SYSC 3203: Midterm #1

Oct 11, 2017

Carleton University, Systems and Computer Engineering

Name: ______________________________ **Student Number:** ____________________

Instructions:

- This test has **6** pages and **5** questions. Answer all questions and subparts. All questions and subparts are worth equal marks.
- You have **80 minutes** to complete this exam.
- This is a closed book exam; however, you are permitted to bring one 8.5"$\times$11" sheet of notes.
- You are permitted to use a non network-connected calculator.
- Answers should be written in this exam document. Write your answers in the space provided.
- If you require more space, attach extra pages to the exam, write your name on the pages, and clearly indicate that extra space was used.
- All electronics components may be assumed ideal, unless stated otherwise.

1. **Electrical Safety** (20 points)

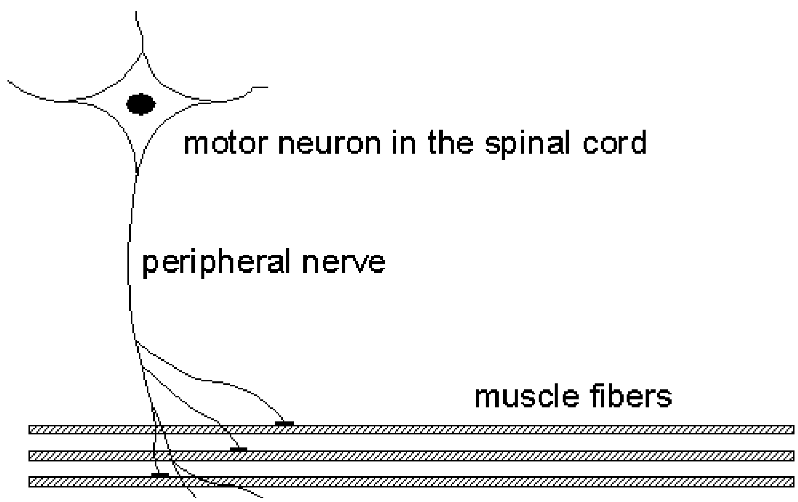
   1A. **i) What is the difference** between *ventricular fibrillation* and *sustained myocardial contraction*? **ii) Indicate which one occurs** at the lower current level and briefly **expain why**?

   1B. **i) Use a diagram to illustrate** a motor nerve and muscle fibres in a motor unit. **ii) Why are all muscle fibres** in a motor unit active at the same time?

1A. **i)** Ventricular fibrillation may occur when an externally applied electrical current (shock) interferes with the normal sinus rhythm of the heart. The heart muscle is still contracting, but its pumping efficiency is greatly reduced. In contrast, during sustained myocardial contraction, the heart muscle remains contracted (tetanus) so that it is not pumping blood at all.

ii) Ventricular fibrillation (Vfib) occurs at a lower current than sustained myocardial contraction. For Vfib to occur, it is only necessary for some regions (cells) of the cardiac muscle to get out of synchronization with the rest of the heart, whereas for sustained myocardial contraction, the current must be large enough to depolarize the whole muscle.

1B. **i)**



Source: signal.uu.se

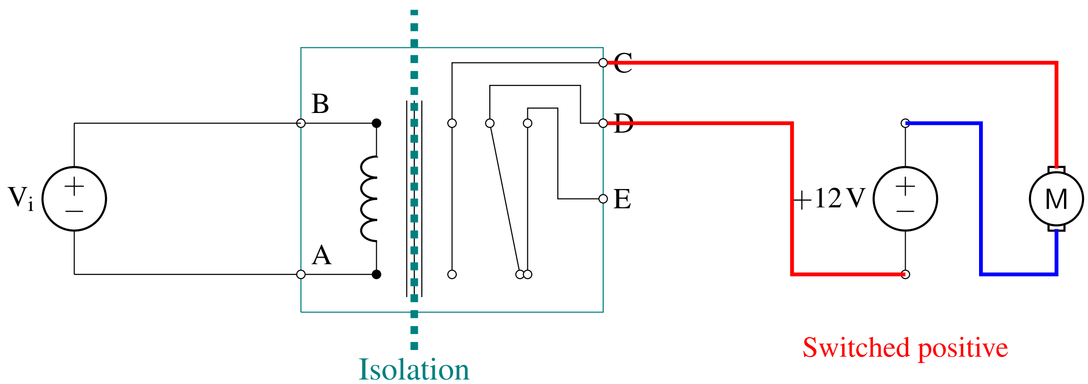
ii) Because all muscle fibres in a motor unit are activated by a single motor neuron.

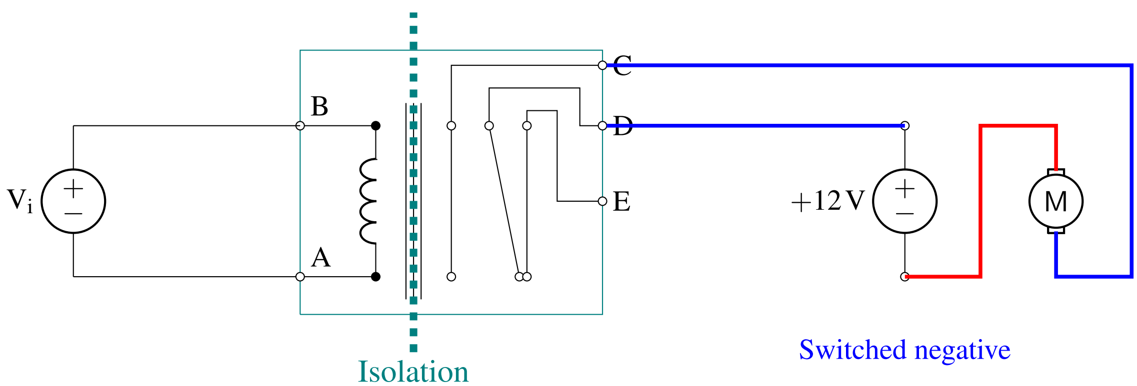
2. **Electrical Isolation** (20 points)

Electrical safety is obviously an important factor in biomedical electronics. A relay (shown below) is designed to provide electrical safety for a powered exoskeleton. The input (V_i) is from an interface to the user. When the user wants the motor to turn on to move the exoskeleton, then $V_i = 5\,V$. When the user wants the motor to turn off, $V_i = 0\,V$ (the relay is currently in this position).

2A. **i) Describe how** a relay works. **ii) Show how** connections C, D and E could be connected to the motor (M), and motor power supply (+12 V) (*there are several correct connections*).

2B. **i) Describe**, briefly, how a relay provides electrical isolation (i.e. electrical safety)? **ii) Indicate** the line of electrical isolation in the circuit below.





2A. **i)** A relay is a switch that is controlled by a solenoid (electro-magnet). When the coil of the relay is energized by passing a current through it, pairs of contacts in the switch are pulled from normally open (NO) to closed and/or from normally closed (NC) to open by the force of the magnetic field.

ii) Connect the positive supply via normally open (NO) contacts D-C such that the circuit is only completed when the relay coil is energized - see upper figure. *A "switched negative" configuration is also acceptable - see lower figure.*

2B. **i)** A relay provides *electromagnetic* isolation. The switching signal takes the form of a magnetic field between the coil and the contacts – there is no electrical path between them and so no current passes from one to the other, at least until the voltage exceeds the breakdown voltage of the medium between them (often air, which has a dry breakdown voltage of approximately $3x10^6\,V/m$ for example).

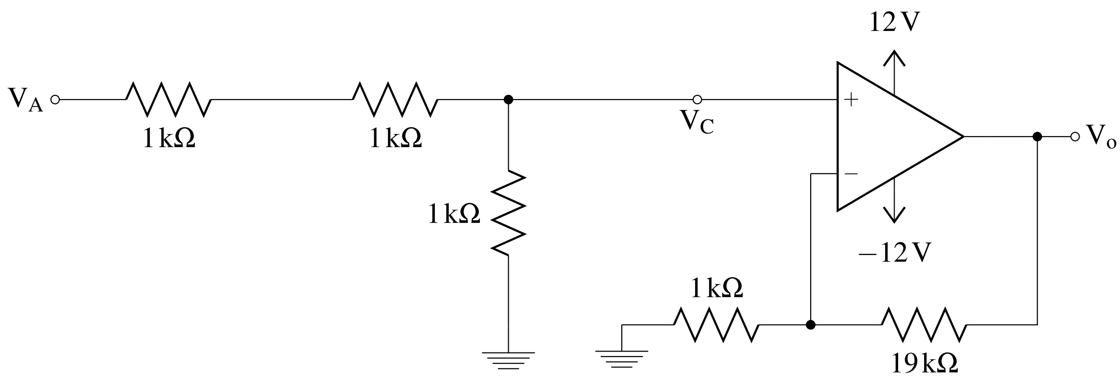
ii) The isolation barrier lies between the coil and the contacts. See figure.

3. **Amplifier Limitations** (20 points)

   Op amps are ideal, except the output, V_o, is limited to the power supply range (from V_{EE} to V_{CC})

   3A. When V_A is as shown below, **sketch the output**, V_C, on the same graph. Indicate voltage levels.

   3B. **Sketch the output**, V_o, on the same graph. Indicate voltage levels and times of any transitions.



Amplifier is NON-INVERTING with gain

$$\frac{V_o}{V_i} = 1 + \frac{19\text{k}}{1\text{k}} = 20$$

Input network is a simple voltage divider i.e.

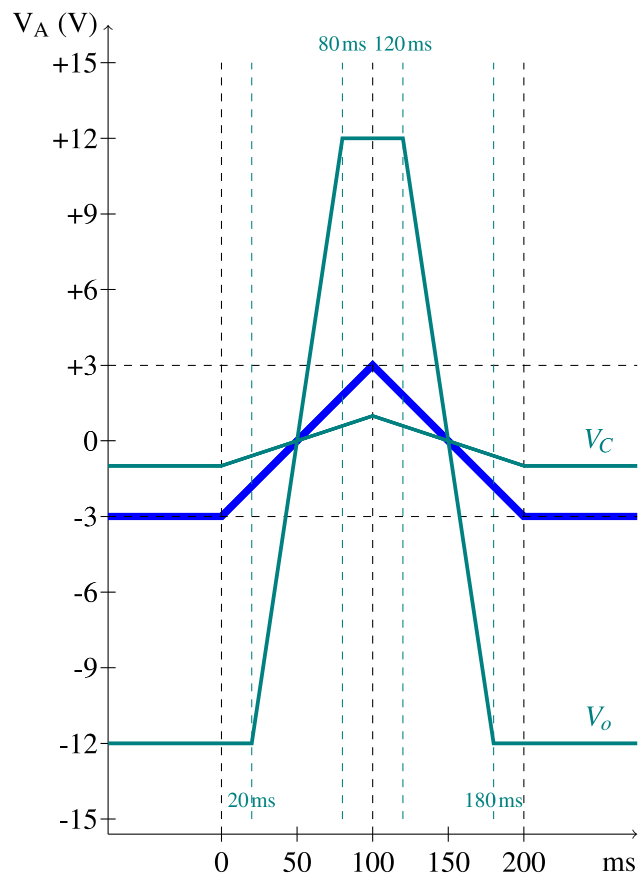
$$V_C = \frac{1}{3} V_A$$

Hence if V_A goes from $-3\,\text{V}$ to $+3\,\text{V}$, then V_C will go from $-1\,\text{V}$ to $+1\,\text{V}$, following the same shape as V_A. V_o will try to from $-20\,\text{V}$ to $+20\,\text{V}$ and back, but will be limited to $\pm 12\,\text{V}$.

The slope will be $40/100 = 0.4\,\text{V/ms}$. Starting at $t = 0$, the output will need to rise from a notional $-20\,\text{V}$ to $-12\,\text{V}$ before it *actually* starts to rise; this takes a time

$$\Delta t = \frac{(-12)-(-20)}{0.4} \frac{\text{V}}{\text{V/ms}} = 20\text{ms}$$

Similarly it will hit $+20\,\text{V}$ at a time 20 ms before 100 ms, stay there until 20 ms after 100 ms, and finally hit $-12\,\text{V}$ again 20 ms before V_A returns to $-3\,\text{V}$ at 200 ms.

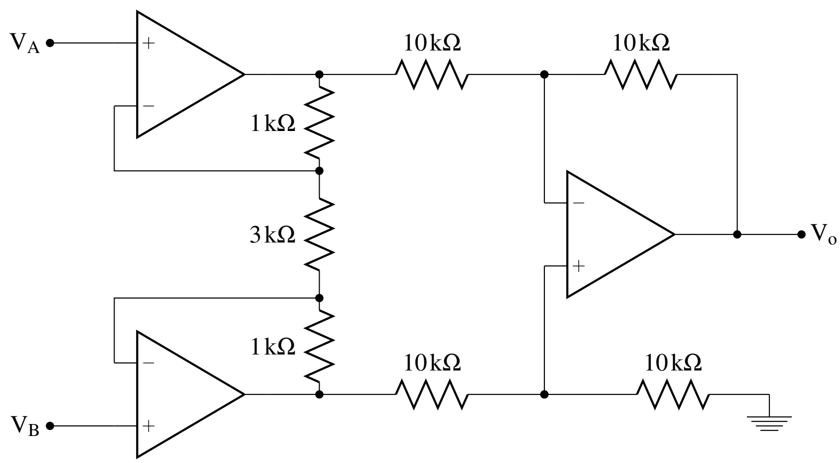


4. **Instrumentation Amplifiers** (20 points)

   Op amps are ideal. The power supply range is $V_{EE} = -15\,V$ and $V_{CC} = 15\,V$.

   4A. When $V_B = -3\,V$, and V_A is as shown below, **sketch the output**, V_o, on the same graph. Indicate voltage levels and the times of any transitions.

   4B. Assume the CMRR is 80 dB (this means resistor values are a fraction of a percent different from the values shown). **What is** V_o **at** $t = 210\,ms$?



The differential gain of the instrumentation amplifier is

$$G_d = 1 + \frac{2R}{R_G} = 1 + \frac{2\,k}{3\,k} = \frac{5}{3}$$

(the gain of the difference amplifier portion is 1). So

$$V_o = G_d V_d = \frac{5}{3}(V_B - V_A)$$

Note the sign – we can tell because the V_A input feeds the inverting side of the difference amplifier. At $t = 0$, $V_A = V_B = -3\,V$ and so $V_o = 0\,V$. At $t = 100\,ms$, $V_B - V_A = (-3) - (+3) = -6\,V$ and

$$V_o = G_d V_d = \frac{5}{3}(-6) = -10\,V$$

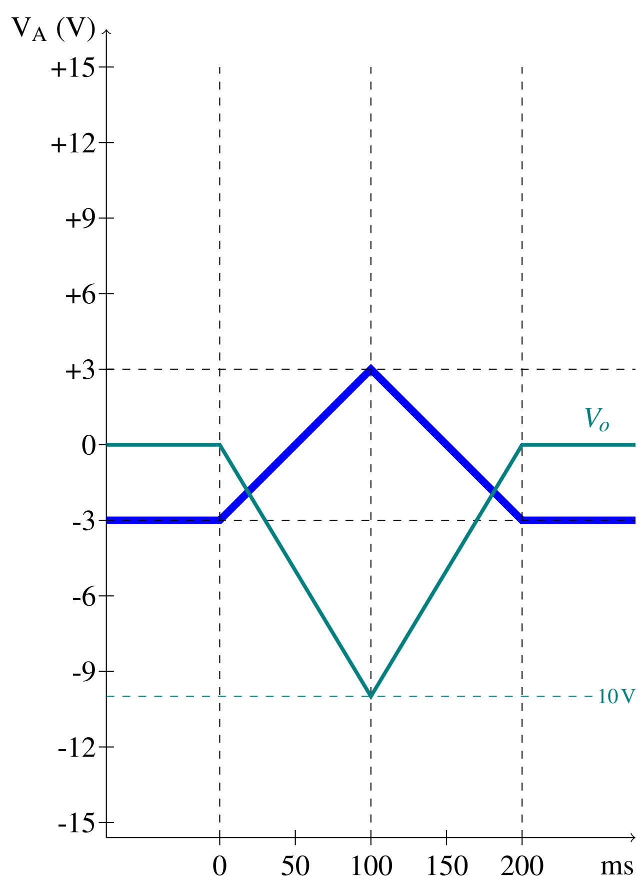
When CMRR = 80 dB,

$$\frac{G_d}{G_{cm}} = 10^{80/20} = 10^4 \implies G_{cm} = \frac{G_d}{10^4} = \frac{5}{3}10^{-4}$$

At $t = 210\,ms$, $V_d = 0$ and $V_{cm} = (-3\,V - 3\,V)/2 = -3\,V$, so

$$V_o = G_{cm} V_{cm} = (-3)\frac{5}{3}10^{-4} = (-)0.5\,mV$$

(We don't actually know what sign it is, since the CMRR really only tells us the ratio of the absolute gains.)

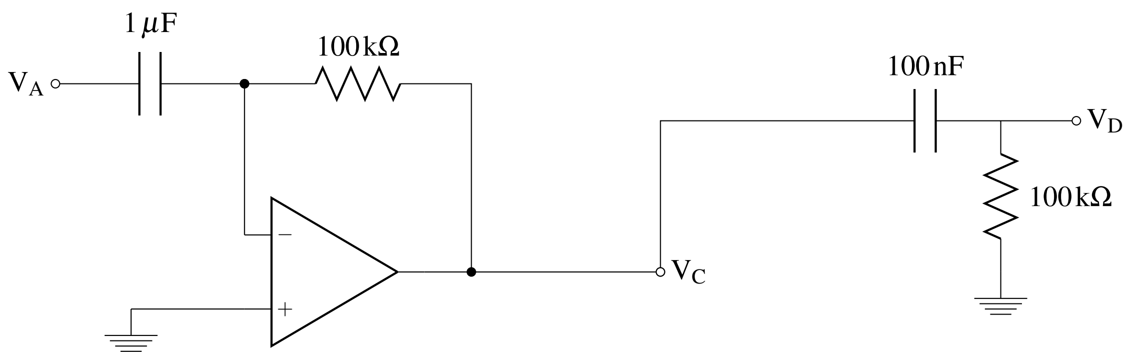


5. **Differentiators and RC filters** (20 points)

   Op amps are ideal. The power supply range is $V_{EE} = -15\,V$ and $V_{CC} = 15\,V$.

   5A. When V_A is as shown below, **sketch the output**, V_C, on the same graph. Indicate voltage levels.

   5B. **Sketch the output**, V_D, on the same graph. Indicate voltage levels (to within 1% accuracy) and illustrate time-constants.



The first part of the circuit is an ideal differentiator with

$$V_C = -RC\frac{dV_A}{dt}$$

To show this, note that the charge on the capacitor is $Q = C(V_A - 0)$ so that there will be a displacement current $i_C = dQ/dt = C dV_A/dt$. Applying KCL at the V^- node, i_C must be balanced by an equal and opposite current $i_R = (V_C - 0)/R$ through the resistor.

In this case, $RC = (100\,k\Omega)(1\,\mu F) = 100\,ms$, while the derivative of V_A goes from 0 to $6\,V/100ms$, to $-6\,V/100ms$, and then back to 0. We get V_o by multiplying dV_A/dt by 100ms. So V_C just goes from 0 V to -6 V, then to $+6$ V, and finally back to 0 V.

The second part of the circuit is a non-ideal differentiator, whose response you should know goes as

$$V_D = \Delta V_C e^{-(t-t_0)/\tau}$$

i.e. a "spike" of magnitude ΔV_C decaying to $1/e$ of its initial value after time τ. Here, the time constant $\tau = RC = (100\,nF)(100\,k\Omega) = 10\,ms$ and there are three ΔV_C excursions at three different t_0 values: first at $t_0 = 0$, $\Delta V_C = -6\,V$; then at $t_0 = 100\,ms$, $\Delta V_C = +12\,V$; finally at $t_0 = 200\,ms$, $\Delta V_C = -6\,V$ again. The values 10ms later will be approximately $-2.2\,V$, $+4.4\,V$, and $-2.2\,V$.