BENG 186B Winter 2017

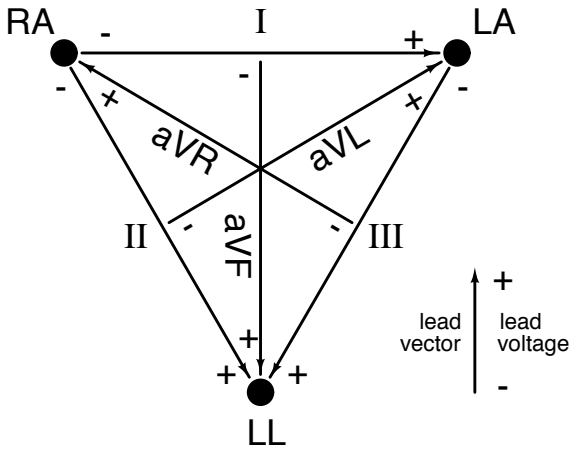
Quiz 3

Monday, March 6, 2017

Last Name, First Name: _____

- This quiz is closed book and closed notes. You may use a calculator for algebra and arithmetic.
- This quiz has 10 pages, including this cover sheet. Do not attach separate sheets. If you need more space, use the back of the pages.
- Circle or box your final answers and show your work on the pages provided.
- There are 4 problems. Points for each problem are given in **[brackets]**. There are 100 points total.
- You have 50 minutes to complete this quiz.

1. **[20 pts]** A differential amplifier is used to record the leads of the frontal electrocardiogram, as shown in the Einthoven's triangle below, by connecting its inputs to different combinations of the electrodes RA, LA, and LL. Assume the triangle is equilateral and the augmented lead vectors (aVR, aVL, and aVF) bisect the bipolar lead vectors (I, II, and III).



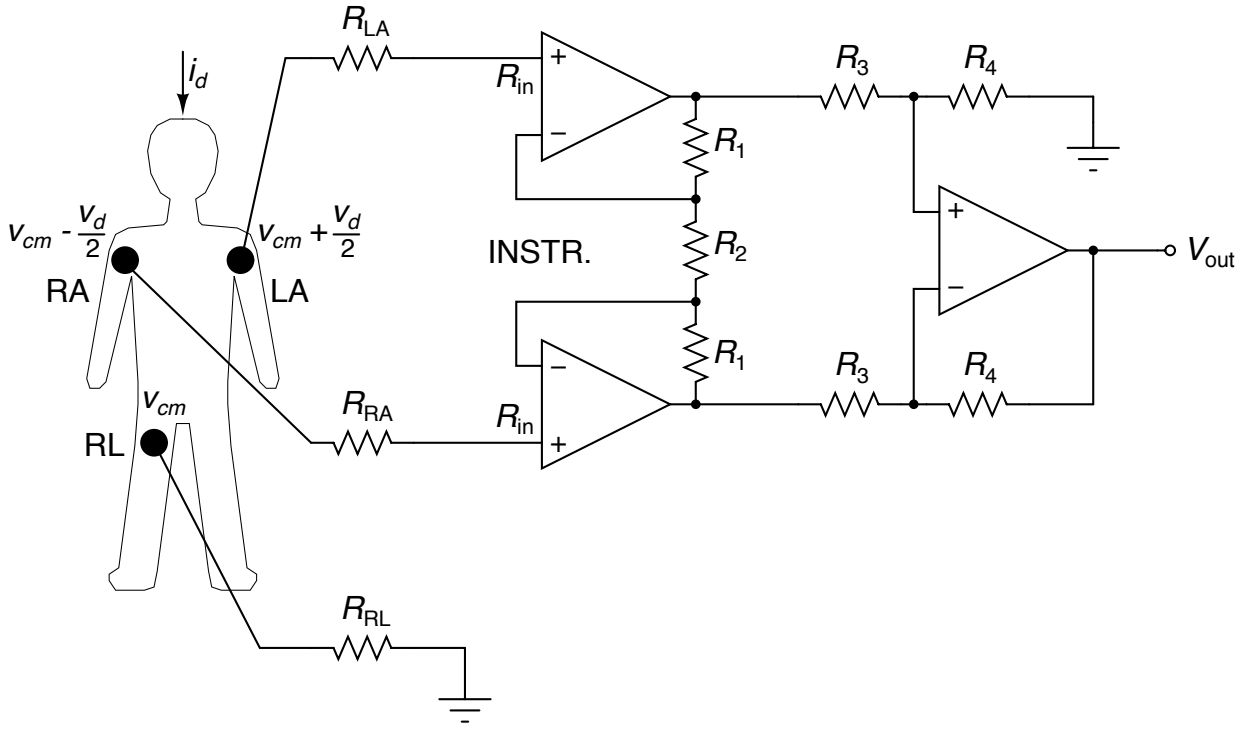
(a) Which of the leads is obtained by connecting the non-inverting input of the differential amplifier to LA, and the inverting input to RA?

(b) Which of the leads is obtained by connecting the non-inverting input of the differential amplifier to LL, and the inverting input to the midpoint of a voltage divider with two identical resistors to RA and LA?

(c) For an adult, the cardiac vector points from the heart to the left leg with magnitude 2.5 mV/m, and the distances from the heart to each of the electrodes are 40 cm. Find the voltage on lead I, and on lead aVF.

(d) How do these voltages differ for a child with the same current dipole but with twice shorter distances 20 cm from the heart to the electrodes?

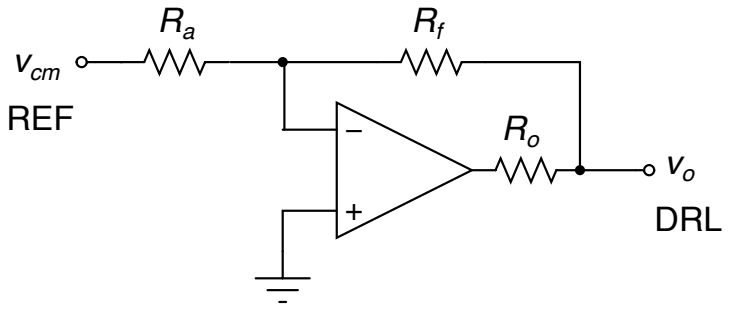
2. **[35 pts]** An instrumentation amplifier is connected to the body as shown below to record a single-lead electrocardiogram. The electrode-skin interface resistances are $R_{RA} = 190$ kΩ, $R_{LA} = 210$ kΩ, and $R_{RL} = 200$ kΩ. The opamp input impedance is $R_{in} = 100$ MΩ to ground. The instrumentation amplifier resistances are $R_2 = R_3 = 10$ kΩ and $R_1 = R_4 = 200$ kΩ.



(a) What ECG lead does the IA output V_{out} represent, and with what voltage gain?

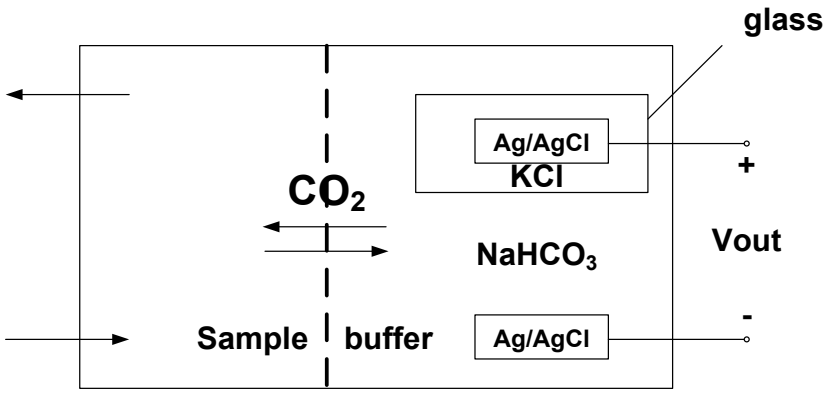
(b) 60 Hz line noise causes a displacement current of peak amplitude $i_d = 10$ μA to enter the body. The peak amplitude of the ECG differential signal on the lead is $v_d = 0.5$ mV. Find the peak amplitude of the 60 Hz common-mode voltage v_{cm} in the body, and the corresponding signal-to-noise ratio (SNR) at the output of the instrumentation amplifier.

(c) A driven-right-leg (DRL) amplifier, as shown below, is now inserted for active grounding. The REF input connects to the RA electrode, and the DRL output connects to the RL electrode which is disconnected from the passive ground in the above diagram. The resistances are $R_a = 200$ kΩ, $R_f = 10$ MΩ, and $R_o = 2$ MΩ. How does this affect the common-mode voltage v_{cm} in the body and the SNR at the output of the instrumentation amplifier? What purpose does the R_o resistance serve?



3. **[20 pts]** Consider the Severinghaus electrode shown below for measurement of PCO_2. The solution internal to the glass membrane is 0.1 mol/L KCl with neutral pH. Assume RT/F ln(10) = 60 mV at room temperature. The following equation may be useful:

$$H_2O + CO_2 \rightleftharpoons H_2CO_3 \rightleftharpoons H^+ + HCO_3^-$$



(a) What voltage V_{out} do you expect for a pH of 6.8 in the buffer solution?

(b) For a calibration sample of PCO_2 = 50 mmHg, we measure V_{out} = 20 mV. Next, for a blood sample we measure V_{out} = 10 mV. Find the PCO_2 of the blood sample.

(c) An additional 0.1 mol of $NaHCO_3$ is added to the 1 L of buffer solution. How do the measurements of V_{out} change for the calibration sample, and for the blood sample?

(d) Do the V_{out} measurements depend on the flow rate of the sample through the instrument?

4. **[25 pts]** Circle the **best answer (only one answer per question)**:

   (a) [4 pts] Two antiparallel diodes are used at the input of a bioinstrumentation amplifier to:

      i. Increase the input impedance for improved CMRR
      ii. Protect the amplifier from accidental over-voltage
      iii. Reduce the input offset voltage of the amplifier
      iv. None of the above

   (b) [4 pts] The compliance of a fluid-filled catheter system depends on:

      i. Elasticity of the diaphragm
      ii. Radius of the catheter tube
      iii. Viscosity of the fluid
      iv. All of the above

   (c) [4 pts] For a quick measurement of systolic and diastolic blood pressure in the doctor's office the instrument of choice is:

      i. A micro-tipped manometer
      ii. A fluid-filled catheter tube
      iii. A sphygmomanometer
      iv. An intraocular tonometer
      v. None of the above

   (d) [4 pts] A range-gated pulsed Doppler ultrasonic flowmeter offers spatial selectivity in imaging blood flow by:

      i. Focusing the source and receiver beam patterns to narrow angle cones
      ii. Performing quadrature modulation of the received return signal with cosine and sine reference signals
      iii. Delaying the reference signal for the Doppler measurement of the received return signal by a variable amount of time
      iv. Positioning the source and the receiver at orthogonal angles to the blood vessel of interest
      v. All of the above

(e) [9 pts] Indicate for each statement below whether it is true or false:

i. **TRUE / FALSE**: Internal catheter-based pressure transducers measure blood pressure directly so they have a high frequency response while being inexpensive and reusable.

ii. **TRUE / FALSE**: The inertance of a fluid-filled catheter increases with the length of the catheter tube.

iii. **TRUE / FALSE**: The Fick technique for measuring cardiac output operates by integrating measured concentration over time after a rapid bolus injection.

iv. **TRUE / FALSE**: Indicator-dilution methods provide an average of cardiac output by observing the rate of change in the concentration of the indicator over time as it passes through the blood stream.

v. **TRUE / FALSE**: The sensitivity of the electromagnetic flowmeter is directly proportional to the externally applied magnetic field.

vi. **TRUE / FALSE**: The platinum electrode in the Clark PO_2 sensor gets consumed over time.

vii. **TRUE / FALSE**: The IMFET transduces concentration of targeted antigens into an electrical conductance.

viii. **TRUE / FALSE**: A "resistive T" can be used to increase the sensitivity of an ISFET H^+ sensor.

ix. **TRUE / FALSE**: Adding a capacitance in parallel with the feedback resistance in a transresistance amplifier gives the potentiostat a high-pass filter characteristic.