SYSC 3203: Midterm Impovement Quiz

December 1, 2016
Carleton University, Systems and Computer Engineering

Name: ______________________ **Student Number:** ______________

Instructions:

- This test has **7** pages and **8** questions. Answer all questions. Marks are indicated.
- You have **60 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 0.05dB											
2	21.58	68.23	215.77	2.162	1.664						
4	3.37	5.89	10.42	0.885	1.334	1.221	2.500				
6	1.90	2.67	3.85	0.569	1.279	0.870	2.176	1.091	2.759		
8	1.48	1.86	2.39	0.422	1.261	0.670	2.072	0.912	2.544	1.050	2.861
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
FILTER = Chebychev 2.00dB											
2	8.13	25.59	80.91	0.907	2.114						
4	2.14	3.65	6.41	0.471	1.924	0.964	2.782				
6	1.46	1.99	2.82	0.316	1.891	0.730	2.648	0.983	2.904		
8	1.25	1.52	1.93	0.238	1.879	0.572	2.605	0.842	2.821	0.990	2.946
FILTER = Chebychev 5.00dB											
2	5.87	18.49	58.34	0.778	2.412						
4	1.86	3.12	5.46	0.415	2.288	0.938	2.870				
6	1.36	1.82	2.55	0.280	2.266	0.715	2.790	0.972	2.943		
8	1.20	1.44	1.80	0.211	2.259	0.561	2.764	0.835	2.894	0.984	2.968

1. **Sensors**

1A. (5 points) **Briefly describe two** of the following differences between a thermistor and a thermocouple: i) suitability for high temperatures, ii) requirement for a calibration circuit, iii) cost, and iv) ability to give a quick response time.

i. The maximum operating temperature of a thermocouple is essentially only limited by the melting point of the two dissimilar metals used in its construction. For example, a platinum-rhodium (Type B) thermocouple may be used up to 1820°C. In contrast, thermistors which are based on sintered metal oxides (NTC type) or ceramic / carbon polymer (PTC type) typically have a usable range of only a few hundred °C.

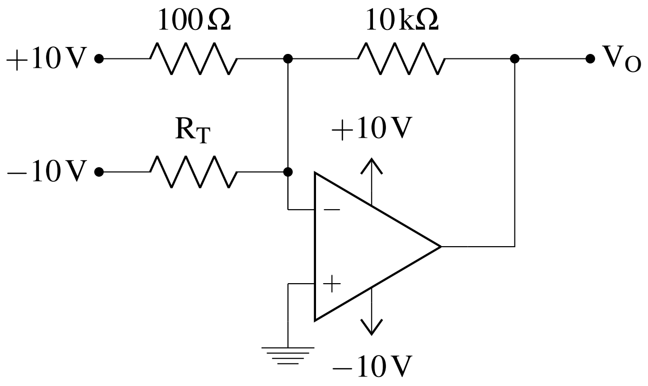
ii. Thermocouples require a reference (calibration) circuit, because their output is a voltage that depends on the temperature *gradient* between the measurement junction and reference junction (Seebeck effect). In contrast, the resistance of a thermistor depends on absolute temperature (often modelled according to the Steinhart-Hart equation).

iii. Thermocouples are simple, rugged metallic devices that may be used “bare”. In contrast, NTC thermistors are typically made from sintered metal oxides that are susceptible to degradation by environmental factors (in particular, moisture ingress) and so must be encapsulated, usually either in glass or epoxy beads. This makes their individual cost somewhat higher than that of a typical thermocouple. However the thermocouple has the added expense of the reference circuit.

iv. Because they do not require encapsulation (see above), thermocouples can have a small thermal mass, allowing them to respond quickly to temperature changes.

1B. (5 points) A thermistor, $\mathrm{R_T}$ is used in the circuit below. At 35°C, $\mathrm{R_T} = 100\,\Omega$ and at 36°C, $\mathrm{R_T} = 101\,\Omega$. **What is** $\mathrm{V_O}$ **for** at 35°C and 36°C?

1C. (5 points) **What is the sensitivity** of at the output of the sensor, $\mathrm{V_O}$, in V/°C over the range from 35°C to 36°C?



The circuit is a summing inverting amplifier, whose output we can therefore write as

$$\mathrm{V_O} = -10\,\mathrm{k}\Omega\left\{\frac{10\,\mathrm{V}}{100\,\Omega} - \frac{10\,\mathrm{V}}{R_T}\right\}$$

At 35°C, $\mathrm{R_T} = 100\,\Omega$ and so $\mathrm{V_O} = 0\mathrm{V}$, while at 36°C, $\mathrm{R_T} = 101\,\Omega$ and so

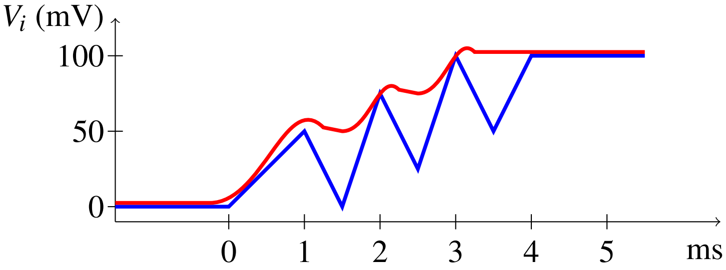
$$\mathrm{V_O} = -\frac{10\,\mathrm{k}\Omega}{100\,\Omega}\left\{1 - \frac{1}{1.01}\right\}(10\,\mathrm{V}) = -9.90\,\mathrm{V}$$

from which the sensitivity is seen to be $-9.90\,\mathrm{V/°C}$.

2. **Filters**

2A. (5 points) The muscular force is measured which activates a circuit when it is large enough. The force is measured, and gives the rising signal, $\mathrm{V_i}$, which is input into the comparator, which compares the force to a threshold.

Explain how this waveform could cause multiple transitions of the comparator. **Explain how a low-pass filter** can reduce multiple transitions. (Calculations and exact graphs are not required; an explanation and a sketch is sufficient)



A simple comparator's output switches (from low to high, or from high to low, depending how it is configured) each time its input voltage crosses a preset threshold, either from below or from above. In the figure shown, there is no single threshold that we could choose which $\mathrm{V_i}$ crosses only once. You should be familiar with several countermeasures for this problem:

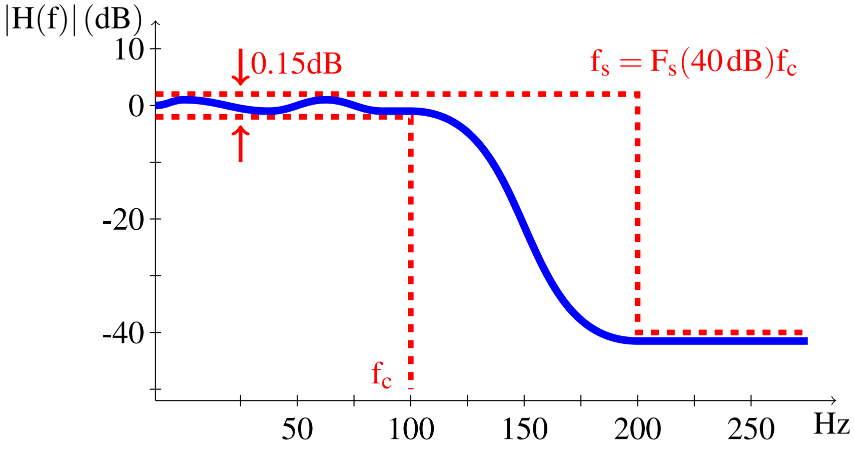
- Add **hysteresis** to the comparator circuit using a Schmitt trigger configuration (*positive feedback*). This has the effect of moving the threshold away from the signal voltage each time the threshold is crossed, reducing the chance that it will be re-crossed multiple times.
- Accept the multiple transitions, but follow the comparator with a **non-retriggerable monostable** circuit.
- **Filter** the input signal $\mathrm{V_i}$ to reduce the amplitude of any high-frequency excursions to a point that it becomes essentially monotonic.

The time-domain representation of a low-pass filter is a leaky integrator - exactly what we built in the lab to smooth the rectified EMG signal before the input to the LT1011 comparator.

The signal shown rises non-monotonically and then stabilizes after 4-5 ms, indicating a *fundamental frequency* somewhat below $1/0.005 = 200\,\mathrm{Hz}$. Hence a filter that has 40 dB attenuation at frequencies above 200 Hz will substantially remove the shorter scale signal fluctuations, resulting in a signal that rises monotonically and hence only crosses the comparator threshold once during the period (see modified figure above).

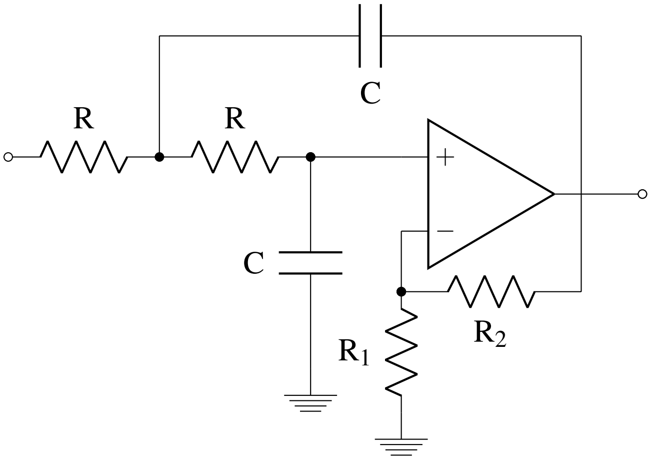
2B. (5 points) A low-pass filter is required to smooth out the input into a comparator circuit. It is allowed to have a maximum deviation of 0.15 dB in the passband (which extends from DC to 100 Hz) and is required to attenuate all frequencies above 200 Hz by at least 40 dB. **Sketch the filter requirements.**

2C. (5 points) **Design the first filter stage**, using a Salen-Key filter. Use the values $R = R_1 = 100\,k\Omega$.



To achieve at least 40 dB attenuation above $f = 200Hz$ with a cutoff frequency $f_c = 100\,Hz$, we need normalized stopband edge frequency $F_s(40\,dB) < 200\,Hz/100\,Hz$. For reasons of cost, we should choose the minimum filter order *n* that satisfies all the requirements. From the filter table on page 1, choose either:

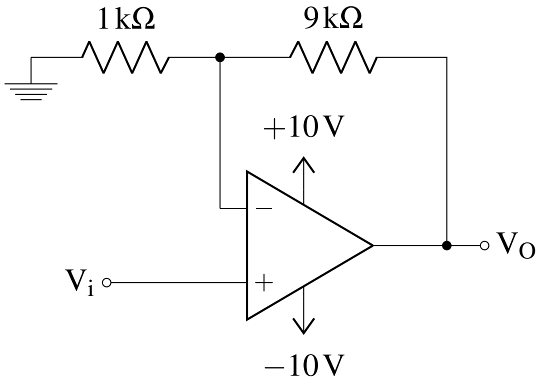
	$0.1\,dB, n = 6$	$0.05\,dB, n = 6$	
$F_s(40\,dB)$	1.81	1.90	Units
f_n	0.513	0.569	-
G	1.332	1.279	-
$\omega = 2\pi f_c f_n$	322.33	357.51	$rad.s^{-1}$
$C = 1/\omega R$	31	28	nF
$R_2 = (G-1)R_1$	33	28	kΩ



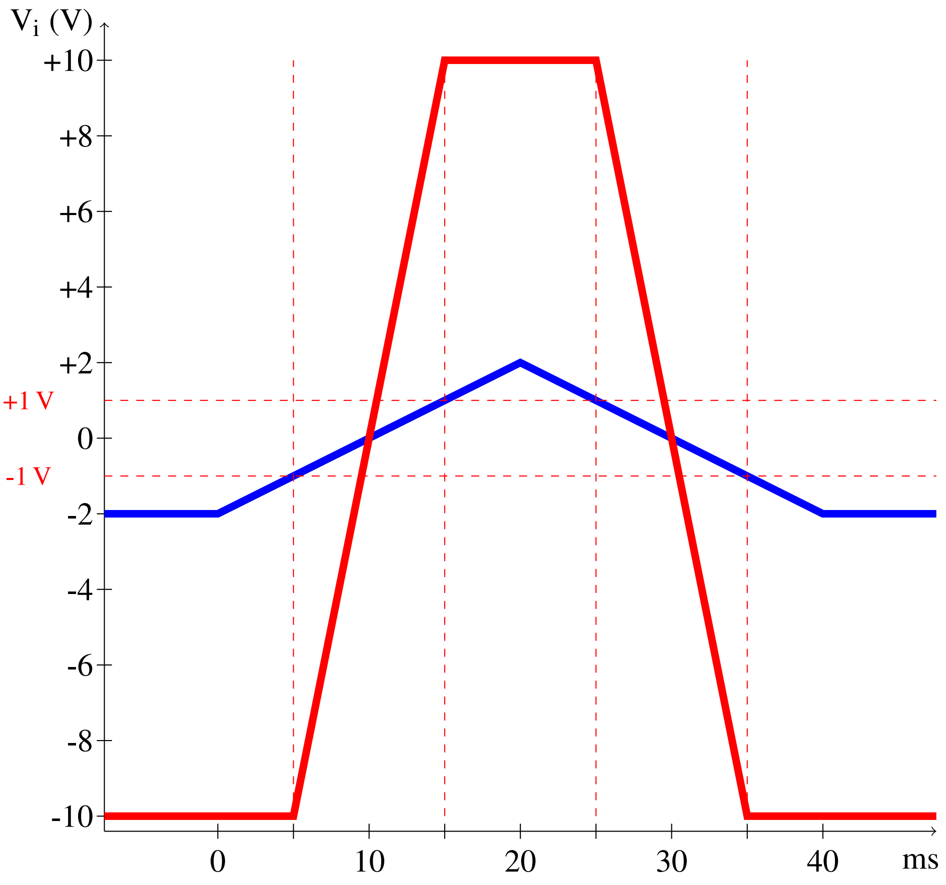
3. **Amplifiers**

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

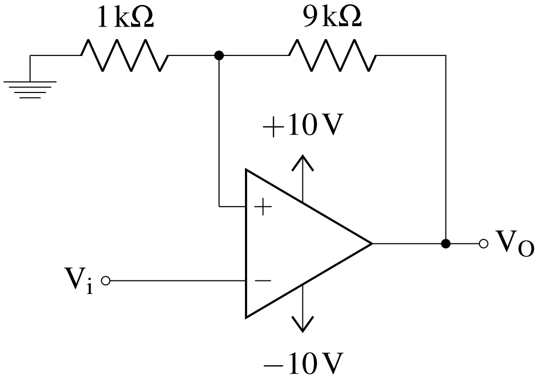
3A. (10 points) For the input, V_i, below, **sketch the output**, V_O, on the same graph. Indicate voltage levels and the times of any transitions.



Non-inverting amplifier. The gain is $G = 1 + 9k\Omega/1k\Omega = 10$ but saturates at ±10V which occurs when $V_i = \pm 1$V. **The response is linear between these limits**.



3B. (10 points) For the input, $\mathrm{V_i}$, below, **sketch the output**, $\mathrm{V_O}$, on the same graph. Indicate voltage levels and the times of any transitions. (The only difference from the previous question is the inputs are flipped)



Schmitt trigger (inverting). Thresholds are $(1k\Omega/10k\Omega)(\pm 10\text{V}) = \pm 1\text{V}$, which V_i crosses at 15ms and 35ms. **It is important to note that the transitions always occur at the more distant threshold i.e. the signal rises until it crosses the higher threshold, then falls until it crosses the lower threshold**.