SYDE 544: Biomedical Measurement and Signal Processing

Assignment 2: Biopotential Electrodes and Amplifiers

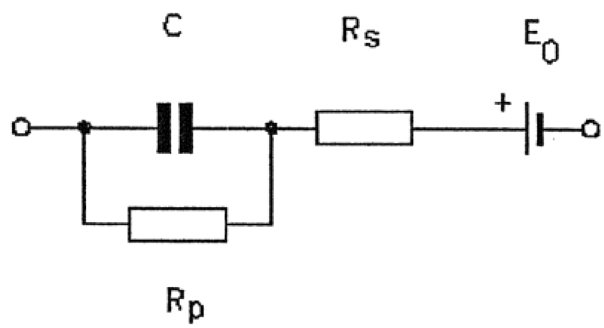
Instructor: Steven Pretty

Due Date: Wednesday, Feb 8th, 2023 (11:59 PM, EST)

Instructions: Solutions to the following problems should be submitted to the LEARN drop box in PDF format.

Part 1: Model of a Biopotential Electrode (4 points)

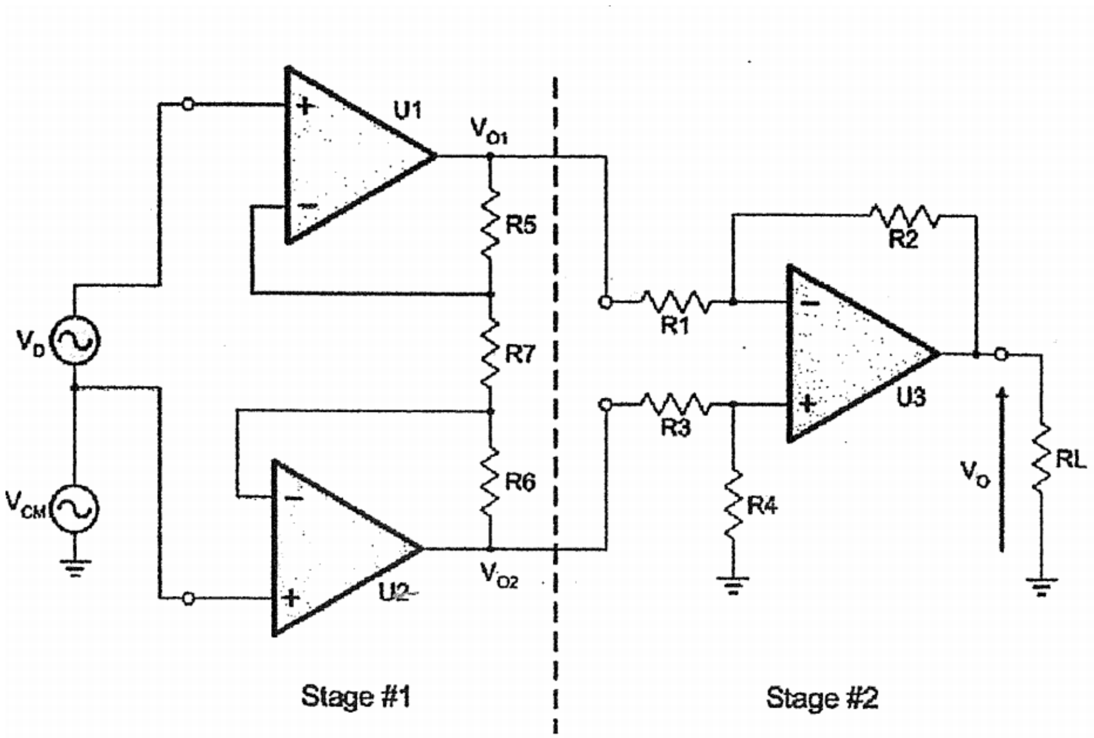
1. Identify each component ($C, R_p, R_s, \text{and } E_O$) and its physical origin in the following equivalent circuit of a biopotential electrode (2 points):



2. During the lectures, we exclusively discussed electrodes used for surface recordings (placed on the surface of the skin). Now please discuss how each of above components might change and why for invasive electrodes, such as a needle or a wire. Assume that the ionic concentrations of electrode gels match interstitial fluid (2 points).

Part 2: Biopotential Amplifiers (10 points)

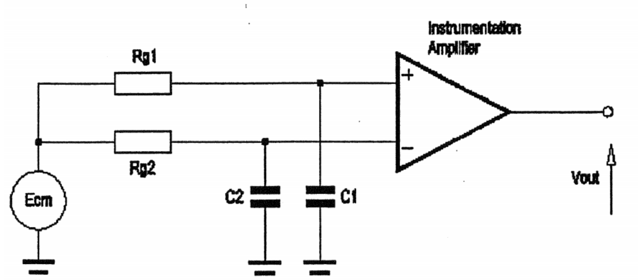
3. In order to improve CMRR of bio-potential amplifier with a single OA design, the follow three-OA design is commonly used:



What is the differential gain of this design (i.e., $A_D = \frac{v_{oD}}{v_D}$)? (3 points)

4. What is the CMRR of the design in question 3? (2 points)

5. An ideal instrumentation amplifier is connected to a bio-potential source with two coaxial cables ($C1$ and $C2$) and two electrodes (R_{g1} and R_{g2}), as shown in the figure below. Assuming the instrumentation amplifier has both infinite CMRR and input impedance, while its differential gain is A_D, what will the actual CMRR be, considering the effect of the cables and the electrodes? Sketch the CMRR against frequency and identify all break frequencies. (3 points)



6. Assume the two cables are identical standard 3-meter co-axial with $C1 = C2 = 58pf/m$, and the resistance of the two electrodes are: $R_{g1} = 10k\Omega$ and $R_{g2} = 11k\Omega$. In what range does the amplifier's CMRR fall below 80dB and what is the CMRR at 60 Hz? (2 points)

Part 3: Electrical Safety in Biopotential Recording (6 points)

7. In the ICU of a hospital, a patient with a trans-venous catheter connected to an external pacemaker, which is operated by batteries and is considered as isolated (from the Main). The patient is lying on a hospital bed. The height and posture of the bed is adjustable with an electric motor.

   Unfortunately, the ground lead of the motor of the bed is broken and the metal bed rail is no longer connected to the ground. Now capacitive coupling between the motor and the bed rail exists. A nurse comes to check on the patient, he/she touches the electrode lead of the pacemaker. The patient, in the effort to turn his face to talk to the nurse, is holding on the metal bed railing. The nurse, in order to see the patient better, switches on a bedside light whose switch toggle is grounded.

   Assuming the following parameters (p = patient; n = nurse; s = skin; b = body):

Patient & Nurse:	
Skin Resistance	$R_{ps} = R_{ns} = 100\ k\Omega$
Body Resistance	$R_{pb} = R_{nb} = 500\ \Omega$
Hardware:	
Electrode Lead Resistance	$0\ \Omega$
Electrode Contact Resistance	$R_e = 1\ k\Omega$
Motor/Rail Coupling Capacitance	$C_c = 2500\ pF$
Motor Voltage	$V_{ac} = 120\ V$ AC @ 60 Hz

   Determine:

   a) The electrical equivalent circuit of the situation (2 points)

   b) What will happen to the nurse at the instant when he/she touches the light switch? Hint: Calculate the current flowing through the nurse (2 points)

   c) What will happen to the patient? Hint: Calculate the current flowing through the nurse (2 points)