-4}{4} \times 10L = \boxed{2.5L}$

(e) Circulation (4 pts): For any true/false question, if you choose false then make corrections.

(i) (True or False): Oxygen-rich blood from the lungs is delivered to the heart's right atrium by the preliminary vein.

(ii) (True or False): Oxygen is carried in the blood by messagolubin molecules in white blood cells.

(iii) If the cardiac output is 93 mL/sec and the heart rate is 70 beats/min, then the heart's stroke volume is about 80 mL.

(i) False left, pulmonary

(ii) False hemoglobin, red

(iii) $CO = HR \times SV \rightarrow SV = \frac{93\ mL/s}{70\ beat/min \times min/60s} = 79.7\ mL \sim 80\ mL$ $\boxed{\text{True}}$

(f) Blood Pressure Measurement (5 pts): Choose true or false for each of the following statements. If you choose false, then make corrections.

(i) The mitral and pulmonary valves are open during diastole.

(ii) Systolic pressure is indicated by the second Tchaikovsky sound in the auscultatory method.

(iii) The oscillometric method provides stochastic atrial pressure.

(iv) A systolic pressure of 1.7 psi is indicative of hypotension.

(i) False Tricuspid

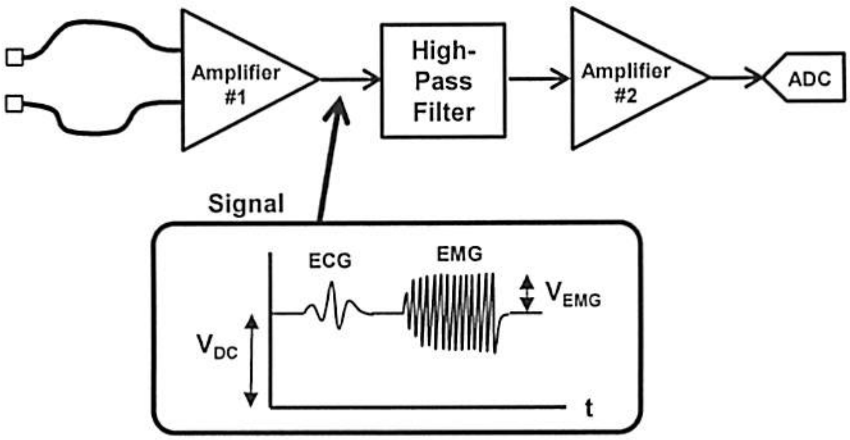
(ii) False 1st Korotkoff

(iii) False mean arterial pressure (MAP)

(iv) $1.7\ psi \times \frac{760\ mmHg}{14.7\ psi} = 88\ mmHg$ < Low! $\boxed{\text{True}}$

Problem #2: EMG Amplifier (25 pts)

You are asked to design an EMG amplifier to measure skeletal muscle activity with a pair of surface electrodes. As shown in the figure, the Amplifier #1 output is sent through a high-pass filter (HPF) to remove the DC offset as well as any ECG (i.e. cardiac) content. The filtered signal is sent through Amplifier #2 before data acquisition. Both amplifiers are powered by +/- 5V, so assume their outputs are limited to within 1V of each supply. The ADC operates from 0V to +5V.



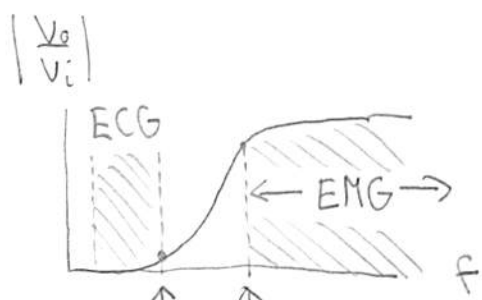
- The output of Amplifier #1 has three components:
  - The DC component V_{DC} can be as large as 1V.
  - The EMG signal amplitude V_{EMG} can vary from 0.01% to 1% of V_{DC}.
  - The EMG frequency content is between 100 Hz to 2 kHz.
  - The patient heart rate can be between 40 to 180 beats/min.
- The HPF frequency response is given by: $\left|\frac{V_{out}}{V_{in}}\right| = \frac{(f/f_H)^2}{\sqrt{1+(f/f_H)^4}}$, where $f_H = 1/(2\pi RC)$.

(a) Suppose that a frequency is passed by the HPF if $|V_{OUT}/V_{IN}| \geq 0.95$. Furthermore, suppose a frequency is blocked by the HPF if $|V_{OUT}/V_{IN}| \leq 0.05$. The available resistor values are R = 680 ohm, 6.8 kohm, 68 kohm, and 680 kohm. Assuming the filter uses a 0.1 uF capacitor, which resistor is the best choice? Show all work.

Hint: Think carefully about the frequency content of the various signal components!

(b) Suppose Amplifier #2 has V_{REF}= 2.5V and can have a gain A_2 = 50, 100, 200, 500, or 1000. Which is the best choice of gain for Amplifier #2? Show all work.

(a) Want To pass EMG freq
block ECG freq



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

100Hz

(extra sheet for work) let $(f/f_H) = x$

- $\left|\frac{V_{OUT}}{V_{IN}}\right| = \frac{x^2}{\sqrt{1+x^4}} > 0.95$ @ $f = 100\,Hz$ (+3)

$$x^4 > (.95)^2 (1+x^4)$$

$$[1-(.95)^2]\,x^4 > (.95)^2 \rightarrow x^4 > 9.256$$

$$x > 1.744$$

$$2\pi RC(100\,Hz) > 1.744$$

$$R > \frac{1.744}{2\pi(0.1\times10^{-6})(100)}$$

$$> 27756.6\,\Omega$$

$R > 27.8K$ (+5)

- $\left|\frac{V_{OUT}}{V_{IN}}\right| < .05$ @ $f = 3\,Hz$ (+3)

$$\frac{x^2}{\sqrt{1+x^2}} < .05$$

$$[1-(.05)^2]\,x^4 < (.05)^2 \rightarrow x < 0.224$$

$$2\pi RC(3\,Hz) < .224$$

$$R < \frac{.224}{2\pi(.1\times10^{-6})(3)}$$

$R < 118.7K$ (+5)

Choose **$R = 68K$** (+3)

(b) Max $V_{EMG} = (.01)\times 1V = .01V$

Amp #2 → 4, 2.5 ↑(+) ↓(−), Anc → 0

$V_{Meas} = 2.5 + A_2 \times .01 < 4$ (+)

$$A_2 < \frac{4-2.5}{.01} = 150$$

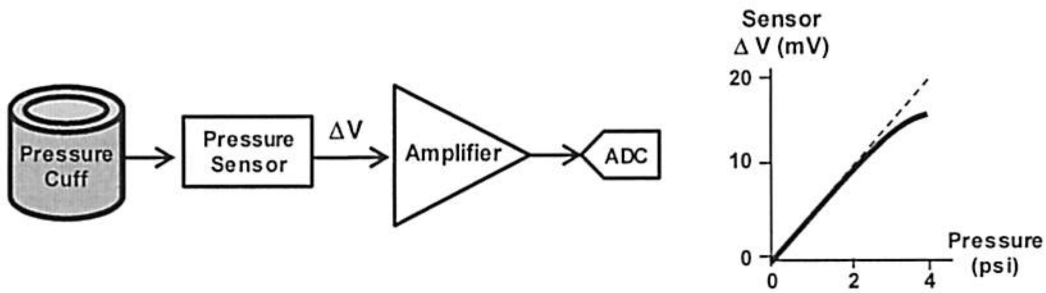
$2.5 + A_2 \times (-.01) > 0$ (−)

$$A_2 < 250$$

Choose **$A_2 = 100$** (+6)

Problem #3: Blood Pressure (25 pts)

You are asked to design a blood pressure measurement system with a maximum pressure reading of at least 205 mmHg. The desired sensitivity is 0.25 mmHg over the entire measurement range. The electronic hardware consists of a piezoresistive pressure sensor, instrumentation amplifier, and analog-to-digital converter (ADC).



- The sensor calibration curve is nonlinear, and can be fitted with a polynomial equation given by $\Delta V = aP - bP^3$, where a = 5 mV/psi and b = 0.05 mV/psi³. For example, the sensor output voltage is ΔV = 9.6 mV when P = 2 psi.
- There are two available amplifiers: (A_{d1} = 75, V_{N1} = 0.2 mV) and (A_{d2} = 125, V_{N2} = 0.3 mV). Both amplifiers have V_{REF} = 1.5V and are powered by +5V and GND. Assume the amplifier outputs are limited to within 1V of each supply.
- The ADC operates from 0 to 5V (12 bits) with V_N = 0.5 mV.
- NOTE: The total noise from two components is computed by: $V_{N,TOTAL} = \sqrt{V_{N1}^2 + V_{N2}^2}$

➢ Are all the design requirements satisfied by one, both, or none of the amplifiers? You must explain why an amplifier works or doesn't work. Show all work!

Hint: Be careful with the nonlinear response of the pressure sensor!

(a) $P_{max} = 205\ \text{mmHg}\ \frac{14.7\ \text{psi}}{760\ \text{mmHg}} = 3.965\ \text{psi}$ $\quad \Delta P_{min} = .25\ \text{mmHg}\ \frac{14.7}{760} = .00484\ \text{psi}$

$\text{Max } \Delta V = 5\ \frac{\text{mV}}{\text{psi}} \times 3.965\ \text{psi} - .05\ \frac{\text{mV}}{\text{psi}^3}(3.965\ \text{psi})^3 = 16.71\ \text{mV}$ (+3)

4 / 1.5 / 1

Method #1: $V_{meas} = 1.5 + A_d \Delta V < 4V \quad A_d < \frac{4 - 1.5V}{.01671V} = 149.6$ (+5) Both amps OK

Method #2:

Amp1: $V_{meas} = 1.5 + 75 \times .01671 = 2.75V$ ✓

Amp2: $V_{meas} = 1.5 + 125 \times .01671 = 3.59V$ ✓

∴ Both amps OK

✱ NOTE: Cannot compute P_{max} for V_{meas} = 4V due to nonlinear sensor response.

(extra sheet for work)

Sensitivity: $\Delta P_{min} = \dfrac{\Delta V_{min}}{\frac{\partial V_{Meas}}{\partial P}}$ ← $\Delta V_{ADC} = \dfrac{5-0V}{2^{12}-1} = 1.22\,mV$

$V_{N1,Total} = \sqrt{.2^2 + .5^2} = .54\,mV$

$V_{N2,Total} = \sqrt{.3^2 + .5^2} = .58\,mV$

(+5)

$V_{Meas} = V_{Ref} + A_d \overbrace{(aP - bP^3)}^{\Delta V}$

$\dfrac{\partial V_{Meas}}{\partial P} = A_d \underbrace{(a - 3bP^2)}$

Depends on pressure!

✻ worst case is smallest $\dfrac{\partial V_{Meas}}{\partial P} \rightarrow 5\,\frac{mV}{psi} - 3\left(.05\,\frac{mV}{psi^3}\right)(3.965\,psi)^2$

$= \underline{\underline{2.64\ mV/psi}}$ (+6)

So, $\Delta P_{min} = \dfrac{1.22\,mV}{A_d\left(2.64\,\frac{mV}{psi}\right)}$ $= .051\ mV/mmHg$ Too high

Amp #1: $A_d = 75 \rightarrow \Delta P_{min} = \dfrac{1.22}{(75)(2.64)} = .0062\,psi$ ✗

$= .0062 \times \dfrac{760}{14.7} = .32\,mmHg$ ✗

(+6)

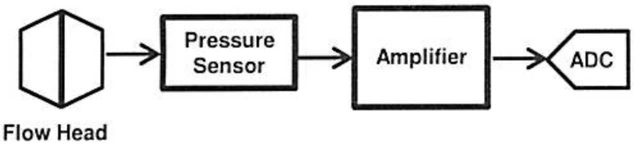
Amp #2: $A_d = 125 \rightarrow \Delta P_{min} = \dfrac{1.22}{125\,(2.64)} = .0037\,psi$ ✓

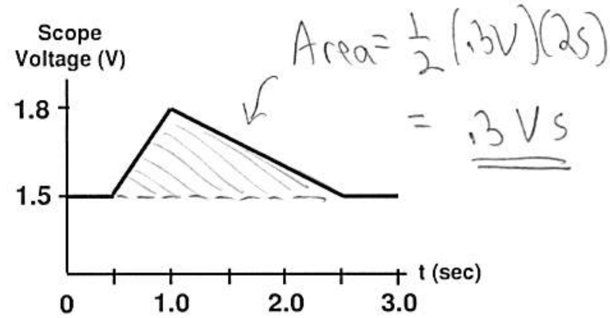
$= .0037 \times \dfrac{760}{14.7} = 0.19\,mmHg$ ✓

Winner is $\boxed{A_d = 125}$!

Problem #4: Spirometer (25 points)

You are asked to design a flow spirometer system to measure a maximum flow of F_{MAX} = 25 L/s with a sensitivity of ΔF_{MIN} = 0.045 L/s. You know the instrumentation amplifier has A_d = 1000 and V_N = 5 mV. It is powered by 10V and GND, so you can assume the amplifier output is limited to +9V (max) and 1V (min). The ADC operates from 0 to 5V with 12 bits and V_N = 2 mV. The system is calibrated by injecting 2 liters of air into the spirometer. The measured voltage is shown below.



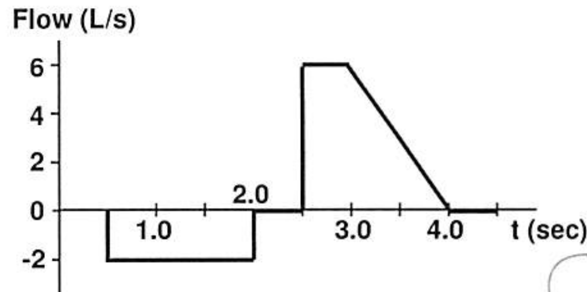


(a) Does the current system satisfy both, one, or none of the design specifications? Show all work!

(b) You have the option of replacing **ONE component**. A new amplifier has A_d = 800 and V_N = 4 mV while a new ADC operates from 0 to 10V with 12 bits and V_N = 5 mV. Should you replace the amplifier or the ADC? Show all work and justify why a component works or does not work!

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

(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!



(a) $V_{Meas} = 1.5 + A_d SRF$

$\int (V_M - 1.5)\,dt = A_d SR \int F\,dt \rightarrow SR = \frac{0.3\,Vs}{1000 \cdot 2L} = 1.5\times10^{-4}\ V{\cdot}s/L$

$0.3\ V{\cdot}s$; 1000 ; $2L$

+3

Too low

Method 1

$V_{max} = 5 = 1.5 + A_d SRF_{max} \rightarrow F_{max} = \frac{5 - 1.5\,V}{1000 \times 1.5\times10^{-4}\ V{\cdot}s/L} = 23.3\ L/s$ X

$V_N = \sqrt{5^2 + 2^2} = 5.4\ mV$

$\Delta F_{MIN} = \frac{.0054V}{1000\,(1.5\times10^{-4}\ V{\cdot}s/L)} = .036\ L/s$ ✓

$\Delta V_{ADC} = \frac{5-0}{2^{12}-1} = 1.22\ mV$

+8

Does NOT satisfy F_{max} but does satisfy ΔF_{min}

Method 2 (extra sheet for work)

$V_{Meas} = 1.5 + 1000\,(1.5\times10^{-4}\ \frac{V\cdot s}{L})(25\ L/s) = 5.25V$ X Too High

$\Delta F_{min} = \frac{.0054V}{1000\,(1.5\times10^{-4}\ V\cdot s/L)} = .036\ L/s$ ✓ ← Only this is satisfied

(b) Method 1

New amp: $V_N = \sqrt{4^2 + 2^2} = 4.5\ mV$

Replace the amplifier! (+1)

$F_{max} = \frac{5 - 1.5V}{800\,(1.5\times10^{-4}\ V\cdot s/L)} = 29.2\ L/s$ ✓

(+3)

$\Delta F_{min} = \frac{.0045V}{800\,(1.5\times10^{-4}\ V\cdot s/L)} = .0375\ L/s$ ✓

New ADC: $V_N = \sqrt{5^2 + 5^2} = 7.1\ mV$ ← ΔV_{min}

$\Delta V_{ADC} = \frac{10-0}{2^{12}-1} = 2.44\ mV$

$F_{max} = \frac{9 - 1.5}{1000\,(1.5\times10^{-4})} = 50\ L/s$ ✓

(+3)

$\Delta F_{min} = \frac{.0071}{1000\,(1.5\times10^{-4})} = .047\ L/s$ X

Method 2

New amp: $V_M = 1.5 + 800\,(1.5\times10^{-4})(25) = 4.5 < 5V$ ✓

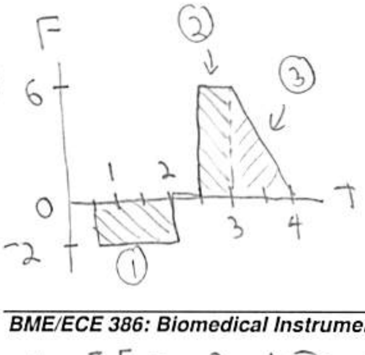
winner!

$\Delta F_{min} = \frac{.0045}{800\,(1.5\times10^{-4})} = .0375\ L/s$ ✓

New ADC: $V_M = 1.5 + 1000\,(1.5\times10^{-4})(25) = 5.25 < 9V$ ✓

$\Delta F_{min} = \frac{.0071}{1000\,(1.5\times10^{-4})} = .047\ L/s$ X

(c)



(2) Max V = 6 × .5 = 3L

(3) Max V = ½ · 6 · 1 = 3L

(1) Max V = −2 × 1.5 = −3L

(+7)