 Name: Solutions

BME154L (Palmeri)

Spring 2010

Exam #1

Instructions:

- Write your name at the top of each page.
- Show all work (this is *critical* for partial credit!).
- Only work in the space provided. Ask for extra paper if necessary.
- Read through each complete question before starting to work (this may save you some time).
- Remember to include units with all answers and label all plot axes.
- Clearly box all answers.
- Assume that all components are ideal unless otherwise stated.
- Assume that op amps rail at $\pm$ 12 V unless otherwise stated.

Exam Stats
70 ± 15
Range: 25–97

In keeping with the Duke Community Standard, I have neither given nor received aid in completion of this examination.

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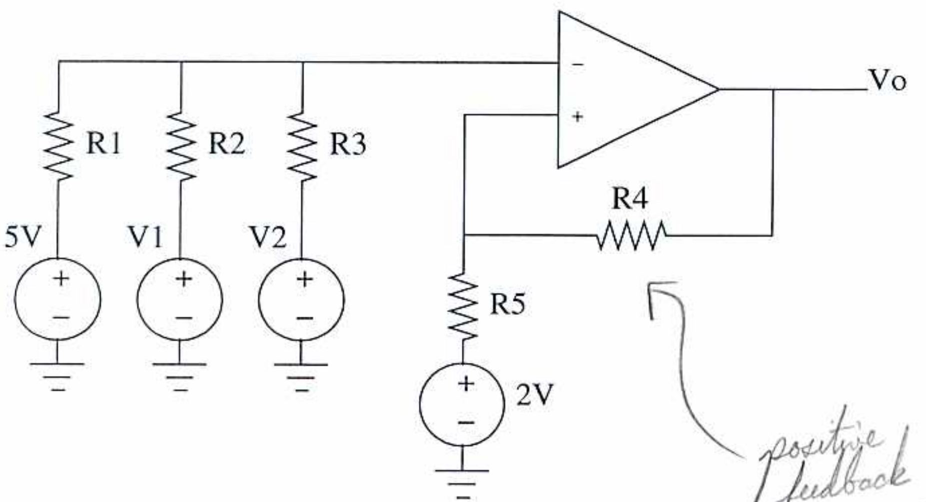
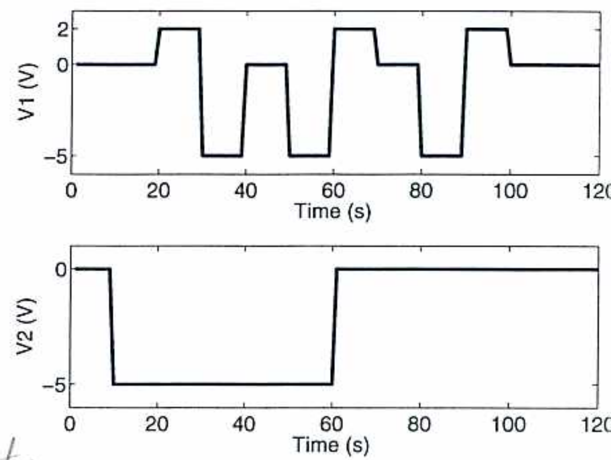
Problem #1 [20 points]

Class
12 ± 6



positive feedback
∴ comparator



- $R_1 = R_2 = R_3 = \cancel{R_4} = R_5 = 1\ \text{k}\Omega$; $R_4 = 9\ \text{k}\Omega$
- Assume that the op amp rails at ± 12 V and V_o = -12 V at t = 0

(a) Given $V_1(t)$ and $V_2(t)$, sketch the voltage on the non-inverting input of the op amp through time.

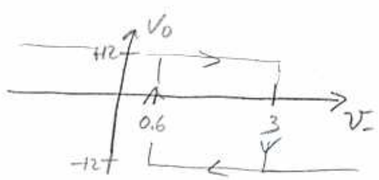
(b) Sketch the output voltage, $V_o(t)$.

What can V^+ be? $V_o = \pm 12V$

$\xrightarrow{+12V} V^+ = (V_o - 2V)\left(\frac{R_5}{R_4+R_5}\right) + 2V = (10V)\left(\frac{1}{10}\right) + 2V = 3V$

$\xrightarrow{-12V} V^+ = (-14V)\left(\frac{1}{10}\right) + 2V = 0.6V$

So...



$v^- = \frac{v_1 + v_2 + 5V}{3}$, so transitions when

$\xrightarrow{v^- = 0.6V} v_1 + v_2 = -3.2V$ (v_o: $-12 \to +12V$)

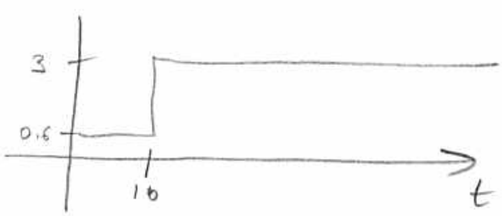
$\xrightarrow{v^- = 3V} v_1 + v_2 = 4V$ (v_o: $+12 \to -12V$)

quick inspection above, $v_1 + v_2$ never $\geq 4V$

∴ v_o never $+12V \to -12V$

$v_1 + v_2 \leq -3.2V$ first happens @ 10s

(a) $v^+ (V)$



(b) $v_o (V)$

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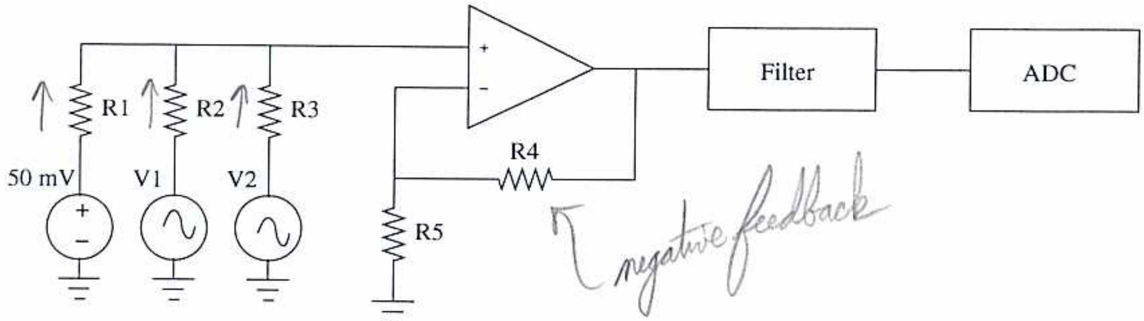
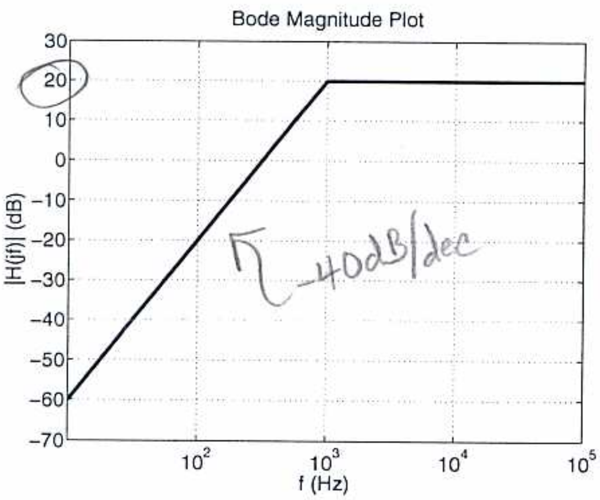
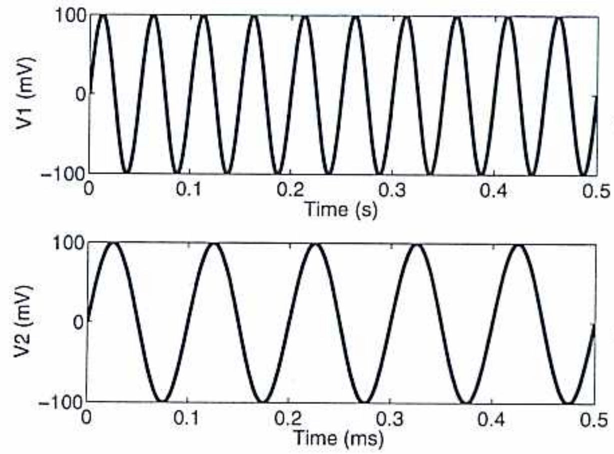
Problem #2 [45 points]

Class
32±8



NOTE: The polarity of the op amp inputs are flipped compared to those in the first problem!!





f=20Hz

f=10kHz

- V_1 and V_2 are continuous AC voltage sources with sample time waveforms shown in the plots above.
- $R_1 = R_5 = 5\ \text{k}\Omega$, $R_2 = R_3 = R_4 = 10\ \text{k}\Omega$

(a) Write an expression for the voltage output from the op amp before the filtering stage. (Don't worry about simplifying your answer too much.)

(b) The op amp is setup to be what type of amplifier? (Note - we did not directly cover this in class, but it is a variant of something that we did cover.)

(c) The reason why we didn't cover this amplifier in class is because it has a very bad input characteristic. Solve for the input impedance as seen from the 50 mV DC voltage source going "into" R_1. Why is this "bad"? (Again, don't worry about simplifying your answer too much.)

(d) Design a filter to achieve the characteristics shown in the Bode plot. (Note that the phase characteristics of this filter have not been specified.)

There is more on the next page...

(e) What is the voltage level associated with the least significant bit if the ADC generates an 8-bit number that covers the full range of the signal from the filter? You do not need components of the input signal that are removed by the attenuation band of the filter to be captured by the ADC (Don't worry about an incorrect answer from an earlier part affecting your answer here; just continue to solve these questions with the waveform that you have, which hopefully is realistic.)

(f) What is the ADC's theoretical minimum sampling frequency to accurately capture the frequency content of the input signal? In practice, what would be a more reasonable minimum sampling frequency?

(g) Compare/contrast the benefits/drawbacks of using a flash ADC versus a successive approximation ADC.

(h) Given your more realistic sampling frequency, if you had 16 kilobytes (kB) of memory, how long could you continuously sample data from this circuit before you would fill your memory register?

(a) Negative feedback $\rightarrow v^+ = v^-$

$$v^+: \frac{50mV - v^+}{R_1} + \frac{v_1 - v^+}{R_2} + \frac{v_2 - v^+}{R_3} = 0$$

$$v^+ = v^- = v_o\left(\frac{R_5}{R_4+R_5}\right)$$

$$\boxed{v_o = \frac{\left(\frac{50mV}{R_1} + \frac{v_1}{R_2} + \frac{v_2}{R_3}\right)\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right)^{-1}}{\left(\frac{R_5}{R_4+R_5}\right)}}$$

(b) Non-inverting summing amp

(c) $$Z_{in}\Big|_{50mV} = \frac{v_{in}}{i_{in}} = \frac{50mV}{i_{in}} \rightarrow \frac{50mV - v^+}{R_1}$$

function of $v_1 + v_2 \rightarrow$ not constant: input dependent $\downarrow$ bad!!

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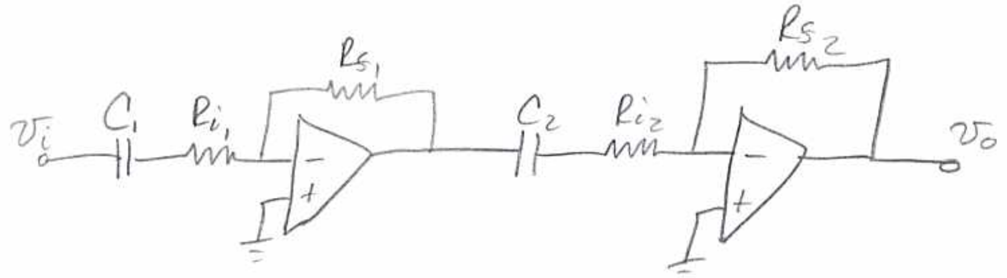
(d) Active HPF w/ -40 dB/dec attenuation + $+20$ dB passband gain

$f_c = 1\,kHz \rightarrow \omega_c = 2\pi f_c$



$G_1 = 10 = \left| -\frac{R_{s_1}}{R_{i_1}} \right| \qquad G_2 = 1 = \left| -\frac{R_s}{R_i} \right|$

$f_{c_1} = \frac{1}{2\pi R_{i_1} C_1} = 1\,kHz = \frac{1}{2\pi R_{i_2} C_2}$

(R_x need to be $k\Omega$s)

(e) DC (50mV) + 20 Hz killed by HPF; only 10 kHz signal left

Scaling from summer $\rightarrow \pm 75\,mV_{p-p} \xrightarrow{G_{HH}=10} 750\,mV_{p-p}$

$\frac{1.5V}{2^8-1} \cong 5.9\,mV = V_{LSB}$

(f) $f_{Nyq} > 2 \cdot f_{max} \longrightarrow 20\,kHz$

Want 5-10x $f_{Nyq} \longrightarrow 100\,kHz$

(g) Flash $\rightarrow$ fast, but \$ (2^n-1 op amps)

Succ. Approx $\rightarrow$ slower (binary search), fewer op amps, need memory + DAC

(h) 16 kB $\rightarrow$ 16000 bytes $\rightarrow$ 16000 samples $\times \frac{1\,s}{100000\ \text{samples}} = 160\ ms$

1 byte = 8 bits = 1 sample

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Problem #3 [35 points]

Class
26±7

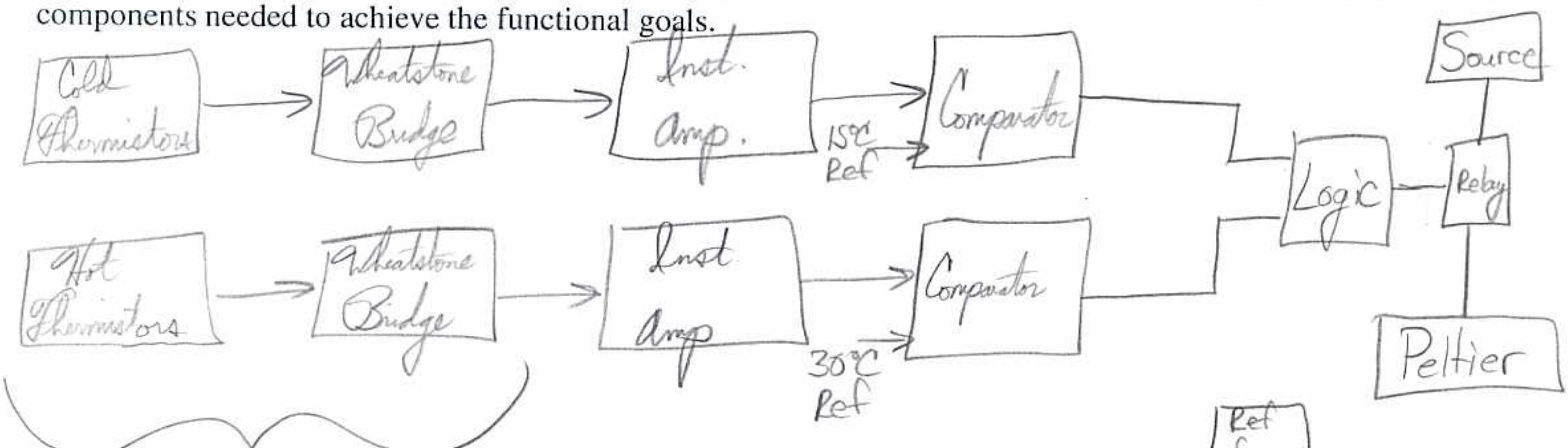
Thermoelectric cooling relies on the Peltier effect to create a heat flux between two different materials. A Peltier device acts as a solid-state "heat pump" that cools one material while heating the other. You need to design a Peltier device to cool a bioreactor to 15 °C. You want the cool side of the Peltier device to stay near this temperature, but you can't run the device if the hot side exceeds 30 °C, otherwise you'll destroy the unit.

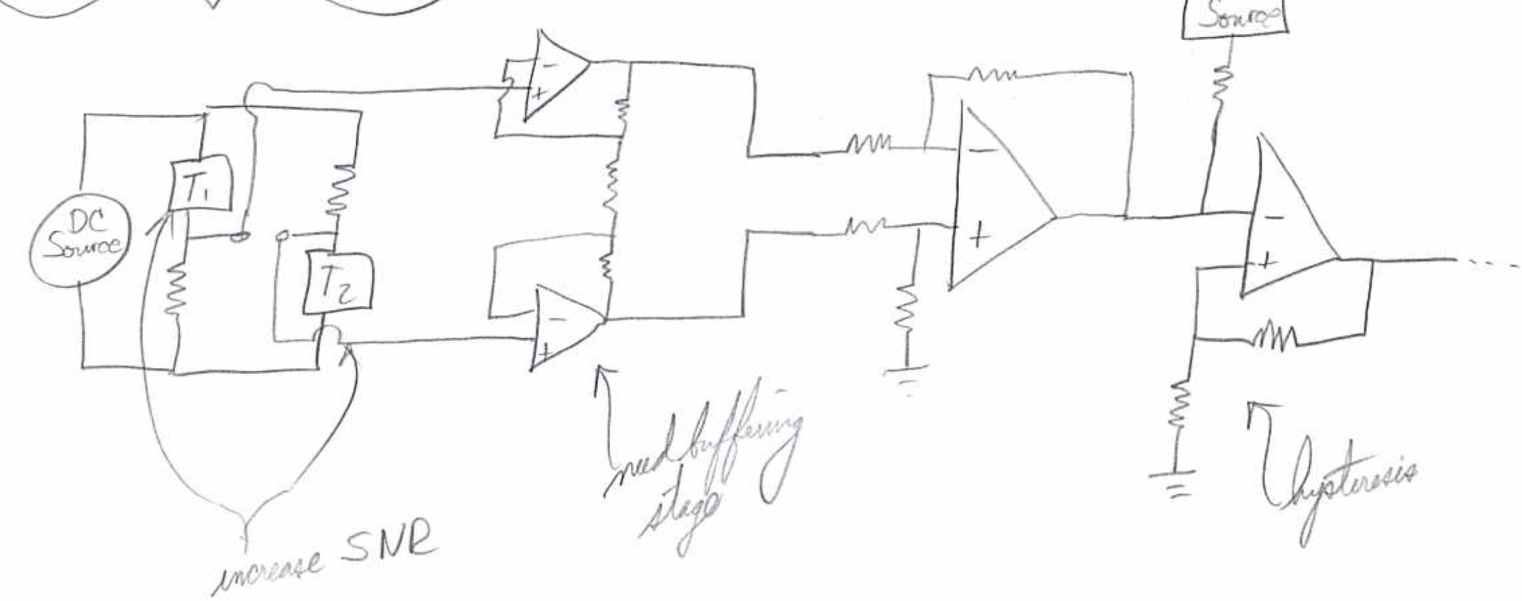
You have 4 thermistors that you can use to monitor the cold and hot sides of the Peltier device; these thermistors are identical and have a behavior governed by the equation $\Delta R = k\Delta T$, where $k = 1 \pm 0.02\ \Omega/°C$ and $R = 10$ kΩ at $T = 25$ °C.

When the Peltier device is "on", it requires 12 V DC and draws a current of 4 A; therefore, it needs to be electrically isolated from any transduction / control circuitry.

Design a feedback circuit, similar to what you did in lab and the problem sets, to (1) turn on the Peltier device when the cold side of the Peltier device is > 15 °C, but (2) only when the hot side of the Peltier device is < 30 °C.

There are lots of ways to do this!! Show all of your work, including a block diagram, and state all of your assumptions. In addition to the thermistors (you don't have to use all 4 if you don't want to), you can use whatever resistors, power sources, op amps, capacitors, inductors, logic gates, etc. that you would like in your circuit. Full credit will be awarded for circuit designs that maximize SNR and minimize the number of circuit components needed to achieve the functional goals.





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Setup each comparator to yield 0 or 5V w/ following logic:

Cold $\leq 15°C \rightarrow 0V$

$\boxed{> 15°C \rightarrow 5V}$

Hot $\boxed{< 30°C \rightarrow 5V}$

$\geq 30°C \rightarrow 0V$

$\rightarrow$ use AND logic gate $\xrightarrow{+5V}$ activate relay + deliver power to Peltier device

Solving for Rs, ref voltages, etc. $\rightarrow$ major brownie points!