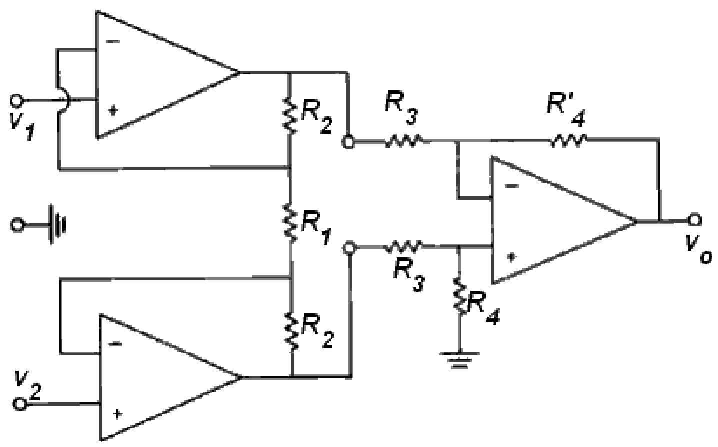
Introduction to Biomedical Engineering: 2018 Spring Final

June 28, 2018

120 points in total. Close book, 170 minutes. (PM 1:10~ 4:00)
You may use calculator, but any electronic device with internet access, like smart phone, is not allowed.

1. 請以 20-60 字解釋下列名詞 (24%)
   (1) 12-lead ECG (12 通道心電圖)
   (2) Let-go current
   (3) Hounsfield unit
   (4) Central slice theorem (i.e., Fourier slice theorem)

2. (Amplifier, 24%) One key source of interference during the measurement of biopotentials is from electromagnetic interference at power line frequency (60 Hz in Taiwan). Consider an instrumentation amplifier as shown below.
   (1) Given R_1 = 1 kΩ, $R_2 = R_3$ = 10 kΩ, and $R_4 = R_4'$ = 20 kΩ, calculate the differential gain of this circuit. (6%)
   (2) Calculate the common-mode gain when R_1 = 1 kΩ, $R_2 = R_3$ = 10 kΩ, R_4 = 20 kΩ and R'_4 = 20.5 kΩ. (6%)
   (3) Assume the amplitude of the cardiac R-wave is 2 mV and the magnitude of power line interference reaches 120 mV, what CMRR is required so that the difference signal is 10 times larger than the interference? With the resistance given in (2), is the amplifier able to satisfy the requirement? Assume the common-mode voltage (Vcm) is totally contributed by the power line interference. (6%)
   (4) Huge CMRR of the instrumentation amplifier can effectively eliminate the common-mode signals. However, it is still possible to observe weak but interfering 60-Hz signal after differential amplification. Why? (6%)



3. Given a time-varying signal as below

$$x(t) = 10\sin(2\pi\, 10t) + 5\sin(2\pi\, 100t)\text{ , for } 0 < t < 100 \text{ ms}$$
$$10\sin(2\pi\, 50t) - 5\sin(2\pi\, 200t)\text{ , for } 100 < t < 200 \text{ ms}$$

Now you are asked to perform the analog-to-digital conversion (ADC), followed by the short-time Fourier analysis to monitor its spectrum over time.

(1) What is the minimal sampling frequency to accurately record this signal? (6%)

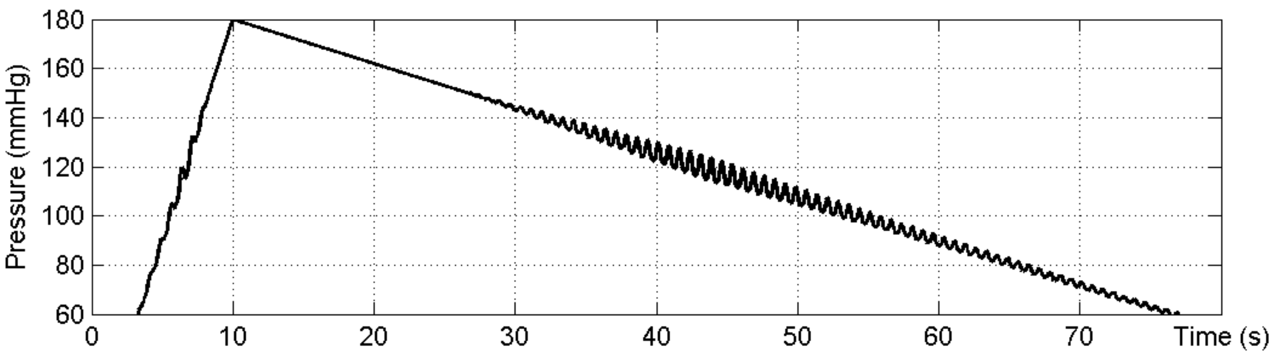
(2) Assume a rectangular window function without overlapping is considered in the short-time Fourier analysis. Do you think a window width of 20 ms is appropriate here? Explain why. (6%)

4. Heart sounds is the vibration generated by the beating heart and the resultant flow of blood through it.

(1) Please draw the normal PQRST waveform of electrocardiogram (ECG). Illustrate the corresponding phonocardiogram (心音圖) and mark the presence of the first (S_1) and the second (S_2) heart sounds. (6%)

(2) What is the main reason to cause the first (S_1) and the second (S_2) heart sounds? Please indicate which part of the heart is involved respectively. (6%)

5. An indirect blood pressure instrument (i.e., sphygmomanometer) is usually implemented with an inflatable cuff (可充氣的束帶) surrounding the arm. At the beginning, the cuff is inflated rapidly and then deflated gradually. The cuff pressure is measured and shown in the figure below (amplitudes of oscillation are exaggerated from those in an actual system). From this curve, roughly estimate: (1) systolic pressure, (2) diastolic pressure, and (3) the heart rate. (12%)

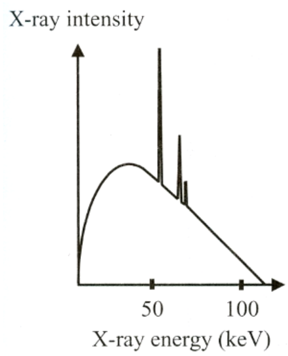


6. The energy spectrum generated by a clinical (臨床的) X-ray tube are shown right. Sketch the corresponding spectrum with the same X-ray tube by

(1) increasing the kVp by 50% (3%)

(2) increasing the mAs by 50% (3%)

(3) the expected effect on the X-ray imaging by doing (1) and (2). (6%)



7. SPECT and PET are two imaging modalities (造影模式) that are common used in nuclear medicine. Please compare these two techniques in terms of:
   (1) signal source (also make an example of radioactive isotope for each technique) (8%)
   (2) the difference in composing hardware (4%)
   (3) image resolution (4%)

8. MRI is a non-radioactive medical imaging technique that are able to produce good contrast between soft tissues. MRI scanners use strong magnetic fields, electric field gradients, and radio-frequency waves to generate images of the organs in the body.
   (1) What is the pulse duration of a 90-degree excitation for proton (^1H nucleus)? Given that the main magnet field (B_0) is 1.5 Tesla and the excitation field (B_1) is 0.5 Gauss. The gyromagnetic ratio of ^1H is 42.58 MHz/Tesla or $2\pi \times 42.58 \times 10^6$ radian/Tesla. (6%)
   (2) What will become double when the main magnetic strength is increased from 1.5 to 3.0 Tesla? (可複選, 6%)
   (A) the resonance frequency (Larmor frequency) corresponding to B_0 field; (B) the maximal additional magnetic field that can be generated by the gradient coil; (C) the central frequency of the receiving signal.

感謝各位同學參與這學期的課程，期末考批閱完畢後會立即上網公告，若是有疑問的同學可於下週一 **7/2 下午 2-4 點**到我的辦公室(EC8006)看考卷，該時段若有困難請儘早以 email 聯絡。

最後，祝各位擁有一個充實的暑假！