SYSC 3203: Final Exam

December 12, 2016

Carleton University, Systems and Computer Engineering

Instructions:

- This exam has **13** pages and **12** questions. Answer all questions. All questions have equal marks.
- You have **180 minutes** to complete this exam. Write your answers in the space provided.
- This is a closed book exam; however, you are permitted to bring one 8.5"×11" sheet of notes.
- You are permitted to use a non network-connected calculator.
- All components may be assumed ideal, unless stated otherwise.
- You may need the following table of filter properties.

N	F_s(40dB)	F_s(60dB)	F_s(80dB)	f_n	G	f_n	G	f_n	G	f_n	G
FILTER = Chebychev 0.10dB											
2	18.11	57.28	181.13	1.820	1.697						
4	3.10	5.41	9.55	0.789	1.384	1.153	2.542				
6	1.81	2.54	3.64	0.513	1.332	0.834	2.249	1.063	2.784		
8	1.43	1.79	2.30	0.382	1.314	0.645	2.155	0.894	2.592	1.034	2.876
FILTER = Chebychev 0.20dB											
2	15.21	48.08	152.05	1.535	1.745						
4	2.85	4.95	8.75	0.701	1.452	1.095	2.589				
6	1.72	2.40	3.44	0.460	1.402	0.803	2.330	1.038	2.810		
8	1.39	1.73	2.21	0.343	1.386	0.623	2.246	0.878	2.642	1.021	2.892
FILTER = Chebychev 0.50dB											
2	11.99	37.84	119.67	1.231	1.842						
4	2.55	4.42	7.78	0.597	1.582	1.031	2.660				
6	1.61	2.23	3.19	0.396	1.537	0.768	2.448	1.011	2.846		
8	1.33	1.64	2.09	0.297	1.522	0.599	2.379	0.861	2.711	1.006	2.913
FILTER = Chebychev 1.00dB											
2	9.95	31.41	99.31	1.050	1.955						
4	2.34	4.03	7.08	0.529	1.725	0.993	2.719				
6	1.54	2.11	3.01	0.353	1.686	0.747	2.545	0.995	2.875		
8	1.29	1.58	2.01	0.265	1.672	0.584	2.489	0.851	2.766	0.997	2.930

Background: After graduation, you get a job with a company which is building exoskeletons to help elderly patients walk. The idea is to provide a power assist to the legs. As shown in the figure below, the device makes EMG measurements on the leg muscles of the device user, and uses them to drive the motors in the exoskeleton which surrounds the patient as they walk.

In this course, you have learned about many of the elements of this design, from the EMG electrodes, amplifiers, to the A/D converters and motors which form part of the design.

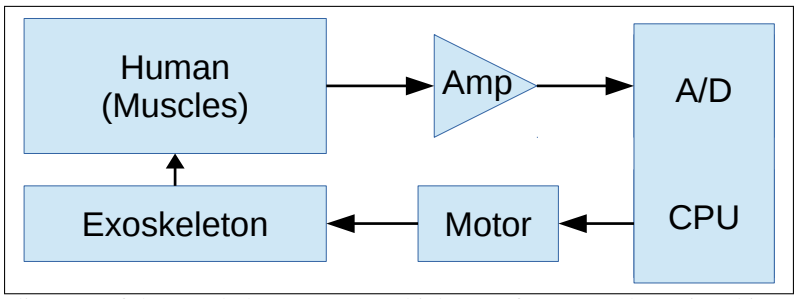


Figure: block diagram of the exoskeleton system which your future employer is asking you to design.

1. **Electrodes and Electrical Safety**

   Your employer is (naturally) concerned about the safety of the design. A decision has already been made to use 12 V batteries, which must be removed from the exoskeleton during charging. (Note, we are only concerned with electrical safety in this question; the motors and exoskeleton pose their own safety concerns)

   1A. (5 marks) **What type of shock hazard** does this system represent: macro- or micro-shock? **Describe one physiological effect of electricity** which could happen to the user if she or he were shocked, and what threshold is relevant?

1B. (5 marks) The user's EMG is measured using stainless steel electrodes which are placed onto the skin. **What are the following effects and how do they contribute to the measured voltage**: i) the polarization effect, and ii) the activation (i.e. 1/2-cell potential). (Both electrodes are the same metal, and you can assume they are at the same temperature).

1C. (5 marks) It is decided to use optical isolation to protect the device user from potential shocks through the electrodes. **Describe** one optical isolation technology, **using a sketch, describe** how it works and show the isolation barrier.

2. **Amplifiers**

Your company has decided to use the XYZ123 instrumentation amplifier manufactured by BigElectronicsCompany (The rumour inside your company is that the CEO was playing golf with a sales representative from BigElectronicsCompany and the decision was made after many drinks).

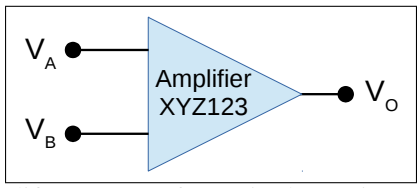


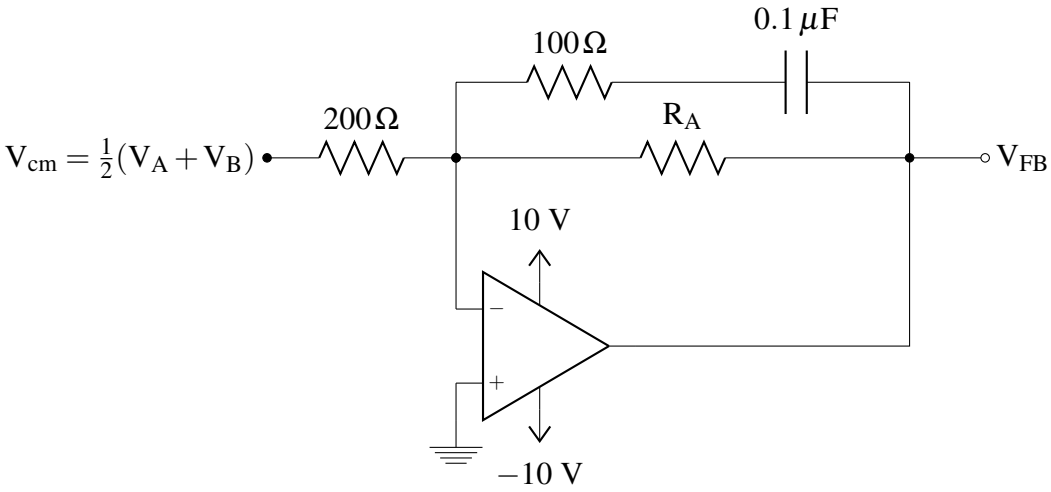
Figure: Amplifier XYZ123 from BigElectronicsCompany, Inc.

2A. (5 marks) In order to determine the DC amplifier imperfections of the XYZ123, the following calibration data were measured. Different values of V_A and V_B were input to the amplifier and the output, V_O, measured. (Not all values in the table are required to answer the question)

V_A (mV)	-20	-20	-20	0	0	0	+20	+20	+20
V_B (mV)	-20	0	+20	-20	0	+20	-20	0	+20
V_O (V)	-0.004	-1.002	-2.000	+0.998	0	-0.998	+2.000	+1.002	+0.004

For the XYZ123, calculate the i) differential and ii) common mode gain, and iii) the CMRR (in dB).

2B. (5 marks) A “driven-leg" circuit is used (below) in which the common-mode signal from the XYZ123 amplifier is used to drive a negative feedback signal (V_{FB}) to the body to reduce the common-mode input at V_A and V_B.

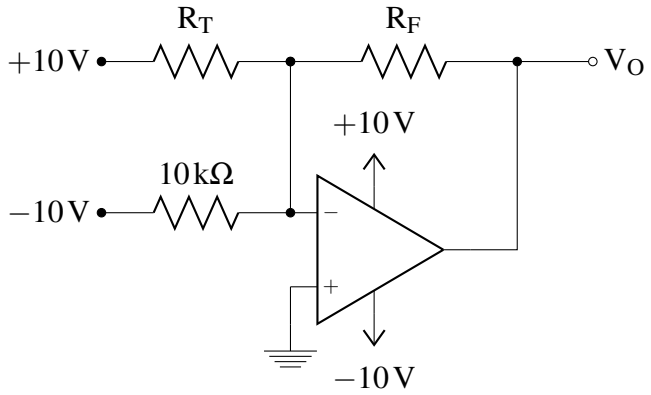


Calculate R_A such that the low frequency gain ($G = V_{FB}/V_{CM}$) is -100, and **estimate** the frequency at which this gain begins to decrease.

3. **Sensors and Analog to Digital Converters**

One important aspect for user comfort and safety is to ensure that the exoskeleton does not overheat and burn the user's skin. To do this, we need to measure the temperature of the leg where it touches the system.

3A. (5 marks) A thermistor (R_T) is chosen and used in the following circuit



At body temperature (37°C), $R_T = 10.3\,k\Omega$, while when hot (40°C), $R_T = 9.4\,k\Omega$. **Calculate** R_F so that V_O changes by 3 V as the temperature goes from 37 to 40°C?

3B. (5 marks) An A/D converter is used to measure the temperature. It has a range of $\pm 10\,\mathrm{V}$ and samples at 10.0 samples/sec. **What is the required resolution** so that the temperature can be measured to a precision of 0.01°C? **What is the minimum number** of converter bits, B?

4. **Motors and Actuators**

A brushless DC motor is used to drive the movement of the exoskeleton. The mechanical structure of a cross section of the motor is shown below.

4A. (5 marks) On the diagram below, indicate i) **the location** of the poles of the permanent magnet, ii) **the location** of the wiring for the electromagnet, including which parts should be wound in opposite directions. Connect the wires to the terminals below the figure.

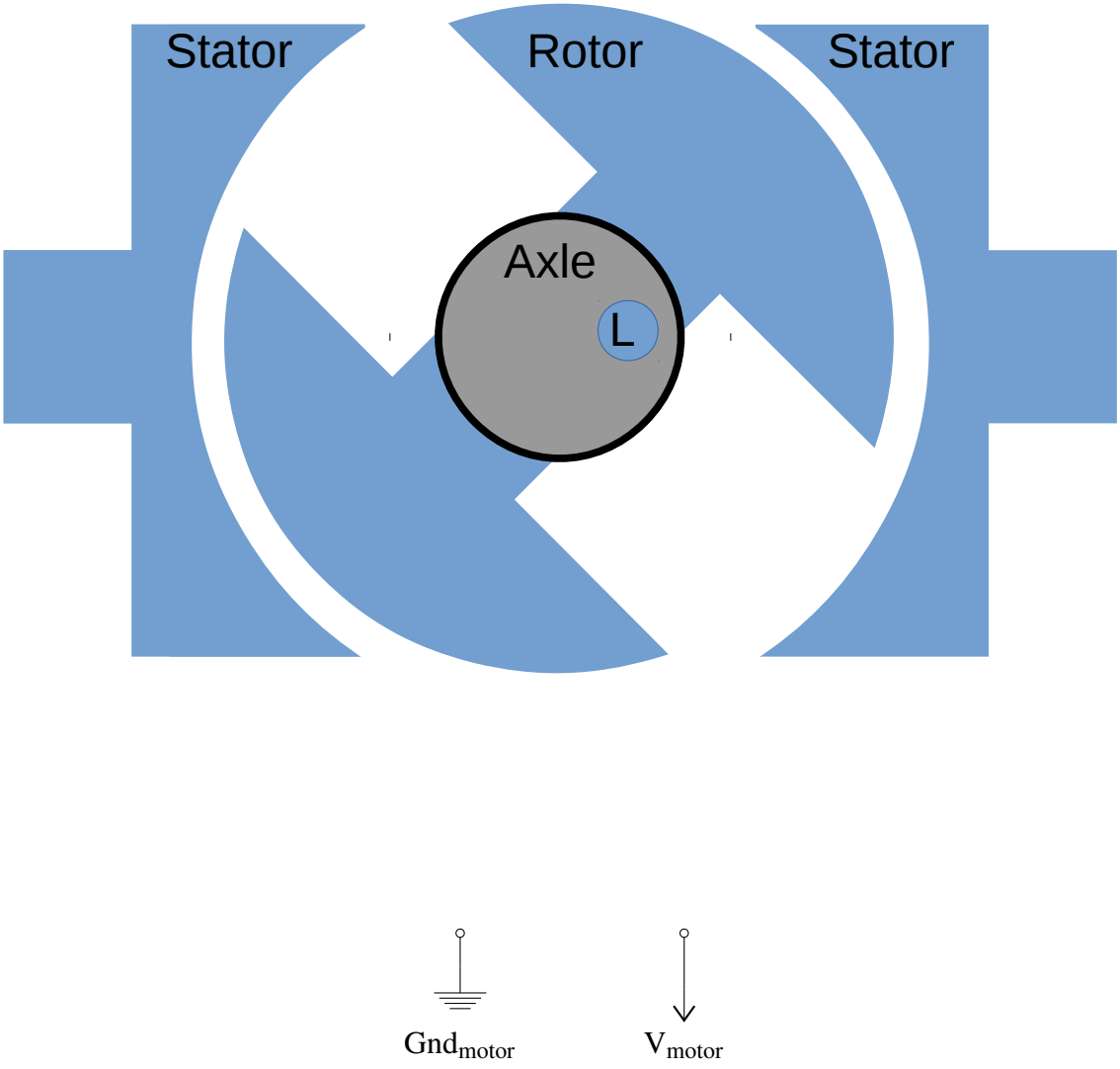
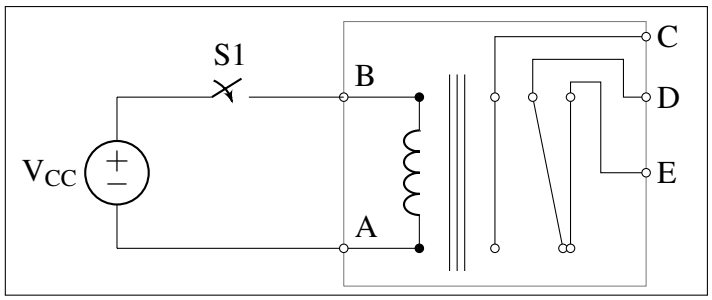


Figure: DC motor outline. The point **L** indicates a spot onto which light shines to measure the rotation.

4B. (5 marks) A relay is used to control the motor. An optical sensosensor controls the switch S1. When S1 is open, E is connected to D. When S1 is closed, C is connected to D. Switch S1 opens and closes each time the axle turns.



Given power supply connections of $+10\,V$, $-10\,V$ and Ground, **show how** to connect the relay to the power supplies and to the motor, so that current flows in one direction when S1 is closed, and another when S1 is open. (Your diagram should have eight connections: power supplies ($+10\,V$, $-10\,V$ and Ground), motor connections (V_{motor} and Gnd_{motor}), and relay terminals C,D and E)

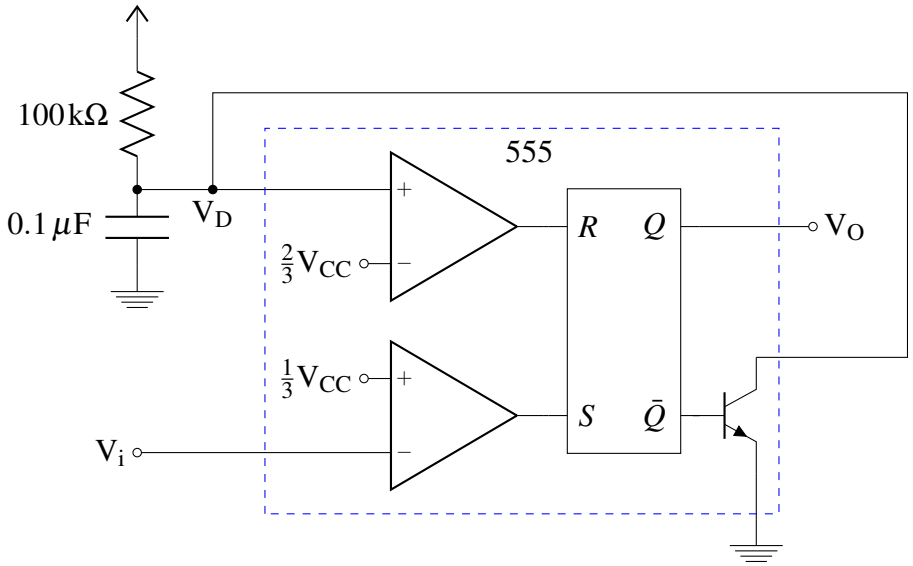
5. **Filters and Circuits**

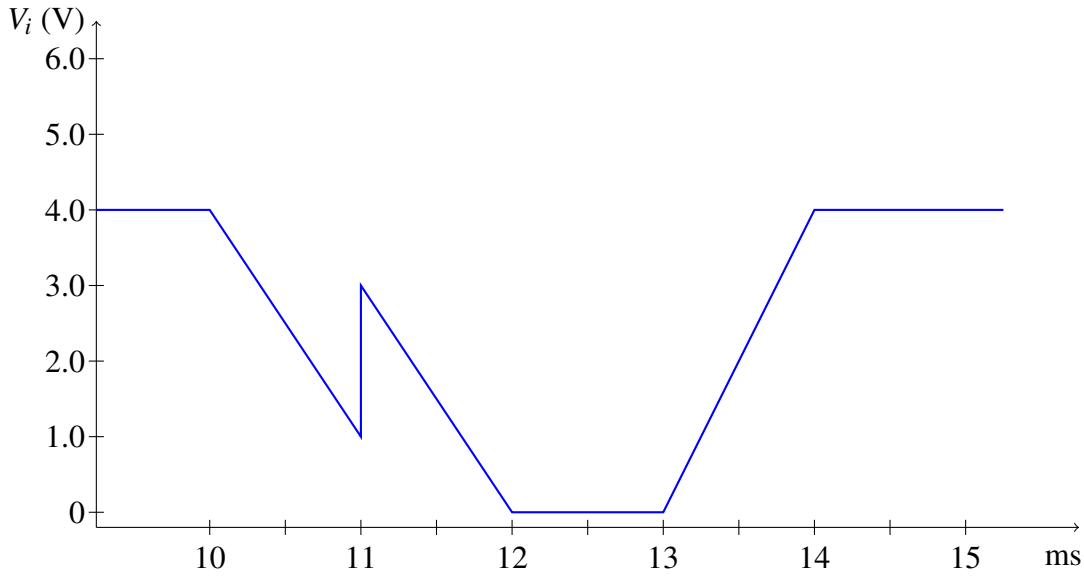
A photodiode is connected so that it collects the reflected signal from the light **L**. However, this signal is noisy and needs to be low-pass filtered.

5A. (5 marks) **Sketch the specifications** of a low-pass filter which achieves 40 dB of attenuation for signals above 3 kHz, while passing signals below 1 kHz with a maximum passband deviation of 0.5 dB. **Choose a filter from the table** which meets these requirements, and **using a Sallen-Key** topology, write the gain and cut-off frequency of each stage.

5B. (5 marks) In order to eliminate multiple transitions at a comparator, a 555-based monostable design is used. The 555 has voltage supplies of $V_{CC} = 6\,V$ and ground.

Sketch signal S as a function of time for the input V_i shown (you may sketch S on top of the graph provided). Indicate the times of any transitions.





5C. (5 marks) **Sketch signal** V_D, R and V_O as a function of time for the input V_i shown in the previous question. Next, **describe the problem of multiple transitions**, and **explain** how this circuit addresses it.