BENG 186B Winter 2013

Quiz 3

March 8, 2013

NAME (Last, First):

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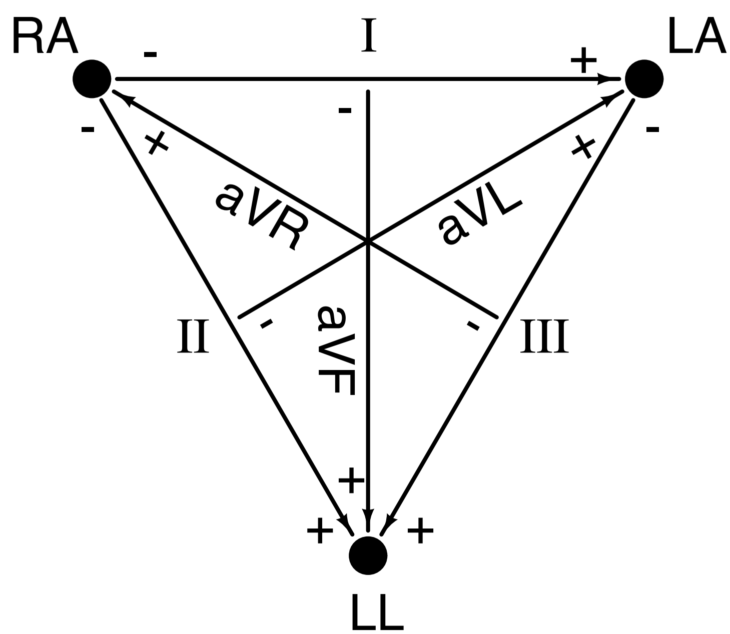
- This quiz is closed book and closed note. You may use a calculator for algebra.
- Write your final answers in the space provided; show your work only on the pages provided.
- Do not attach separate sheets. If you need more space, use the back of the pages.
- Points for each problem are given in [brackets], 100 points total. The quiz is 50 minutes long.

1	/15
2	/40
3	/20
4	/25
Total	/100

1. [**15 pts**] Using Einthoven's Triangle, write the lead voltages I, II, III, aVR, aVL, and aVF in terms of the electrode voltages RA, LA, and LL.



I = ______________________

II = ______________________

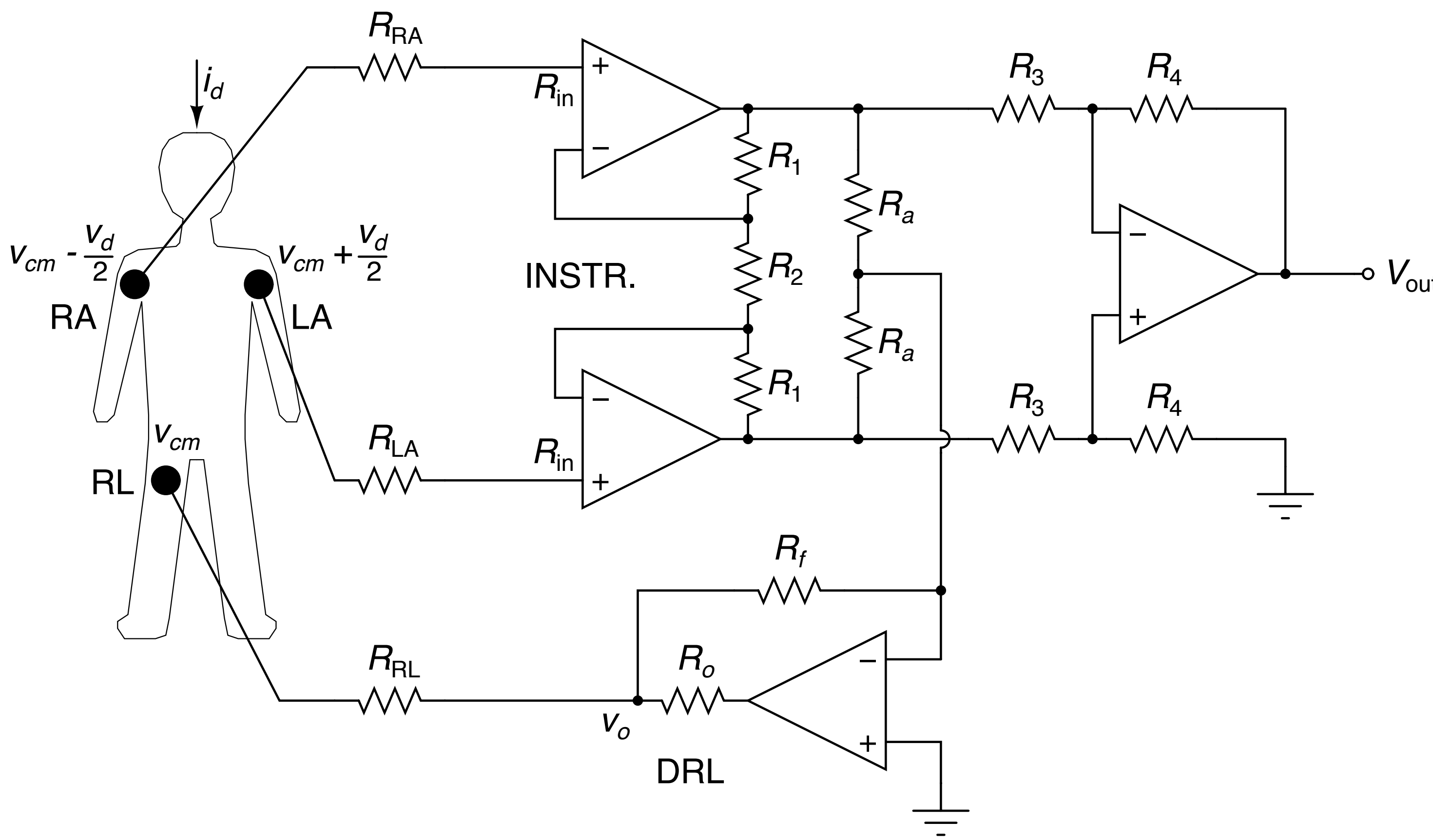
III = ______________________

aVR = ______________________

aVL = ______________________

aVF = ______________________

2. [**40 pts**] Consider a single-lead ECG instrumentation amplifier with driven right leg (DRL), and with three electrodes RA, LA and RL connected to the body as shown below. The electrode-skin interface resistances are R_{RA} = 50 kΩ, R_{LA} = 150 kΩ and R_{RL} = 100 kΩ. The opamp input impedance is R_{in} = 1 GΩ to ground. The instrumentation amplifier resistance values are $R_2 = R_3$ = 1 kΩ and $R_1 = R_4$ = 100 kΩ, and the DRL resistance values are R_a = 100 kΩ, R_f = 10 MΩ, and R_o = 1 MΩ, all exactly (with zero tolerance).



a. [5 pts] What ECG lead does V_{out} represent? What is the polarity of the lead in V_{out}?

Answer:

ECG Lead = ____ Polarity = ____ (+/–)

b. [15 pts] Find the values for differential gain A_d and common-mode rejection ratio CMRR of the instrumentation amplifier connected to the RA and LA electrodes on the body.

Answer:

A_d = __________ CMRR = __________

c. [10 pts] Find the driven right leg (DRL) effective electrode resistance, defined as $R_{\text{RL eff}} = v_{cm} / i_d$.

Answer:

$R_{\text{RL eff}}$ = ___________ kΩ

d. [10 pts] Assume a displacement current of peak amplitude $i_d = 10\ \mu A$ from 60 Hz line noise enters the body, and an ECG differential signal of peak amplitude $v_d = 1$ mV is generated by the heart. Find the amplitude of the resulting 60 Hz common-mode component of the voltage output $V_{out\ cm}$, and the corresponding signal-to-noise ratio SNR_{out} at the output.

Answer:

$V_{out\ cm}$ = __________ SNR_{out} = __________

3. [**20 pts**] An ENT doctor uses a laser Doppler vibrometer to measure the health of the eardrum. The 800 nm wavelength laser beam reflects off the eardrum and returns to a collector located at the same place as it was emitted. The doctor produces single-pitch sound at 20 kHz that causes the eardrum to vibrate sinusoidally with peak amplitude of 100 μm. Find the peak Doppler frequency shift recorded in the returning laser light. *HINT*: light wave frequency is given by $f = c/\lambda$ where $c = 3\ 10^8$ m/s is the speed of light, and λ is the wavelength.

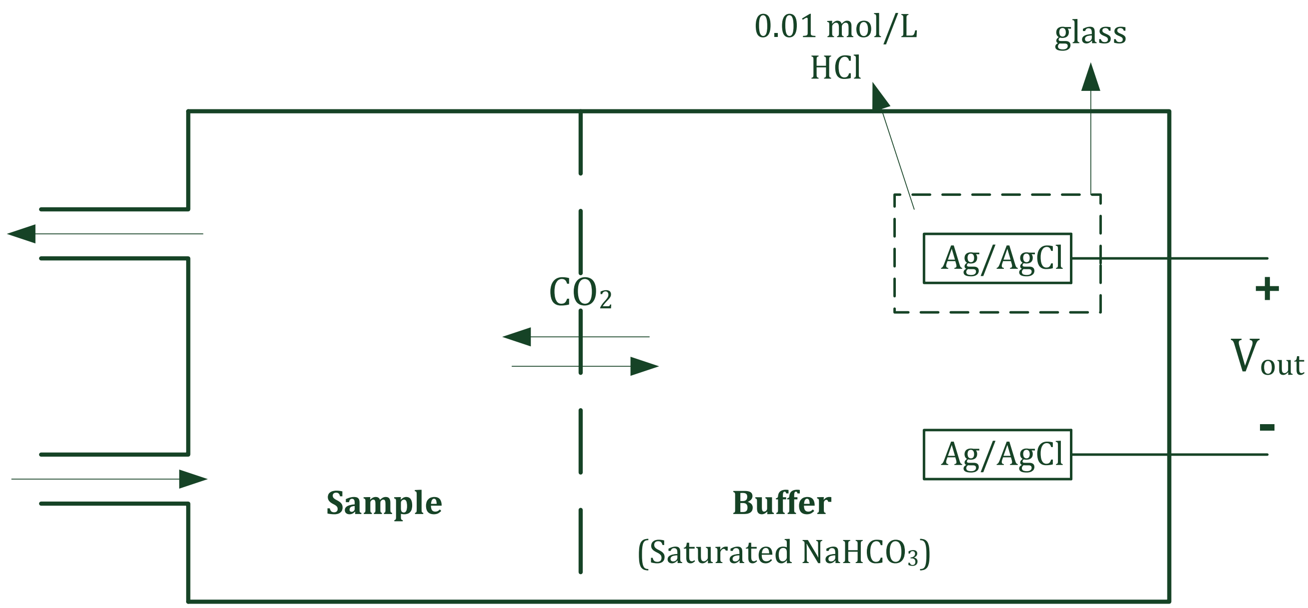
A laser Doppler vibrometer (Polytec) interrogating the eardrum

Doppler frequency shift:

$$\Delta f \;=\; f_R - f_S \;\approx\; \frac{v}{c}\,(\cos\theta_S + \cos\theta_R)\, f_S$$

Answer: Δf_{peak} = ___________ MHz

4. [**25 pts**] A Severinghaus electrode for PCO_2 measurement is shown below. The inside compartment of the glass electrode contains a solution of 0.01 mol/L HCl, and the buffer contains a 0.1 mol/L solution of $NaHCO_3$. The two Ag/AgCl electrodes are identical with half potential $E_{Ag/AgCl} = 0.223$ mV. The membrane between the sample and buffer is permeable to CO_2 only, equalizing the concentration on both sides.



The Nernst potential for ion type A^n of valance n at room temperature is given by:

$$E_{\text{Nernst}} = \frac{60mV}{n} \cdot \log_{10} \frac{\left[A^n\right]_o}{\left[A^n\right]_i}$$

and the relationship between PCO_2 and $[H^+]$ and $[HCO_3^-]$ in the buffer at room temperature is given by:

$$PCO_2 = \frac{100 \text{ mmHg}}{(\text{mol/L})^2} [H^+] [HCO_3^-]$$

a. [10 pts] Write V_{out} as a function of the pH of the buffer solution.

Answer: V_{out} = ______________________________

b. [10 pts] Write V_{out} as a function of the PCO_2 of the sample solution.

Answer: V_{out} = ____

c. [5 pts] For a given PCO_2, does the output V_{out} depend on the flow rate of the blood sample in and out of the instrument? Does it depend on the temperature of the instrument? Explain.

Answer: V_{out} depends on sample flow rate: __________

V_{out} depends on temperature: __________