Introduction to Biomedical Engineering: 2011 fall Midterm

November 17, 2011

Close book, 120 minutes (PM 1:10~PM 3:10)

Do **not** leave your answer along without any brief explanation.

Equations for reference:

a. 1-D Fourier transform

$$X(\omega) = \int_{-\infty}^{+\infty} x(t) \cdot e^{-j\omega t} dt$$

$$x(\mathrm{t}) = \frac{1}{2\pi} \int_{-\infty}^{+\infty} X(\omega) \cdot e^{j\omega t} d\omega$$

b. Discrete-time Fourier transform (DTFT)

$$X(\omega) = \sum_{n=-\infty}^{+\infty} x[n] \cdot e^{-j\omega n}$$

$$x[n] = \frac{1}{2\pi} \int_{2\pi} X(\omega) \cdot e^{j\omega n}$$

c. Nernst equation (of a permeable ion C)

$$E_C = v_i - v_o = \frac{kT}{qZ} \ln \frac{[C]_o}{[C]_i}$$

k (Boltzmann's constant): 1.38×10^{-23} Joule/K

T: Kelvin scale of absolute temperature (K)

Z: ionic valence

q(the magnitude of electron charge): 1.6×10^{-19} Coulomb

d. Goldman equation

$$E = \frac{kT}{q} \ln \left(\frac{P_K[K^+]_o + P_{Cl}[Cl^-]_i + P_{Na}[Na^+]_o}{P_K[K^+]_i + P_{Cl}[Cl^-]_o + P_{Na}[Na^+]_i} \right)$$

1. 解釋名詞 (25%)
   (1) refractory period
   (2) motor unit
   (3) motion artifact (or movement artifact) of electrode
   (4) linear variable differential transformer
   (5) short-time Fourier transform

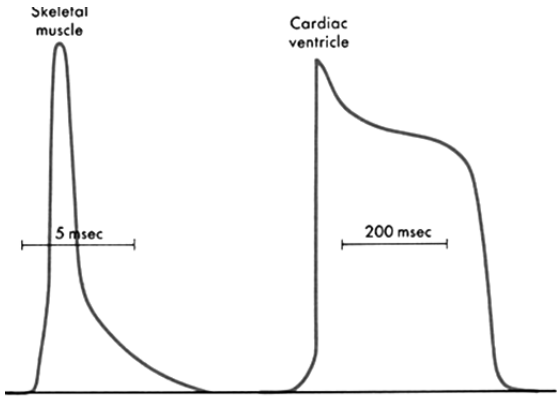
2. (Biopotentials, 18%) The following steady-state concentration of different ions was measured in a living creature found on Mars. As known the average surface temperature on Mars is 210 K and body temperature is 240 K.

Ion	Cytoplasm (mM)	Extracellular (mM)
K^+	155	40
Na^+	12	135
Cl^-	136	32

   (1) Find the Nernst potential for Cl^-. (6%)
   (2) Assume that life on Mars requires a cell potential of +50 mV. Which species of ion will have the highest permeability? Explain why. (6%)
   (3) What is the direction of diffusion and drift for Cl^- ions? (6%)

3. (Biomedical signals, 12%)

(1) As shown below, the action potential waveform of cardiac ventricular muscle with a prolonged plateau looks so different from that of skeletal muscle. Why? (6%)



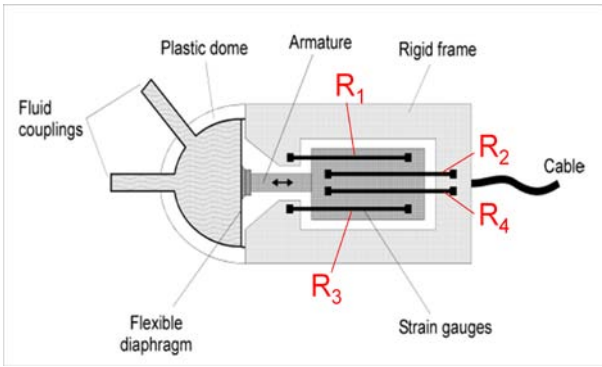
(2) Both magnetoencephalography (MEG) and electroencephalography (EEG) are used to detect bioelectric activity of human cerebral cortex (大腦皮質). What is the advantage and disadvantage of MEG over EEG? (6%)

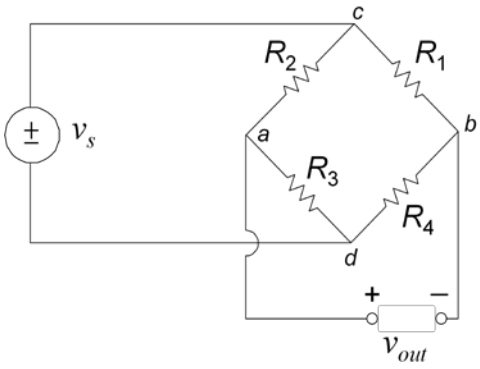
4. (Biosensors, 18%) The structure of a strain-gage pressure sensor and its corresponding equivalent circuit are illustrated as below.

(1) The equivalent circuit is also known as Wheatstone bridge. What is the null condition of the output voltage (v_{out})? (Hint: The relationship between v_{out} and v_s has to be known first.) (6%)

(2) Explain how pressure of fluid can be measured by this instrument. (6%)

(3) Assume all the registers in the diagram has an initial value of R_0. Given that the variation of pressure leads to a decrease of R_1 and R_3 by 2% and an increase of R_2 and R_4 by 2%, calculate v_{out} if v_s = 5V. (6%)

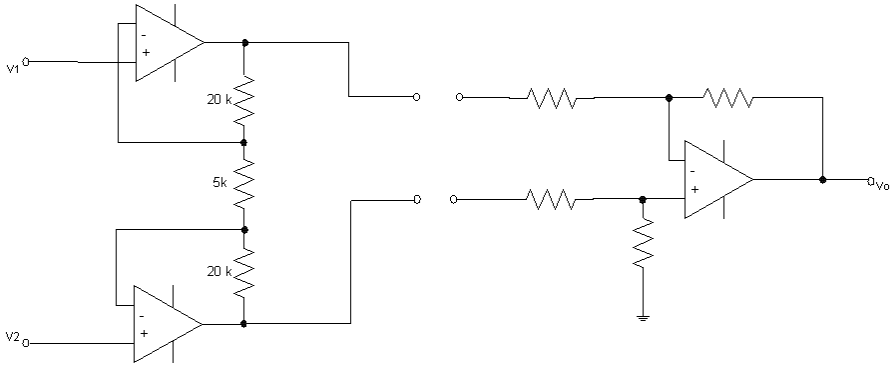




5. (Amplifier, 12%) The figure below shows a differential amplifier consisting of two stages. Stage 2 has a known CMRR of 500.

(1) Calculate the CMRR of the first stage. Then calculate the total CMRR (both stages combined). (6%)

(2) This huge CMRR of the differential amplifier can effectively eliminate the large common-mode signals that usually exist on the body, such as 60-Hz interference. However, it is still possible to observe weak but interfering 60-Hz signal after differential amplification. Why? How can you further reduce it? (6%)



Stage 1 *Stage 2*

6. (Signal processing, 15%)
   (1) As known, the frequency of EEG is generally not higher than 100 Hz. Given that a 50% extra bandwidth is considered sufficient, what is the minimal sampling frequency to record EEG signal? (6%)
   (2) A period of EEG was recorded at a sampling frequency of 250 Hz. After applying discrete Fourier transform (DFT), a discrete spectrum of EEG can be obtained. How can you achieve a spectral resolution of 0.1 Hz? (6%)
   (3) In the evoked potential (or evoked response) experiments, it is important to measure the response time, which is at the scale of few milliseconds (ms), at different cortical (大腦皮質) regions or by different kinds of stimuli (刺激). Do you think the sampling frequency in (a) is enough to estimate the response time precisely? (3%)